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GCC Power Marketing Industry Framework During Initiation Period to Improve Energy Managements and Reliability for GCC Countries

A Thesis submitted in partial fulfillment of the requirements for the Ph. D. Degree in Engineering (Electrical Engineering)

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January, 2016



Defense committee's approval

University of Bahrain

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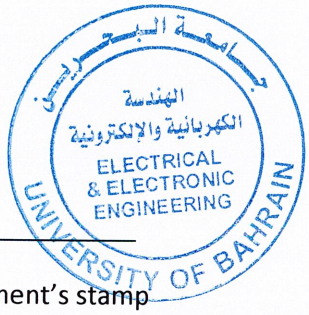
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Abstract

This is an applied study to initiate a Regional Power Market to utilize Member States energy resources for electricity sectors with an acceptable level of reliability. The present study has focused on creating Regional Electricity Market (REM) in the GCC region and continue Al-Muhawesh (2007) research in Saudi Arabia Electricity Market. Three steps used to recommend a new REM Model. The first step is to study and assess the status of member states in terms of development towards the energy trading market. The second step is shaping and defining the business model proposed by studying global experiences in the RES. The third step is to identify gaps between the member state status and the recommended REM. Followed by a list of recommendations and propose REM. In this regards, the member states readiness and their feedback are studied and views the expected REM. These steps used to present the level of development in GCC electricity sectors and the gap analysis toward REM.

In practice, it is necessary to know the load demand and generation availability so that the demand can be satisfied economically. For this reason, prediction of the long term load demand becomes quite important. In this thesis, the Long Term Load Forecasted (LTLF) for the GCC countries is carried out by utilizing multi-regression analysis, curve fitting and Artificial Neuro-Fuzzy Intelligent systems (ANFIS). Opportunity model for Power Trading between MSs has been modeled to forecast the trading opportunity in term of time and quantities.

Energy prices calculated for the production cost in the GCC using different methods. The Marginal cost calculation for GCC generation units modeled using AURORA and PROMO software. The obtained results illustrated, compared and discussed using uniformed and international fuel prices. The results presented in term of range of prices. Power Trading opportunities, benefits calculated based on the results found earlier. In addition, the expected benefits from the forecasted opportunities and energy prices are calculated, and the economic benefits of Value of Lost Load (VoLL) and energy exchanged are calculated.

System reliability necessitates studying the effect of machine switching and corresponding loss of load expectation (LOLE) in the interconnected systems. Machine switching reliability is modeled by means of Laplace Transforms and ANFIS software. LOLE is calculated by utilizing AURORA software and Monte Carlo simulations. The results obtained from these analysis has shown that the delays satisfy the GCC requirements of being loss than 5 hours per year.

In conclusion, this study presents the recommended Multi Zone Border to Border Regional Market Model to be implemented in the GCC region. The LTLF, unit cost, marginal cost, opportunity model, system reliability and economic benefits have been developed to satisfy the proposed market model.

Dedication

To spirit of my Mother, Father, Wife, brothers and sister.

Many thanks....

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ABBREVIATIONS

ADWEA	*Abu Dhabi Water and Electricity Authority*
ADWEC	*Abu Dhabi Water and Electricity Company*
AER	*Authority for Electricity Regulation*
ANFIS	*Artificial Neuro Fuzzy Intelligent System*
ARC	*Advisory and Regulatory Committee*
ASP	*Ancillary Services Price*
ATC	*Available Transfer Capability*
AURORA	*Software with functions and tools for required by Electricity Market Operator requirement*
BAH	*BAHrain*
BL	*Business Line*
BOO	*Build Own Operate*
BTU	*British Thermal Unit*
CAP	*CAPita*
CBM	*Capacity Benefit Margin*
CC	*Combined Cycle*
CCGT	*Combined Cycle Generation Turbine*
CMS	*Congestion Management System*
COA	*Center Of Area*
CONE	*Cost Of New Enter*
CSP	*Content Security Policy*
CWE	*Central West European*
DA	*Day Ahead*
DEWA	*Dubai Electricity and Water Authority*
DISTCO	*DISTribution COmpany*

DSO	*Days Sales Outstanding*
DSP	*Distribution Service Price*
DTA	*Developing Transmission Area*
ECRA	*Saudi Electricity & Co-generation Regulatory Authority*
EEU	*Expected Energy Unserved*
EIA	*Energy Information Administration*
ELD	*Economic Load Dispatch*
EMMA	*European Market Management Algorithm*
EMMS	*Energy Market Management System*
EOR	*Emergency Operation Reserve*
EP	*Multiplication of Electricity Consumption by Population*
EPLF	*Electric Power Load Forecasting*
ESI	*Electricity Supply Industry*
ETC	*Existing Transmission Commitments*
EU	*European Union*
EUP	*End User Prices*
EWA	*Electricity and Water Authority*
FACTS	*Flexible AC Transmission System*
FERC	*Federal Energy Regulatory Authority in USA*
FEWA	*Federal Electricity and Water Authority*
FIS	*Fuzzy Inference System*
GA	*Genetic Algorithm*
GA & PETA	*General Agreement & Power Exchange and Trading Agreement*
Gal	*Gallon*
GCC	*Gulf Cooperation Council*
GCCIA	*Gulf Cooperation Council Interconnection Authority*
GDP	*Gross Domestic Product*

GEC	*General Electricity Corporation*
GENCO	*Generation Company*
GRIDCO	*Grid owning Company*
GT	*Gas Turbine*
GW	*Gega Watt*
hPa	*hectoPascal*
HVDC	*High Voltage Direct Current*
IAEA	*International Atomic Energy Agency*
ICC	*Interconnection Control Center*
IEA	*International Energy Agency*
IOU	*Investor Owner Utility*
IPP	*Independent Power Producers*
IRO	*Interconnector Right of Operation*
ISO	*Independent System Operator*
ITVC	*Interim Tight Volume Coupling*
IWPP	*Independent Water and Power Producers*
KAHRAMAA	*Arabic translation for* كهرماء *which is Arabic name for Qatar General Electricity and Water Corporation*
KSA	*Kingdom of Saudi Arabia*
KUW	*KUWait*
kW	*kilo Watt*
kWh	*kilo Watt hour*
LCOE	*Levelized Cost Of Electricity generation*
LF	*Load Factor*
LINDO	*Linear Interactive & Discrete Optimizer*
LOEE	*Loss of Energy Expectation*
LOLD	*Loss of Load Duration*

LOLE *Loss of Load Expectation*

LOLF *Loss of Load Frequency*

LOLP *Loss of Load Probability*

LOSS *Power System LOSSes*

LP *Linear Programming*

LR *Lagrange Relaxation*

LT *Laplace Transforms*

LTLF *Long Term Load Forecast*

MARAFIQ *Arabic translation for مرافق, which is the name of Power and Water Utility Company*

MATLAB *MATrix LABoratory (Mathworks, Inc)*

MEW *Ministry of Electricity and Water*

MHEW *Ministry of Housing, Electricity and Water*

MIBEL *Market Iberian Electricity*

MLP *Multilayer Perceptions*

MLR *Multi Linear Regression*

MO *Market Operator*

MTLF *Medium Term Load Forecast*

MW *Mega Watt*

NBD *National Bank of Dubai*

NCM *Nodal Congestion Management*

NEA *Nuclear Energy Agency*

NEM *National Electricity Market in Australia*

NEMMCO *National Electricity Market Management Company in Australia*

NERA *National Economic Research Associates*

NGC *National Grid Company in England & Wales*

NPV *Net Present Value*

NPVEG	*NPV of net Electricity Generation*
NTC	*Net Transfer Capacity*
OA	*Operating Area*
OASIS	*Open Access Same Time Information System*
OCGT	*Open Cycle Generation Turbine*
OMN	*OMaN*
OPF	*Optimal Power Flow*
PCR	*Price Coupling Regions*
PES	*Public Electricity Suppliers in UK*
POP	*POPulation*
PP	*Power Pool*
PPA	*Power Purchase Agreement*
PPI	*Process Planning Improvement*
PROMO	*PROgram MOdel*
PSP	*Power Service Providers*
PV	*Photo-Voltaic*
PURPA	*Public Utilities Regulatory Policy Act in USA*
PVG	*Photo Voltaic Generation*
PX	*Power Exchanger*
QAT	*QATar*
QEWC	*Qatar Electricity and Water Company*
REC	*Regional Electricity Company*
REM	*Regional Electricity Market*
REN	*RENewable*
RES	*Renewable Electricity Supply*
RI	*Regulatory Institute*
RIA	*Refined Immune Algorithm*

RP	*Regulation Price*
RSP	*Retailing Service Price*
RTO	*Regional Transmission Organization*
RTR	*Red de Transmission Regional*
SA	*Settlement Administrator*
SAP	*Systems Applications and Products*
SAPP	*South Africa Power Pool*
SC	*Schedule Coordinator*
SCADA	*Supervisory Control And Data Acquisition*
SCUC	*Security Constrained Unit Commitment*
SEC	*Saudi Electricity Company*
SED	*Saudi Electricity Distribution*
SEE	*South East Europe*
SEM	*Single Electricity Market*
SENG	*Saudi Electricity National Grid*
SESI	*Saudi Arabia Electricity Supply Industry*
SESOM	*Saudi Electricity System Operation and Marketing*
SEWA	*Sharjah Electricity and Water Authority*
SIEPAC	*Sistema de Interconexion Electrica de Paises de America Central*
SLA	*Service Level Agreement*
SMP	*System Marginal Price*
SO	*System Operator*
SRMC	*Short Run Marginal Calculation*
ST	*Steam Turbine*
STLF	*Short Term Load Forecasting*
SWCC	*Saline Water Conversion Corporation*

TCM	*Transmission Congestion Management*
TEAR	*Techno Economic Analysis Report*
TOP	*Trading Outside the Pool*
TP	*Transmission Provider*
TQM	*Total Quality Management*
TRANSCO	*TRANSmission COmpany*
TRM	*Transmission Reliability Margin*
TSO	*Transmission System Operator*
TSP	*Transmission Service Price*
TTC	*Total Transfer Capability*
TVA	*Tennessee Valley Authority*
TWh	*Tera Watt hour*
UAE	*United Arab Emirates*
UC	*Unit Commitment*
USD	*United States Dollar*
VoLL	*Value of Lost Load*
VSTLF	*Very Short Term Load Forecasting*
VTN	*Valid Trading Notification*
WA	*Weighted Average*
WAS	*Western Australia State*
WEC	*Water and Electricity Company*
WMP	*Wholesale Market Price*
ZCM	*Zonal Congestion Management*

DEFINITIONS

Ancillary Services are required to maintain a reliable system (stable frequencies and voltages). Ancillary services mostly include (Spinning and standby reserves, frequency regulation, available capacities of generators, voltage control and black start capability.

AURORA is a software with functions and tools for required by Electricity Market Operator requirement. It used to build the Electric Market Model.

Bilateral Contract is a mutual agreement between a seller (generator or retailer) and a buyer (end-use customer, retailer, or other generator) in the quantity and the price of electricity.

Contract for Differences is a type of bilateral contract where a seller (generator or retailer) is to pay the wholesale market price plus or minus the difference between the contracted price and the wholesale price. In the same way, a buyer (end-use customer, retailer, or other generator) is required to pay the wholesale market price plus or minus the difference between the contracted price and the wholesale price.

Distribution Companies manage and maintain the electricity distribution network. Including technical support, assets management, planning services, financial support, and operating & maintaining of all distribution networks (it can reach up to less than 110 KV down to energy meter.)

Distribution Network Service Providers (DNSP's) operate the distribution networks in the NEM that distribute electricity from transmission networks, and in some cases from generators, to end use customers.

GENCO is a company that owns and operates more than one power plant.

GRIDCO is a company that owns the electric grid. It provides transmission open access without dispatches generators or operates the market.

Independent Power Producer (IPP) is a power plant that owns and operates one or more generator, which has no affiliation to any of the market participants.

Independent System Operator (ISO) operates the transmission facilities to provide non-discriminatory open access to the transmission wires to all market participants. It is to be independent from any of the participants.

Lends a software tool for solving linear programming problems.

Market Operator (MO) is the entity responsible for operating the wholesale market. It joined with the system operator under one entity or it separated.

Market Power is unlike a competitive market where service providers can control the prices rather than controlled by the market prices.

Market Rules are the operational rules cited by the regulator to be mandatory for all market participants as the market and technical operation guidelines.

Natural Monopoly refers to a situation where one firm can produce a given level of output at a lower total cost than can any combination of multiple firms.

Power Pool is the entity responsible for wholesale power purchase between power producers and buyers with primary emphasis on maintaining the system stability and reliability.

Retailers are bulk purchasers of electricity and supply it to their customers over the electricity networks.

Spot Price is the price in a wholesale market at the point where the aggregated supply curve intersects with the demand curve for each trading interval, e.g. every one hour.

System Marginal Price (SMP) is the price offered by the last power plant dispatched (according to merit order) to meet the demand in a given period. Such price considered as the trade price for all transactions in the given period.

Chapter 1

Introduction to the Study

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Chapter 1

Introduction to the Study

1.1 Introduction

Countries around the world are increasingly pursuing and benefitting from the integration of national electricity markets into larger regional power markets to provide reliable, affordable electricity to consumers. Increased cooperation in the trade of power among countries can bring numerous benefits.

Power trading is a new industry that just came into the picture in the oil Arab Gulf region. This type of industry was introduced after the implementation of the largest transmission line project done in the region between the GCC countries, which was commissioned in 2009. The project was built by a counterpart authority take the responsibility and the development of a network interconnecting the six GCC countries. Figure (1-1) shows the interconnected member state which gained the main benefits of the interconnection in the power trading opportunities.

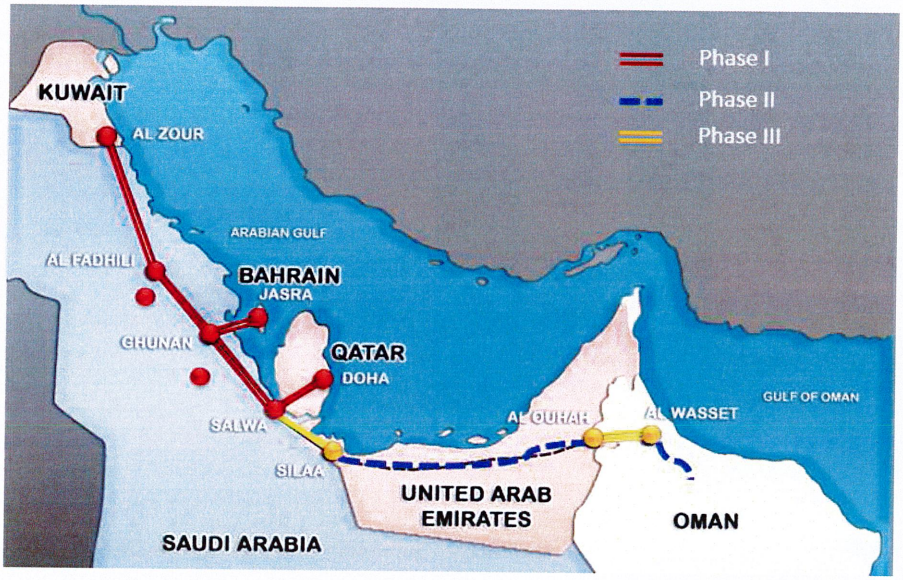


Figure (1-1): Geographical Layout of the GCC Interconnection

1.2 Background and Motivation

After years of economic developments, the people of the GCC countries become none tolerant to any load shedding whether it is short time or litter longer similar to the people of developed countries. They demand continuous supply of electricity. Therefore, countries are under the pressure of continuous power supply within an affordable cost. It is apparent that every supply has a certain cost and no country on the world has unlimited budget for every supply. Hence, the continuous power supply should be provided within economical constrains. This concept is not actually possible because of random system failures mostly outside the control of the utility sector. In reality, the probability of load curtailment can be reduced by increasing the investment during the planning, operating stages or both. On the other hand, increase the investment in the mentioned stages will lead to increasing in the operational cost for the energy unit, which will increase the cost in the tariff structure or lead to increase the government subsidies to the consumer side. Since the energy subsidized to the customers, the economic constraint has become one of the major subjects of the governments in the region. Beside that reducing the investment in this sector may lead to more load curtailment and lower Growth Demand and development in the country.

GCC electricity sectors need to be developed for more flexibility and ability to manage their resources. Some of these countries started their movements to develop their electricity sector by changing the ministries into authorities and companies. Saltant Oman and United Arab Emirates are an example of such reforms, where still there are more obstacles holding member states from managing their resources.

The cooperation in the trade of power between the member states will help them in achieving many benefits, including:

- Increased energy security
- Improved reliability
- Access to resources
- More efficient and effective use of infrastructure
- Economies of scale in investments
- Facilitation of financing for new investments
- Increased energy efficiency
- Greater renewable energy penetration
- Reduced environmental impact, that is, reductions in greenhouse gases
- Reduced cost of supply for consumers

This thesis evaluates the current structure of the electricity industry in the GCC Region, focusing on existing and potential trade in reliable electricity. There are several benefits of a more liberal trade regime due to large variation in the energy prices. The benefits are not limited to the economical subject, but also include the technical benefits. The improvement of security of supply and managing the energy resources in the Gulf region and improved economic efficiency due to the economies of scale are part of the benefits from the interconnection. The technical benefits for the electricity sector are having on lower reservation margin requirements and reduce peak load in the integrated system.

1.3 Market Barriers

Establishing regional markets is more complex than creating a single wholesale market within one nation and one regulatory umbrella. The number and scope of risks increase with the number of nations and markets targeted to be interconnected.

Many Regional Electricity Markets (REM) development efforts around the world are facing challenges that slow progress and reduce the benefits of regional integration. It is important to understand these challenges when designing a strategy for increased trade between the GCC countries. The challenges include:

- Difficulty in aligning national and regional investment decisions
- Differences in regulatory environments between countries
- Limited scope of regional institutions
- Limited financing
- Changes in political framework
- Concerns about national sovereignty and energy independence
- Political matter will participate in the power trading

In general the load patterns for the interconnected countries are most similar pattern. Therefore, the major obstacles to trading the power between these interconnected countries are being in the same location and having a similar culture, behavior, and having same peak periods due to having similar weather condition. Beside that these countries having only two types of fuel could be used to generate electricity, which are crude oil and natural gas. The peak time for these countries will be viewed and discussed in this thesis.

Unfortunately there are differences in utility unbundling among the GCC countries. Some member states have not started to breakdown the structural foundation of the electricity utility. In these countries the ministry or a single authority are responsible for the power stations, transmission and distribution of electricity till customers. There is no active electricity trade among member states based on economical factors. The only participation among the states occur when there is emergency situations. In reality having a power trade within economical basis would certainly benefit to all countries.

1.4 Thesis Research Area

GCC nations is undergoing to couple the markets of the GCC countries and encourage them to participate in the Regional Market Trading evaluate. The current structure of the electricity industry in the Gulf Country Council region will be studied and analyzed. Therefore, this thesis research covers the following subjects:

- Propose Market Model suggested for GCC Regional Power Market
- Modeling the Electricity Load Demand for REM
- Modeling the generation unit costs for REM
- Finding a trading opportunity Model and exploring the trading potential for the interconnected countries
- Evaluating the reliability standard for the interconnected countries and the reliability margin for the trading system

1.5 Thesis Objectives

The objective of this thesis is to propose Multi Zone Border to Border Regional Market Model for the GCC countries in order to improve energy management and reliability. Such an objective requires finding out the answers of the following sub-objectives:

1) Market Model implemented for both GCC nations and Regional Power Market
2) Trading Opportunity Model to exploring the trading potential for the interconnected countries
3) Create Long Term Load Forecasting (LTLF) Model for the Electricity Load Demand for the MS's using Multi-Regression and Artificial Neuro-Fuzzy Intelligent System (ANFIS). Then demand load forecasted for GCC countries.
4) Create Zone Price Model for GCC Country and calculate the Energy Prices in the production cost in the GCC using AURORA and PROMO.
5) Calculate the Benefits Opportunity between MS's using LTLF Model and Zone Prices Model.
6) Create Machine switching reliability modeled using both curve fitting, and ANFIS methodology.
7) Create System reliability Model for LOLE using the Monte Carlo simulation methodology and AURORA software to Evaluating the reliability standard for the trading system.

The following techniques are employed in order to achieve the above listed sub-objectives:

- Academic Survey of the types of Market Model applied in different places in the world

- Visits to member states during this study
- Data collection
- Neuro-Fuzzy techniques
- Laplace Transforms technique
- Curve-fitting technique
- Markov process
- Multiple linear regression technique

The software used in the above techniques are:

- MATLAB, Simulink 7.10 package
- AURORA software
- PROMO software
- Microsoft excel sheet

Beside the above listed objectives and methodology, this study achieves many results and generate the Models targeted. Also, calculation for many outcomes like the benefits are achieved.

1.6 Scientific Contributions

This is an applied research thesis addressing actual problems in the development of REM, which opens the door for the six member states to achieve high saving from operational and maintenance of the generation units available in these countries. This research addressing issues in the GCC Regional Market, such as Power Trade Model, LTLF Model and opportunities Model created for GCC. In addition, feasibility of trading was founded by discovering the power trading opportunities between member

states where the Modeling for this opportunity were presented to member states.

The contribution in reliability side is creating two models for starting-up, Derating and Down States for the machines using Laplace Transforms, and ANFIS Model. The MATLAB Simulink 7.10 package is used to obtain the same results, where it is found that they are almost identical results. The transient state-probabilities for the four TVA models presented in Biggerstaff et al (1969) and at the same interval of time these solutions are reproduced by Laplace Transforms. For each model the three-state probabilities of the TVA models are derived. Each model is considered as 3-state model, where its equations are obtained using the curve fitting technique and Neuro-Fuzzy techniques. The results indicate that the transient – state probabilities are almost identical for both techniques. Most of each state – probabilities model formulated so far mainly employ transient state modeling to estimate the transient probability values of the TVA model.

The contribution in activating GCC Power Markets identifying the Market Players, study and obtain the market barriers, and finding the initiatives suggested to create the Regional Electricity Market. A survey was done to identify the Market Players in the GCC region. This survey is used to identify the states of the GCC electricity market and its readiness for such power trade. In conclusion, recommendation and a way forward to build a region Power Market presented and discussed. In addition, a model is recommended for structuring Regional Power Market and the requirement to restructuring to have an active Regional Electricity Market.

There is innovation in regard of modeling the Power Trading Opportunities, where Radar Power Trading Opportunities Model is created and Zone Power Trading Opportunities Model for both Week Ahead and Day Ahead Markets are created. The strength of this generated model is easy for visualizing and demonstrate the power trading opportunities between member states. The weakness of a given model is not covering the off peak periods and winter periods, where the same model could generate after studying it.

In addition, more contributions by modeling the LTLF through two studies and using three methodologies, which are curve fitting, Multi Linear Regression (MLR) and ANFIS to Estimate the LTLF for the Kingdom of Bahrain as an example. The results of the models used are presented in chapter 4.

The MLR Model use the main variables affects the peak load demand and will be selected to be used for the proposed Model. GCC Population and GDP are used to create the Models using the curve fitting, and Neuro-Fuzzy techniques. Different GDP growth scenarios based on development in the country will be taken in consideration. The growth rate, peak load and the growth rate of GDP use in different scenarios. The study formulate a simple equation which can be used to forecast the Peak Load Demand for GCC countries. This equation could be modified and updated in yearly basis to have more visibility for the Peak Load Demand. The average error output for the given models found for the Neuro-Fuzzy technique is equal to 0.53%, where 2% error is found in the multi regression method.

The strength of this study is showing the advantage of using model the MLR which has a simple equation that can be used in different types of software to calculate demand forecasting and different output requested by decision makers. Also, it presents the strength of ANFIS model that present a low mean error percentage of the forecasted load demand. The weakness in this study is modeling the LTLF for only Bahrain, and simplifying the equation used for MLR.

Moreover, in contribution in the Energy Price calculation, where the production cost for member state calculated using different methods and software's. The production cost, which named also the marginal cost calculation, for GCC generation units modeled using AURORA and PROMO software where the results presented. The strength of this study is by creating more data to calculate the production cost and the results was calculated based on electrical parameters. It is important to mention that variation of oil prices does effect the cost of power generations in the GCC countries. The drawback of this study is not comparing the fix and variable costs of different models to have a clear idea about the results.

The contribution in the economic side of this study presented in calculating the power trading opportunities benefits based on the results found earlier. The strength of that is to present the driver of going forward with REM, and the economic benefits of the interconnection for the services provided to member states in shape of avoiding load shedding by calculating Value of Lost Load (VoLL) and value of emergency support during the incidents. Also, the study shows the value of benefits earned by member states by exchanging the energy during the day. The strength of this study is to present the saving and benefits from the interconnection. But this study

need to calculate the benefits of sharing the install capacity and the benefits of sharing the spinning reserve between member states.

1.7 Thesis Outline

The thesis consists of seven chapters. Chapter 1 covers the background and motivation of the thesis, the market barriers presented. Then the thesis area of research, objectives and scientific contributions described. Chapter 2 is introducing the GCC interconnection and electricity market through a literature review, where it covers different types of RES, marginal cost price, experience form developed nations and RES, market status and barriers, methodology for market restructure, development of power trading prospects, interconnection market players and mechanism, historical of power trading, and option for market design. After that the results for GCC REM Model presented, including benefits required from RES.

GCC national electricity networks covered in chapter 3, where GCC national power system Introduced and power sector structure presented. Readiness of GCC for REM presented in the results, with challenges to the development of a GCC power market. In conclusion, the path to develop effective GCC power market towards presenting with recommendations.

Chapter 4 covers the GCC load demand forecast modeling & opportunity modeling. Types of load forecasting presented, and data collected to create the load forecasting demand model for the GCC countries. Results of forecasted LTLF using the model presented at the end of this chapter and ended by conclusion in this regards.

In Chapter 5, the opportunities for the power trading is modeled for GCC countries, where the market analyzed, and the REM operators described. The market size, trends, growth rate, profitability, industry cost structure, distribution channels, challenges and key success factors are described for the GCC REM. After that, results and observation from the diversity between the MS's peak load presented. In addition, opportunities in Spot Market obtained and summarized.

In Chapter 6, generation cost are modeled. Cost of electricity generation calculated, where the trend of it presented worldwide. Unit generation cost is calculated. Cost of electricity generation calculated at average, peak and base load cost in the generation units in GCC. The results are obtained for the marginal cost of GCC countries. On the other side, benefits were calculated for the GCC for the previous years. The chapter ended by presenting the system reliability model using curve-fitting technique method and ANFIS.

Chapter 7 is a summary of the thesis research, results, conclusion and recommendations for REM in the GCC Region. It followed by a references and appendices.

Chapter 2

Theoretical Framework and Review of Literature

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Chapter 2

Theoretical Framework and Review of Literature

2.1 Introduction

The six founding members of the GCC have started thinking on interconnecting their electricity networks since early 1980s. With the beginning of the first gulf war in the region and sudden turbulences in the global energy provisions, the GCC countries decided to ensure the security and stability of their electricity networks through building an interconnector to support each other at times of need, to share installed capacities and to reduce recurring costs over the coming years.

In this chapter a literature survey is carried for five different subjects. The first two subjects will present the different types of national and regional markets in regards of gaining the experience to develop these markets in the GCC region. The third subject was about Long Term Load Forecasting Model to create the LTLF for GCC. The fourth subject was about power trading opportunities between member states. The fifth subject was about reliability of switching the machine using Nuro-Fuzzy Artificial Intelligence Model.

2.2 Literature Survey on GCC Interconnection

The idea of having interconnection connecting the GCC envisioned interconnecting their electricity networks since early 1980s. A number of studies were carried before creating the interconnection. Some of these studies were done during the period 1980s - 1990s, a number of studies were carried as mentioned by Al-Asaad et al (2008) to see the feasibility through a techno-economic studies conducted to justify the technical needs and financial benefits for the building of an interconnector that stretches from the south of Kuwait till the north of the UAE, passing through Saudi Arabia, Qatar and Bahrain.

Al-Ebrahim (2003) presents the threats and challenges in developing Electricity Markets in the GCC, where the author spots the lights on a number of issues and barriers related to the establishment of the regional power market. There were a number of studies done by Al-Ebrahim to explore in 2004 the road towards creating competitive electricity markets between gulf countries and the way to create a competitive market in the Middle East countries in (2005). These studies have suggested a Market Model for this regional electricity market, which needs to be developed between the 6 countries of the GCC and across.

Al-Ebrahim (2008) explores the opportunity of power exchange and trade between the Gulf Countries where he presents a great potential for power trading between the countries proposed to be interconnected. Such studies promised that the GCC states would receive further benefits from interconnecting such as reduction of operating costs, sharing of operating and installed capacity reserves and raising the level of electrical network's

stability and reliability. The development of this project was halted due to the Iraqi invasion of Kuwait in August 1990 and its impact on the region.

The project was classified as described by Al-Asaad et al (2008) into three phases and based on the benefits the shares found in this study and presented in Table (2-1) the project budget were allocated also. The project was planned to be realized in different phases based on the interconnection topology illustrated in Figure (1-1). After completion of phase I, the Techno Economic Analysis study was updated in new report called "2004 TEAR", where it was presented with the expected benefits of US$2.5 billion saving for phase I of the project, where more benefits will be gained from the formation phase II & III reaches to about US$3.5 billion of expected saving.

Table (2-1) GCC countries' shares allocated for building the Interconnection

Country	Phase I%	Phase II& III%
Kuwait	33.8	26.7
Saudi Arabia	40.0	31.6
Bahrain	11.4	9.0
Qatar	14.8	11.7
UAE	---	15.4
Oman	---	5.6
TOTAL	**100**	**100**

Transforming the GCC Power Sector into a Major Energy Trading Market was presented by Al-Asaad et al (2010) base on SNC-Lavalin International Incorporated study, "GCC Electrical Interconnection Grid Market Study Report" done in March 2004. The study was done after commissioning in 2009 the interconnection between the national grids of Kuwait, Saudi Arabia, Bahrain and Qatar, which is the first phase of the

GCC interconnection project. To establish a regional market for GCC, Al-Asaad et al (2010) recommend the following measures in sequence:

1. Allow competition at entry in the generation through the introduction of IPP's and set up a single buyer;

2. Establish vertical and/or horizontal separation to enhance competition.

3. Establish open access to transmission to allow generators to wheel power to distributors and large customers.

4. Form a national wholesale market and ultimately a regional power pool.

These studies did not cover the barriers might stop the trading between the member states.

2.2.1 Marginal Cost Price in REM

It was projected that the interconnection would create an active environment for power trading between the interconnected countries. The member states would consider establishing rules and regulations that support and enable cross-border power trading. Al-Ebrahim et al (2010) present in their paper "Launch Pad of GCC Electricity Market" a wheeling Model for the interconnection, where a simulation of economic benefits presented and Marginal Cost Curves for all member states obtained as shown in Figure (2-1) to Figure (2-5).

From this study the Marginal Cost Curve for all member states were calculated and presented. The market type used was the bilateral model which required as mutual agreement between the traded party on prices and quantities regardless of the marginal cost of the member states.

Although, there was a well-developed agreements which address all related subjects, and jointly Authority with a task to facilitate the commercial activities, the trading was not activated between them.

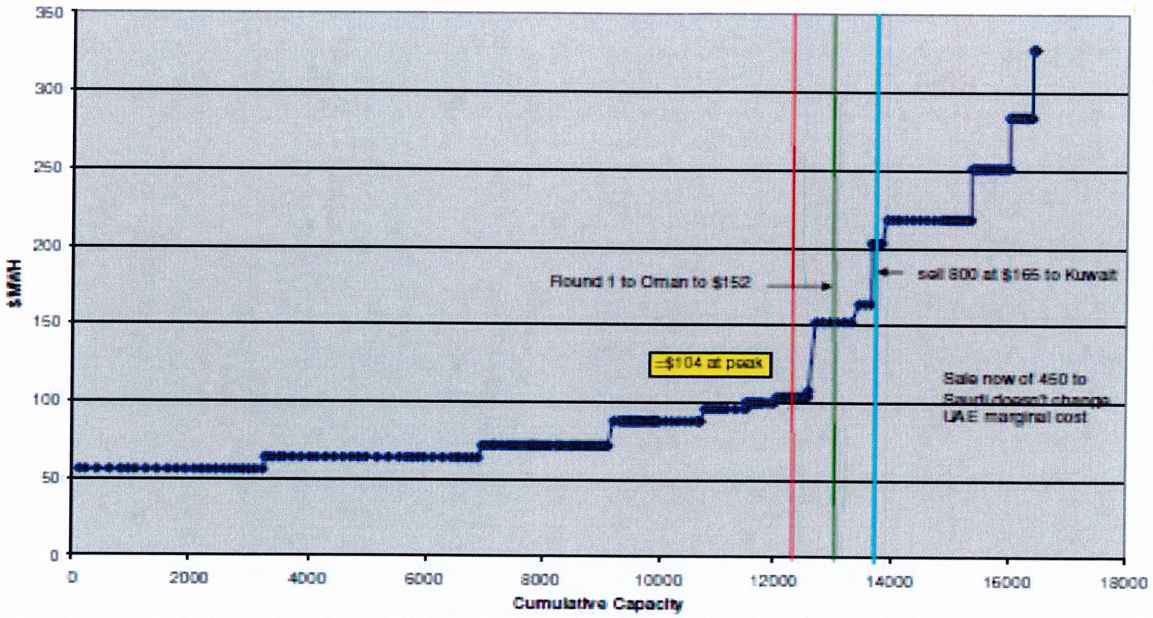


Figure (2-1) Marginal Cost Curve for UAE

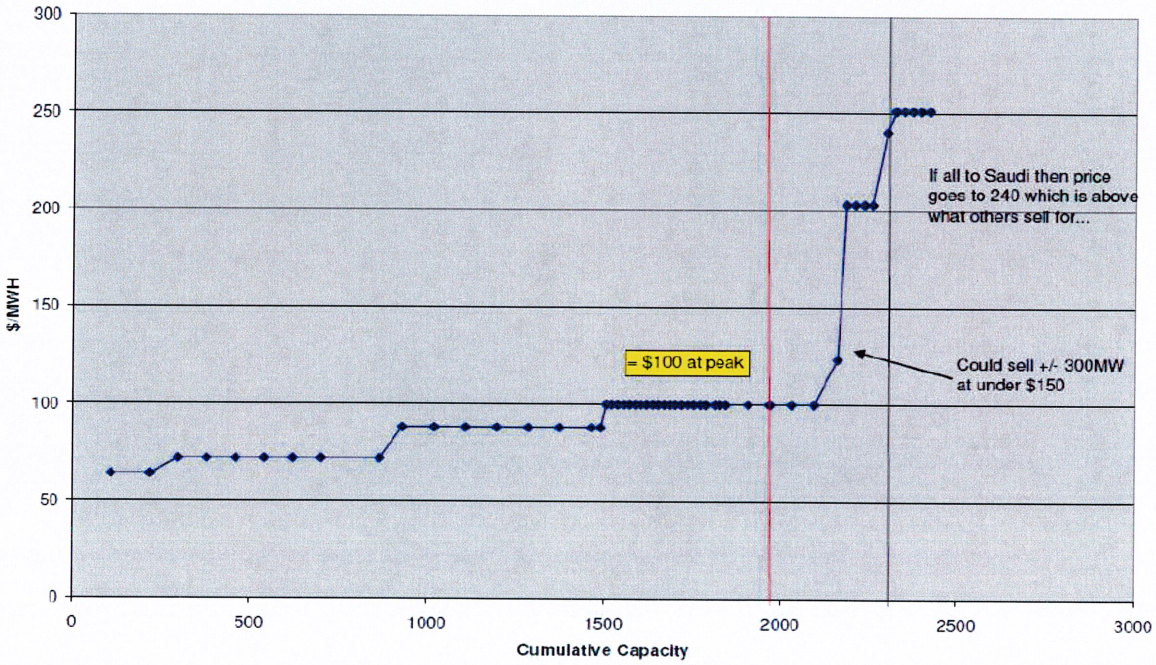


Figure (2-2) Marginal Cost Curve for Bahrain

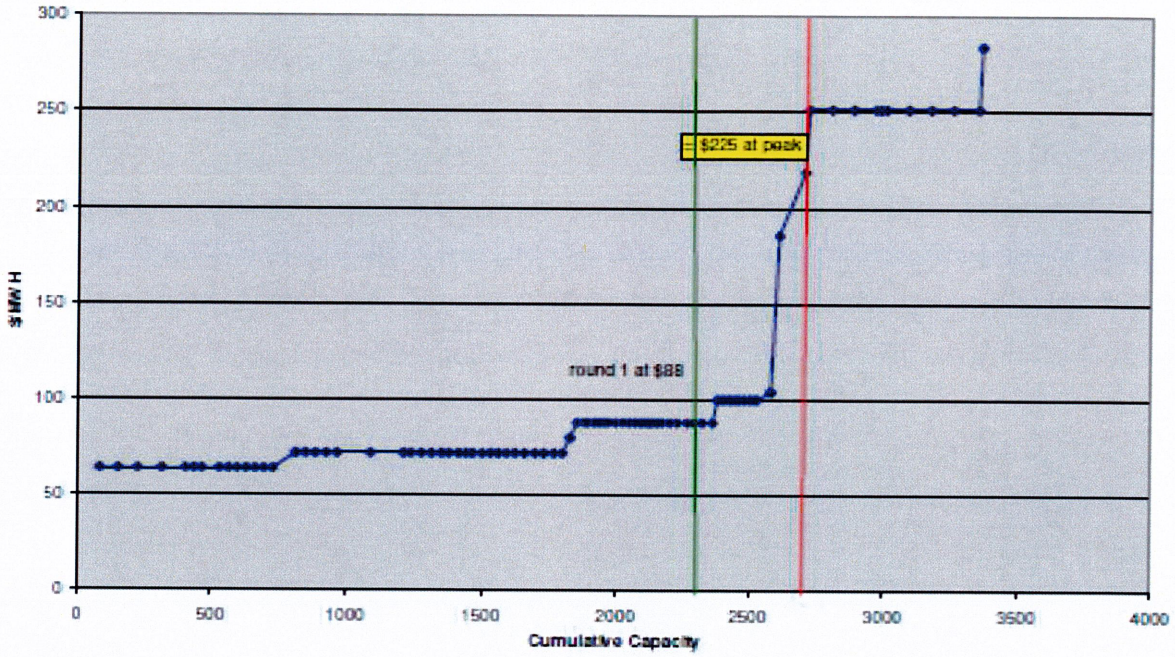


Figure (2-3) Marginal Cost Curve for Oman

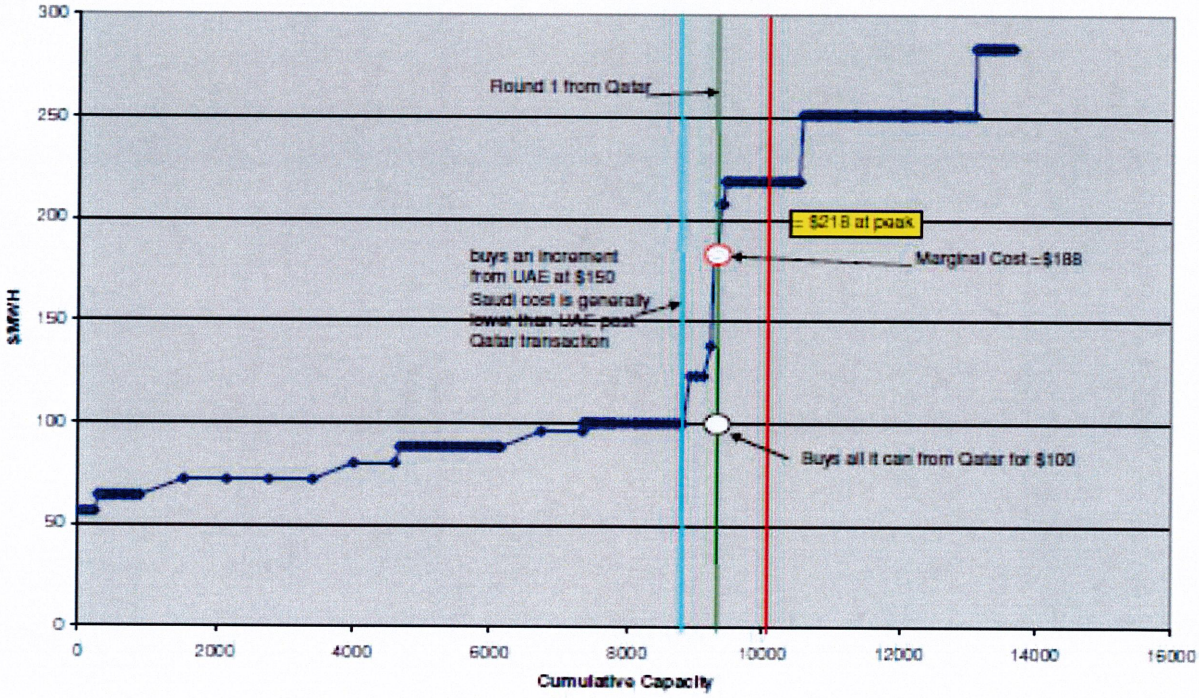


Figure (2-4) Marginal Cost Curve for KSA

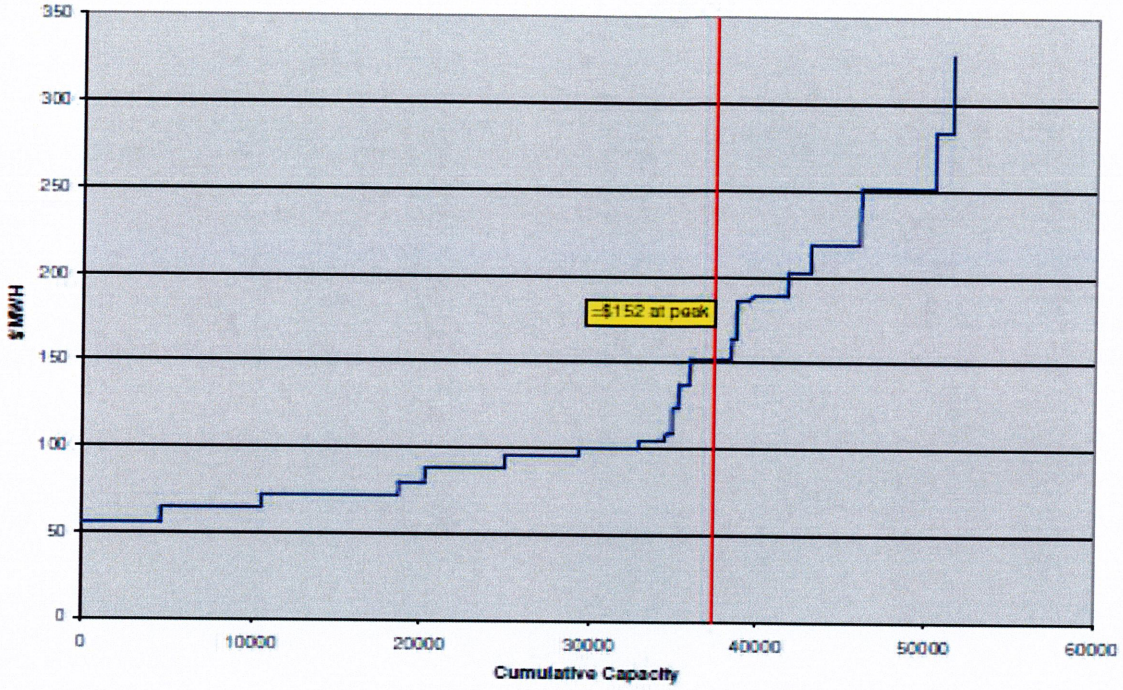


Figure (2-5) Marginal Cost Curve for GCC Countries

2.2.2 Experience form Developed National and Regional Markets

The wholesale national electrical power trading market is a new revolution in concept in the electricity industry. Historically the first wholesale market found in Chilly as a trend for electricity market liberalization began in the early 1978. Al-Sunaidy et al (2005) present the start of electricity markets in Chilly. It formed the first wholesale pool market in 1978, where the generators are selling their power to retailers. Also, they present the world's first multi-national electricity market in 1996 which called Nord Pool when Norway established customers a choice of supplier and electricity pool in 1991. Then their network extended to join the Sweden Network in multi-national market for electric energy. This shows the importance of the development of national markets in the development of the regional markets.

Steiner (2001) in his paper and Stoft (2002) in his book both introduced the electricity wholesale markets, where Stoft point that perfect competition equilibrium resulting in higher profits and less production.

The Electricity Pool was established as the setting for competition between generators in England and Wales in 1990. They develop the pool market to allow consumers to choose their supplier by early of 1998. Norway established its electricity pool in 1991. The rules were developed to allow the customers to choose the supplier. First multi-national electricity market in the world's was the Nordic Power Exchange (Nord Pool) which was established in 1993 as a Voluntary market where Zonal price is implemented. The Australian state of Victoria sets arrangement in the pool market in 1994. After that, New South Wales established the Wholesale Electricity Market in New Zealand in 1996.

Cepeda and Finon (2011) in their paper test the effects of different market designs on interconnected local markets within a regional market. They have developed a system dynamics model consisting of two interdependent markets, assuming a perfectly competitive regional market constrained by interconnection capacity. A comparison was made between cases where price-capping and capacity mechanisms are introduced. The simulations show effects which are different on short-term and on long-term. The simulations show energy-only market acting as if a capacity adequacy policy is in place.

The potential for interconnections and increasing market integration in the Irish Single Electricity Market (SEM) study was carried out by Nepal and Jamasb (2012). The authors used a time-varying Kalman filter technique to assess the degree of market integration between SEM and other large,

mature and interconnected wholesale electricity markets in Europe including Great Britain (GB). The study shows that the current state at that time of market integration between SEM and GB is just 17% indicating potential to improve market integration via increased interconnector capacity. Their results suggest that significant opportunities exist to improve the market integration between SEM and other markets via increased interconnection.

Sam (2014) presents in Figure (2-6) nine organized electric markets in Northern America are well-functioning markets includes retail competition. It is in the Pennsylvania, New Jersey, Maryland Interconnection (PJM), New York, New England, Texas and two in Canada. Most of United State of America states had considered the possibility of electricity deregulation at late 1990s.

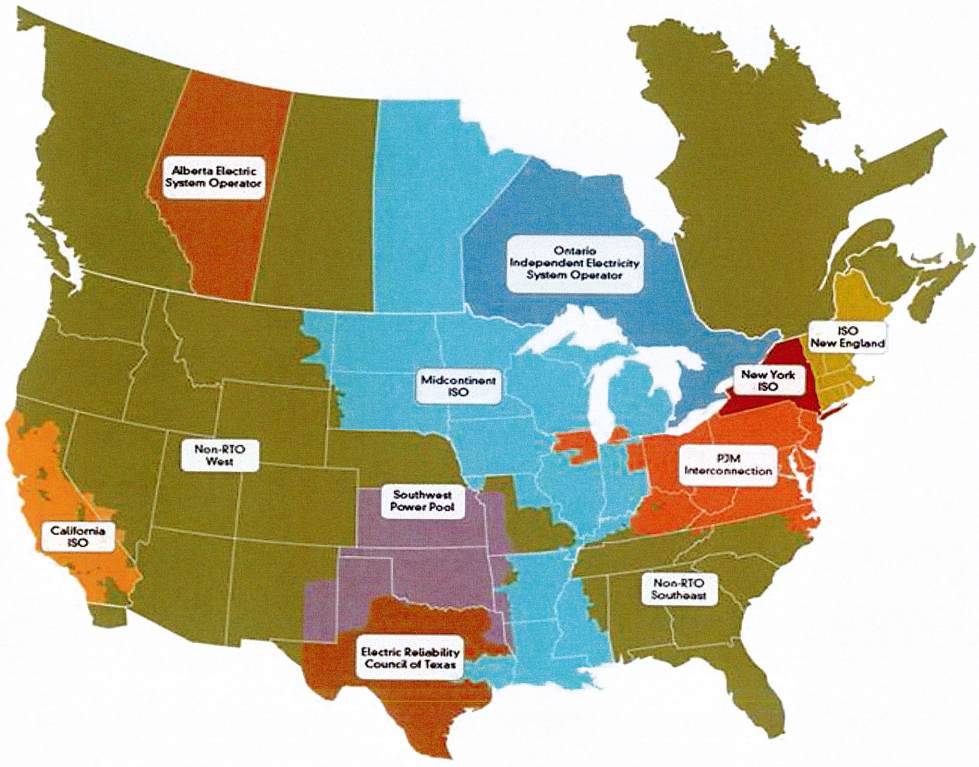


Figure (2-6) Organized Markets in North America

Glachant et al (2003) discuss the recent developments in the European electricity markets. Al-Sunaidy and Green (2005) present that the electricity market got great support when a European Union request from its Member States to adopt a number of deregulatory policies in the electricity utility sector. They indicate that the price coupling at Europe started from Nordic countries from 1993 to 2000. After that the Market Price integrated between the markets in the Netherlands, Belgium and France in 2006. Spain and Portugal started market coupling in 2007 through the Market Operator MIBEL. The Czech Republic and Slovak Republic established their market coupling in 2009.

Market integrating between the Netherlands, France, Belgium and Germany came into operation in 2010 through Central West European Market Coupling (CWE). The CWE region and the Nordic and Baltic regions coupled in 2010 through the Interim Tight Volume Coupling (ITVC). The CWE was integrated with Nordic ITVC through the NorNed cable in 2011, where market coupling between Italy and Slovenia were started. Hungary which was integrated with the Czech and Slovak Republics, coupled its market with them. The market coupling for both North-West Europe and South West Europe have taken place during 2010 to 2014 based on Price Coupling of Regions (PCR) which could be presented in Figure (2-7) from Al-Sunaidy et al (2005).

Southeast Europe Market SEE combined with the potential for future European Union (EU) membership, Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Kosovo, Macedonia, Montenegro, Romania, Serbia, and the EU signed the treaty establishing the Energy Community in 2005.

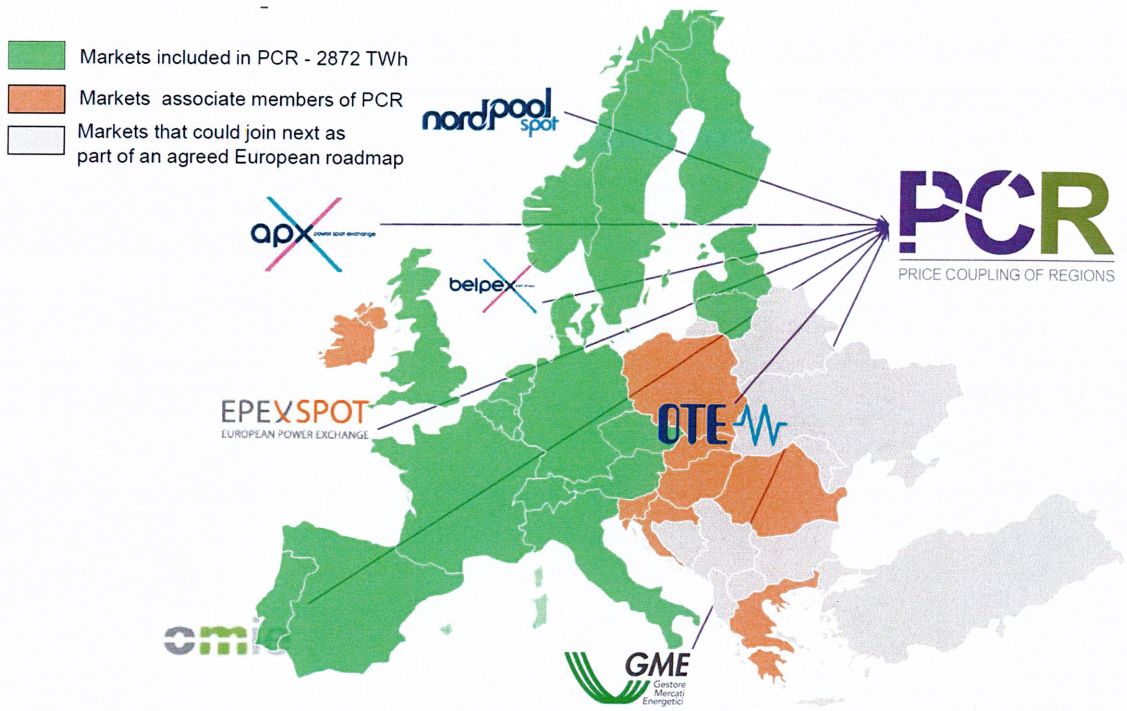


Figure (2-7) Present status and indication of possible developments for PCR

In the same period of initiation GCC interconnection, the Central American Electrical Interconnection System (SIEPAC) interconnection initiated, at Central America's connecting six member states. They come up with an idea of seventh market as their Regional Electricity Market. Economic Consulting Associates (2010) present the regional trade solution through SIEPAC consists of two interdependent projects. These projects are:

1- The first project was the development of a regional electricity market (REM) based on a standard set of trading rules at the regional (supranational) level. Part of the REM initiative is the creation of a regional institutional structure, including regional regulator and a regional transmission operator. The shape of the six

national markets, and MER's interrelation with them is shown in Figure (2-8) from Economic Consulting Associates (2010).

2- The second project was the development and completion of a new 1,800 km international transmission line, running from Panama in the south to Guatemala in the north, that will increase transfer capacity at all borders in the region to 300 MW. The transmission route is shown in Figure (2-9) from Economic Consulting Associates (2010).

The objective of the SIEPAC project is to achieve potential gains from integration. The REM is supported by a regional market and the system operator (EOR) and a regional regulator, with associated technical and market codes.

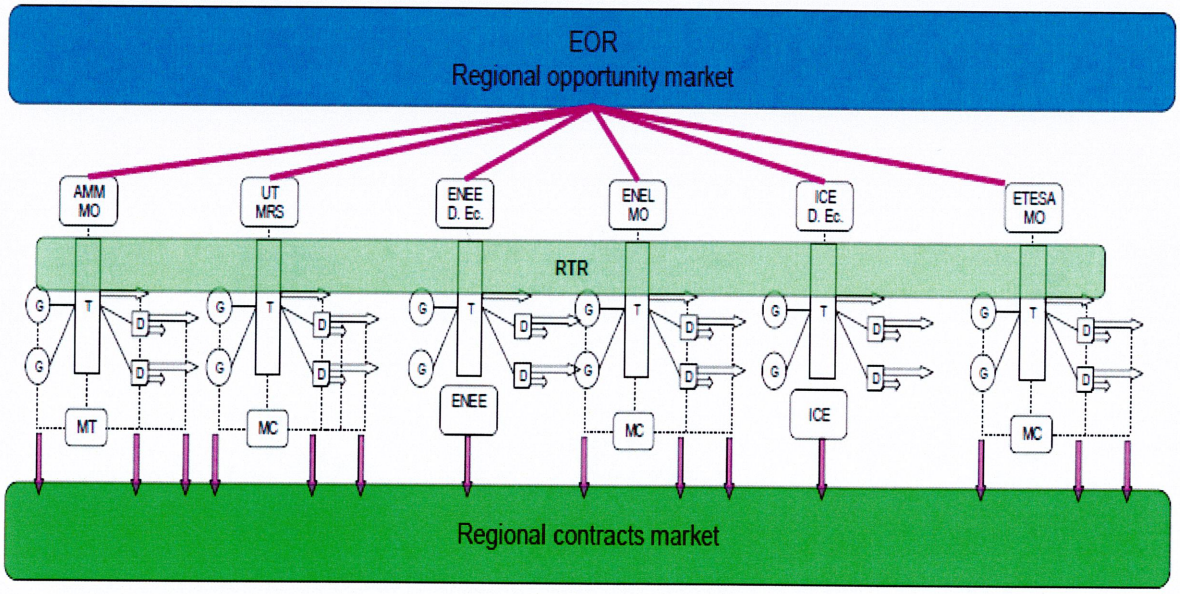


Figure (2-8) Regional Electricity Markets the Seventh Market besides the Six National Markets



Figure (2-9) SIEPAC transmission line route

Although some trade has occurred already in the REM using the existing Regional Transmission Ringmain infrastructure, but several challenges and opportunities found as follows:

1- Encouraging trade while reserve margins are low.
2- Demonstrating the reliability of the new trading system, particularly its institutions.
3- The lack of regulatory harmonization among the countries.
4- Going forward with regional-level investments, especially in the private sector.

South Africa Power Pool SAPP Regional Market (Economic Consulting Associates, 2010) and interconnection were formed through an intergovernmental Memorandum of Understanding formed in 1995 as shown in Figure (2-10). The main driver for this market was to optimize use of

resources across the region and support each other during emergencies. A cooperative pool formed based on bilateral trade. This market developed as a short-term energy market, which started in 2001 followed by the balancing market in 2002. Moreover, the day ahead market was developed in 2009, imbalance settlements in 2010.

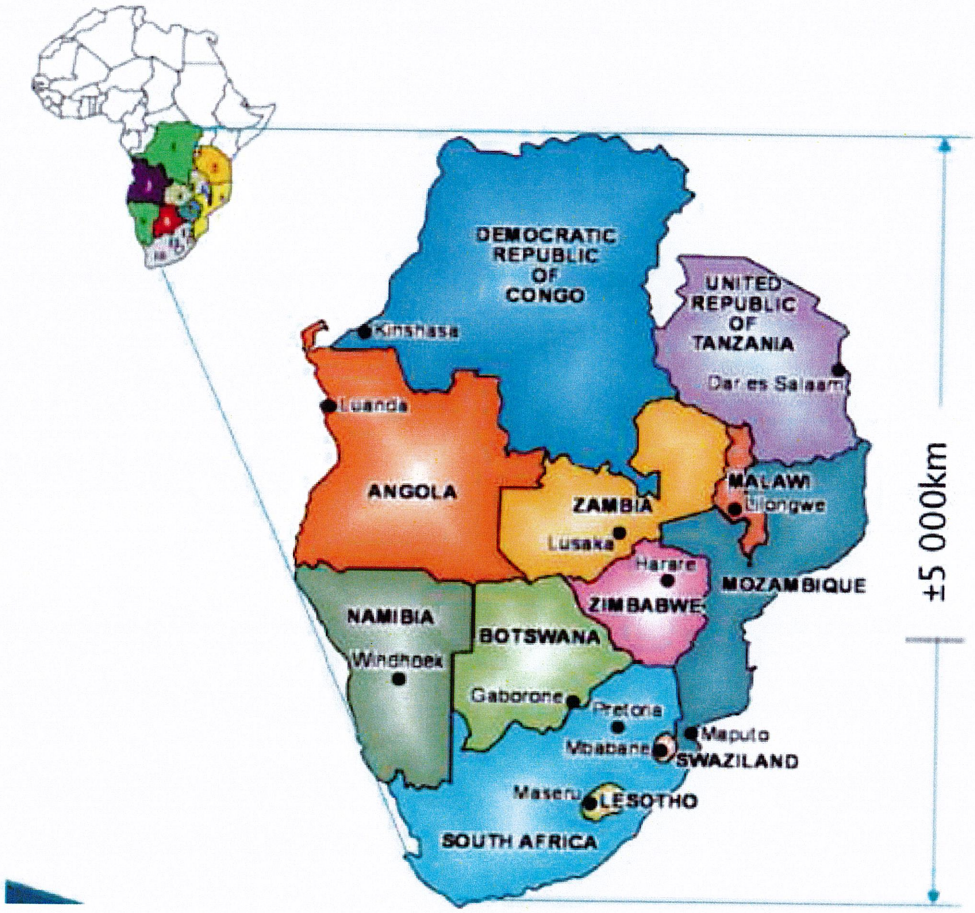


Figure (2-10) SAPP interconnected Region

This case of market would like to be developed from the cooperative shape into competitive level of the energy market to achieve the following:

- Better utilize resources
- Reflect accurate prices
- Enable demand-side response
- Correct investment signals

The challenges in this market could be summarized in the following:

1. Shortfalls in reserve capacity
2. Subsidized tariffs
3. Poor telecommunications
4. Congested transmission

Economic Consulting Associates (2010) present also the Australia NEM interconnection and Regional Market presented as shown in Figure (2-11). It formed as a national electricity market by five jurisdictions in 1998. United market agreed by the states. Therefore, incentives provided by federal government to the states, which help to open the market to competition. Queensland interconnected in 2000, Tasmania interconnected in 2005 and Western Australia State (WAS) interconnected in 2007.

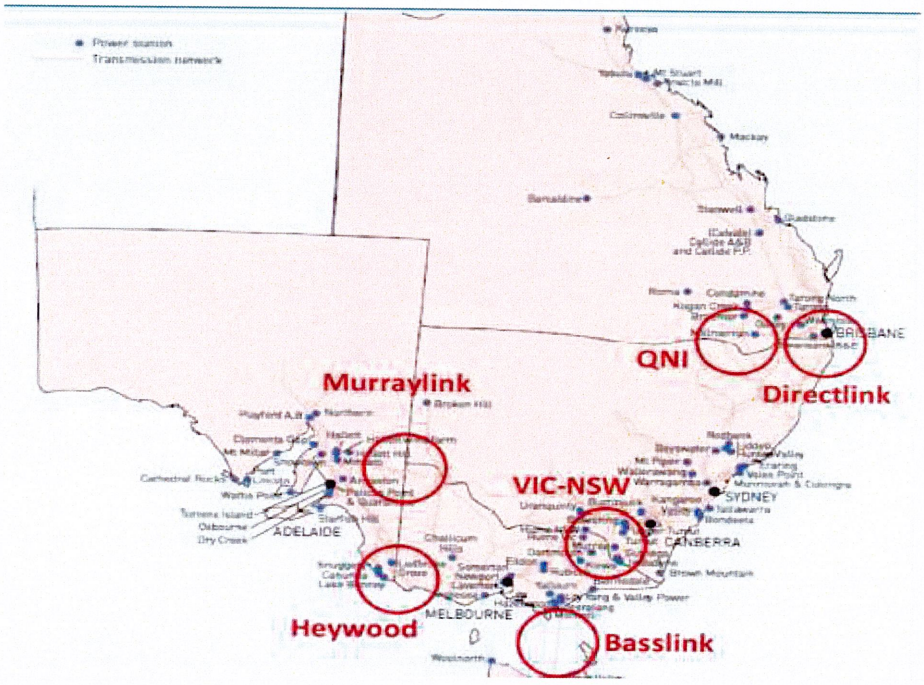


Figure (2-11) Australia NEM interconnected States

Zonal pricing implemented between the states, where one zone considered for each state. In regard to organize the interconnection and the market, one federal regulator took over the responsibilities from 13 state

regulators in 2009. Any changes must approved by each state to be implemented. Australia has a master agreement to smoothen process between all states.

2.3 Methodology for Market Restructure in GCC Region

The present study will focus on the requirements of having active Regional Electricity Power Market, where the target of this study will focus on the requirements of having acceptable levels of member state's readiness toward participating in the Regional Electricity Market. Both developments considered the journey to liberalize the GCC electricity market for National and Regional Markets. Unbundling electricity utilities might be considered as one measurement indication of member state's readiness. The member states readiness is important to have an acceptable level of market platform and participation from market players. The Regional Power Market required development to open all member states electrical industry to each other. This helps to bring more benefits to GCC countries and utilize the natural resources in the Gulf region.

In this study, the four basic options (models) are presented and introduced to design electricity markets. These models are listed and evaluated. The requirements for building region Power Market presented and discussed. In addition, a model will be recommended for structuring Regional Power Market and the requirement to restructuring it to have an active Regional Market.

The methodology is introduced and applied, which is illustrated in Figure (2-12). It shows the applied methodology to bring the barriers to activate regional power market in the GCC region. The methodology started

with collecting the data required about the utilities interacted with the regional power market and classify them according to their natural activity. Then a work on identifying the barriers holding activating GCC Power Market is curried out. After that, different types of market model are listed down as an option available and suggested to be solutions to the given barriers. At the end, a recommendation raised based on the analyzed information and nature on interconnection available and agreements used between the member states.

The given methodology will be used in both the present chapter and Chapter 3 to have an acceptable level of member state's readiness toward participating in the Regional Electricity Market and the Regional Electricity Market Model suggested for the interconnected member states.

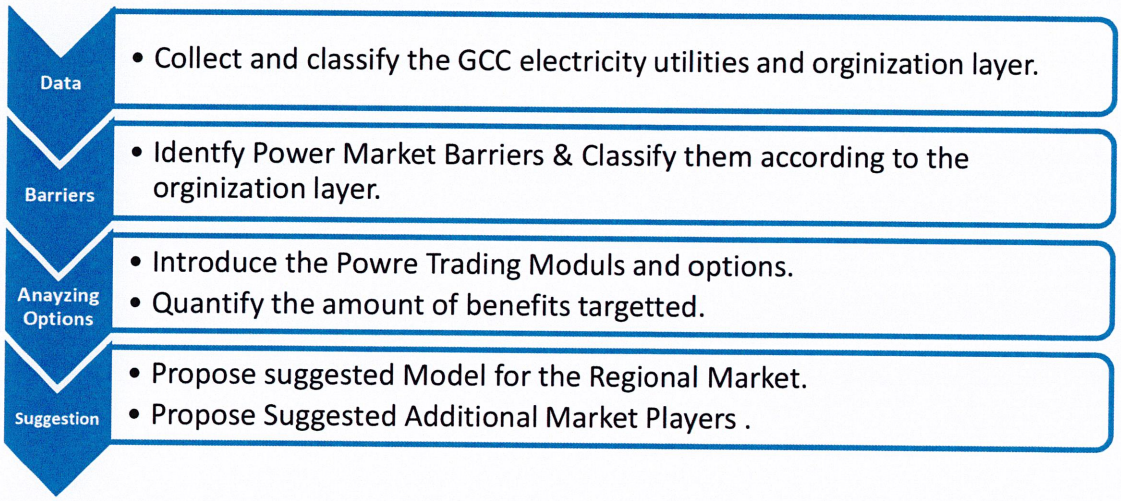


Figure (2-12) Methodology proposed

To have more understanding of the barriers holding activating the power market, it is required to understand the organization level for the national power markets, market mechanism and power trading history.

The organization level for the Gulf Countries Power Market are consist of one regulatory layer, two business layers and one physical layer. The

Advisory and Regulatory Committee (ARC) represents the regulatory layer. This committee is represented by two members from each of the six member states. They have a regular meetings and looking after all regulatory aspects related to the interconnection and GCC Interconnection Authority (GCCIA).

The first Business layer is the Bilateral Contract Market. In this layer, the member states can formulate Power Trading Agreement. The buyer or seller should reserve the Interconnector Right of Operation "IRO" to be able to exchange the power between them. The IRO allocated through auction carried periodically using Energy Market Management System EMMS. The bilateral contract will be valid only when the traders collect approval from GCCIA using valid trading notification form "VTN". The Interconnector Control Center "ICC" will arrange the scheduling for the trading where the Market Operations Section will arrange the financial and energy settlements.

The second Business layer consists of six transmission operators, which signed the Power Energy Trading Agreement. They have the right in utilizing the interconnector for the benefits mentioned in the agreement. This agreement allows more market to be involved in this market.

2.4 Market Status and Barriers

The GCC national networks integrated when the member states were vertically integrated system. Its electricity sectors need to be more liberal and flexible to be able to manage their resources. The next step for these countries is to start unbundle their systems to build their National Electricity Power Market. Al-Ebrahim (2009), El-Katiri (2011) and Al-Haddad et al (2013) introduced a number of barriers holding these countries from

participating in power trading between the member states and can be summarized as follows:

- **Differences in local regulations towards cross-border power trading.**
  - Some regulation entities in the region have not addressed the issue of cross-border power trading nor has treated it in local policies. Power trading to some local regulators is labelled as undefined and not within the jurisdiction.
- **Misconception about the role and benefits of the GCC Interconnector for the member states.**
  - The concept of using and depending on the Interconnector for emergencies and contingencies is overwhelming the benefits and better utilization of the interconnector for power trading. Member states still operate and think in isolated networks mind set and accounting for the interconnector only at times of need.
- **Lack of power trading awareness.**
  - The concept of power trading is very new to this region. There is virtually no local expertise or knowledge base that are related to this kind of commercial trade.
- **Slow realization of power trading concepts within the electrical utilities.**
  - Although the member states have signed the PETA in July 2009, some utilities didn't show visible signs in serious implementation and embedding the agreement's concepts and forms of power trading within their systems as described by Fattouh et al (2012).
- **Political weight of the energy sector.**

- In this oil-rich region, energy is considered a national asset that defines the weight and importance of each member state. Developing this asset into a commercial commodity needs time and effort. Energy policies are always within the local governing bodies control and manipulation.

- **Dependency on government-supported subsidies.**
  - Figure (2-13) shows the average subsidy rates for domestic fuels in selected countries in percentage in 2010. The domestic sector receives the highest allocation of subsidy due to its overwhelming demand and nature. The given figure shows clearly how the power sector is thriving on governmental support as described by Richard (2009).

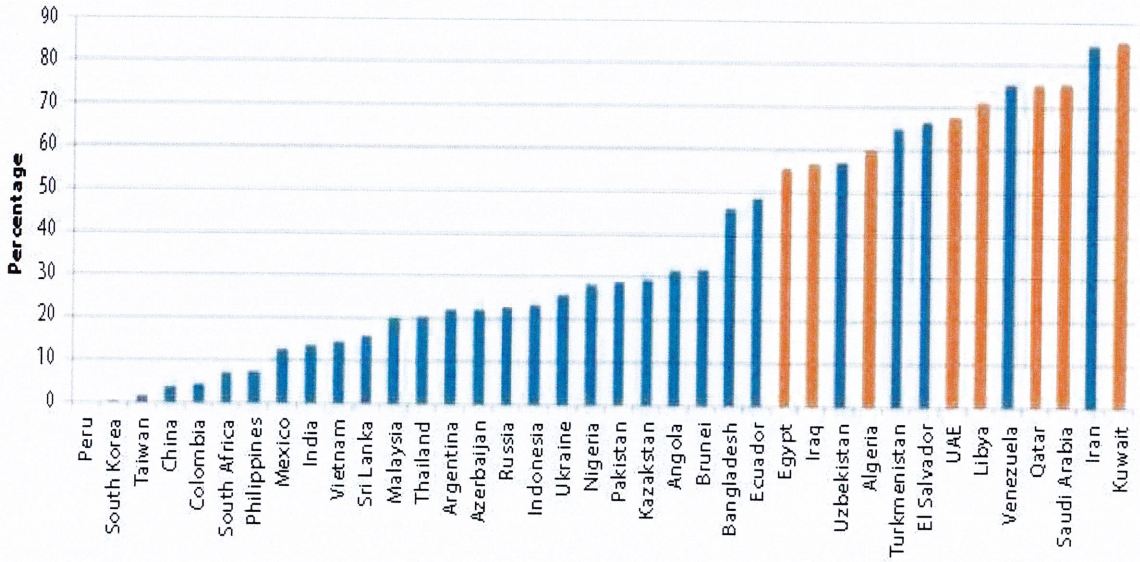


Figure (2-13) Average subsidization rates for domestic fuels in selected countries in percentage in 2010 - El-Katiri (2012)

- **Differences in utilities organizational structure.**
  - It has been reported by the World Bank study of the Arab League interconnection that there is variation in the progress of utility unbundling across the region. This has caused concern in adoption of new concepts such as power trading and sharing of reserves.

- **Limited Number of market participants in the power sector.**
  - The single buyer single seller model is the dominant type. There is almost no local power market in the region. With such situation, the local power market is assumed to be monopolized.
- **Limitation of access to the Interconnector.**
  - Connection to the Interconnector is handled by the member states TSOs only. Though the Power Exchange and Trade Agreement dictates that additional participants can sign-in, no new players have been introduced yet due to apparent local restriction to access the grid.
- **Non-existent cheap resources of energy generation.**
  - Due to availability and cheap fuel in the gulf, Fattouh et al (2012) stated that member states started recently to seek alternative resources in order to conserve and strategically market its oil production, instead of dedicating it for increasing load demand. Figure (2-14) shows the current type of fuel to generate electricity in the region.

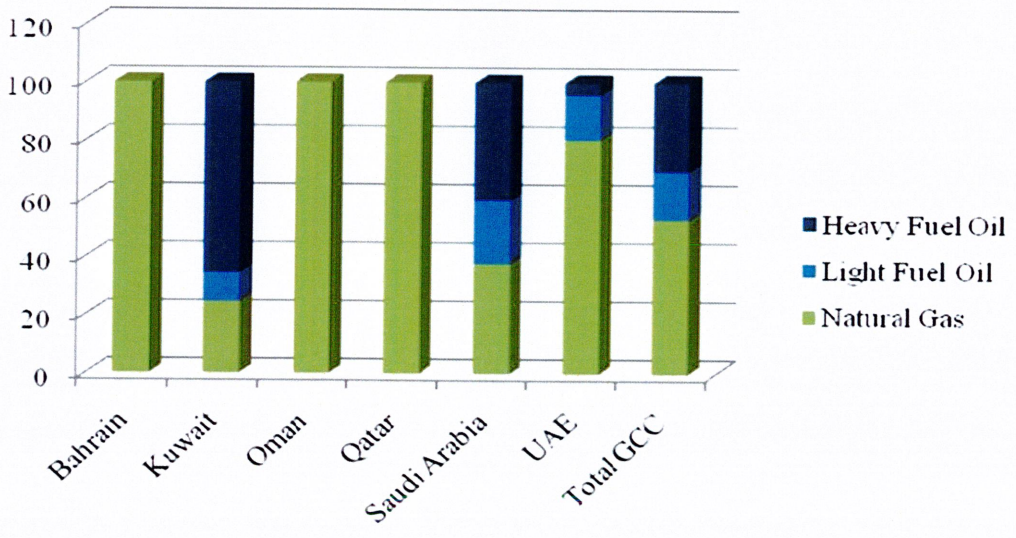


Figure (2-14) GCC Fuel Consumption in Percentage for the Power Sector in 2012 - El-Katiri (2012)

The consolidated list above has been gathered through multiple meetings and discussions with key-officials and technical related staff from GCC utilities. It has been noted that most of the issues are common and they construct a wall against development of effective power trading between the member states. It can be seen that there are issues that could be of common origin and can be addressed in a suitable applicable proposal that would be practicable, acceptable and in line with the member states long term strategic planning and vision.

There are differences in utility unbundling in the GCC countries. National markets stand still in the first level of unbundling development. The market organization layers shown are symbolizing the structure for the organization layers found in the GCC Power Market. The GCC countries' participation was still not an active participant in the market by offering or requesting power for trading on an economic basis. The participation found was due to the emergency energy requirement.

In this study, these barriers were classified into different levels, but it has a certain level of effect on active participation in power trading. Classification for these barriers found distributed according to the organization layers introduced as shown in Figure (2-15). The organization layers consist of four layers, which are the regulatory, business layers 1 and 2 and the physical layers. Each layer has its own-targeted utilities in the GCC. Some utilities are taking the responsibility of two or more layers. Success unbundling presented when each utility is working with only one layer. This class will help in focusing on the problem found in the GCC regional market and helps in addressing the trading barriers.

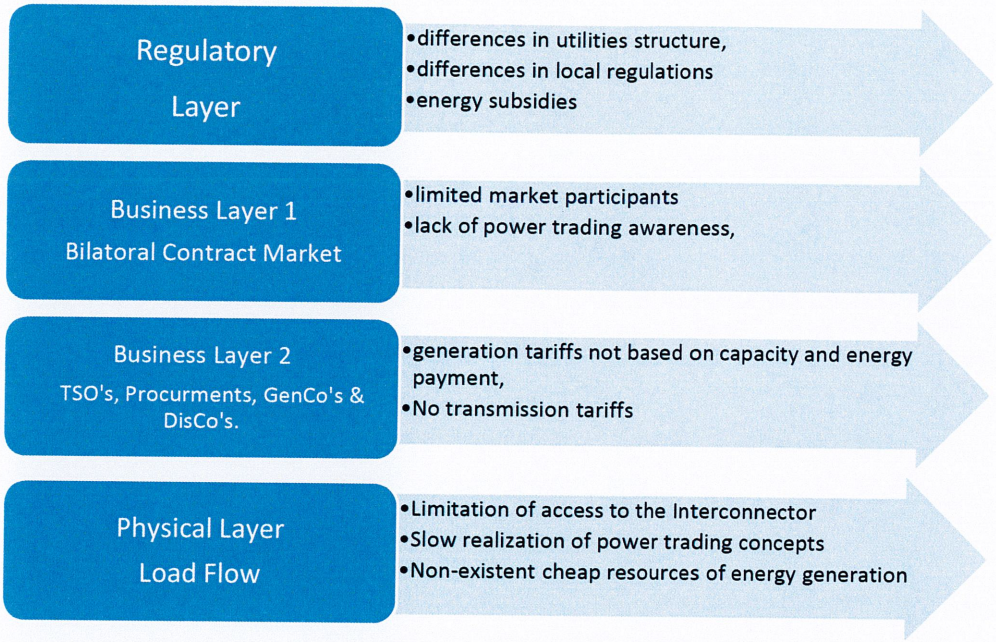


Figure (2-15) The Organization Layers for the GCC Power Market

The barriers classified for each layer are as follows:

A. Regulatory Layer Barriers: There are three barriers in this layer, which are as follows:

1- Differences in utilities organizational structure;

2- Differences in local regulations towards cross-border power trading;

3- Energy subsidies;

The general agreement imposes a committee called Advisory and Regulatory Committee (ARC). The committee is responsible for the regulation of the regional utilities between the GCC countries. The local regulation towards cross-border could organize through the ARC committee, which has a representative from each member state. This committee requested to harmonize the regulations between the interconnected countries.

Energy subsidies are one important subject which required many efforts to be addressed during the unbundling the electricity utilities in each member state.

B. Business Layer Barriers: There are five factors affecting trading activities on the business layer. They are as follows:

1- Having limited number of market participants in the power sector,

2- Lack of power trading awareness,

3- All generation tariffs and Power Purchase Agreements (PPAs) not based on capacity and energy payment to recover costs,

4- Transmission tariffs not allocated for trading activities,

5- Taxation and royalties on export of electricity declared for power trading.

C. Physical Layer Barriers: There are three main problems, which listed as follows:

1- Limitation of access to the Interconnector.

2- Slow realization of power trading concepts within the electrical utilities.

3- Nonexistent cheap resources of energy generation.

2.5 Development of power trading prospects in the GCC region

The main purpose of the interconnection is to have emergency support. The trading was placed as additional benefits and could gain from the interconnection, where the electricity industry is developed in the region. The economic studies shown earlier presents a technically feasible

demonstration that the interconnection among the GCC member countries. It shows that the main benefits presented in terms of reserve sharing, emergency support and economic exchange of electricity. These benefits could be achieved by developing the regional electricity market between the gulf countries. Therefore, the GCC countries need to reform its power sector to facilitate regional trade.

There were different ways to commercialize power as shown in Figure (2-16). The selected market model as per the signed agreement for power energy trade PETA is the Over-The-Counter or bilateral. The basic concept of the regional market is based on bilateral contracts between these countries, which was the module agree by the GCC countries to have as Market Model. At that time, GCC countries were in shape of Ministries. Some member states were planning to develop their electricity sector to be as a single buyer to directly contract with power suppliers as price and quantity for a well-defined amount of power which are determined bilaterally between both parties. The parties are modelled to interact between themselves as shown in Figure (2-17).

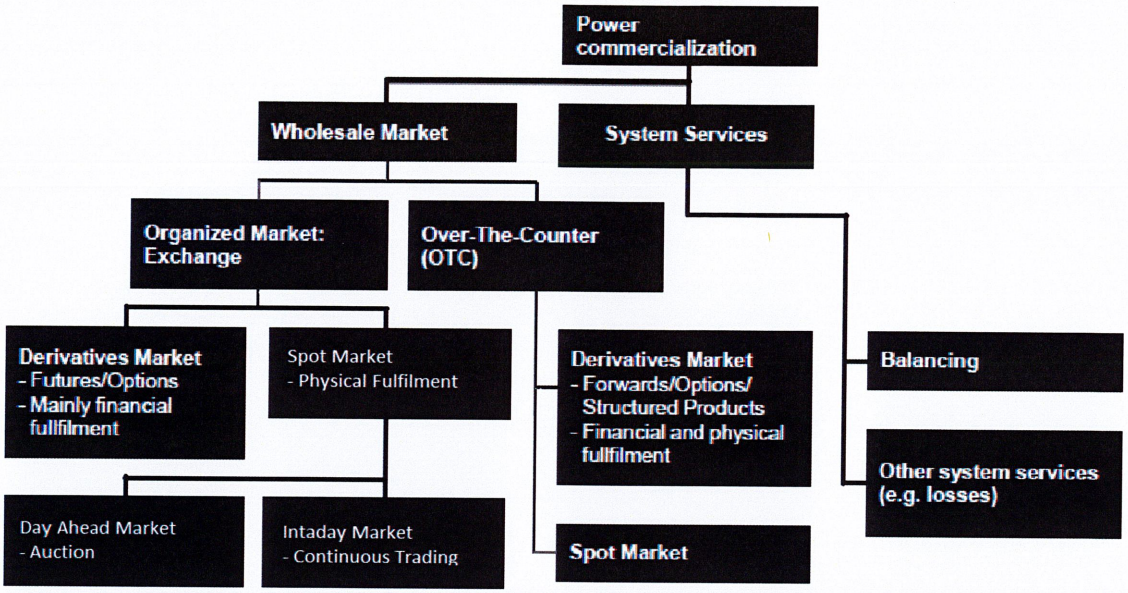


Figure (2-16) Different Ways of commercializing power

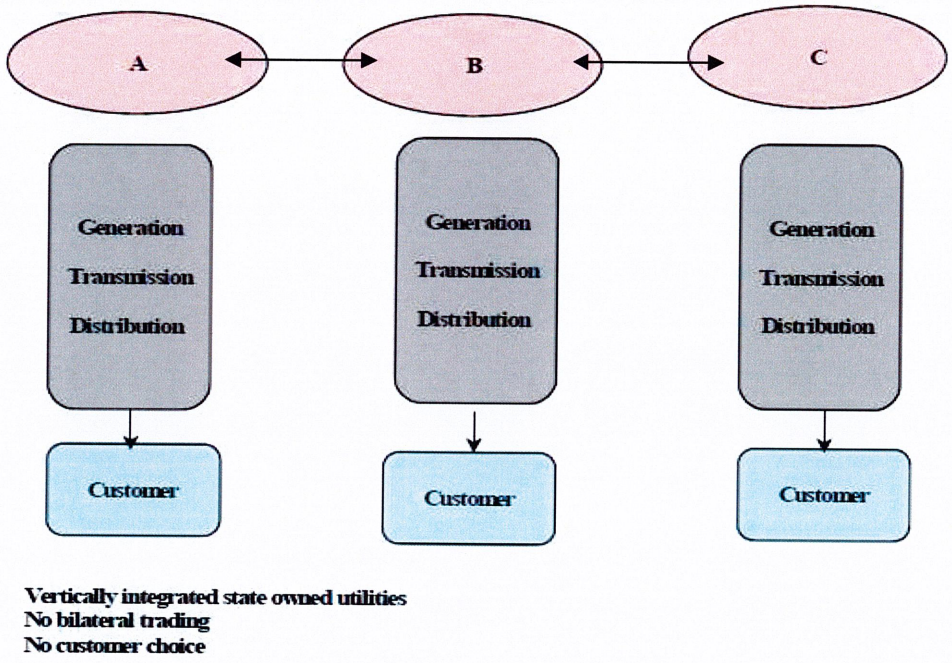


Figure (2-17) Current Electricity Market Model

The market players are the parties which signed the PETA agreement, where they are determined by the structure and legislation of each member state. The parties are consisting of transmission system operators and the

procurement parties who sale the power and energy. Currently, there are nine parties considered as market players.

There are two agreed path for trade on the GCC interconnection and two paths considered as an excessive use of system for trading. The two agreed paths are the scheduled and unscheduled power exchanges. The scheduled power exchange comes when there is a freely negotiated between the procurement parties until they have a deal formed in shape of bilateral agreement between the two parties. So, the prearranged bilateral trades between member states will be scheduled after getting the valid trading notification after reserves the right to transfer the energy agreed in the bilateral contract. The parties can procure the transmission right of operation for use of the GCC interconnection from the GCCIA through an auction system. The GCCIA must release a periodically auction, start from yearly, monthly, day ahead auctions, where the parties must go for these periodically auction systems to get the interconnection rights for operation through the Energy Market Management System which is used to carry out these types of auctions. The auction allocation for the transmission capacity rights for operations or interconnection rights for operations is generated automatically through the EMMS system. The distributed scheduling for the agreed trading is the last step to be done before dispatching the confirm energy trading transaction between the buyer and the seller.

The trading activities between member states are limited to the GCCIA interconnection capacity. All member states are interconnected through at least two electricity lines. Most of the countries are interconnected by overhead lines where the Kingdom of Bahrain is interconnected with submarine cable. KSA is interconnected to the GCCIA interconnection

through HVDC substation because of differences in frequency used in this country, where Sultanate Oman is interconnected to the GCCIA interconnection through UAE transmission company "TRANSCO". The connection module used to interconnect the six member states is unique and gives more opportunity to utilize the interconnection between member states. The trading capacity is limited to the Available Transfer Capacity (ATC) which is the portion of the Net Transfer Capacity and is not allocated and remains available for further commercial use by way of Interconnector Rights for Operations. The limiting condition should be taken into consideration; where they are the thermal, voltage and stability limits. The GCCIA combined all system limiting conditions in turn to calculate the Total Transfer Capacity (TTC). The calculation of the ATC value, including the limitation conditions effect will be addressed in this study. The trading capacity available for trade between member states should be calculated from time to time and presented to the member states for trading purposes.

The transmission capacities calculated using Total Transfer Capacity (TTC), Transfer Reliability Margin (TRM) and Net Transfer Capacity (NTC). TTC is the maximum exchange program between two Transmission Networks compatible with security standards applicable to those Transmission Networks. TRM is the security margin that copes with uncertainties on the computed TTC values. NTC is the maximum exchange between two transmission networks compatible with security standards applicable to both transmission networks and taking into account the technical uncertainties on future network conditions. It is calculated as follows:

$$NTC = TTC - TRM \qquad (2\text{-}1)$$

ATC Computation Process is using the segment wise values and taken into consideration the stability constrained. Al-Ebrahim (2008) presents the methodology of calculating TTC, where Al-Asaad et al (2008) presents the ATC values.

The electrical trade is linked to the availability of surplus generation capacity in a different time and seasonal variations in demand or with different cost structures. Large access of generation capacities with the market players is one of the most important indicators of possible increased electron trade in electricity. As per GA and PETA agreements all member states should fulfill their install capacity for the next five years. Therefore, all member states have additional capacity, which avoids the shortage of power for the upcoming 5 years.

GCC is looking forward to create and activate the regional power market to manage their energy resources and gain more economical benefits from the interconnection. This will lead also to improve their system efficiency. The electric utilities affected by the fuel energy market because both oil and gas fuel price increases in the last decade. Changing crude oil prices rapidly increased in the last decade, which leads to change the unit price of the energy in the GCC countries.

In the last 5 years the GCC countries success in interconnecting their National Grids and gained from the network security, emergency support, reduction install capacity reserve, reduction in operating reserve and more from direct and indirect benefits like opening the door for integration of nuclear and renewable energy resources and reduce carbon emission.

2.5.1 GCC Interconnection Market Players

To overcome these barriers there is a need to start with understanding the market for the interconnected countries; it is required together the data about the organizations and utilities working in the electricity sector. Therefore, a survey is made to collect the data about the market player in this region. The results of the survey done in this thesis, which illustrate in Table (2-2), shows the electrical utilities that areas part of the power market structure in the GCC region.

All restructure typed for the interconnected member's state counties are called the vertically integrated system except Oman and UAE. These two member states have a single buyer model. Some GCC member states start unbundling, reform their utility power sectors to be more liberal, and developed power sector. They place their plans to motivate the private sector to participate in the electrical utilities activity. In addition, they work to attract the private sector investment in power generation sector.

GCCIA is a joint stock company subscribed by the six Gulf States, which are Kuwait, Saudi Arabia, Bahrain, Qatar, UAE and Oman. These interconnected countries connected with at least two circuits along with the long geographical region interconnection cover as shown in Figure (2-18). Oman interconnected to UAE National Grid System with three sub-circuits.

Table (2-2) Players in the Electricity Utilities in the GCC Region

Country	Regulator	Generation	Opetator	Market Operator	Transmission	Distribution	Retailer	Prequrment Party
Bahrain	Electricity and water Authority (EWA)	1- Electricity and Water Authority (EWA) 2- Al-Ezzel Power Company (Al-Ezzel PC) 3- Hidd Power Company (HPC) 4- Al Dur Power and Water Company (Aldur)	EWA					
Kuwait	Ministry of Electricity and Water (MEW)							
KSA	Electricity and cogeneration Regulatory authority (ECRA)	8 privet companies including Saudi Electricity Company (SEC)	National Grid	Expected Single Buyer	SEC			
Qatar	Qatar General Electricity and Water Corporation (KAHRAMA)	1- Qatar Electricity and Water Company (QEWC) 2- Ras Lafflan Power Company (RLPC) 3- Ras Girtas Power Company 4- Q Power 5- Mesaieed Power Company	KAHRAMA					
Oman	Authority for Electricity Regulation (AER)	1- SMN Barka Power Company 2- Al Rusail Power Company 3- Sohar Power Company 4- ACWA Power Barka 5- United Power Company 6- Al Kamil Power Company 7- Al Ghubrah Power and Desalination 8- Al Rusail Power Company 9- Wadi Al Jizzi Power Company 10- Rural Areas Electricity Company 11- Ministry of Defense (generates electricity and sells it to OPWP) 12- Petroleum Development Oman (PDO)	- Oman Electricity Transmission Company - Rural Areas Electricity Company	-	- Oman Electricity Transmission Company - Rural Areas Electricity Company	- Rural Areas Electricity Company - Muscat Electricity Distribution - Company Mazoon Electricity Company - Majan Electricity Company	-	- Oman Power and Water Procurement Company (OPWP)
UAE								
-Abu Dhabi	- Abu Dhabi Water and Electricity Aughority (ADWEA) - Regulation and Supervision Bureau (RSB) - Federal Authority for Nuclear Regulation (FANR)	1- Al Mirfa Power Company (AMPC) 2- Emirates CMS Power Company 3- Gulf Total Tractebel Power 4- Shuweihat CMS International Power Company 5- Arabian Power Company 6- Taweelah Asia Power Company 7- Emirates SembCorp Water and Power Company 8- Fujairah Asia Power Company 9- Ruwais Power Company 10- Shuwaeihat Asia Power Company	Abu Dhabi Transmission and Dispatch (TRANSCO)					
-Dubai	Dubai Electricity and Water Authority (DEWA)							
-	Sharjah Electricity and Water Authority (SEWA)							
-The National Emirates	Federal Electricity and Water Authority (FEWA)							

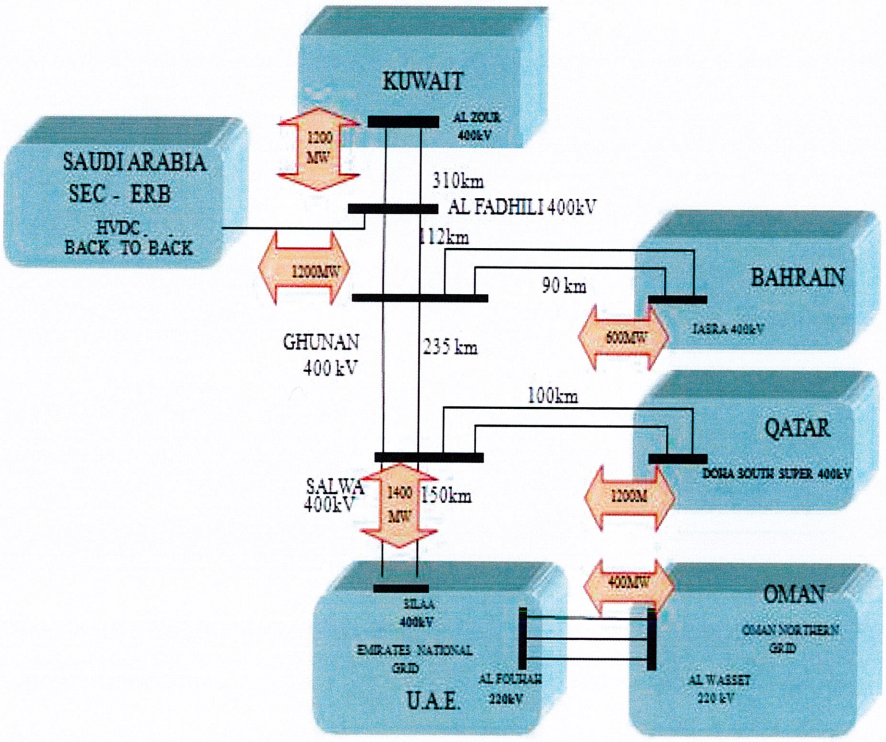


Figure (2-18) Single Line Diagram of Interconnection

2.5.2 Market Mechanism

Both General Agreements and Power Energy Trading Agreement are organizing the mechanism of power trading between member states. This study presents the shape of mechanize applied to the power trading activities between the member states as shown in Figure (2-19). The trading usually starts from the procuring party in the GCC players, where they request a quotation for electricity quantity and period. The transaction process will be followed as describe in the first business layer.

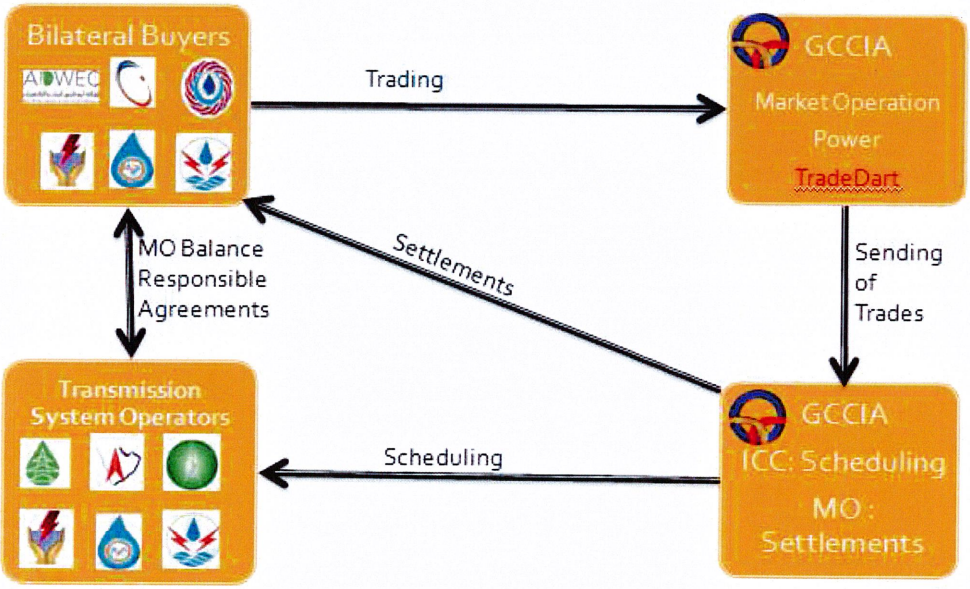


Figure (2-19) Trading Model applied in the GCC Electricity Market

2.5.3 Historical of Power Trading

Al-Haddad et al (2013) and Al-Hamad et al (2014) present the recorded power trading transactions between the member states. The first trading case was in 31 August 2010 as shown in Figure (2-20), due to fuel disturbance in one Member State. The second trading case happened through two bi-lateral trading contracts in July 2011 to fulfil shortage of capacity due to delay in commissioning new power plant in buyer side.

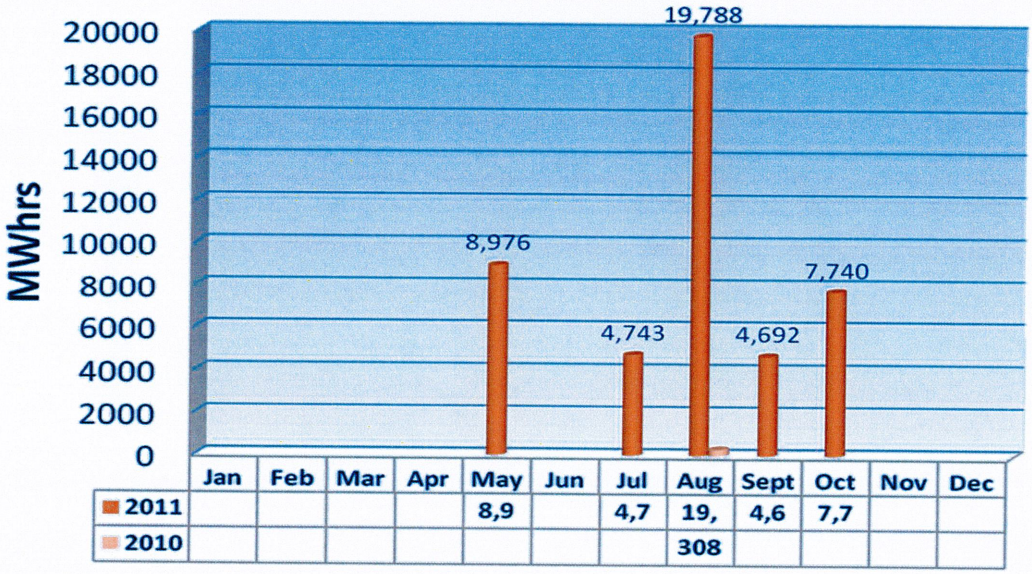


Figure (2-20) Volume of Power Trading during 2010-2013

2.5.4 Options for Market Design

There are two main classifications of the market type which are mandatory market based on the principle of centralized power dispatch and voluntary Market Model base on bilateral contracting. The base for this study and the outcome gained from different market types presented studied and experience earlier. There are four basic options or models for the design of electricity markets. These four models are as follows:

1) Single Buyer Model: It refers to the structural option where either all electricity capacity and generation or less still having a significant share of electricity purchased by a central body. GCC countries right now have a central body purchasing almost the available generation. This model does not require unbundling but it limits competition. This approach would not require a radical reform of the power sector. It is not required to have a wide-ranging separation of vertically integrated utilities.

2) Mandatory Pool Model: This is the mandatory participation model where the "market" makes substantial intervention into unit commitment into the GCC generation scheduling. This model required to have a satisfactory number of market players for the pool price to be set competitively. In this model usually the generation sector are hedging the prices to provide the eligible consumers to avoid the risk of changing the price of electricity. Therefore, price hedging becomes a mandatory subject in pool model. They will contract with each other at a fixed price outside the pool.

3) Bilateral Contracts Model: This is the model, which used right now in the regional market. The generators would dispatch themselves according to the bilateral contracted amounts they are required to deliver in each period. The System Operator (SO) with the total generation uses central dispatch instruction only for balancing the total load forecast. The balancing market used for ensuring system reliability by balancing the residual amounts of energy between total load and generators notified production.

4) Multi Market Model: One of the most common market designs in the competitive electricity market is a multi-market model combining a Day Ahead (DA) forward market managed by the Power Exchange (PX). A real time market and the possibility to contract bilaterally either physically or financially. The functions of the PX to establish prices for each hour that clear the forward markets for Day Ahead trading. Power exchanges operate on the principles of self-scheduling and market clearing.

2.6 Results of GCC Regional Market Model

Countries around the world includes GCC countries are increasingly pursuing and benefitting from the integration of national electricity markets into the larger regional power market to provide reliable, affordable electricity to consumers. The electricity networks for GCC, which were interconnected through a backbone of 400kV super grid network, share member states installed capacity and operating reserves, thus reducing the individual member state reserve requirements for the same reliability level, and providing emergency support services through an in-kind compensation framework. However, the GCC interconnection also avails getting into contracts for the provision of operating reserve and trading energy through bilateral energy transfer. Although many benefits have already been achieved from this interconnection since its commissioning in 2009, the interconnector is not yet utilized to the required level of power trading for more benefits to the interconnected countries.

2.6.1 Benefits Required from Regional Electricity Markets

Increased cooperation in the trade of power among countries can bring number of benefits of power trading that can be summarized as follows:

- Economical:
  - Reduced cost of supply for countries through optimizing fuel resources and increased economic efficiency
  - Increased energy efficiency by reduction of fuel costs for energy generation
  - More efficient and effective use of infrastructure from spare generation capacity
  - Streamlining of the power prices
  - Maximizing of shareholder benefits
  - Optimal payback on excess installed capacity investments
  - Economies of scale in investments
  - Access to resources
  - Facilitation of financing for new investments
- Environmental:
  - Reduction of carbon emissions impact
  - Preservation of fossil fuel resources
  - Facilitate integration of alternative energy resources (RES)
- Technical:
  - Improved reliability
  - Increased energy security
  - Reduction of operational costs and lifetime extension of equipment
  - Accommodation to sudden changes in network topology and demand behavior

- To improve performance and reduce power outages for customers
- Greater renewable energy penetration

- Social:
  - Creation of jobs and skills
  - New element to national growth
  - Improvement of quality of life
  - Mutual prosperity between interconnected nations

Usually changing the market should reflect the level of acceptable benefits, which encourage the market player to move forward with the new proposed market to achieve a remarkable benefit. Therefore, this thesis spot the light on a very important points, which will bring the attention to suggested movement.

Based on the GCC Regional Committee for large electric system Bulletin Statistical of the year 2012, the fuel consumption for the GCC countries used to calculate the cost of energy used to generate electricity in the GCC countries.

Table (2-3) illustrates the amount of fuel consumed during 2012 in the GCC countries, which is collected from GCC Regional Committee for Large electric System (2013). There are no big differences in GCC internal operating practices and source of fuel used in the member states. The GCC countries either they have only gas to generate the electricity like Qatar and Bahrain, having gas fuel with minor crude oil for emergency of remote area like UAE and Oman, or heavy depending on crude oil beside the gas fuel like KSA and Kuwait.

Table (2-3) Fuel Consumption for the GCC countries in 2012

GCC Countries	Gas (Million Cubic Meter)	Light Fuel (X 1000 Barrel)	Heavy Fuel (X 1000 Barrel)	Total (X 1000 Equiv. Barrel)	Total Oil Cost at rate 100$ per Barrel (Billion $)
UAE-Abu Dhabi	30720	2603	1933	168281	16.8281
Bahrain	5969	*	*	0	0
Oman	6744	17706	*	17706	1.7706
KSA	42366	86040	186300	528998	52.8998
Qatar	11127	*	*	0	0
Kuwait	21412	10234	38891	163330	16.333
Total In Equiv. Barrel	660802	117594	227124	1005520	100.552

The value of crude oil used in the year 2012 was approximately 100 Billion United States Dollar "USD" to generate the electricity mainly in KSA, Kuwait and UAE. The value of crude oil in the international market is much greater than the value of electric energy used to generate subsided electricity in the GCC countries.

AFESD (2012) presents the average unit price was calculated in this study using PROMO software for member state and illustrated in Table (2-4). The results, which will be presented in chapter 6 shows that Kuwait has the highest electricity unit price where Qatar has the lowest unit price in the interconnection.

Table (2-4) Average cost of Electricity in year 2012

AV. Cost	BAH	KSA	KUW	Qatar	UAE
($/MW)	$75	$137	$147	$67	$86

The cost benefits from that are to save the cost of power system production and installed generating capacity. The amount of yearly energy could be imported from the interconnection could be calculated using the

physical layer data. For example, member states can imports are 10.5TWh from the interconnection, so the expected saving based on the average cost of electricity for KSA is 735 Million USD. Beside that an additional benefit achieved by selling the barrel of crude oil used to generate 10.5TWh in the oil market. The amount of crude oil saved from this operation depends on the generators heat rate of the machine used by the imported party.

2.6.2 Feedback Results from Market Players

During visits, meetings, and events carried with the member states number of existing challenged recorded and number of foreseen challenges funds that could impede in the establishment and development of Power Market. The limited number of commercial power trading activities that took place between Member States in the past four years have revealed that some challenges need to be addressed and dealt with at various levels.

The following challenges could slow progress and reduce the benefits of regional integration. It is important to understand these challenges when designing a strategy for increased trade between GCC countries. The major challenges that could impede the development process of the GCC power market are as follows:

1) Energy price distortion due to different levels of subsidies in GCC countries
2) Difficulty in aligning national and regional investment decisions
3) Differences in regulatory environments between national energy policies in the countries
4) Differences in local regulations towards cross-border power trading

5) Differences in national power sector structure
6) Limited scope of regional institutions which leads to lack of knowledge to manage the electricity costs and the benefits that can be achieved by power trading
7) Low number of market participants
8) Limited financing
9) Changes in political framework
10) Concerns about national sovereignty and energy independence

Establishing regional markets is more complex than establishing single-country markets because the risks and scope are considered for a number of countries, and increase with the number of countries involved. The technology risks related to electrical energy trade are relatively minor, because generation, transmission, distribution, and fuel-delivery technologies are developed for a long time. Also, the economic risks are relatively minor if electricity tariffs reflect costs. Both economic risks, reliability and security are reduced because the GCC power markets were integrated through 400kV backbone grid, as this would increase the number of potential buyers of services.

The demand is significantly increasing in all GCC countries, while increasing demand reduces market risk by increasing the probability of a buyer for generation and transmission services. Also, it reduces the risks in places increasing pressure on the financial, economic, and technical capacity of each country. Developing a regional market with regional coordination and governance would reduce risks also because it would optimize the generation, transmission planning and operations for the broader region.

The legal, regulatory, and governance structure should be taken in place conducive to international trade, even if the trade is only bilateral between two countries. The GCC countries have a regulatory committee, which takes the responsibility of doing so, but need to be developed to become a body of doing these responsibilities. The participating countries must have the political well to relink a portion of their energy supply responsibilities.

2.7 Conclusion and Recommendations

From this study and the expected benefits that the GCC countries should start to develop its business model. The Multi Zone Border to Border Market Model with ancillary services market recommended to the GCC region to develop the power sector in their countries. A Day Ahead explicit auction mechanism recommended being as soon as an adequate auction platform and the procedure for settlement of the purchased capacity are putting in place. There is an economic benefit of developing the market model in level of billions of dollars yearly. There is a need to analyze all member states to find the way of activating the regional market between the member states and shift the cooperative shape into competitive levels of the energy market to achieve the following:

- Better utilize resources
- Reflect accurate prices
- Enable demand-side response
- Correct investment signals

The proposed solution to set up the market rules and to solve the regulatory level barrier in the interconnection is by creating Regional

Regulatory Body to harmonize the rules and regulation to develop the Regional Electricity Market (REM).

Also, it is suggested to increase the number of market players by involving Dubai, Sharjah, and Northern Emirates networks in the Power Market as individual market player and to shift the subsidies in all GCC countries from generation sector to customer sector. The tariff of the energy suggested to be based on the capacity and energy payments. In such a way, the generation sector will be able to recover their costs.

In conclusion, Member States would like to give the jointly shared entity more roles in establishing Regional Market. They would like to give this entity the role in the development from the freeze state of market "Trading base on energy need" toward voluntarily market participant as shown in Figure (2-21). For doing that, the national market should be studied and analyzed. The target of developing the GCC regional market is to shift the type of this market from Bilateral Contracts Model to the voluntarily Multi Zone Border to Border Regional Market Model. This model has both bids demand side and offers from generation, where single buyers in GCC are playing this rule. The Model have two limitation factors which are the system capacity connecting countries and demand peak time. All these factors will be represented in shape of energy price at each zone of border to border connection.

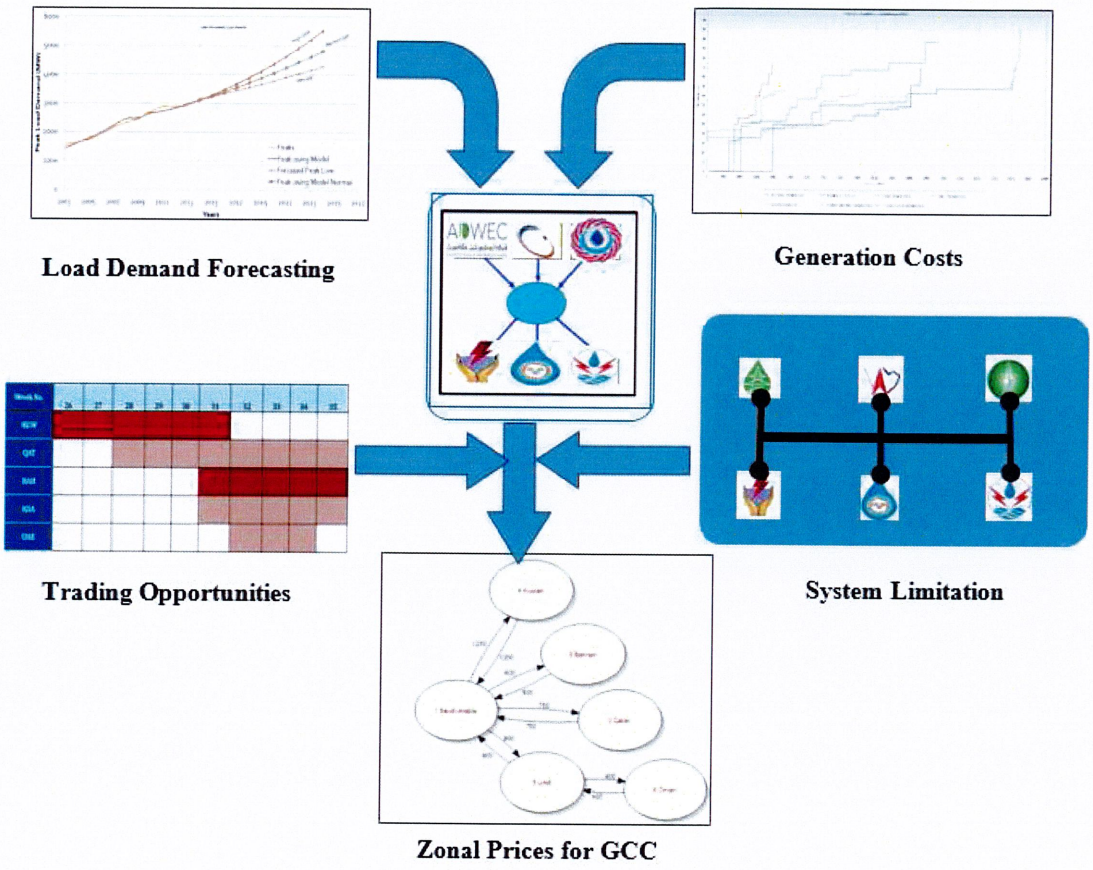


Figure (2-21) New Market Model Proposed (Multi Zone Border to Border Regional Market Model)

It can be seen from the above that there is a remarkable potential to receive mutual benefits between the GCC countries if the interconnector is utilized efficiently and practically for power trading. One of the long term goals of this project is the mutual prosperity of the nations of the gulf region as well as industrial growth of its energy sector. Thus, if an active form of trade such as power trading is to be efficiently activated in the region using the available platform which is the GCC Interconnector. Optimistically, it can be assumed that member states would gradually receive benefits such as cost reductions, network security and stability, as well as a dependable second source of national income. This will help the GCC nations to mature

and develop the main driver in this study. The GCC interconnector is the platform to be seriously considered for cross-border activities and system expansion.

It was noticed from the power trading activities which have taken place during 2010 and 2011, the trading was based on sudden shortage in supply to meet the load demand during the summer period. It captured from Member States feedback and meetings, issues and concerns on the matter of power trading will be treated as official stance and as part of the proposed approach towards creating a local energy market in the nations.

It could be seen that to establish a new industrial growth in the oil-rich region, multiple angles and issues such as local politics, industrial reform and adoption of new global trends are some of the main points that need to be taken in consideration and addressed. The development could started from the joint committee like the planning committee and operation committee where all member states are presented, and their target is to work on the path to develop effective GCC power market towards a shared future.

Chapter 3

GCC National Electricity Networks

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Chapter 3

GCC National Electricity Networks

3.1 Introduction

Some states in the GCC region have already started the process to reform their power sectors. They have different levels of structure, regulation, and unbundling level. Some states have begun receiving a single purchaser in their arrangement and having reforms planning where others do not. Thus, the states which have taken initiatives in the recent past to restructure the power sector and projects doing everything to induce private sector actions and attract private sector investment.

3.1.1 Historical Power Sector Structure in the GCC Region

The reforms undertaken and future programs to reform the electric power sector of each member states are summarized in the forthcoming sections. El-Katiri (2011) illustrated in Figure (3-1) the direct relation between GDP Growth and consumption Growth in GCC countries. The energy subsidies in GCC used to encourage the growth in these lands. The energy tariff is not reflecting the actual cost due to big subsidies applied in all gulf countries as shown by El-Katiri (2011) in Figure (3-2). In addition, Figure (3-2) presents the position of some Gulf countries in terms of energy subsidies compared to the number of countries around the world.

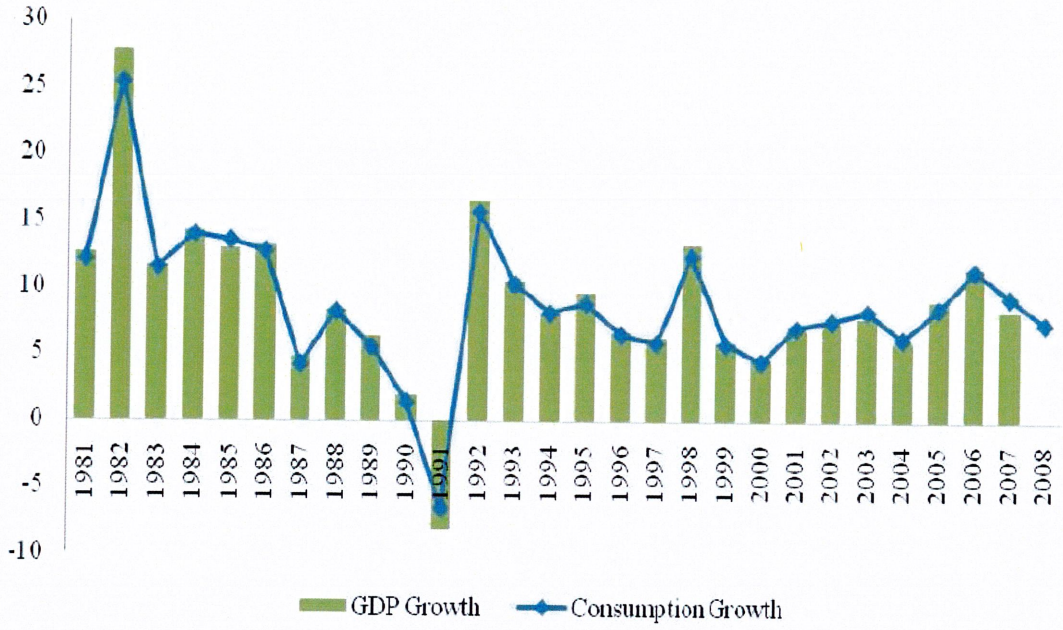


Figure (3-1) Electricity Consumption Growth for GCC Vs GDP Growth in percentage

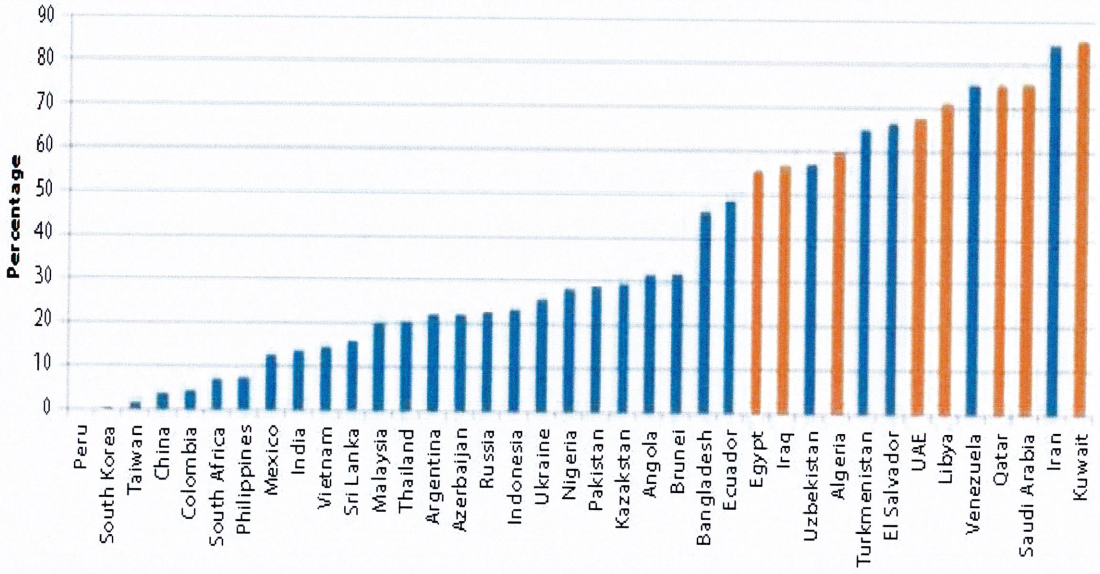


Figure (3-2) Average subsidization rates for domestic fuels in selected countries in 2010

Power trading is a new industry that has just appeared in the oil-rich Arab Gulf region. This type of industry was introduced after implementation of the largest transmission line project undertaken in the region by the six countries

commissioned in 2009. The project built by a counterpart authority, and was bears responsibility and the development of a network interconnecting the six countries. Figure (3-3) collected from the Interconnection Control Center (ICC) as presented in Al-Hamad (2013) et al shows the instant support that MS can get from the interconnection.

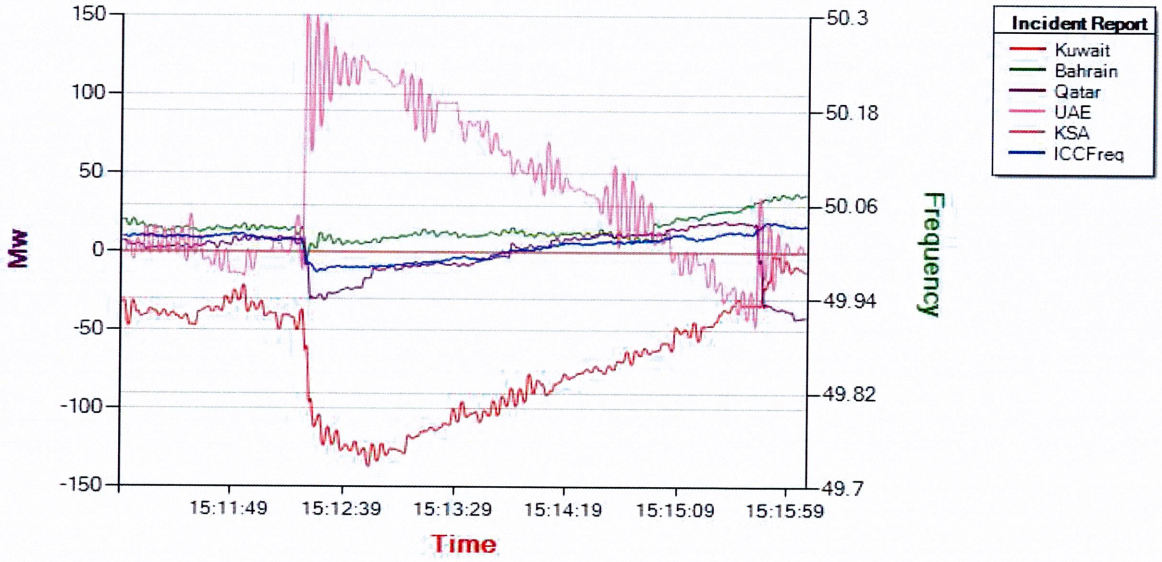


Figure (3-3) Member States system frequency during incident, (Source: Al-Hamad et al (2013))

On the other hand, the power sectors in these six countries, which were in the form of an old traditions, power electrical energy industry in the beginning of this century are now moving to reform their electricity sectors. The MS's development in the electricity sector will affect the RES shape and opportunities of power trading between each other. Al-Ebrahim (2009) and Al-Haddad et al (2013) explained these effects, which explored in the related section.

One of the major obstacles noted by the previous authors that it may be faced in power trading, is having the same load, and peak at the same time due to the similarity of weather conditions for the region. In general, the load

patterns for the interconnected countries are almost the same. The peak time for these countries has analyzed and discussed. This research focuses on the actual data collected about the peak load in these countries and the possibility of having power trading among them.

3.1.2 Weather Environments in the GCC

The GCC countries are located in a desert region. The four weather seasons in the year have more or less similar weather conditions for all six interconnected countries. The GCC peak demand data collected, and analyzed to obtain a clear picture for the peaks accordance in the region.

Gulf countries are located in tropical and subtropical areas, where the hot and wet season occurs during the summer time especially in the area facing the Arabian Gulf. Desert areas are traditionally associated with hot dry weather in the daytime. Ambient temperature at nighttime in these countries falls more than the areas located next to the sea.

The summer period in this region is very hot, as the temperature reaches around 45°c at noon period, while it is around 30°c during the night. The dew point, also used here, reflects the water-to-air saturation temperature. It is associated with relative humidity as shown in Table (3-1) as presented in Al-Hamad (2013) et al.

Air conditioning is the most load factor raising the power consumption in all these interconnected countries. When people feel uncomfortable, they start immediately their air conditioning units to feel cool.

Table (3-1) Dew Point and Relationship to Human Comfort,
(Source: Al-Hamad et al (2013))

Dew point °C	Dew point °F	Human perception[1]	Rel. humidity at 32 °C (90 °F)
> Higher than 26 °C	> Higher than 80 °F	Severely high. Even deadly for asthma related illnesses	65% and higher
24–26 °C	75–80 °F	Extremely uncomfortable, fairly oppressive	62%
21–24 °C	70–74 °F	Very humid, quite uncomfortable	52–60%
18–21 °C	65–69 °F	Somewhat uncomfortable for most people at upper edge	44–52%
16–18 °C	60–64 °F	OK for most, but all perceive the humidity at upper edge	37–46%
13–16 °C	55–59 °F	Comfortable	38–41%
10–12 °C	50–54 °F	Very comfortable	31–37%
< 10 °C	< 49 °F	A bit dry for some	30%

3.1.3 Saudi Arabia National Network,

The Kingdom of Saudi Arabia started unbundling its utilities in the year 2000 by establishing the Saudi Electricity Company (SEC), which is a public joint stock company. The Saudi Government owns 80% of this company. The SEC was the outcome of a merger of the 10 regional power companies, which include four Saudi Consolidated Electric Companies, SCECO – East, West, South and Central. These companies were responsible for 85% of the country's power supplies before the merger. The information presented in this section collected from ECRA Annual Report (2014).

To liberalize the electricity market and to facilitate private investment, privatization of Saudi Arabia's electricity sector is under way. The government, in its drive to restructure the industry, has plans to unbundle the electric sector and separate the generation, transmission and distribution functions. It was expecting that the process of unbundling the electric sector to start soon and the introduction of competition in the generation sector to occur simultaneously through the development of the IWPP (Independent Water and Power Producer) program, allowing private developers to bid

tenders to supply SEC, most likely on a long-term PPA (Power Purchase Agreement) basis. As a step towards reform, Saudi Arabia has assigned the task of regulating the electricity industry to an independent regulator.

KSA Power Utility Structure

The Saudi Electricity Company (SEC), a vertically integrated monopoly, dominates all aspects of Saudi Arabia's electric supply. The SEC is a joint-stock company, with its shares traded publicly on the Saudi Capital Market, though the government and the Saudi Arabian Oil Company own about 81 percent of the company.

The Saline Water Conversion Corporation (SWCC), Saudi Aramco, the Tihamah Power Generation Company, the Power and Water Utility Company (MARAFIQ), the Water and Electricity Company (WEC) and a number of large industrial firms also generate electricity. The SEC is responsible for tendering and procurement of IPPs, while the WEC, which owned by the SEC and SWCC, is responsible for tendering and procurement of independent water and power producers (IWPPs).

Government agencies involved in the electricity system include the Ministry of Water and Electricity, which establishes policy, plans and strategy for the electricity sector, and the Electricity and Cogeneration Regulatory Authority (ECRA), which reviews electricity costs and tariffs. Electricity prices in Saudi Arabia must reflect the economic costs of providing the service and the industry is not entitled to government subsidies.

Figure (3-4) shows the population and peak load demand in KSA eastern side. The peak load demand collected where the population were collected from the World Bank Data (2015).

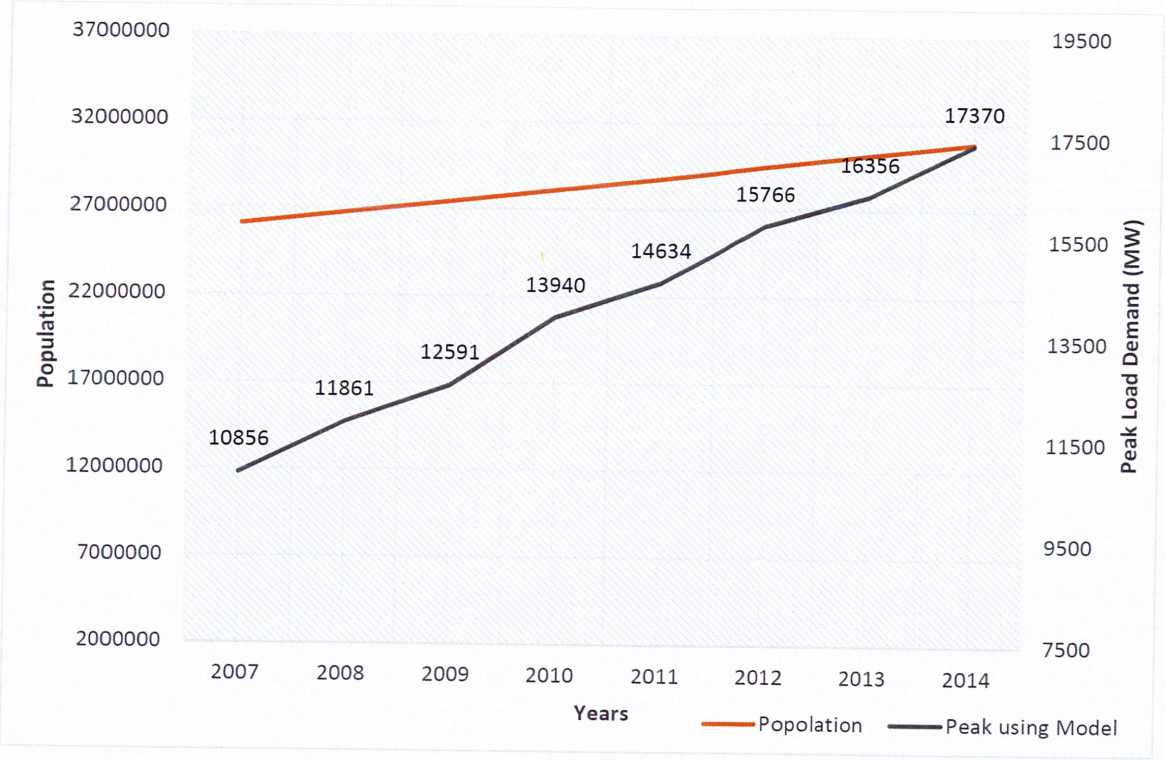


Figure (3-4) KSA Population and Electricity Peak Load Demand

The Saudi Electricity and Co-generation Regulatory Authority (ECRA) provides regulatory oversight and issues licenses to entities engaged in activities in the electricity and water desalination industry. ECRA is a financially and administratively independent Saudi organization. Its mission is to develop and pursue a regulatory framework in accordance with government laws, regulations, policies, and standards, as well as international best practices, to guarantee the provision of safe, reliable, reasonably priced, and efficient electric power and desalinated water to consumers in Saudi Arabia. A key responsibility of ECRA is to encourage private sector participation and investment in the electricity sector, which considered essential to the development and sustainability of the sector.

A 2005 law vested joint responsibility with the Ministry and ECRA for transitioning the power sector to a competitive market. The law vested the joint responsibility for encourages the private sector to invest in the electricity sector and ensure consumers' right to choose their electricity supplier. It also ensures third-party access to the transmission and distribution networks and guards against uncompetitive behavior and abuse of market power. ECRA has approved a transmission grid code and a distribution code to govern the operation and use of the grid.

Saudi Arabia is in the process of having a competitive electricity market at this time, which will include unbundling and third party access to the transmission system. The first stage of the unbundling planned for implementation in 2011 but the plan has not been implemented yet. At present, it appears that the SEC will be unbundled as shown in Figure (3-5). The proposal is to have SEC as a holding company for one Transmission Company, one Distribution Company, Independent System Operator, Procurement Body, and Generation Companies. The SEC holding company would also be responsible for fuel procurement on behalf of all generators in the country. The transmission company, which has already been established, will lease the transmission assets from the SEC holding company. Later, it is expected that distribution will be further unbundled into four or more companies.

The proposal for KSA Electricity market is illustrated in Figure (3-5). SEC currently is under restructuring process. More separation is expected during this period of unbundling process.

It is anticipated that there will initially be a single-buyer market structure with the single buyer purchasing all generations in the country and selling all

power to wholesale buyers like the DSO. The single buyer will be within the SEC holding company. It will be some time before any significant competition is introduced in the electricity sector.

Retail tariffs in Saudi Arabia are far below the economic cost of supply. The World Bank reports (2009) that residential customers consuming 700 kWh per month pay only 8 percent of a benchmark tariff.

Saudi Arabia's electricity sector is summarized as follows:

- ***Reform***: Underway with the enactment of a new law, but progress is slow.
- ***Market structure***: Vertically integrated, but there are plans for the unbundling and implementation of a single-buyer market.
- ***Separate regulator***: Yes.
- ***Open access***: No.
- ***Grid code/distribution code***: Yes/yes.
- ***Private sector participation***: Yes, in generation.
- ***Tariffs***: Subsidized.

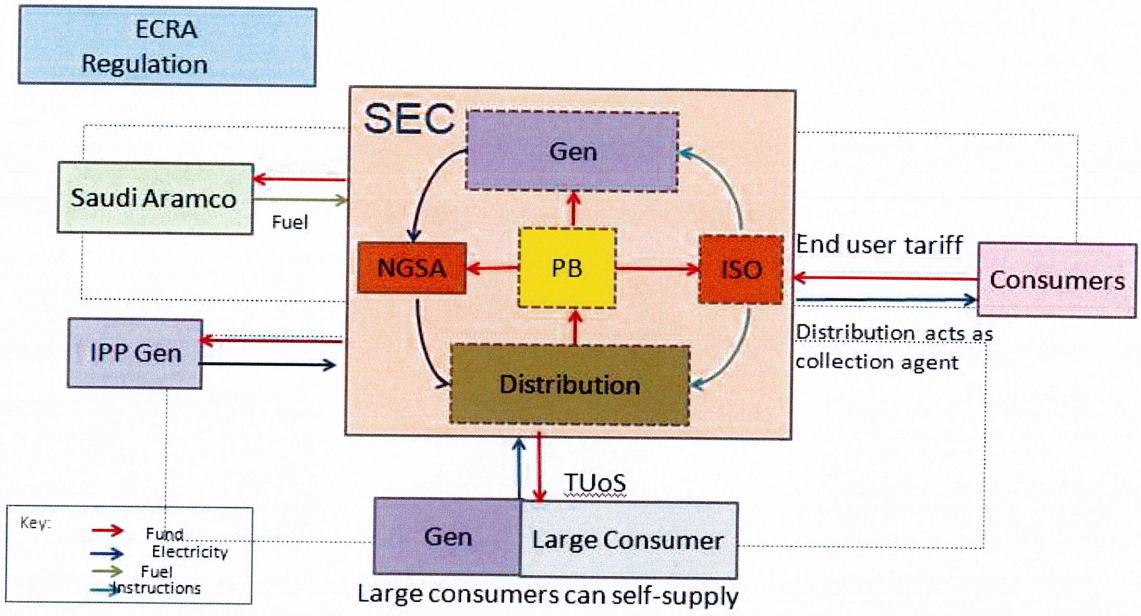


Figure (3-5) Saudi Electricity Market
(Source: ECRA Annual Report (2014))

KSA weather condition at Peak time

KSA peak load recorded was 14388MW on Wednesday 4 August 2012 at 14:59Hrs. Figure (3-6) illustrates data collected from World Bank (2015) and ICC, which represents the weekly load pattern where peak loads occurred at the end of that week. It shows the temperature and humidity for the week where peak load occurred from Saturday 28 July to 4 August 2012.

Peak load was recorded on Saturday, which was the first working day in KSA at that time. The maximum load recorded on the day before the peak load was less than the peak load by more than 1000MW. It is noticed that there is no big difference in load demand during the week variation, where the next peak load demand found is 7% less than that peak.

Even though there is a strong correlation between ambient temperatures and the peak load, but peak load recorded at ambient temperature at noontime

was 40°c, where it measured more than 42°c during the week. It reaches 46°c at Sunday where the peak comes after 6 days.

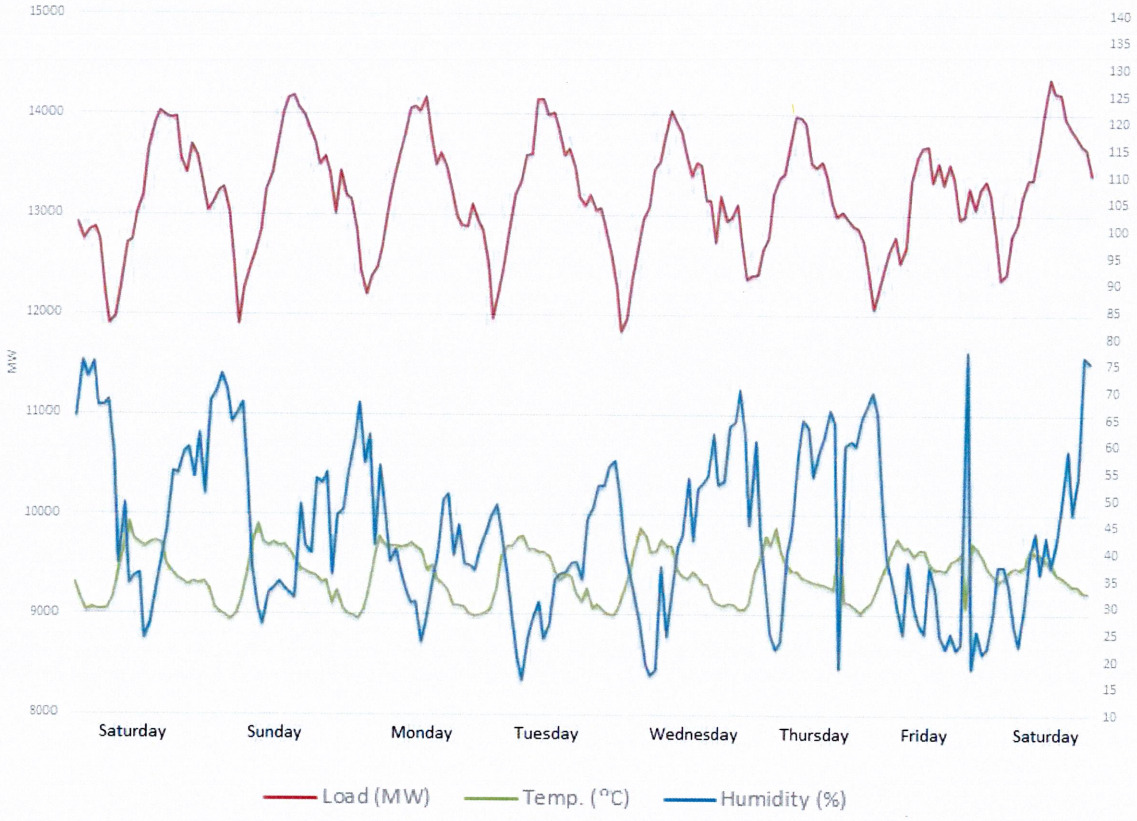


Figure (3-6) Weekly Peak Load, Temperature and Humidity Patterns for KSA, (Source: Al-Hamad et al (2013))

The Eastern electricity network in KSA is located in the Al-Dahna'a desert and facing the Arabian Gulf. It has a very high temperature exceed 46°c in the summer time. Temperature elasticity is high. It is fluctuating from 27°c to 46°c every day. The weather in this region is dry due to its geographical location.

The humidity registered on peak day as shown in Figure (3-7) was 21% on average; it reached 36% but dropped at peak time to 6%. Therefore, the weather was very dry at peak time and air conditioning systems could not

function efficiently during this period, resulting in the consumption of more energy to cool the air for the people.

On 13 August 2012, the peak load recorded for the Eastern side of KSA network where the weather Condition is illustrated in Figure (3-7).The temperature at the load peak time was 47°c. The wind was blowing from the North side during the day. Minor variation in the wind direction was noticed during the peak load time. The wind speed recorded in the early morning was 25 mph / 24kmh. It dropped slightly to 15mph/24kmh before the peak time when it registered a sharp drop in wind speed of less than 4 mph/6kmh. At the same time, the air pressure dropped to 994hPa and was around 999hPa during the six days before the peak day. The Dew Point recorded16^{O}c from the morning to the peak time when it dropped at evening time. The Dew Point was within the acceptable level range. The humidity registered on peak day was 21% average; it reached 36% maximum and dropped at peak time to 6%. Therefore, the weather was very dry at peak time when air conditioning systems could not function efficiently, resulting in the consumption of more energy to cool the air for the people.

Table (3-2) presents the maximum, minimum and average values for the weather temperature, dew point, humidity, wind speed, sea weather pressure, and visibility during the day.

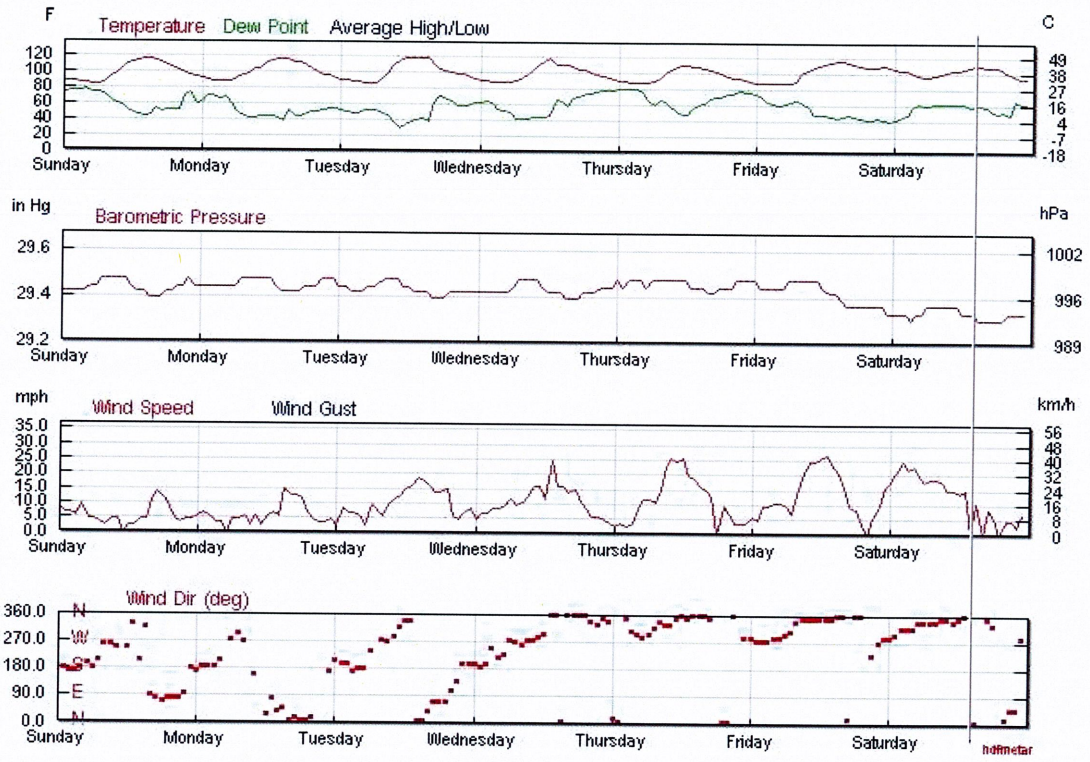


Figure (3-7) KSA Weather Condition at Peak Load Time - 2012 08 13
(Source: The Weather Company (2015))

Table (3-2) Weather Observations for the KSA During Week Peak
(Source: The Weather Company (2015))

Daily Observations

2012	Temp. (°C)			Dew Point (°C)			Humidity (%)			Sea Level Press. (hPa)			Visibility (km)			Wind (km/h)		
Jul	high	avg	low	high	avg	low	high	avg	low	high	avg	low	high	avg	low	high	avg	high
29	47	38	29	26	17	7	79	37	9	998	996	995	9	7	6	23	10	-
30	47	39	31	21	11	3	52	23	7	998	997	996	-	-	-	24	10	-
31	48	39	30	21	10	-1	36	21	6	998	996	995	-	-	-	29	13	-
2012	Temp. (°C)			Dew Point (°C)			Humidity (%)			Sea Level Press. (hPa)			Visibility (km)			Wind (km/h)		
Aug	high	avg	low	high	avg	low	high	avg	low	high	avg	low	high	avg	low	high	avg	high
1	48	39	31	26	16	6	63	30	9	998	996	995	9	8	6	39	14	-
2	44	38	32	27	20	9	75	42	12	998	998	996	8	7	5	40	14	-
3	47	39	31	24	12	4	62	24	9	998	996	993	8	5	1	42	18	-
4	44	39	35	19	14	5	37	23	10	994	993	992	9	3	1	39	24	-

3.1.4 Kuwait National Network

The Ministry of Electricity and Water, which represents the Kuwaiti government, is the proprietor of the electricity supply industry. It is responsible for the performance, development and expansion of the power sector in its state. MEW is a vertically integrated structure, and just allow the IPP's to construct their power stations. Broadly speaking, the Kuwaiti government has no plans to restructure the electric power sector and it persists in taking responsibility of power sector.

The peak load demand and population data collected from World Bank (2015) and ICC for the years from 2003 to 2014 is observed in Figure (3-8). It shows that the demand increases with increasing in population.

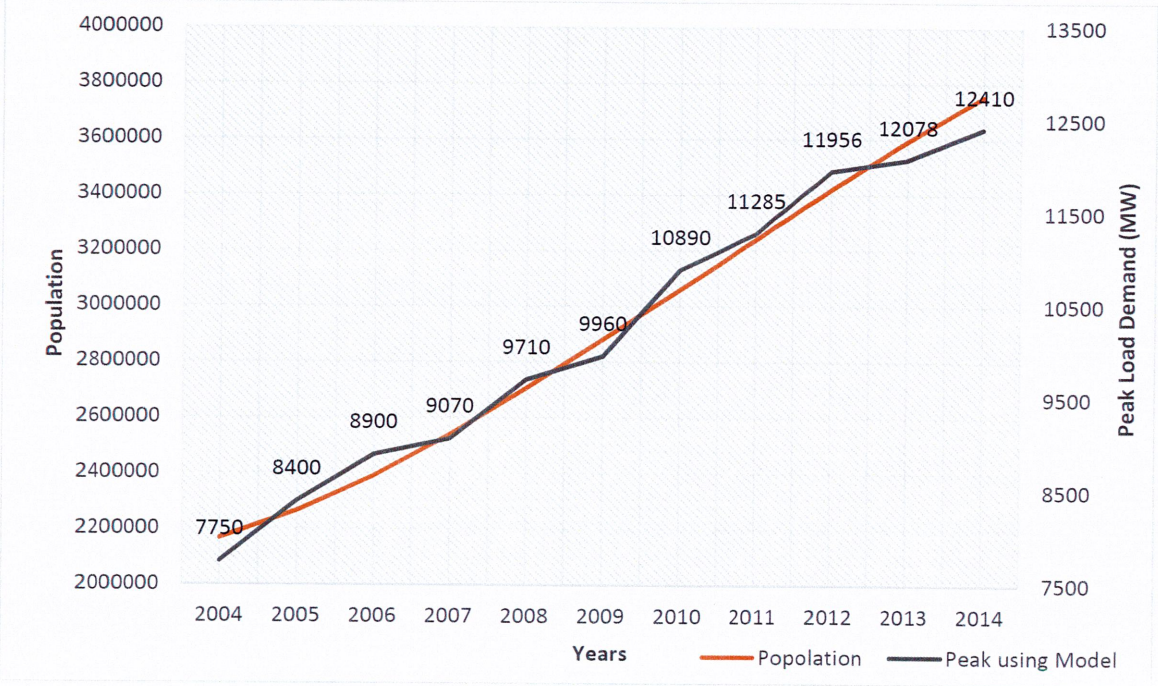


Figure (3-8) Kuwait Population and Electricity Peak Load Demand

Kuwait Electric Utility Structure

Kuwait's power sector is ruled by a vertically integrated utility owned and controlled by the Ministry of Electricity and Water. There has been little reform—there is no regulation and Kuwait has only recently approved its first IPP.

There are five steam or gas turbines generating stations located along the Arabian Gulf coast. With high levels of forecast demand growth, Kuwait needs over 18 GW of new generation capacity by 2020. It has announced plans to tender new generation capacity requiring investment exceeding $2.5 billion. Nevertheless, the projected new plants will receive a total nominal capacity of only 4.8 GW, making Kuwait a prime prospect for long-term electricity purchases over the GCC interconnection.

Retail tariffs in Kuwait are far beneath the economic cost of provision. The World Bank reports (2009) that residential customers in Kuwait consuming 700 kWh per month pay only 4.5 percent of a benchmark tariff.

Kuwait's electricity sector is summarized as follows:

- ***Reform***: Limited.
- ***Market structure***: Vertically integrated with no unbundling.
- ***Separate regulator***: No.
- ***Open access***: No.
- ***Grid code/distribution code***: No/no.
- ***Private sector participation***: One.
- ***Tariffs***: Subsidized.

Kuwait Climate Condition at Peak Time

Kuwait peak load recorded was 11956MW on Tuesday, 1 August 2012 at 13:44Hrs. The average yearly growth rate in the load demand was 12%. The growth last year dropped to less than 7%. Figure (3-9) illustrates represents the weekly load pattern where the peak load recorded was at the end of this week "assuming that the week starts from Sunday". The difference between the peak load and the load demand in the day before the peak load was approximately 1000MW. It is noticed that there are three days with high load demand during the week where the next peak load demand found is 10% less than that peak.

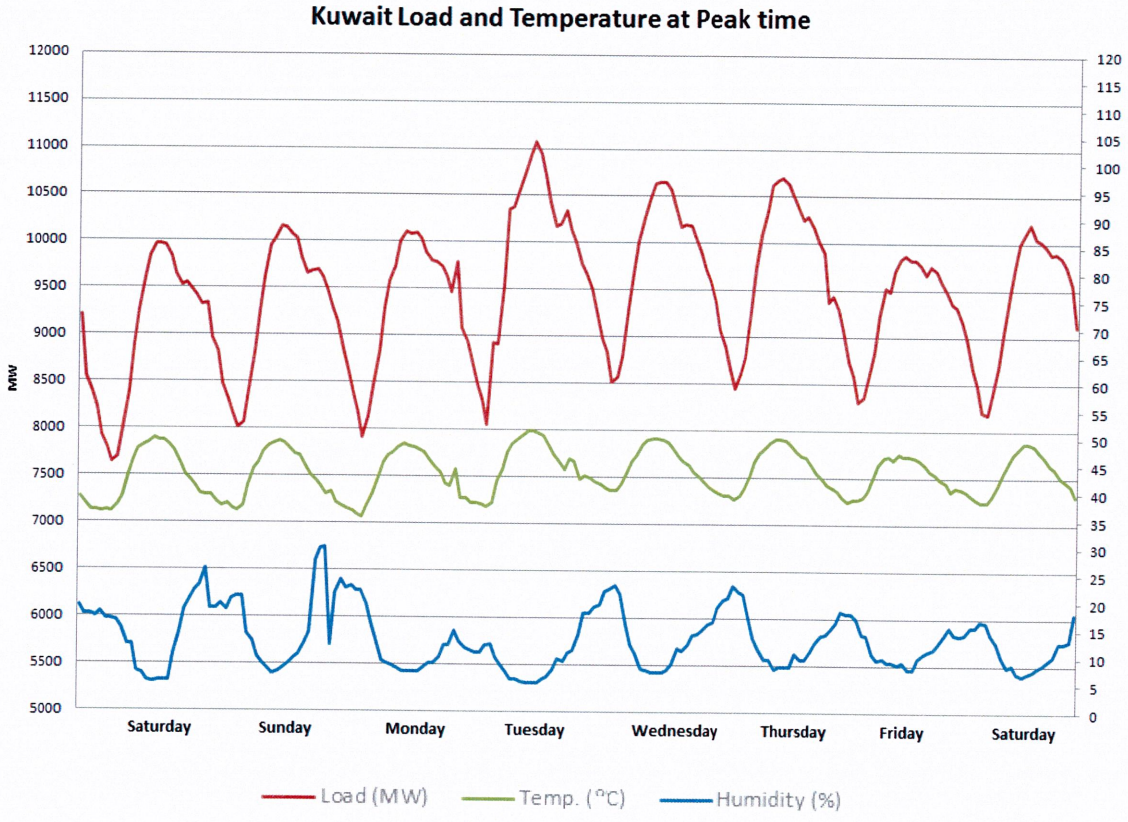


Figure (3-9) Weekly Peak Load, Temperature and Humidity Patterns for Kuwait, (Source: Al-Hamad et al (2013))

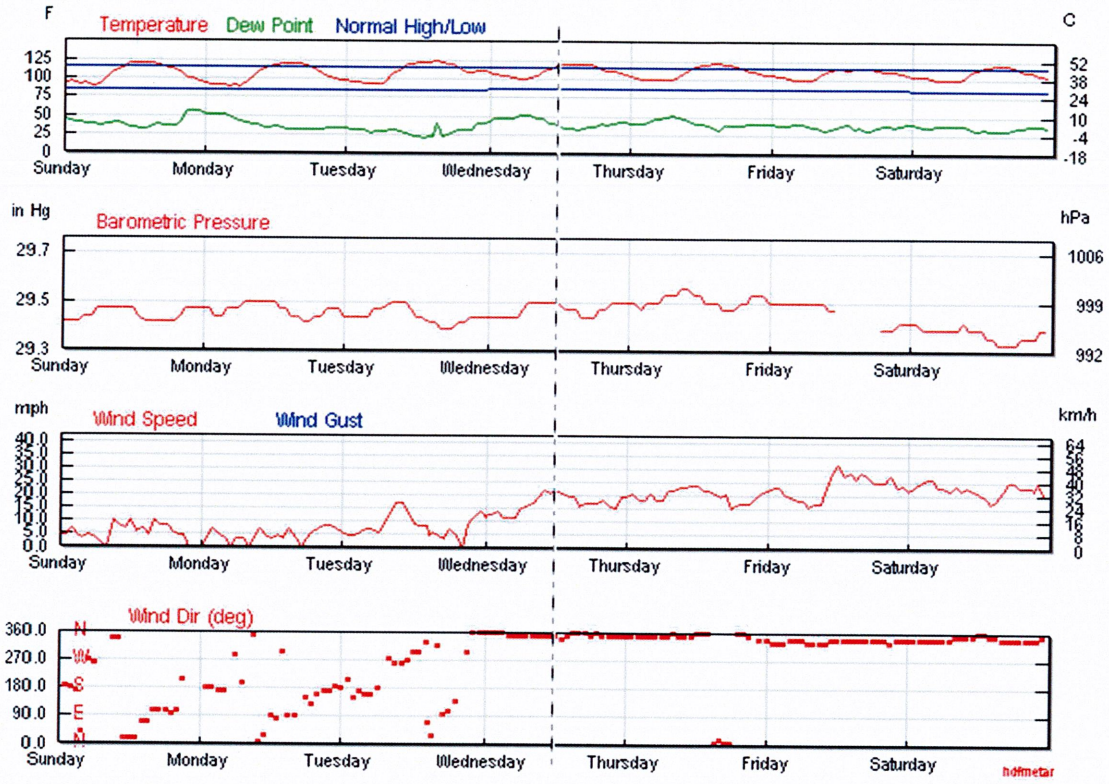


Figure (3-10) Kuwait 2012 08 01 Weather Condition at Peak Time
(Source: The Weather Company (2015))

Figure (3-10) shows weather conditions for the days of same period from 28 July until 04 August 2012. The peak load in Kuwait occurred when the wind direction was blowing from Northern side of Kuwait. The wind speed was increases from a speed of less than 15 mph in previous days to more than 15 mph. At peak time, the air pressure did not change from previous days where its value recorded was about 999hPa.

The main driver for the peak load in Kuwait was high temperature and very low humidity. The temperature recorded at peak time was 50°C, where the humidity dropped to the lowest value during the week.

3.1.5 Bahrain National Network

The Electricity and Water Authority (EWA) is responsible for the generation, transmission and distribution of electricity in the Kingdom of Bahrain. Bahrain has planned for the unbundling of the generation sector from the existing force structure. They kept the transmission, part of generation and distribution functions within the authority activities. In parliamentary law to facilitate the reform of the electricity sector, Bahrain has plans to put up an independent regulator and the required legal framework will be put up for the establishment of an independent regulatory body.

Figure (3-11) illustrates data collected from World Bank (2015) and ICC, which represents growth in demand and the installed capacity for the Kingdom. It observes that there is an extra under-utilized power available in their system. This power will remain unused for the couple of years coming without any beneficial revenue to the Government.

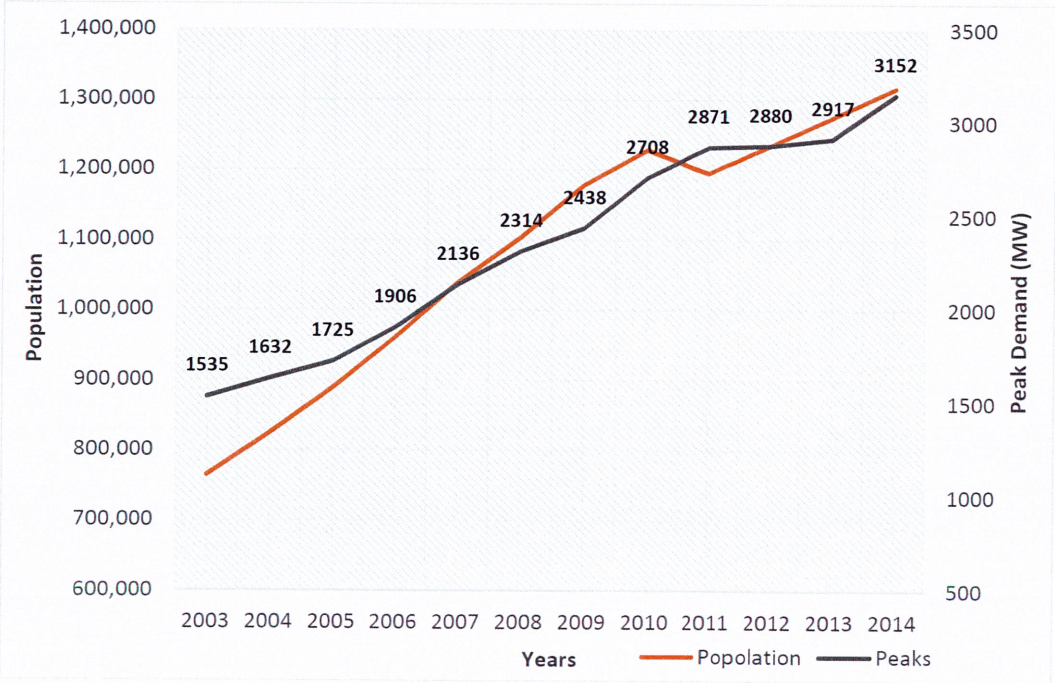


Figure (3-11) Bahrain Population and Electricity Peak Load Demand

Bahrain Electric Utility Structure

Generation in Bahrain follows the build-own-operate (BOO) model, with several privately owned facilities, in building the new generations. EWA acts as the single buyer of power from the BOO plants. All the same, it also works as the regulatory authority for the power sector, hence there is a non-dependent regulatory agency. EWA is responsible for electricity generation, transmission and distribution in Bahrain.

Bahrain is a very small player in the region in terms of electricity, with only about 3,535 MW of installed generating capacity in 2015. At present, two combined water and power production complexes and two smaller electricity-only plants provide all of Bahrain's electricity.

Bahrain's retail electricity prices are far below the economic cost of supply. The World Bank reports (2009) that residential customers in Bahrain consuming 700 kWh per month pay only 4.5 percent of a benchmark tariff.

Bahrain's electricity sector is summarized as follows:

- **Reform:** Limited.
- **Market structure:** Single buyer, partial unbundling.
- **Separate regulator:** No.
- **Open access:** No.
- **Grid code/distribution code:** No/no.
- **Private sector participation:** Yes, in generation.
- **Tariffs:** Subsidized toward commercialized structure with classes.

Case Study: Bahrain Climate Weather Conditions at 2012 Peak Time

Bahrain peak load recorded was 2880MW on Monday 23 July 2012 at 14:38Hrs.

Figure (3-12) shows electricity demand for Bahrain is electricity grid, the ambient temperature and humidity during the period from 21 until 28 July 2012, where the data was collected from World Bank (2015) and ICC. The difference between the peak load and the load demand in the day before the peak load was approximately 500MW.

The electricity demand was following the temperature variation. The peak of the electricity demand was recorded at the same time of the temperature peak during the days. The humidity peaks were recorded early night dropping with increases of temperature by less than 25%.

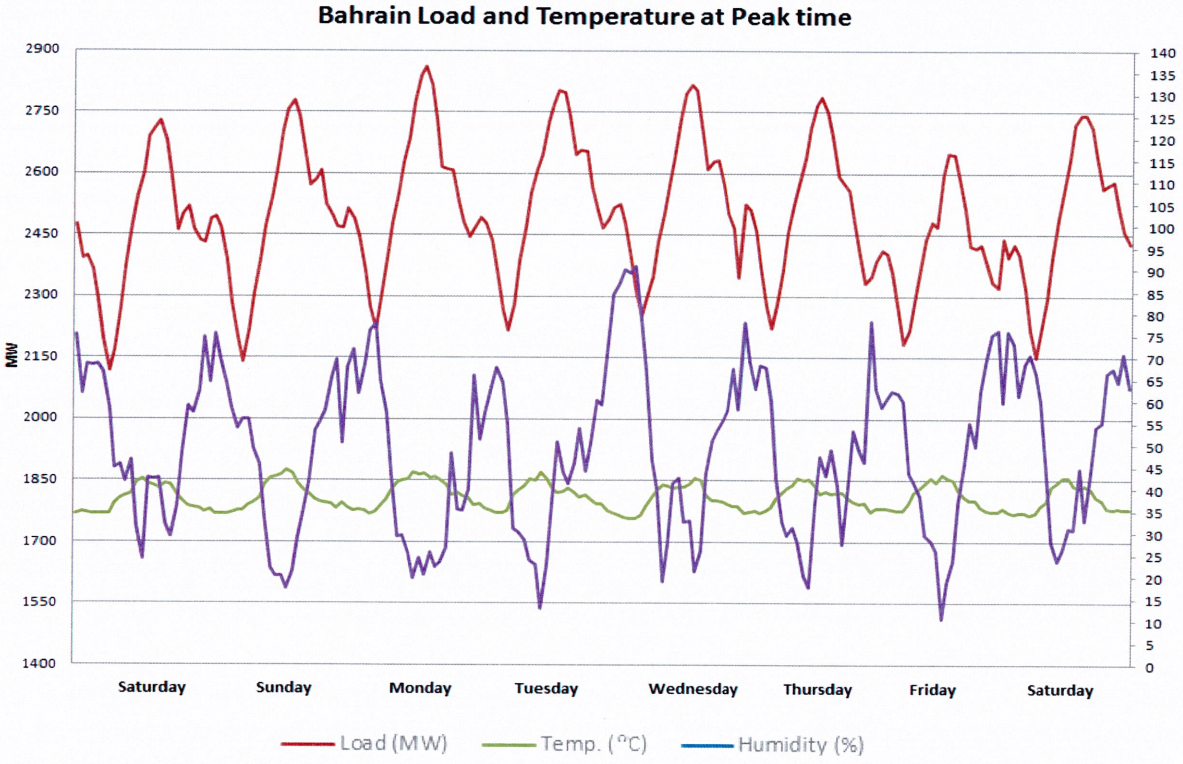


Figure (3-12) Weekly Peak Load, Temperature and Humidity Patterns for Bahrain, (Source: Al-Hamad et al (2013))

Bahrain has tropical weather conditions with a very high temperature exceed 40°c. Its temperature variation is less than the rest of the Gulf countries

due to high humidity levels. Usually humidity has low elasticity with the ambient temperature.

A more focused study was undertaken on the weather conditions during the week where the peak load is recorded and observed in Figure (3-13). The peak load of Bahrain occurred on Monday, 23 July 2012 at 14:38hrs. At peak, the wind direction changed from the eastern side to the northern side of the Kingdom of Bahrain. The wind speed dropped from 15 mph/8kmh to 5 mph/8kmh. In addition, at peak time the air pressure dropped to less than 996 hPa. The load demand in Bahrain dropped when the wind speed started to pick up to reach 20 mph/8kmh in the northern side of the country. The weather temperature recorded at peak time was 44°C.

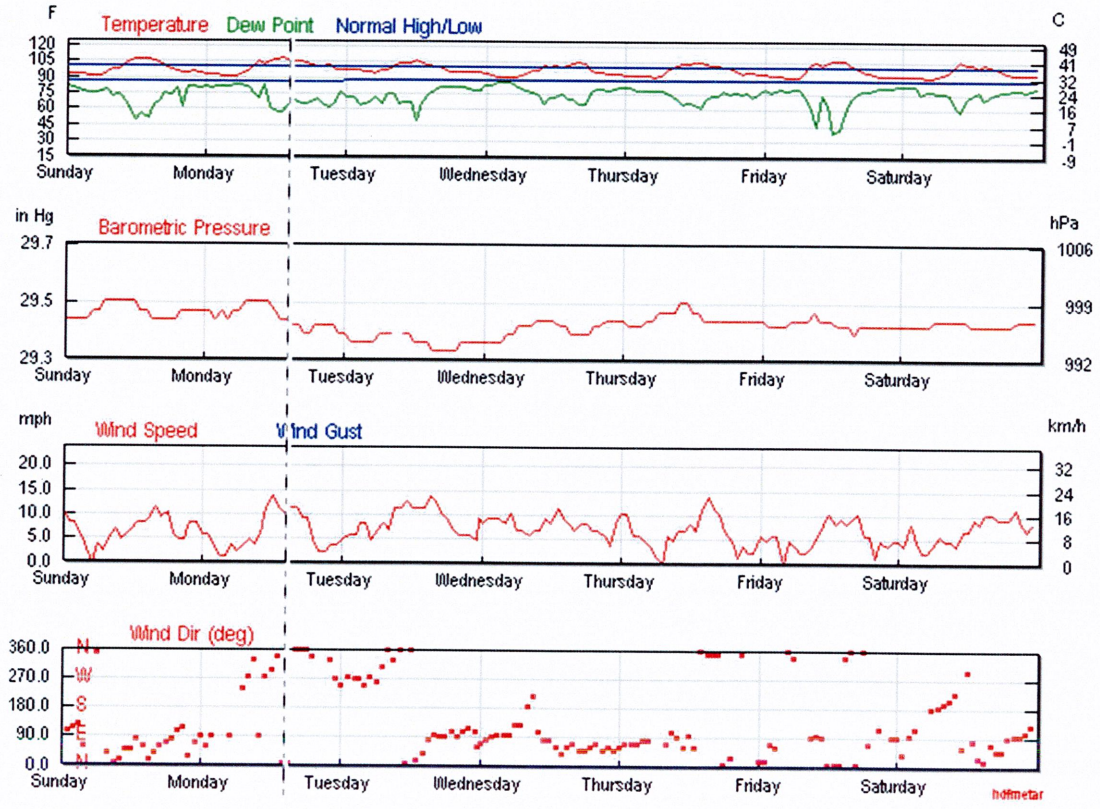


Figure (3-13) Bahrain 2012 Weather Conditions at Peak Time.
(Source: The Weather Company (2015))

3.1.6 Qatar National Network

The regime of the State of Qatar has already pioneered a plan for the restructuring and privatization of electricity and water sectors. Qatar General Electricity and Water Corporation (KAHRAMAA), which is the single buyer for Qatar established in July 2000. KAHRAMAA is entrusted with the responsibility of planning and implementation of projects, as well as the operation and maintenance of electrical facilities. KAHRAMAA was set up as a public corporation owned by the Government of Qatar with an exclusive monopoly over transmission and distribution in the country, and it's power generation and water production assets that transferred to Qatar Electricity and Water Company (QEWC).

There are plans to restructure KAHRAMAA into a holding company having subsidiaries of Electricity Transmission and Distribution Company and Water Transmission and Distribution Company. Given the small size of the transmission and distribution system, the government is considering a Single Buyer Model. It will allow competition in generation and all electricity will be sold to the Single Buyer, who will act as a wholesaler or a bulk trader of electricity.

Qatar Electric Utility Structure

Qatar has embarked on the restructuring and privatization of its electricity sector. All power generation in Qatar is done by the private sector and IWPPs. Qatar Petroleum supplies the IWPPs with natural gas, and the Qatar General Electricity and Water Corporation (KAHRAMAA) buys power from the IWPPs. KAHRAMAA is responsible for planning new generating capacity, and it is operating on several large-scale power projects with foreign societies. The installed generating capacity in Qatar in 2010 was 7,660 MW. Planned

additions will bring the total to 8,750 MW in 2011. KAHRAMAA is required to privatize its power and water transmission and distribution systems, but a firm date for the privatization has not yet been established.

Figure (3-14) shows the population and peak load demand for Qatar. The peak load demand was collected where the population was gathered from the World Bank report (2015).

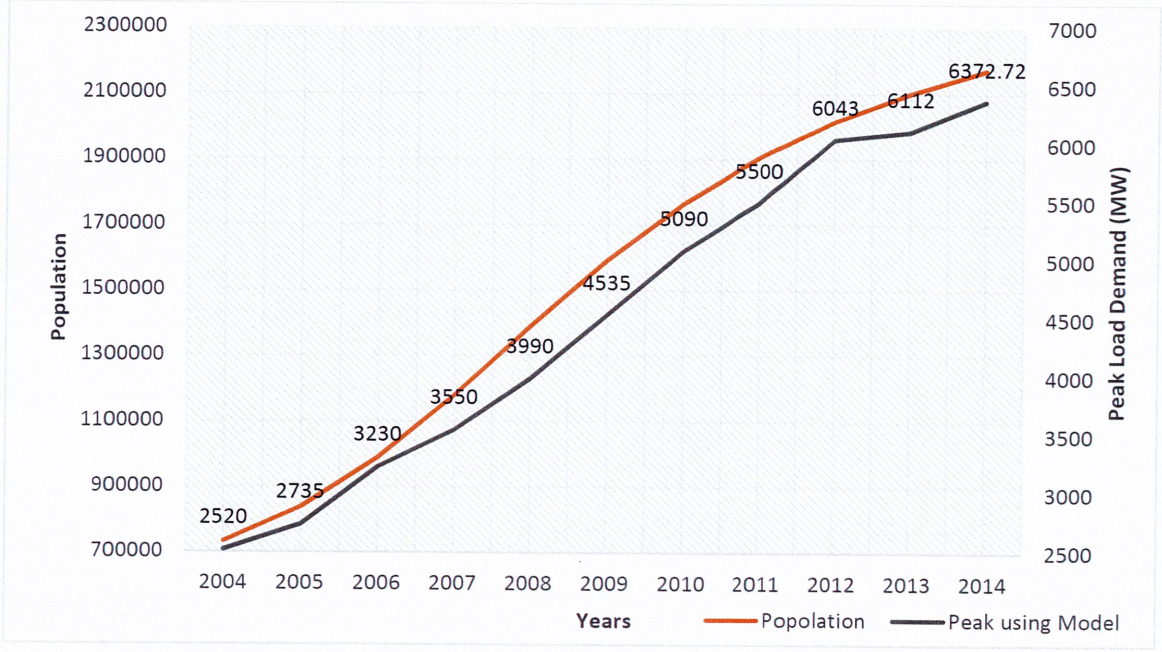


Figure (3-14) Qatar Population and Electricity Peak Load Demand

Qatar's residential tariff is 2.2 US cents/kWh for consumption up to 4,000 kWh/month, and 2.7 US cents/kWh for consumption above 4,000 kWh/month. The World Bank reports (2009) that residential customers in Qatar consuming 700 kWh per month pay only 12 percent of a benchmark tariff. Qatar's electricity sector summarized as follows:

- **Reform:** Under Way.
- **Market structure:** Moving to a single buyer with some unbundling.
- **Separate regulator:** No.
- **Open access:** No.

- **Grid code/distribution code:** Yes/yes.
- **Private sector participation:** Yes, in generation.
- **Tariffs:** Subsidized.

Qatar Climate Weather Condition at Peak Time

Qatar peak load recorded was 6243MW on Sunday 6August 2012 at 14:32hrs. The peak load day comes on the second day after a weekend.

Figure (3-15) illustrates the weekly load demand pattern for the Qatar electricity network, the ambient temperature and humidity during the week where the peak load recorded was from 4 until 11 August 2012. The data was collected from World Bank (2015) and ICC.

The dispute between the peak load and the load demand on the daytime before the peak load was approximately 1200MW.

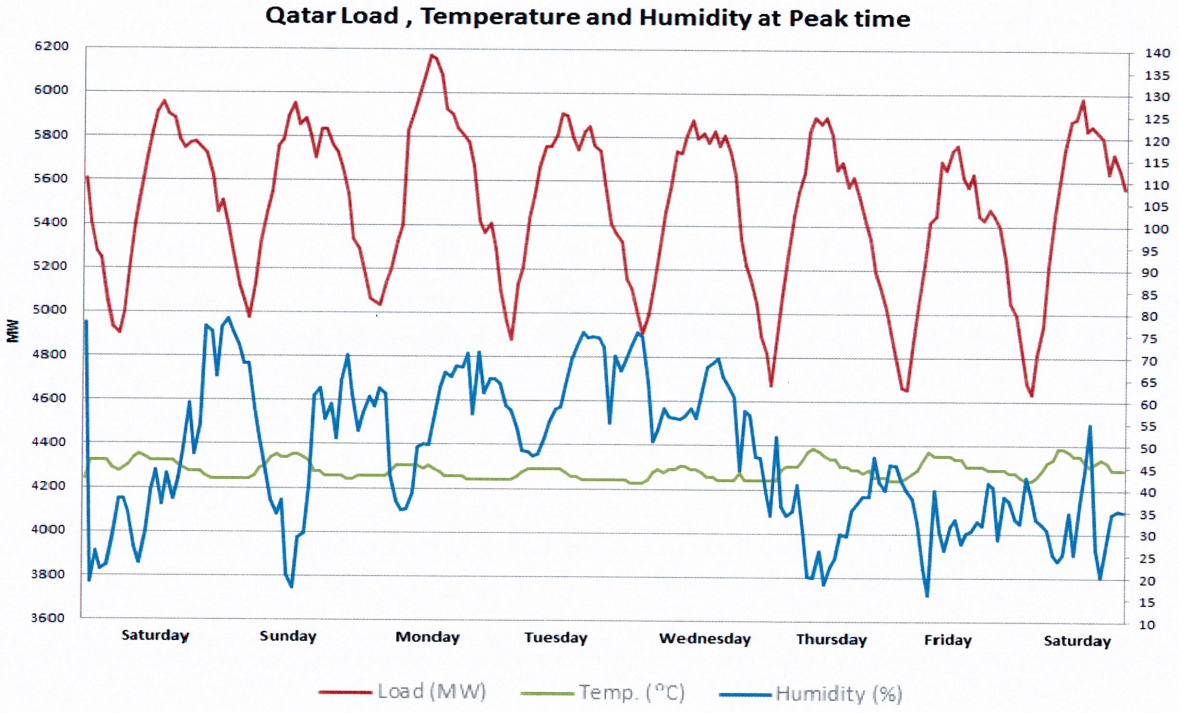


Figure (3-15) Weekly Peak Load, Temperature and Humidity Patterns for Qatar, (Source: Al-Hamad et al (2013))

Generally, Qatar has an arid desert climate. Qatar is a semi island in the middle of the Arabian Gulf. It has a very high temperature exceeding 44°c.

Temperature elasticity was in the medium range due to the geographical location between the desert and the Arabian Gulf. It has a high weather temperature exceeding 45°c. Its peak load was recorded at the same time of UAE peak.

A more focused study done on the weather conditions during the week where the peak load is recorded and observed in Figure (3-16). The temperature at the load peak time for Qatar was found 40°c. The wind was blowing from the east side of the country. The wind pattern was not similar to UAE although the peak was recorded on the same day and in the same period. The wind speed was very low early morning, starting from 5 mph/8kmh then slightly increasing in the peak time where it reached 16 mph/26kmh. Air pressure was around 996hPa. After the peak, the wind speed dropped to 10mph/16kmh. The day before the peak load day was similar to the peak load day, but the Dew Point was higher than the peak load day and the barometric pressure recorded less by 3hPa during the day. On the days after the peak load, the wind direction changed smoother than the days before when the dew point found higher than the peak load time.

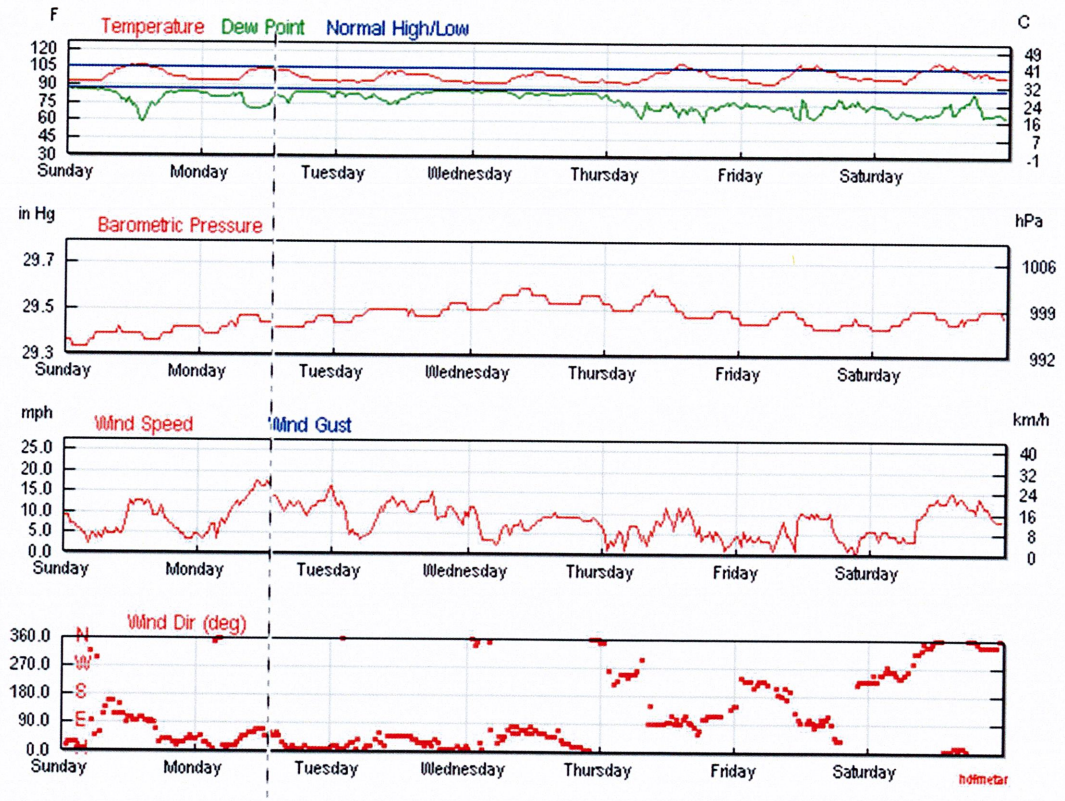


Figure (3-16) Weather condition at Qatar peak time on 6 August 2012
(Source: The Weather Company (2015))

Although there is a strong correlation between ambient temperature and the peak load, the ambient temperature recorded at peak load was 45°c at noontime and it was also recorded at 50°c on two days after the peak load day. Humidity recorded at peak time was 45%, later increasing to 70%.

3.1.7 UAE National Network

In the UAE, four major electricity and water authorities exist covering their respective geographical areas. These are:

(i) Abu Dhabi Water and Electricity Authority (ADWEA),

(ii) Dubai Electricity and Water Authority (DEWA),

(iii) Sharjah Electricity and Water Authority (SEWA), and

(iv) Federal Electricity and Water Authority (FEWA).

During the past few years, a significant reform has taken place in the electricity and water sector of Abu Dhabi. Unbundling and privatization have changed the landscape of Abu Dhabi's electricity sector considerably over the last five years.

ADWEA was established in 1998 and it is the holding company of the following licensed companies:

(i) Abu Dhabi Water and Electricity Company (ADWEC),

(ii) Abu Dhabi Transmission Company

(iii) Abu Dhabi Distribution Company

(iv) Al-Ain Distribution Company, and

(v) Generation and Desalination Companies.

DEWA was formed on January 1, 1992 as a result of the merger between Dubai Electric Company and Dubai Water Department. FEWA was established in accordance with the Federal Law of 1999 to undertake the Ministry of Electricity and Water activities of production and distribution of electricity and water in the Northern Emirates.

UAE Electric Utility Structure

The UAE's power sector is formed differently in each of the seven emirates. Presently, in that location are four service providers: ADWEA, DEWA, SEWA, and FEWA. Each operates as a separate entity, but the Ministry of Energy is studying a common federal framework. The UAE's governing body, the Federal National Council, has sanctioned a plan to privatize FEWA.

Abu Dhabi has one of advanced power reform programs in the GCC, including an independent regulatory agency, the Abu Dhabi Regulation and Supervision Bureau, which regulates all companies undertaking activities associated with electricity production, transmission, and distribution. ADWEA, a public agency owned by the Abu Dhabi government, is a holding company for unbundled electricity entities, including two-generation companies, the single buyer (ADWEC), the transmission company, and two distribution companies. ADWEA also develops, implements, and manages electricity policy. Abu Dhabi has both a grid code and a distribution code to govern connection to, and use of, the networks.

Five IWPPs have been commissioned on a BOO basis as joint ventures between ADWEA and various international companies. In each IWPP, ADWEA has a 60 percent share while overseas private investors own the remaining 40 percent. All IWPPs sell electricity to the single buyer.

Abu Dhabi is the only emirate to implement a privatization program in the electricity sector, and the only emirate to separate the transmission function from generation (albeit under the same holding company) shown in Figure (3-17). However, Dubai has also introduced the IWPP model for a new generation and plans to reform its power sector similar to that of Abu Dhabi and privatize assets as was done with ADWEA.

In 2008, the UAE projected to escalate electricity demand from 15.5 GW in 2008 to over 40 GW in 2020. With natural gas supplies sufficient for only half of this amount, coal dismissed owing to environmental and energy security implications, and renewable energy able to supply only 6 to 7 percent of the needed power by 2020, the UAE is taking steps to embark on a nuclear power program in close consultation with the International Atomic Energy

Agency (IAEA). It has accepted a $20 billion bid from a South Korean consortium to build four commercial nuclear power reactors with a combined capacity of 5,600 MW by 2020.

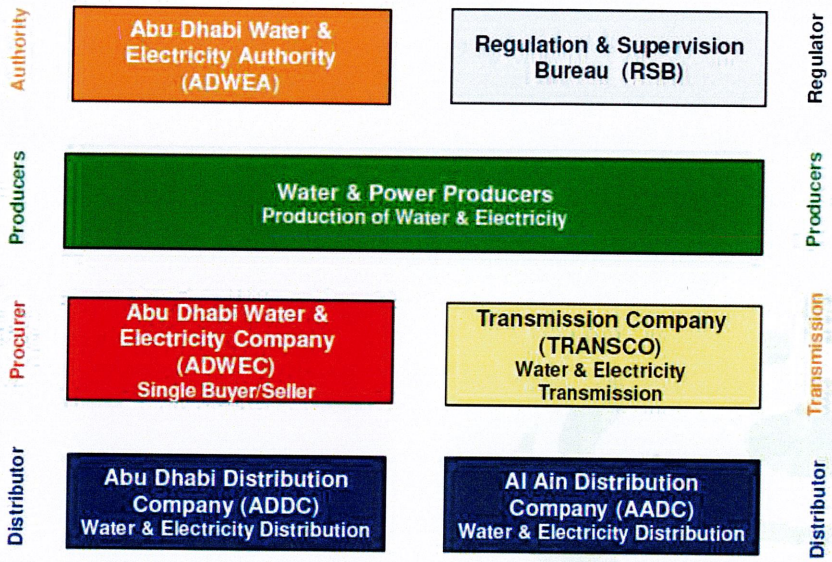


Figure (3-17) Abu Dhabi Unbounded Electricity Entities

Figure (3-18) shows the population and peak load demand for UAE. The peak load demand was collected where population were collected from the World Bank report (2015).

The UAE's electricity sector is summarized as follows:

- **Reform:** Under way in several of the Emirates.
- **Market structure:** Single buyer in Abu Dhabi with partial unbundling. Other Emirates mostly are vertically integrated with little unbundling.
- **Separate regulator:** Yes, in Abu Dhabi; no, in other Emirates.
- **Open access:** No.
- **Grid code/distribution code:** Yes, in Abu Dhabi; no, in the other Emirates.
- **Private sector participation:** Yes, in generation.
- **Tariffs:** Subsidized/commercialized structure with classes.

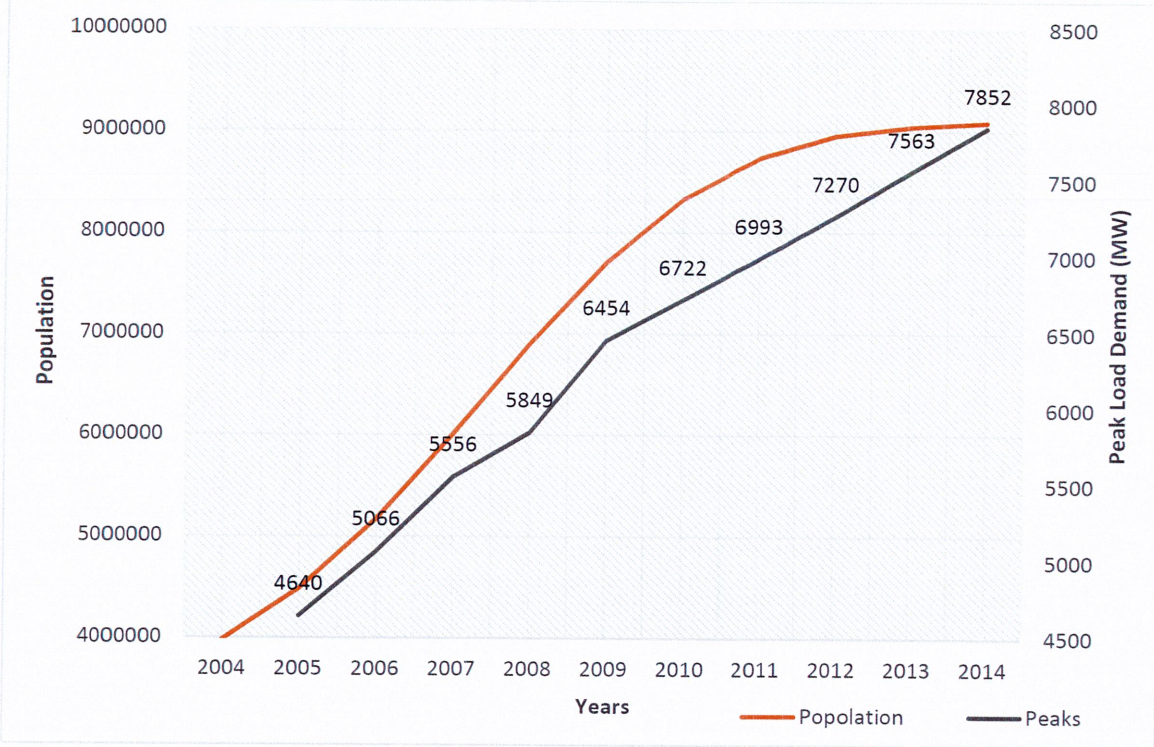


Figure (3-18) UAE Population and Electricity Peak Load Demand

UAE Climate Weather Condition at Peak Time

UAE peak load recorded on 6 August 2012 was 8525MW at 15:39hrs. Figure (3-19) illustrates the weekly load pattern where the peak loads occurred in the middle of this week, and the data were collected from World Bank (2015) and ICC. Figure (3-20) shows the weather conditions for the days during the same period, where the week started from 02 until 09 August 2012. The difference between the peak load and the load demand in the day after, the peak load was approximately 500MW.

UAE geographically is located in west-east side as shown in Figure (3-20). It has a very high temperature exceed 40 ^{O}c. Temperature elasticity was low due to high humidity. The ambient temperature varied from 32°c early morning and increased to more than 47°c at noontime. The temperature at peak load time was recorded at 40°c. The humidity varied from 10% to 75%

every day. It was recorded 14% at peak time. The humidity curve has different shapes from one day to another, so it is not stable, but varied from one day to another.

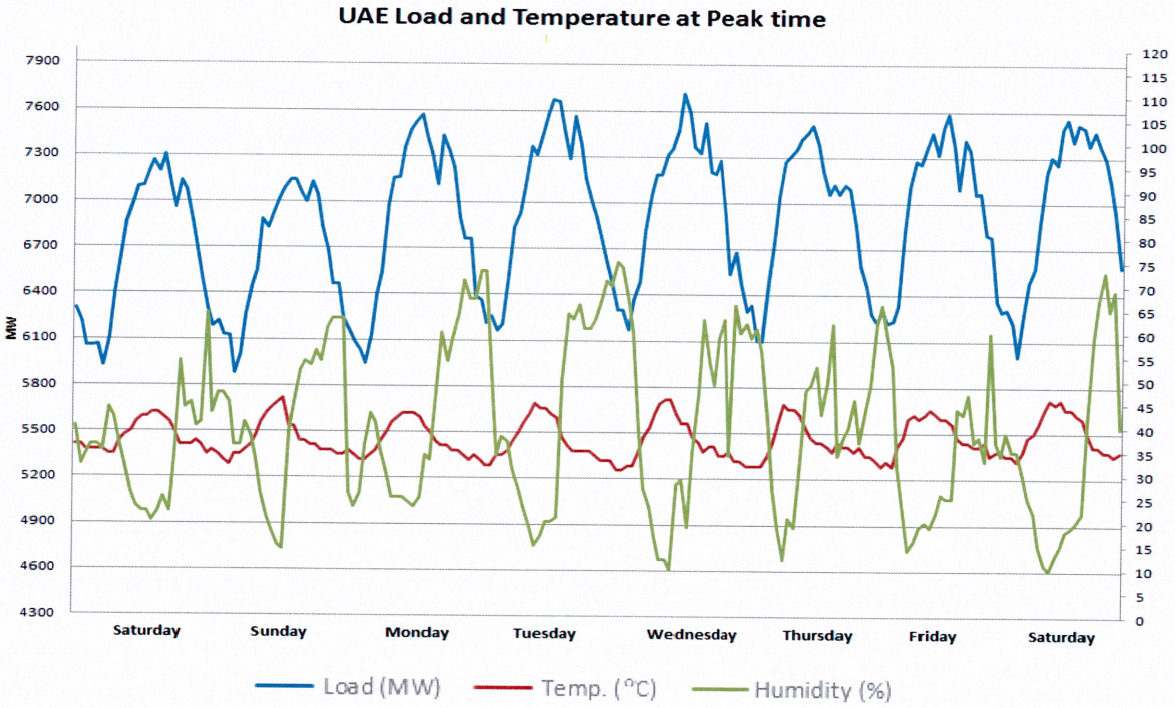


Figure (3-19) Weekly Peak Load, Temperature and Humidity Patterns for UAE, (Source: Al-Hamad et al (2013))

The temperature at the peak load time for the UAE was recorded to be 40°c. The wind direction changed during the peak load time from the eastern side to the northern side where the speed dropped from 15 mph/24kmh to 5 mph/8kmh while the air pressure also dropped to 994hPa. After that, the wind speed picked up to 20 mph/32kmh blowing from the northern side of the country. The day before the peak load day was similar to the peak load day, but the dew point was higher than the peak load day and the barometric pressure was found to be less by 3hPa during the day. The days after the peak load, the wind direction pattern changed smoother than the days before where the dew point was found to be higher than the peak load time.

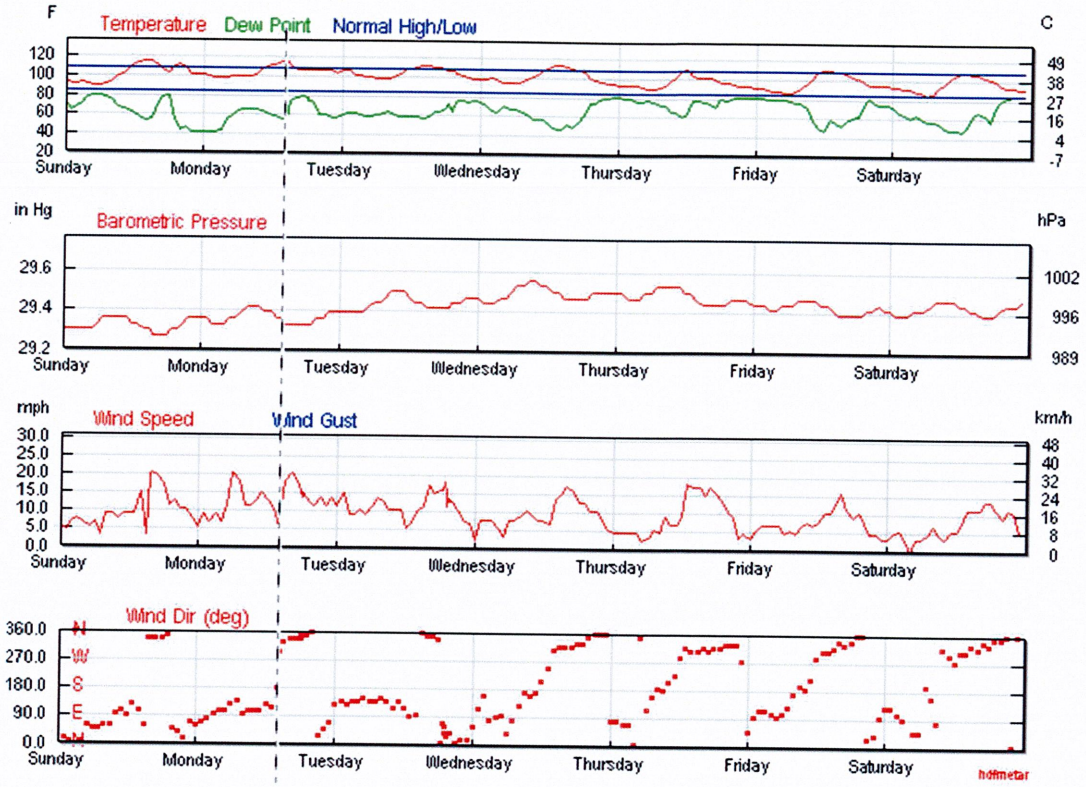


Figure (3-20) Week Weather Condition for UAE Peak Load
(Source: The Weather Company (2015))

3.1.8 Oman National Network

In Oman, the Ministry of Housing, Electricity and Water (MHEW) is responsible for the power sector. The electricity sector is vertically integrated and the Ministry is responsible for the whole electricity supply chain, i.e., generation, transmission and distribution. The Ministry undertakes the task of planning and development of the electric power sector.

Oman's government is undertaking a major reform of the electric power sector. Privatization of the power sector is a key initiative of the government. The government is working on a new legal framework for a privatized power sector. A new sector law, which will provide for further reform, is in a form

and is expected to be enacted within the next year. It is expected that in the next few years, most of the generation, transmission and distribution functions would be privatized. Once privatized, the electricity sector will be governed by the new law, which will provide, inter alia, for the establishment of a specialized regulatory institution, which will govern all participants operating in the new sector structure.

Oman Electric Utility Structure

Oman was the first GCC country to introduce the IPP and IWPP models, and it has successfully privatized many of its power plants. The state-owned Oman Electricity Transmission Company is responsible for the transmission network, while the state-owned Oman Power and Water Procurement Company act as the single buyer, purchasing all electricity from generators and selling it on to the distribution companies and large consumers. The Oman Power and Water Procurement Company is responsible for determining and securing new capacity when needed, subject to regulatory approval, and has the exclusive right to import and export power.

Oman's Ministry of Water and Electricity is responsible for policy while regulation is the responsibility of the financially and administratively independent Authority for Electricity Regulation (AER). AER is also responsible for facilitating privatization of the electricity sector. The law requires AER to document tariffs and quantify the government subsidy to be paid by the Ministry of Finance. AER has approved a grid code, a distribution code, and a formal connection-and-use-of-system charging methodology for

Oman. Figure (3-21) shows the organization of Oman's power sector as presented in Oman Electricity Regulation Authority (2015).

Oman will require between 3,000 and 4,000 MW of new generating capacity by 2016. The Oman Power and Water Procurement Company have initiated competitive procurement for two new gas-fired IPPs, each having a capacity of 650–750 MW, with an expected commissioning in 2013. From Oman's 7 years statement (2010-2016), temporary generating capacity using diesel or open-cycle gas-turbine technology is also under consideration for 2011, where gas use for power generation is expected to double by 2020.

Retail electricity tariffs remain far below the economic cost of supply in Oman. The World Bank reports (2009) that residential customers in Oman consuming 700 kWh per month pay only 15 percent of a benchmark tariff. Oman's electricity sector is summarized as follows:

- ***Reform***: Under way with the passage of new law.
- ***Market structure***: Single buyer with full unbundling. Potential to move to wholesale competition under the new law.
- ***Separate regulator***: Yes.
- ***Open access***: No.
- ***Grid code/distribution code***: Yes/yes.

- ***Private sector participation***: Yes, in generation.
- ***Tariffs***: Subsidized.

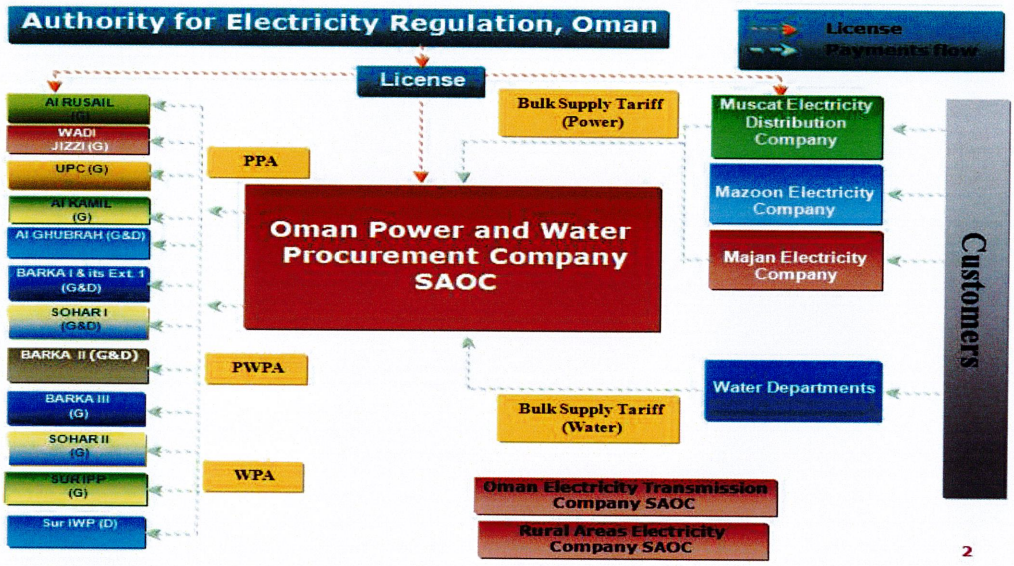


Figure (3-21) Oman's Power Sector (Source: www.aer-oman.org)

Oman data was not available before the 2014; its peak load in the year 2014 was recorded at 14:00 on in 11 June 2014, and the data was collected from World Bank (2015) and ICC and it is shown in Figure (3-22).

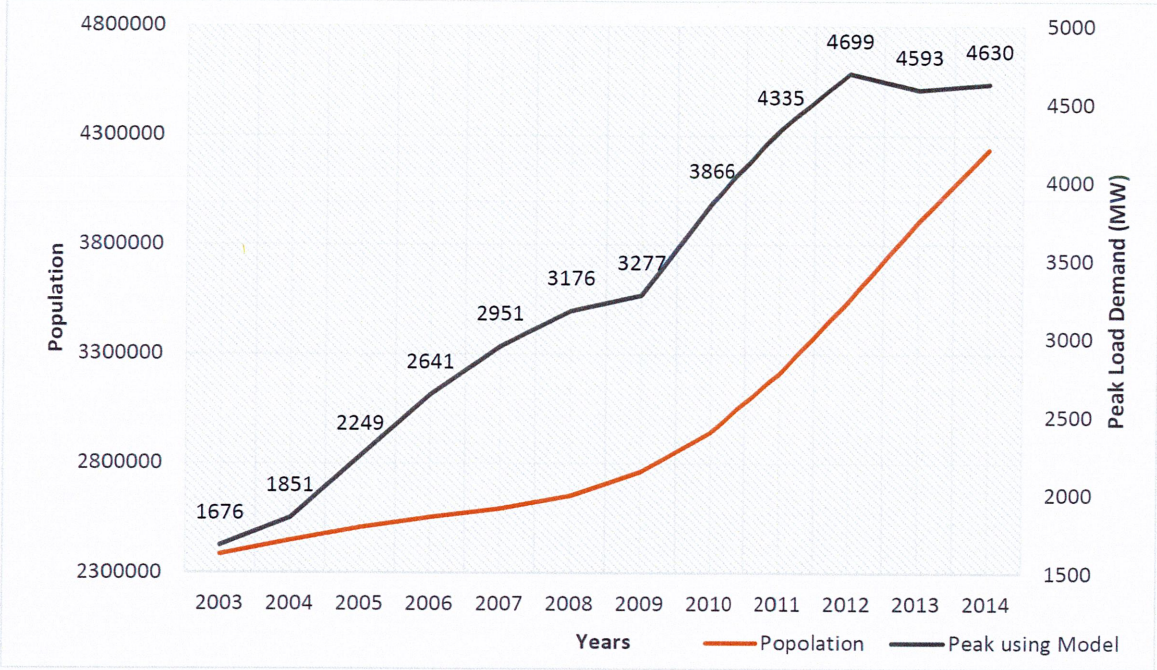


Figure (3-22) Oman Population and Peak Load Demand

3.2 Results of Readiness of GCC for Electricity Market

3.2.1 Structure of the Electricity Utility for GCC countries

There is a development in the GCC national power sector structure, which stated before the interconnection, as shown in Figure (3-23), while Figure (3-24) illustrates the status of national power sector structure for each member states. There was no development recorded in the electricity sector in Kuwait, Dubai, Sharjah, and the National Emirates. Therefore, they represent all power sectors where they are considered owners of the electricity supply industry. The energy market type is vertically integrated in all of them. They are responsible for regulation, operation, generation, transmission and distribution of electricity.

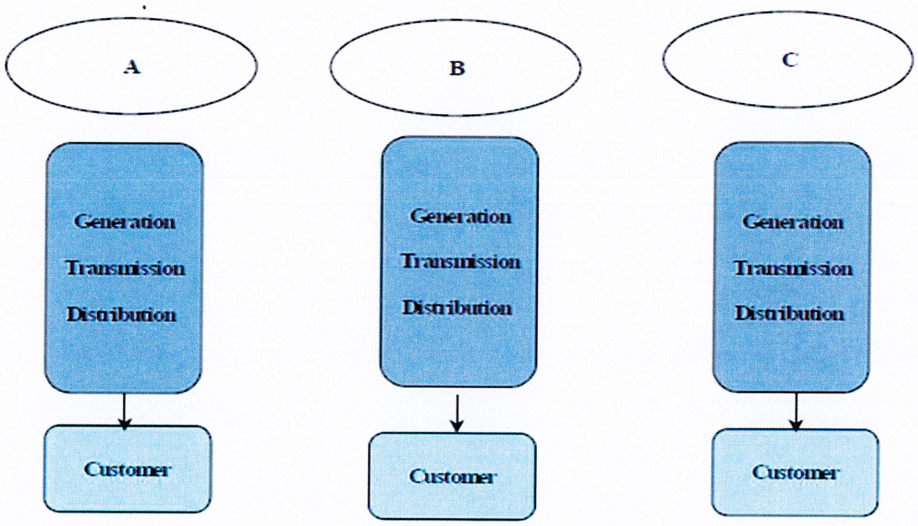


Figure (3-23) Electricity Market Structure before the interconnector, Al-Haddad et al (2013)

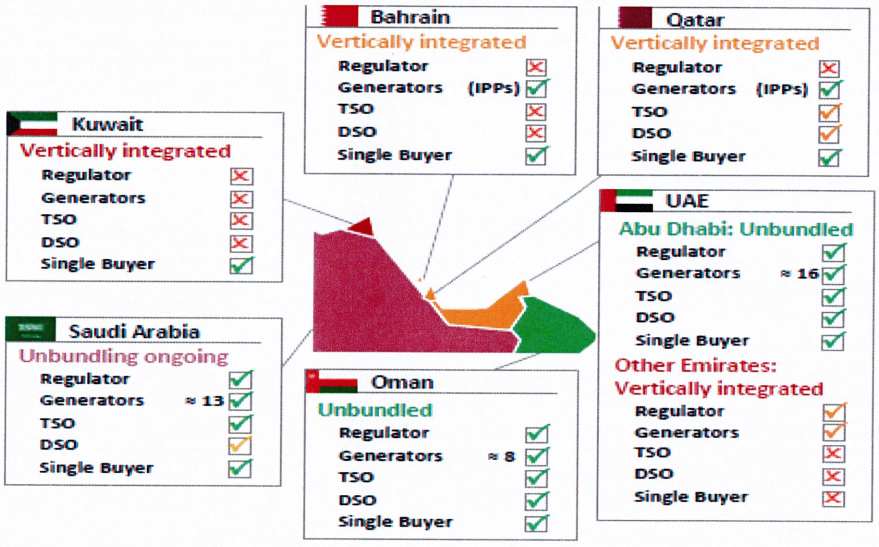


Figure (3-24) GCC National Power Sector Structure in 2015, Pierre (2014).

The energy tariff is not reflecting the actual cost due to heavy subsidies applied in all gulf countries. Figure (3-25) shows the position of some of the gulf countries in terms of energy subsidies and compared to the USA.

The electrical structure of the GCC region is summarized in Figure (3-24). Bahrain, KSA and Qatar are also considered as a vertically integrated system

where they succeed only in the involvement of private investment in the power generation sector in the shape of IPP companies. KSA, Oman and Abu Dhabi have a regulatory body to regulate the electricity sector on a national level. The rest of member states are still self-regulated.

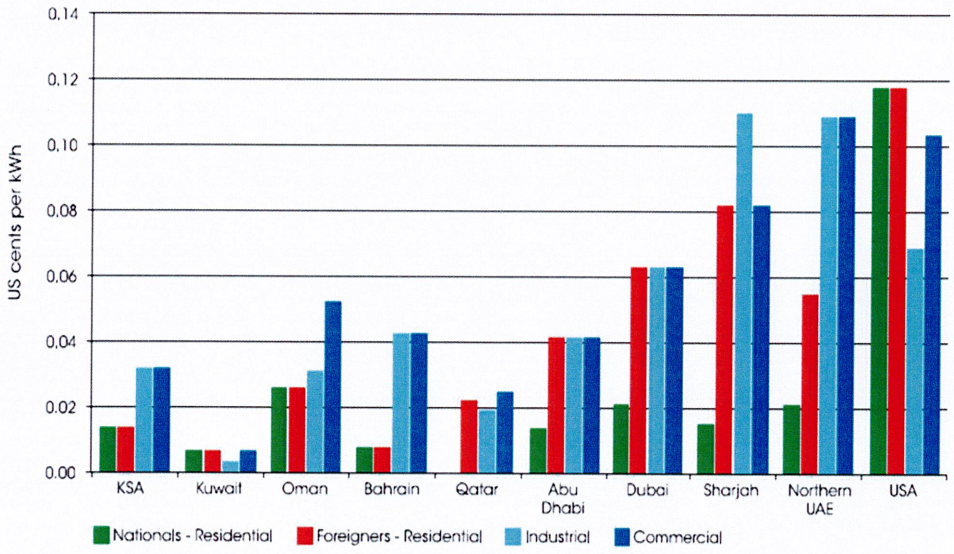


Figure (3-25) Electricity Prices by Sector in the GCC and Compared to the USA in 2011

Oman is the most advanced structure in the GCC region, but it has many rural areas not connected to its national network. The Kuwait system is heavily dependent on crude oil as a main fuel to generate electricity. The country is depending on crude oil is 65%, and gas covered 35% to generate electricity in 2012 as presented by El-Katiri (2011).

3.2.2 Power Trading Through the Interconnector (2010-2012)

Al-Haddad et al (2013) present all recorded power-trading deals between GCC countries. The first case of utilization of the interconnection for commercial benefits was on 31 August 2010 as shown in Figure (3-26), when a fuel disturbance in a Member State (A)'s electrical network caused fear to

develop into a cascading effect on the whole local network. (A)'s utility requested emergency support from the other member states through notifications to the Interconnection Control Centre (ICC). Member states provided security and support to (A)'s system to prevent any further outages or complications that may lead to system collapse, until the local operator would resolve the contingency. The support continued for eight continuous hours until the following day, where the troubled utility declared the need to procure power to ensure meeting demand and security of its network. The power procurement conducted between (A) and (B).

In May 2011, the first in-kind trading took place between (A) and (C) was recorded. Member state (A) announced that due to local generation testing, excess power would be generated and it would be required to channel it through the Interconnector. GCCIA acted as mediator to find suitable trading partners with (A) and through communications with other member states, (C) expressed interest in being the recipient. GCCIA took on the role of facilitating the energy exchanges and ensuring allocation of grid capacity and accuracy of issues schedules. The trading event lasted for 36 dispatch periods during two days, and compensated in kind afterwards through mutual agreement between the two parties.

In July 2011, The second recognized trading event was the tri-lateral trading that took place and involved the same (A) as the recipient and (B) and (D) as providers. Due to delay in contractual obligations and delivery of promised installed capacities, (A) took on the smart approach of using the Interconnector to meet its increasing demand in the summer season. Through GCCIA, (A) declared its intent to procure power on a daily basis during the peak hours.

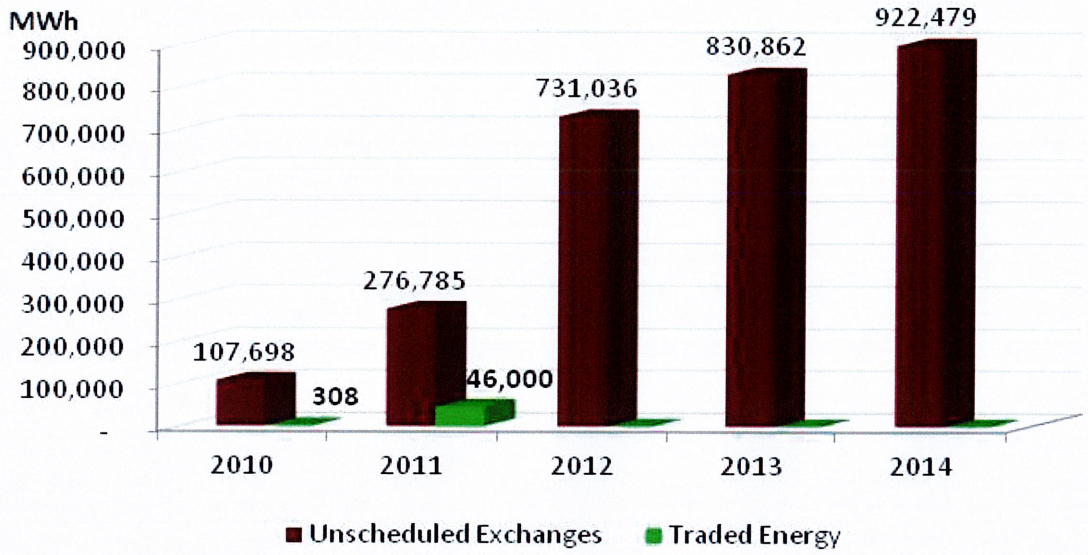


Figure (3-26) Energy Trading and Energy Exchanges (2010 - 2014)
(Source: Al-Haddad et al (2013))

Through, short-term forecasting and planning, (A) contracted with (B) and (D) to provide supply at agreed undisclosed tariff rates. GCCIA took on its assigned role to facilitate the allocation of grid capacity and energy scheduling. This event labelled as Spot Marketing at first due to the sudden and short notice of the request. Because of that, (A) reported receiving other offers at a very high tariff, which could have put off the trading as well as a drive (A)'s utility into resorting to load shedding as an alternative solution.

Figure (3-26) illustrates the amount of energy trading and the energy exchanged since the interconnection was commissioned. It shows that the amount of energy trading is very low in quantities compared with energy exchanged between the interconnected member states. It is clearly showing the amount of energy that member states exchanged free of charges increases year after another where the interconnection was not utilized for power trading after 2011.

Examining the two past cases, it can be determined that power trading conducted to meet sudden changes in network topology and increments in load demand and was deemed as an immediate solution to maintain supply of service and network stability. In relation to the matter, rapid growth of load demand in the GCC region shown in Table (3-3). The Average annual electricity consumption Growth Rate in the GCC for the last three years shown in Table (3-4).

Table (3-3) Demand Growth (MW) in the GCC Region
(Source: Al-Haddad et al (2013))

Year	GCC	KSA	KUW	BAH	QAT	UAE
2009	28672	11739	9960	2438	4535	-
2010	30421	12965	10890	2708	5090	-
2011	39861	13423	11285	2871	5367	7849
2012	42950	14782	11956	2880	6243	8525

Table (3-4) Average Annual Electricity Consumption Growth Rate
(Source: Al-Haddad et al (2013))

Year	GCC	KSA	KUW	BAH	QAT	UAE
2010	5.7%	9.5%	8.5%	10.0%	10.9%	-
2011	23.7%	3.4%	3.5%	5.7%	5.2%	-
2012	7.2%	9.2%	5.6%	0.3%	14.0%	7.9%

After going through this initial experimentation with cross-border power trading, the procuring member state (A) decided to depend on it and plan its short term daily forecast around it in order to maintain meeting its obligations. Such dependence boosted the confidence in the Interconnector and its ability to be a dependable platform for power trading.

Some of the issues that appeared during these power trading events present to some extent the challenges and obstacles to complete such commercial deals. High tariff offers, limited operating reserve at summer time, internal

regulations and delegation of authority are some of the issues that were visible during the power trading events in 2010 - 2011.

3.2.3 Challenges to Development of GCC Power Market

After a brief review of the power trading events, it found that the existing and predicted challenges might block the establishment and development of the cross-border power trading. Through a number of commercial power trading activities between GCC member states, it has been confirmed that some issues remain to the addressed and dealt with variant levels of association. Some of these issues were found to be connected to local regulations, corporate operational economics, isolated technical operations, etc. Such challenges were not in view at the time of authoring previous technical studies for the interconnection project, until power trading between states took on its commercial form.

The following topics are considered, through trial, to be some of the major challenges that would hamper the development process of the GCC power market, if not addressed properly in time:

1. Absence of energy utilization and electricity costs for trading and the benefits that can be achieved by power trading:
    - GCCIA to expand its role as a market facilitator.
    - Improving market liquidity.
    - Optimal utilization of cross-border capacities in order to maximize total social welfare in the coupled markets;
    - Activation of trading in-kind ,
2. Disparity in national energy policies

- Member states to evaluate the production costs "Marginal Production Cost"
- Member States to offer energy quantities with prices for sale and request energy to buy.
- Further, an energy price index can be established to broadcast and forecast energy prices for guidance.

3. High energy subsidies, which leads to energy price distortion in GCC countries
    - The earlier mentioned study will determine the best possible fixed prices for buying energy between MSs, using the same concepts and neutralization as were used for the "Tariffs and Charges" study. It shall determine the suitable price structure during different times of the year/day (peak / off-peak).
    - Reference prices that enhance the use of efficient production units;
4. Divergence in national power sector structure
    - If trading of operating reserve and installed capacities between member states is efficiently utilized through the interconnector, member states can:
        - optimize the operation of its local network
        - reduce fuel dependency
        - cut down on operating costs
        - budget optimization of future capacity projects.
5. Difference in local regulations towards cross-border power trading.
    - GCCIA, in coordination with ARC members, can play an effective role in assisting member states to evolve their current

internal policies to enable efficient power trading in the region and beyond.

- Member states are highly encouraged to introduce and implement local regulations that allow, promote and support power trading through the Interconnector.

6. Low number of market participants
    - Additional market players (more choices to trade and different price plans and offers).
    - Linking renewable energy projects to the Interconnector can provide many solutions to existing issues i.e. geographical limitations, environmental cases and cost of building further generation capacities.

3.3 The Path to Develop Effective GCC power Market Towards a Shared Future

As it can be seen from the challenges above, such issues can block the wheel of development in power sector structure, creation of GCC power market and liberalization and coupling local markets. In order to fulfill these objectives, the challenges mentioned need to be addressed in a politically acceptable approach that would serve member state's interest, to being economically beneficial, support the future strategies and not requiring extreme modifications in the current set-up.

The following factors are deemed a suitable proposal for enabling the establishment of GCC power market and push towards its development in the region. They are as follows:

1. National support for power sector development in its current structural configuration shown in Figure (3-27).

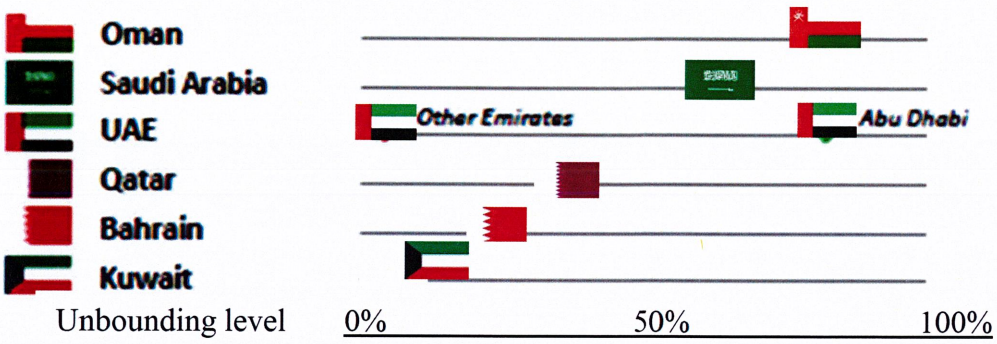


Figure (3-27) Unbundling Level in the GCC Region

2. Develop national regulations to allow generation companies to participate in the regional electricity market, forming a Multi-National Wholesale Model for single buyer and generation companies as shown in Figure (3-28).
3. Develop national regulations to allow different types of market players to participate in the regional electricity market, forming a competitive Multi-National Wholesale Model as shown in Figures (3-28a) and (3-28b).
4. Adoption and integration of alternative energy resources.
5. Reduction in dependency on governmental subsidies shown in Figure (3-25).
6. Access to additional market participants and variety in providing services as shown in Figures (3-29a) and (3-29b).
7. Alignment of local regulations to support and promote power trading.
8. Accounting for the Interconnector in local system operations and generation expansion plans.
9. Support of academic research and awareness towards the benefits of power trading and its effects on the welfare of the nations.

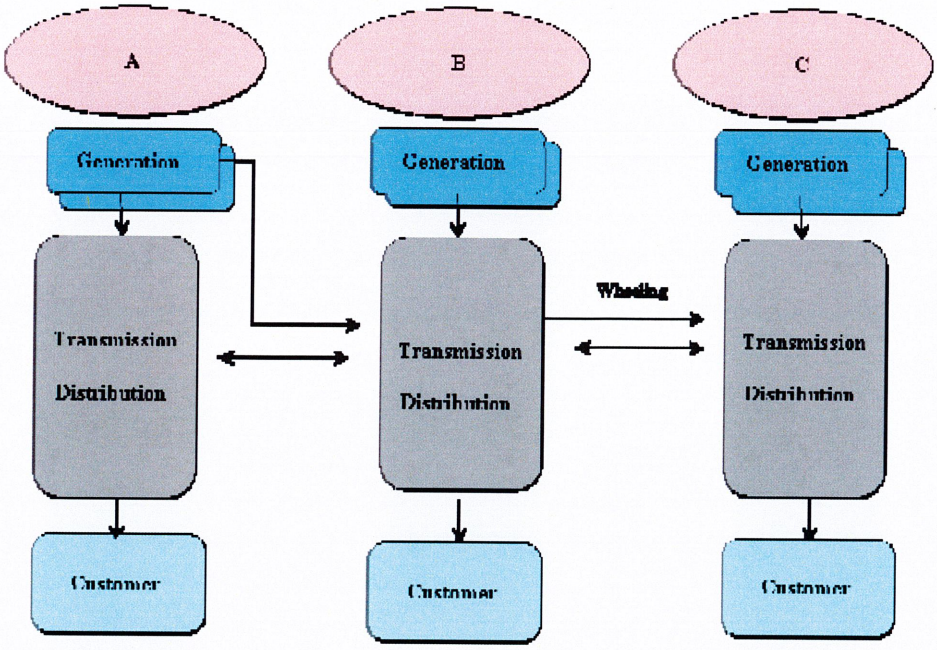


Figure (3-28a) Multi-National Wholesale Model for Single Buyer and Generation Companies

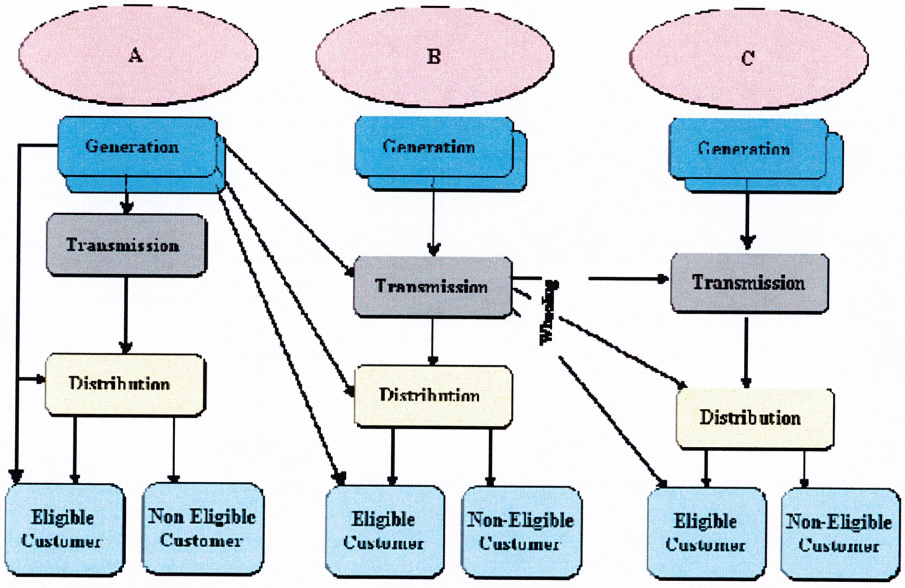


Figure (3-28b) Competitive Multi-National Wholesale Model

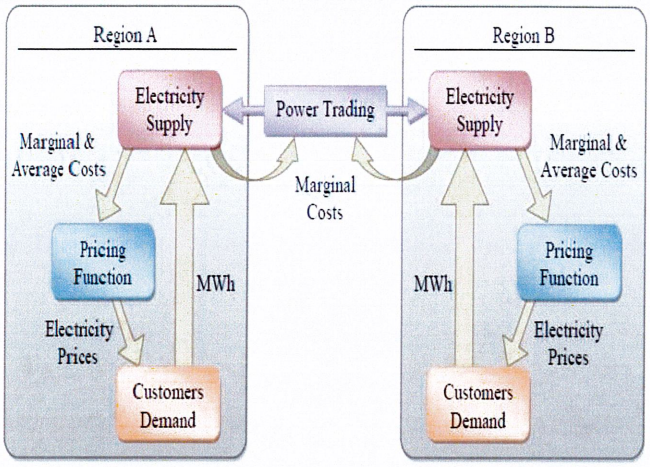


Figure (3-29a) The Process between the Zones of the Multi-National Wholesale Model

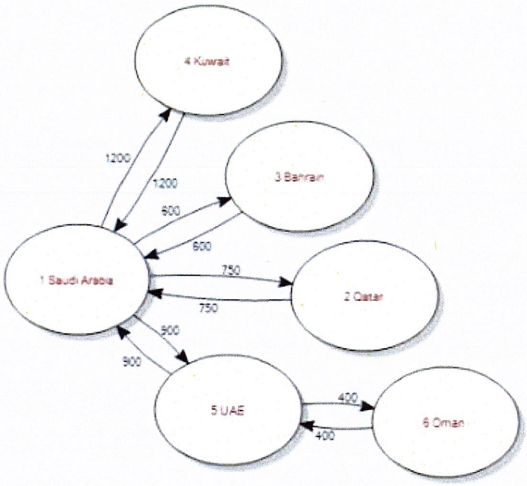


Figure (3-29b) Connection Model between Zones of the Multi-National Wholesale Model

The proposed practical approach recommended for sovereign member states in order to adopt, promote and support power trading is to integrate the following on two levels of power; on the national level and on the energy industry level. The earlier mentioned factors can be summarized in the following approach:

- National energy policy: a strategic national energy policy that would contain the following elements:
  - Progression of local regulations.
  - Introduction of alternative incentives to subsidies.
  - The creation of independent entities that govern and rectify energy policies as shown in Figure (3-24).
- Strategic development plan: a long term-based plan to be implemented by parties in the energy sector to address the following:
  - Adoption of power trading principles and essentials.
  - Liberalization of local market.
  - Acquisition of knowledge and expertise in the power trading industry.
  - Integration of alternative and cost-efficient energy resources.

3.4 Conclusion

As can be seen in the results presented in this chapter, that there is a remarkable potential to receive mutual benefits between the GCC countries, to utilize the interconnector efficiently and practically. One of the long-term goals of this project is the mutual prosperity of the nations of the Gulf region as well as industrial growth of its energy sector. Thus, if an active form of trade such as power trading is activated in the region using the available platform, then the GCC Interconnector will be optimized as can as possible, and the member states will gradually receive more benefits such as cost reductions, network security and stability, as well as a dependable second source of national income.

The well of the GCC nations to mature and develop is the main driver here. GCCIA and the GCC Interconnector are platforms that are seriously considered for cross-border activities and system expansion. As can be seen also with great expectations, the Interconnector would be the connecting bridge between the gulf region and surrounding regions, interconnecting technology, business and hope.

It could be seen that to establish a new industrial growth in the oil-rich region, multiple angles and issues such as local politics, industrial reform and adoption of new global trends are some of the main points that need to be taken in consideration and addressed. The development could start from joint committees, like the planning committee and operation committee, where all member states are presented, aiming to develop effective a GCC power market towards a shared future, as shown in section (3.3).

Chapter 4

Load Demand Forecast Modeling

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CHAPTER 4

Load Demand Forecast Modeling

4.1 INTRODUCTION

In the deregulated economy, the maximum load forecasting is important for the electric industry. Many applications are included such as the energy generation and purchasing. The aim of the present study is to find the most suitable models for the peak load demand for the GCC countries. Many mathematical methods have been developed for maximum load forecasting. Modeling of the maximum load demand, population and GDP at versus years obtained. It is found that the Neuro-Fuzzy is the most suitable and realistic one. Then, the linear modeling is the next suitable one.

In the present study, Multiple Linear Regression Method and Adaptive Neuro-Fuzzy Inference System (ANFIS) Models are designed for output estimated Long Term Estimated Load for the GCC countries. Besides, another study includes curve fitting and Neuro-Fuzzy used to find the three models, where three techniques are used. These three techniques are the exponential, linear modeling and Neuro-Fuzzy. It was designed for output estimated Long Term Estimated Load for the GCC countries.

Three variables used as inputs, which are Present Peak Load, Gross Domestic Product (GDP) and Population versus years. Obtaining the

estimated Peak Loads calculated using the multi linear regression and ANFIS. The MATLAB Simulink 7.10 package used to obtain the estimated peak load for GCC countries. The models obtained using the multi linear regression and Neuro-Fuzzy techniques. GCC Population and GDP used in the Multiple Linear Regression Model. A different GDP growth scenario based on development in the country used and taken in consideration. The results used for the peak demand will compared with actual peak data. The average percentage of error for each model calculated based on data used to generate the model, where the less average error model presented and recommended for the long-term load forecast for the peak load demand.

For the electricity sector decision makers, the energy trading and facility expansion are required. The electricity demand pattern is a multifaceted due to the different types of loads, weather conditions, and socioeconomic factors. Therefore, finding an appropriate peak load-forecasting model for GCC countries peak demand of the electricity network is an important task for a network planning and power trading which interconnected to another five national networks through GCCIA grid. This will help to plan for a reliable and economical operated network.

The present study presents a pragmatic methodology used as a guide to construct Electric Power Peak Load Forecasting Model for the GCC. There are many exogenous variables for the long-term load forecasting (LTLF) – like weather conditions, industrial development, Population Growth and social events in the country. For more simplicity, the Model using the main

variables, which effect on the peak load demand and selected for the proposed Model. Therefore, the GCC Population and Gross Domestic Product (GDP) selected as the variable elements in the Multiple Linear Regression Model.

This chapter deals with the Electrical long-term peak load demand forecasting using Multiple Linear Regression method. There are many forecasting methods were developed to generate equations for the required demand patterns. It is important to have a simple model, which used in different type of software to calculate demand forecasting and different output requested by decision makers. The Model should have an acceptable level of mean errors. Having a simple and pragmatic equation can provide acceptable Model to make plans for periodical operations, energy trading and facility expansion in the electricity sector.

A different GDP growth scenario based on development in the country will take into consideration. This will give the range of peak load demand growth forecast. The GCC data for GDP and Population collected from World Bank records and tabulated in Appendix (A).

4.2 Load Forecasting Types

Literature Survey on Types of Power Load Forecasting

Electric Power Load Forecasting (EPLF) is an essential process in the planning of electrical utilities and the operation of their power systems. Perfect estimation for load forecasting will show the way to significant economic saving in operating and maintenance costs. A number of studies were done a long time ago, where Qamber (2004) model the peak load for Kingdom of Bahrain modulated to forecast the peak load demand for the upcoming year using Neuro-Fuzzy. These types of studies are helping in increasing the reliability of power supply and delivery system, and correct decisions for future development.

Electric peak load demand is the highest recorded demand and supplied by generators. It recorded for different time horizon, which is hourly, daily, weekly, monthly, and yearly periods. EPLF has very different characteristics compared to a different type of energy commodity. This type of energy should consume as soon as it was generated. Electricity Load Forecasting for the peak load that made for various purposes classified into three categories as presented by Heiko et al (2009).These three categories, which are the short-term, the medium-term and the long-term forecasts. These classifications based on the range of the forecasted period.

Henault et al (1970) highlight that in the developing countries like GCC countries, their peak load growth in electricity is mainly based on variables such as economic growth, population, and efficiency standards, coupled with other factors inherent in the mathematical development of forecasting models making accurate projections difficult. Willis (1995) mentioned for the rural

and sparsely populated regions the forecasting electric demand of distribution system it will not have similar variables.

Feinberg et al (2005) in their study concentrate that the Long-Term Load Forecast (LTLF) used to predict the load for more than one year.

Feinberg et al (2005) and Kyriakides et al (2007) present that the Long-Term Load Forecast (LTLF) is used to predict the load for more than one year, where it is usually used for a period of 20 years, and 25 to 30 years in some cases. The target of this type of forecasting is to plan for the install capacity to build it in the future for the expected load demand based on the projects and the master plan of the country. For example, the LTLF helps the country in allocating and involving the independent power companies to participate in bidding in building power generation or to plan purchasing electrical energy for a long period to manage the energy demand in most economical and reliable way.

Gonzalez et al (2006) present that the Medium-Term Load Forecast (MTLF) used to predict the load from one week to one year. The target of this type of forecasting is to enable electricity utilities and trading companies to estimate the load demand for less than one year and greater than STLF period. The MTLF helps the electricity sector companies to negotiate the contracts with other companies and to schedule the operations and maintenance.

Kyriakides et al (2007) present that the target of Short-Term Load Forecast (STLF) is used to predict the load up to one week. It used for daily power system operation. Yang (2006) in the PhD thesis presents part of this classification which is the very short-term load forecast (VSTLF) and used for less than one day forecast to meet the load demand during the day in the energy market.

Literature Survey on Studies Power Load Forecasting

Qader et al (2010) in their paper present study considering the maximum electric load of the Kingdom of Bahrain over a period of five years. Monte Carlo method used, where its basic variables are presented and discussed from the standard deviation and reserve point of view. The results compared to a weekly and yearly basis.

Al-Muhawesh et al (2011) in their study a pragmatic methodology used as a guide to construct Electric Power Load Forecasting models. The methodology they used based on decomposition and segmentation of the load time series. In their study a real data for Kuwait used. Finally, they obtained the results, which helped in getting the forecast load for the future.

Qamber (2012) in his study derived a number of models to estimate the electrical demand for future load in Kingdom of Bahrain. The models derived in a way describing the electric power demand during summer period.

Tawalbeh et al (2012) in their study, presented a nonlinear method to estimate the consumed energy in distribution feeders. The proposed procedure uses the statistical solution algorithm to analyze the active energy monthly consumption, which enables one to estimate the energy consumption during any period of the year. The effectiveness of the proposed method demonstrated by comparing the simulated results with that of real measured data. The results obtained using the curve fitting technique. In the study, it is concentrated on the lower, average and maximum loads. Three scenarios carried out and their models obtained.

Ryu et al (2014) in their study, which carried out on the base of Super Grade Hotels that have high-energy consumption per unit area cause a massive amount of load. The study concentrates on analyzing the energy consumption by using electricity load data. The study carried out to reduce the amount of electricity and peak load through the management and energy efficiency improvement of the large hotels.

Koo et al (2014) in their study performed short-term electric load forecasting using three methods and compared each result. The authors used two factors to eliminate error from calendar based classification before making a forecasting model. The authors compared three methods including the Artificial Neural Networks.

Upshaw et al (2015) in their article discuss the development of a model for evaluating peak load reduction and change in overall energy consumption for a residential air conditioning compressor with and without condenser-side thermal storage. The model used simulated cooling load data for a typical home in Austin (Texas) based on summer 2011. System performance varies depending on weather data.

Kot et al in their paper (2013) review maximum power point tracking algorithms dedicated for small wind turbines. Three algorithms used and discussed. Two of them based on turbine static parameters, where the third one iteratively searches for optimum operating point and it does not require prior knowledge of the turbine.

Barzin et al in their article (2015) present an analysis of a price-based control system in conjunction with energy storage using phase change materials for two applications. Their results showed the importance of selecting a suitable price constraint to examine the benefits.

4.3 Load Forecasting Data

Weather conditions are the most significant factors that considered as a significant influence on the forecasting during the year. Generally, the weather condition repeats its behavior every year. The water temperature varied during the period of the day, week, month and year, where the temperature is always in the range of forty Degree Celsius during the peak time in Bahrain. Soliman et al (2010) mentioned that the same thing is implementing for humidity, wet bulb, wind direction, wind speed, and weather pressure. Therefore, these weather condition factors usually used for STLF and MTLF.

The models and methods applied for the LTLF are different from the other two forecasting categories because it depends on different input data. The factors affect in the load demand are included numerous of element of weather conditions, over seasonal effects, and socioeconomic factors. The socioeconomic becomes the available data, which used as selected data and used as input available at the forecast the LTLF.

The LTLF for peak load demand had used to estimate the future expected peak load to avoid spending money on capacity in case of overestimated peak load forecasted that did not utilize for long period and causes negative economic impact on the efficient use of national resources. In addition, underestimated the peak load forecasted may lead to a shortage in energy available, which may cause a load shedding for the load supplying domestic or industrial area in case.

In the developing countries like GCC countries, their peak load growth in electricity is mainly based on variables such as economic growth, population, and efficiency standards, coupled with other factors inherent in the mathematical development of forecasting models making accurate projections difficult

Soliman (2010) lists the following elements are the main factors that affecting in the for peak load forecasted:

1. The gross domestic product (GDP)
2. The population (POP)
3. The GDP per capita (GDP/CAP)
4. The multiplication of electricity consumption by population (EP)
5. The power system losses (LOSS)
6. The load factor (LF)
7. The cost of one kilowatt-hour.

4.4 Forecasting Process Methods and Model

There are a number of methods could be used to model the long-term peak load of electricity network. Each method has advantages and disadvantages. The method chosen should be suitable for the target and data used for the study. There are many methods could be used for LTLF, where the most famous methods used are the Least Squares Regression Method, the simple linear regression, the multiple linear regressions, the quadratic regression, the exponential regression, the intelligent methods including Fuzzy logic, Artificial Neural Network and Artificial Neural-Fuzzy method.

Going back to the elements, which could considered in the model for peak load forecasting, the social behavior can presented by the first four factors. These factors may vary from country to country. The last three factors interlinked with the electric power system characteristics, load demand and consumption.

4.4.1 LTLF using Curve Fitting Techniques

Based on these annual loads, the model is made using the curve fitting technique through using the software package Graph 4.4.2. Using this package, a number of models are made. Graph 4.4.2 is a program designed to draw graphs of mathematical functions in a coordinate system and similar things. It is a standard Windows program with menus and dialogs. At the same time, it is capable of drawing standard functions, parametric functions, polar functions, tangents, point series, shadings and relations. It is also possible to

evaluate a function for a given point, trace a graph. Graph 4.4.2 is an open source application used to draw mathematical graphs in a coordinate system.

While it is important to determine the estimated peak load based on the actual values for the GCC through the years (2003-2014), it is necessary to find the suitable technique for that purpose which is Graph 4.4.2. The technique helps to find the most suitable model for the available peak load data. The obtained model helps to find the estimated value through the period 2003 till 2024.

Equations (4-1) and (4-2) illustrate the variation of maximum load demand model (Exponential Model) for each country of the GCC through the years (2003-2014). The results coming out of the derived estimate peak load value equation for the period 2003-2024 are shown in the present thesis.

$$MEL\ (x) = (5.7382629*10\text{-}57) * (1.0707155) * x \qquad (4\text{-}1)$$

$$MEL\ (x) = (154.2028*x) - 307365.15 \qquad (4\text{-}2)$$

Where MEL (x) is the Maximum Estimated Load, which means the maximum estimated load as a function of the year (x).

4.4.2 LTLF Using Multiple Linear Regression Technique

The multiple linear regression technique used the given elements affecting the LTLF are presented in equation (4-3). This equation could be simplified by neglecting the last three factors, because the losses and load factor could be considered as a fixed component. The peak-load demand could formulate as a function of country dependency factors, which are the first four factors. Soliman et al (2010) present the formula could write as follows:

$$P_L = P_0 + P_1*(GDP) + P_2*(POP) + P_3*(EP) + P_4*(GDP/CAP) \quad (4\text{-}3)$$

GDP: The gross domestic product,

POP: The population,

EP: The multiplication of electricity consumption by population

GDP/CAP: The GDP per capita

To have more focus on the elements that may affect the forecasted peak load demand, it needed to look into the behavior of each element. Then it is focusing on the elements that have the same behavior of the peak load growth.

4.4.3 Neuro-Fuzzy Inference System Technique

It is well known that the Neuro-Fuzzy consist of two components in one system. These components are fuzzy system and a neural network. Either the fuzzy system can be a fuzzy inference block or the neural network can drive the fuzzy inference block. The fuzzy inference block converts linguistic information for the neural network.

Both S. C. Lee and E. T. Lee (1975) are the first who worked on neurofuzzy systems, especially on fuzzy neural networks. Unfortunately, they did not give any training laws for the network.

Huntsberger and Ajjimarangsee (1990) have proposed that the learning rate coefficient of Kohonen's self-organizing map treated as a fuzzy membership value of the current input sample in the class of each neuron.

Takashi and Ken (1997) have presented an application of artificial neural network for the estimation of peak load demand.

4.4.4 Fuzzy Logic Basics

Fuzzy logic is a logical system associated with human cognitive systems providing a mathematical framework to capture the uncertainties as described in Al-Hamad (2002). The advantages of the fuzzy design are:

1. Reduced and simplified development cycle
2. The implementation is easy.
3. It has efficient performance and used friendly

ANFIS MATLAB tool box is used for the training to produce the output and forecasted the peak load demand for the GCC. The methodology used explained in details in Al-Hamad (2002).

4.5 GCC LTLF for Peak demand

Bahrain as GCC member states chosen as a first example to create the Load Demand Forecast Model. The shape of the peak load demand is a very important item for any type of load demand forecast. Therefore, it needed to explore the shape of the peak load demand for Kingdom of Bahrain. All data used for LTLF was taken from Bahrain Central Information Organization and World Bank.

Generally, Bahrain Peak load demand has continuously increased during the last 12 years where the average growth found 6.3%. Figure (4-1) pointing out the Bahrain peak load demand in the last 10 years which shows a growth of around 6% during the years before 2012 with high growth records during 2006, 2007 and 2010, where it reaches after that 10.8% of growth rate. The growth in the Bahrain peak load dropped to 0.3% in 2012 where it increased after that in the next year to 1.3%. The growth in the peak load returned to its normal rate in the year 2014 where the growth recorded was 7.5% at the peak load 3152MW. The other parameter shall be similar to peak load demand growth pattern presented in Figure (4-1) where data collected from Bahrain Central Information Organization (2015).

4.5.1 Bahrain Gross Domestic Product (GDP)

The GCC countries have almost similar Gross Domestic Product (GDP), which is a market value of all officially recognized final products and services produced by country in defending period.

The Population growth rates in GCC countries were increased last decades very sharp.

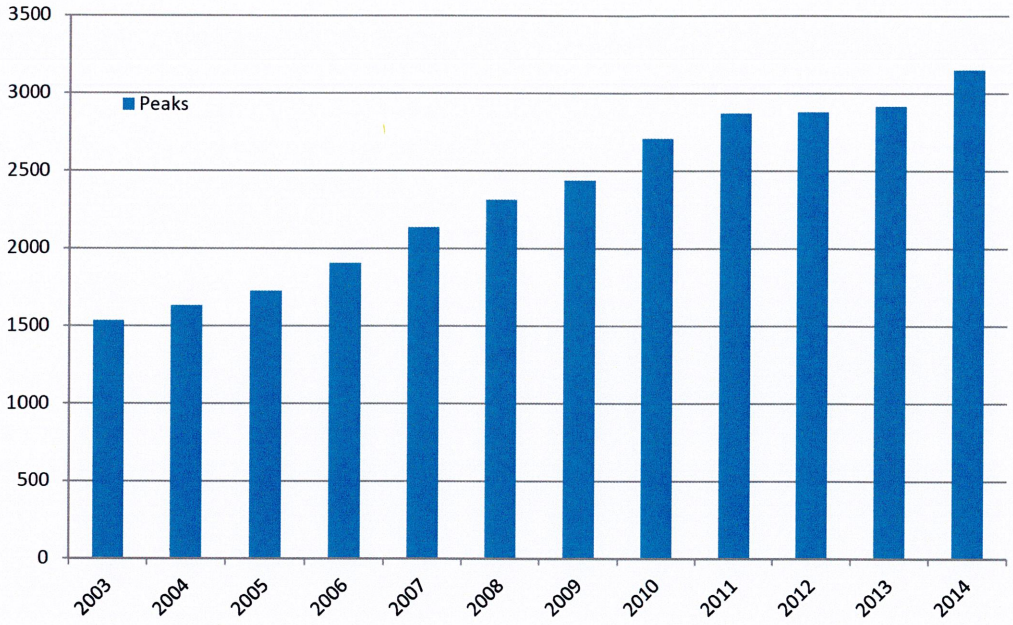


Figure (4-1): Bahrain Peak load demand during the last 12 years.
Source: Bahrain Central Information Organization (2015)

Figure (4-2) presents Bahrain GDP collected from World Bank (2015) in the last 12 years, where the recorded growth illustrates two periods of growths, which faced a drop in growth at year 2009. The average growth in GDP before 2009 found about 15.1%, where it dropped to 11.1% during the years 2010 and 2011. More drop in the growth of the GDP recorded after 2011, where it found 5.2% averagely. Therefore, the GDP has a similar growth pattern to the peak load demand and expected to have a major impact on the peak load forecasting.

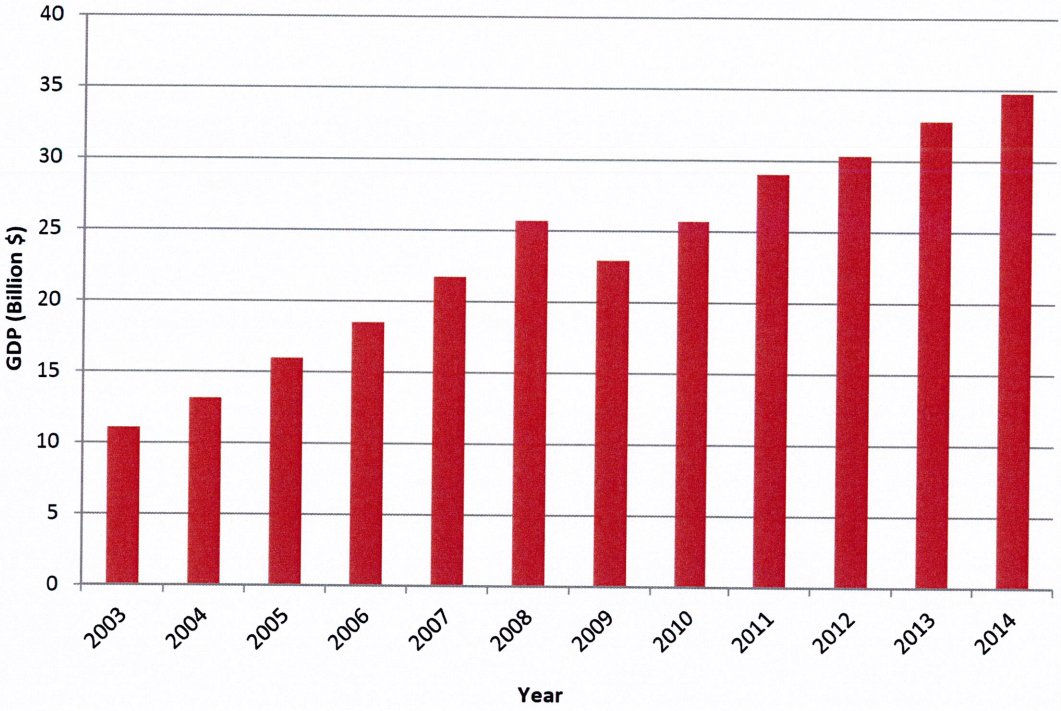


Figure (4-2) Bahrain GDP at last 12 years
Source: Bahrain Central Information Organization (2015)

4.5.2 Bahrain Population

The population of the Kingdom of Bahrain is as shown in Figure (4-3) which illustrates the population for Kingdom of Bahrain and it shows the continuity of population growth except in the years 2009 and 2010. The data collected from Bahrain Central Information Organization (2015). The average growth in Bahrain population before 2009 was in rate of 7% averagely, where the population growth rate was dropped to 3.1% after that.

Table (4-1) presents the Populations growth rates in GCC countries has been increases last decades very sharp. Besides, the number of people living in the GCC countries to cover the shortage of workers in the region also increase dramatically. The population of the Kingdom of Bahrain is as shown

in Table (4-1) has a high number of non-Bahraini nationality. The population of non-Bahraini nationally is 51.07% in 2011. The data show increases in both populations of Bahraini and non-Bahraini quantities since 1992.

Figure (4-3) illustrates the population for Kingdom of Bahrain where it shows the continuity of population growth even after economical problem that the country faced. The average growth in Bahrain population before 2010 was about 7% yearly, where it dropped to 3.2% after 2011. Therefore, the population has a similar growth pattern to the peak load demand and expected to have a major impact on the peak load forecasting.

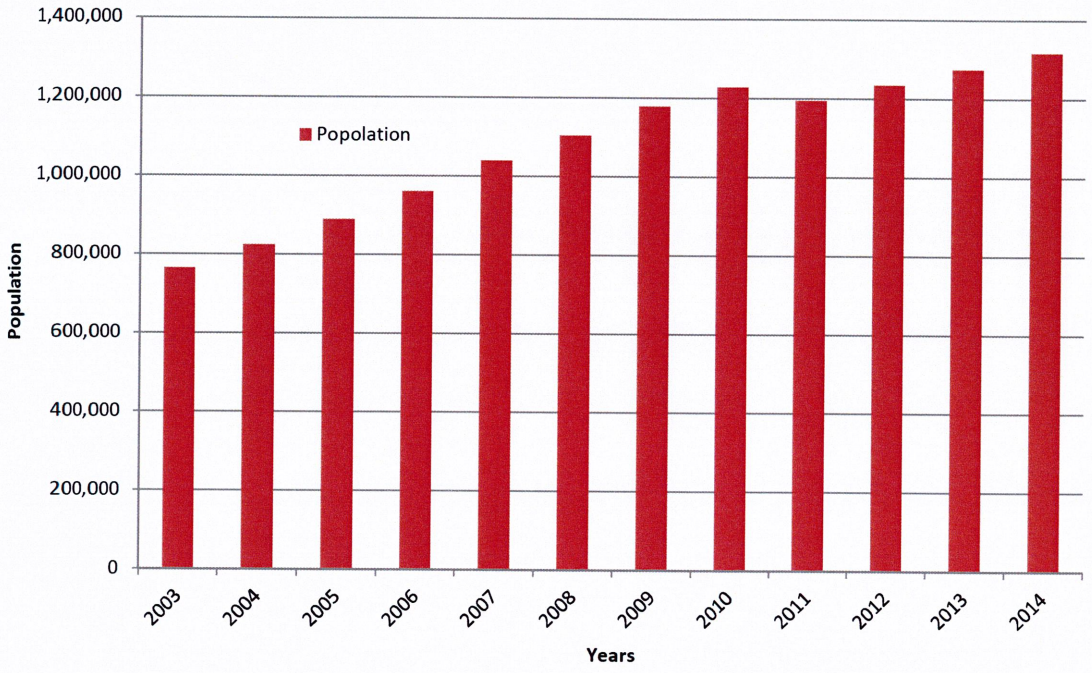


Figure (4-3) Bahrain Population at last 12 years.
Source: Bahrain Central Information Organization (2015)

Table (4-1) Population of Kingdom of Bahrain. Source: www.cio.gov.bh

Year	Popolation / Type الجنسية / النوع								
	Total الجملة			Non Bahraini غير بحريني			Bahraini بحريني		
	كلا النوعين	ناث	ذكور	كلا النوعين	ناث	ذكور	كلا النوعين	ناث	ذكور
	Both sexes	Females	Males	Both sexes	Females	Males	Both sexes	Females	Males
1992	516,458	217,559	298,899	188,232	55,265	132,967	328,226	162,294	165,932
1993	530,225	223,637	306,588	193,974	57,359	136,615	336,251	166,278	169,973
1994	544,366	229,892	314,474	199,887	59,521	140,366	344,479	170,371	174,108
1995	558,879	236,324	322,555	205,979	61,752	144,227	352,900	174,572	178,328
1996	573,792	242,937	330,855	212,262	64,055	148,207	361,530	178,882	182,648
1997	589,115	249,743	339,372	218,738	66,431	152,307	370,377	183,312	187,065
1998	604,842	256,742	348,100	225,407	68,884	156,523	379,435	187,858	191,577
1999	620,989	263,933	357,056	232,275	71,409	160,866	388,714	192,524	196,190
2000	637,582	271,335	366,247	239,361	74,017	165,344	398,221	197,318	200,903
2001	661,317	274,605	386,712	251,698	71,895	179,803	409,619	202,710	206,909
2002	710,554	292,358	418,196	283,307	80,924	202,383	427,246	211,433	215,813
2003	764,519	311,619	452,900	318,888	91,087	227,800	445,632	220,532	225,100
2004	823,744	332,549	491,195	358,936	102,527	256,409	464,808	230,022	234,787
2005	888,824	355,323	533,501	404,013	115,403	288,610	484,810	239,920	244,890
2006	960,425	380,141	580,285	454,752	129,896	324,856	505,673	250,245	255,428
2007	1,039,297	407,223	632,074	511,864	146,209	365,654	527,433	261,013	266,420
2008	1,103,496	426,906	676,590	561,909	158,931	402,978	541,587	267,975	273,612
2009	1,178,415	446,418	731,997	620,404	170,418	449,986	558,011	276,000	282,011
2010	1,228,543	464,186	764,357	657,856	181,951	475,905	570,687	282,235	288,452
2011	1,195,020	453,537	741,483	610,332	164,727	445,605	584,688	288,810	295,878

4.5.3 Bahrain GDP per capita

The GDP per capita calculated by dividing the country's gross domestic product, which adjusted by inflation and the total population. Bahrain GDP per capita from 2006 to 2014 illustrated in Figure (4-4). The data collected from Trading Economics (2015). The GDP per capita was decreasing from year 2006 to 2012. Its behavior was changed after 2012, where it was found to increase rapidly in the last two years. The behavior of Bahrain GDP per capita is not similar to the behavior of peak load demand. Therefore, this element will ignore because of mismatching behavior with peak load demand.

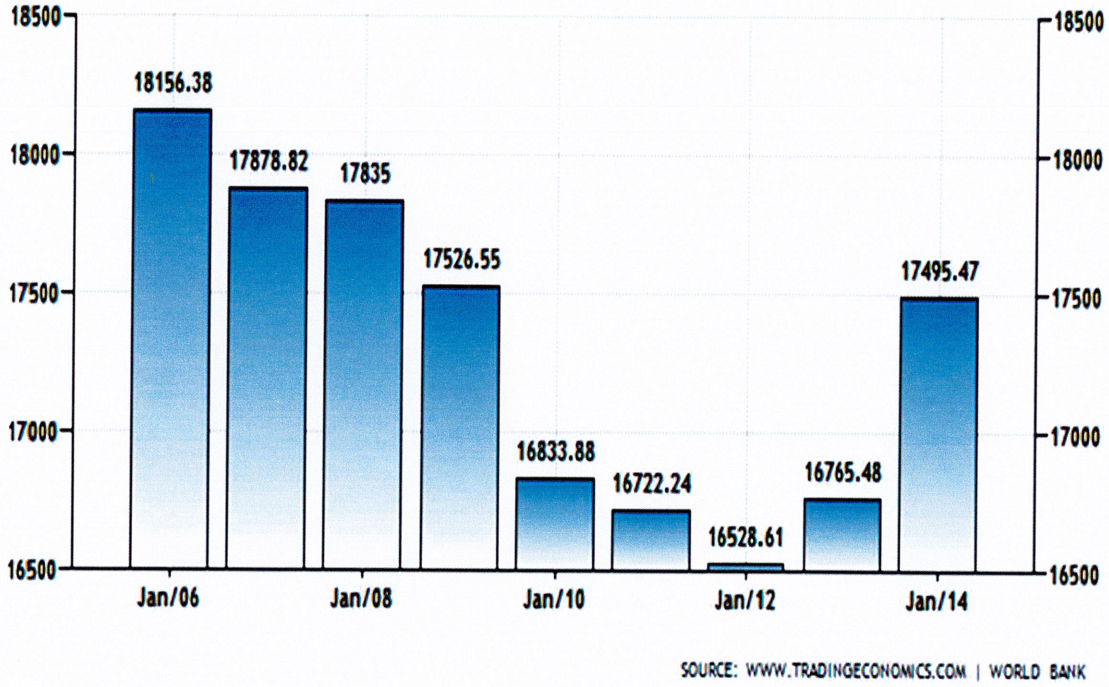


Figure (4-4) Bahrain GDP per capita, Source: Trading Economics (2015)

4.5.4 Electricity consumption by population

This element neglected because the population element already chosen for the equation and the forecasted peak load demand directly related to the electricity consumption. Therefore, it is the same element required to be identified in the forecasted element. Therefore, these elements will eliminated from the given equation, which will be able to identify the forecasted peak load demand.

4.5.5 Peak Load Forecast Model

Finally, the main elements as shown in Figure (4-5) can used to identify the forecasted load demand. These elements are the population and the GDP, which can formulate in equation (4-4) as follows:

$$P_L = P_0 + P_1 * (GDP) + P_2 * (POP) \qquad (4\text{-}4)$$

Figure (4-5) illustrates the relation between the GDP and Population with Power System Peak Load, where both behaviors are similar to the peak load demand.

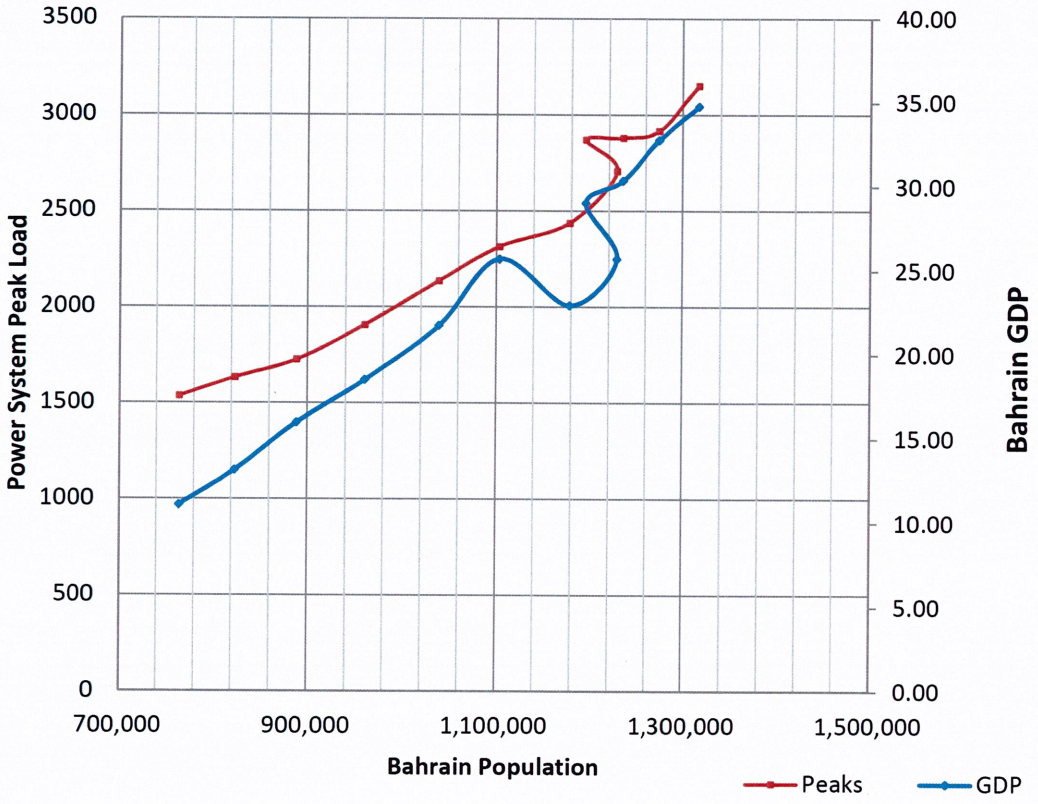


Figure (4-5) Relation between GDP and Population with Peak Load Demand

4.6 Results of Forecasted LTLF Using the Model

4.6.1 Results of multiple linear regression Model

To find the coefficients of the equation (4-4), the historical data of both GDP and population used for forecasting peak load demand. The curve fitting technique used to determine the coefficients found in equation (4-4).

The result of curve fitting in equation (4-4) for the model is as follows:

Bahrain Model:

$$f(POP, GDP) = P_{00} + P_{10} * (POP) + P_{01} * (GDP) \qquad (4\text{-}5)$$

where $P_{00} = -156.2$, $P_{01} = 35.27$ and $P_{10} = 0.001549$

The result of subletting these coefficients in equation (4-5) presented in Table (4-2). Results of peak load forecasting are very close to the actual peaks recorded. The average error calculated for this type and presented in Table (4-2) that shows errors less than 2%. The level of error presented is acceptable error level.

Table (4-2) Results of peak load forecasting and error recorded

Year	Peaks	Calculated Peak uses Model	Errors
2012	2880	2827	-1.82%
2013	2917	2975	1.99%
2014	3152	3110	-1.34%

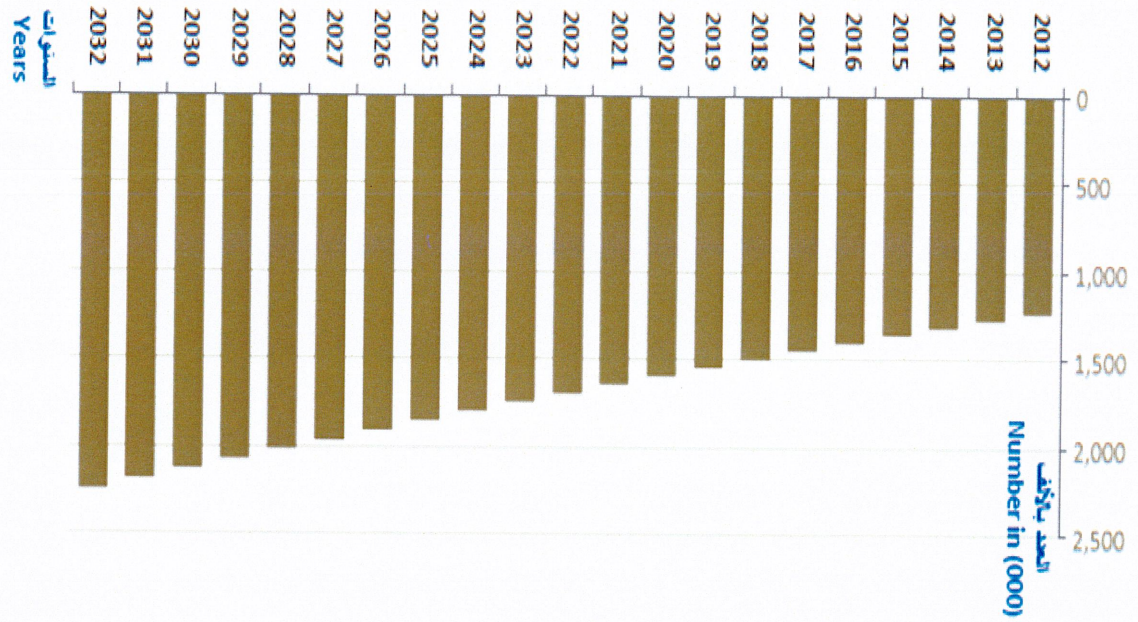


Figure (4-6) Mid-Year Population Projections for Bahrain.
Source: Bahrain Central Information Organization (2015)

The forecasted peak load demand is calculated for the future years based on the forecasted population and forecasted GDP of Kingdom of Bahrain. Mid-year Population Projections for the Kingdom of Bahrain (2012 - 2032) was collected from the Bahrain Central Information Organization (2015) which is presented in Figure (4-6).

Three scenarios such as high, normal and low growth are considered for Bahrain GDP. With these scenarios, it is intended to forecast the peak load demand for the future. It is apparent that any miss-prediction regarding the future peak load would risk the economic growth which is not desired by the decision markers to avoid over or lower investments due to wrong estimation for the growth. The forecasted peak load demand is illustrated in Figure (4-7). The similar forecast for the rest of GCC member states are shown in Figures (4-8) to (4-12). These graphs are produced by using equations (4-6) and (4-10) of the forecast model proposed in this study.

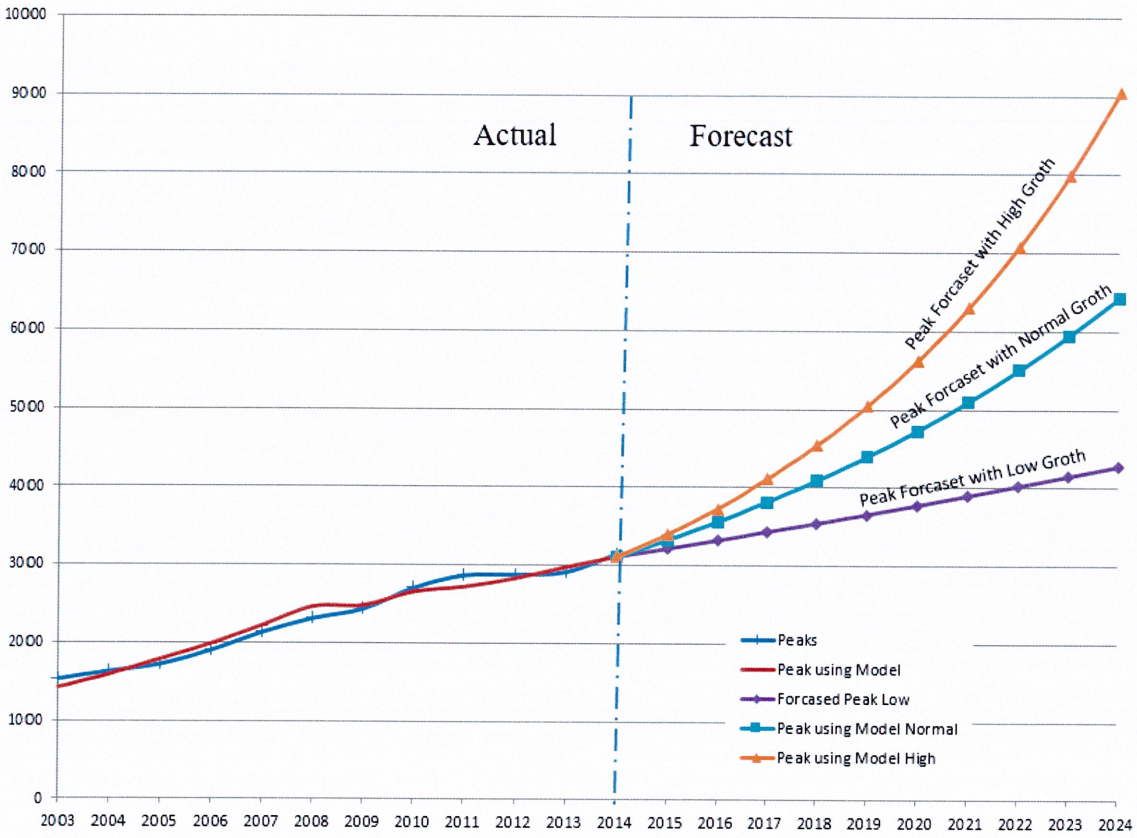


Figure (4-7) Bahrain three scenarios of load forecasted for 2014 - 2024

The historical and estimated data used for all GCC countries tabulated in Appendix (A).

The models created for the LTLF for the GCC countries are as follows:

Kuwait Model: $f(POP,GDP) = p_{00} + p_{10}*(POP) + p_{01}*(GDP)$ (4-6)

where $p_{00} = 3044$, $p_{10} = 0.001665$ and $p_{01} = 1.848*10^{-08}$

KSA Model: $f(POP,GDP) = p_{00} + p_{10}*(POP) + p_{01}*(GDP)$ (4-7)

where $p_{00} = -2.26*10^{+04}$, $p_{10} = 0.001264$ and $p_{01} = 1.245*10^{-09}$

Qatar Model: $f(POP,GDP) = p_{00} + p_{10}*(POP) + p_{01}*(GDP)$ (4-8)

where $p_{00} = 800.6$, $p_{10} = 0.002082$ and $p_{01} = 4.316*10^{-09}$

UAE Model: $f(POP,GDP) = p_{00} + p_{10}*(POP) + p_{01}*(GDP)$ (4-9)

where $p_{00} = 1917$, $p_{10} = 0.0003383$, and $p_{01}=6.302*10^{-09}$

Oman Model : $f(POP,GDP) = p_{00} + p_{10}*(POP) + p_{01}*(GDP)$ (4-10)

where $p_{00} = 1688$, $p_{10} = -0.0007538$, and $p_{01}= 7.605*10^{-08}$

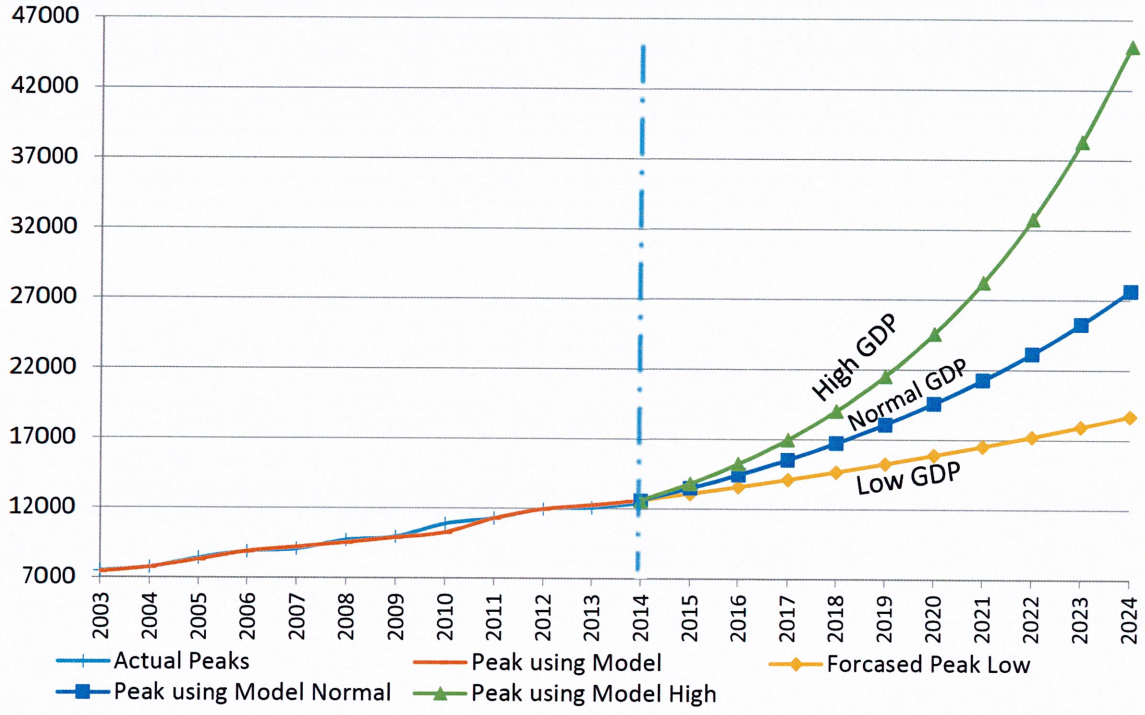


Figure (4-8) Kuwait three scenarios of the load forecast for 2014 – 2024

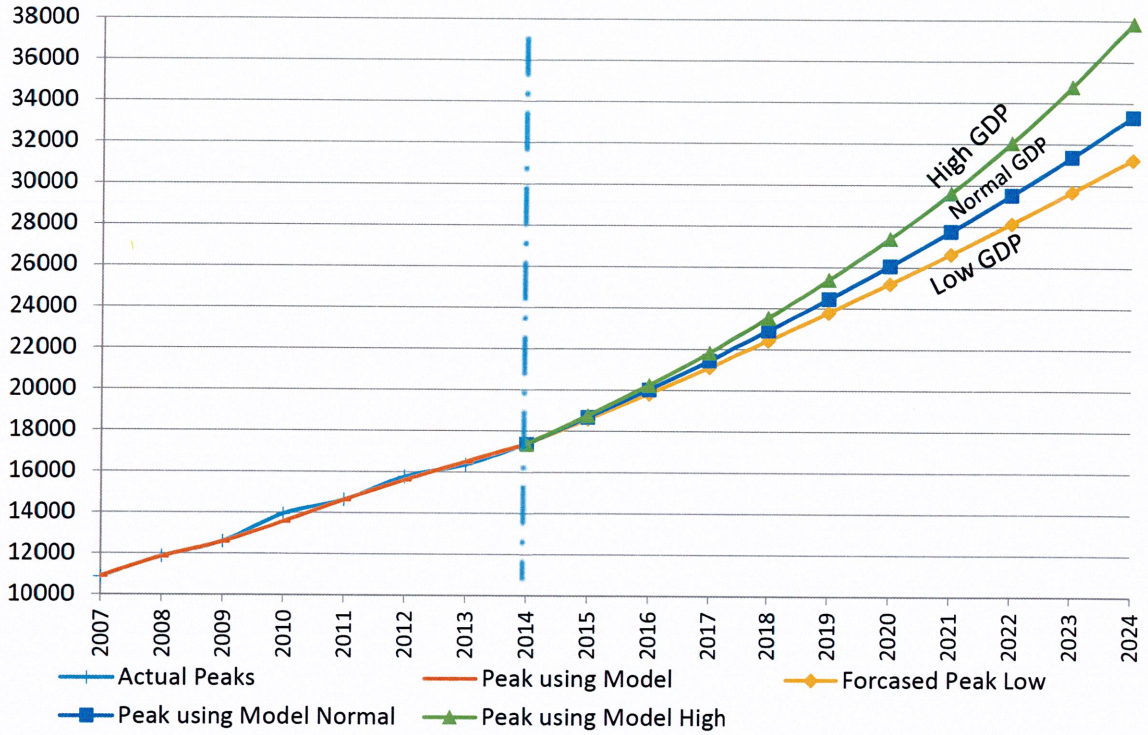


Figure (4-9) KSA three scenarios of the load forecast for 2014 – 2024

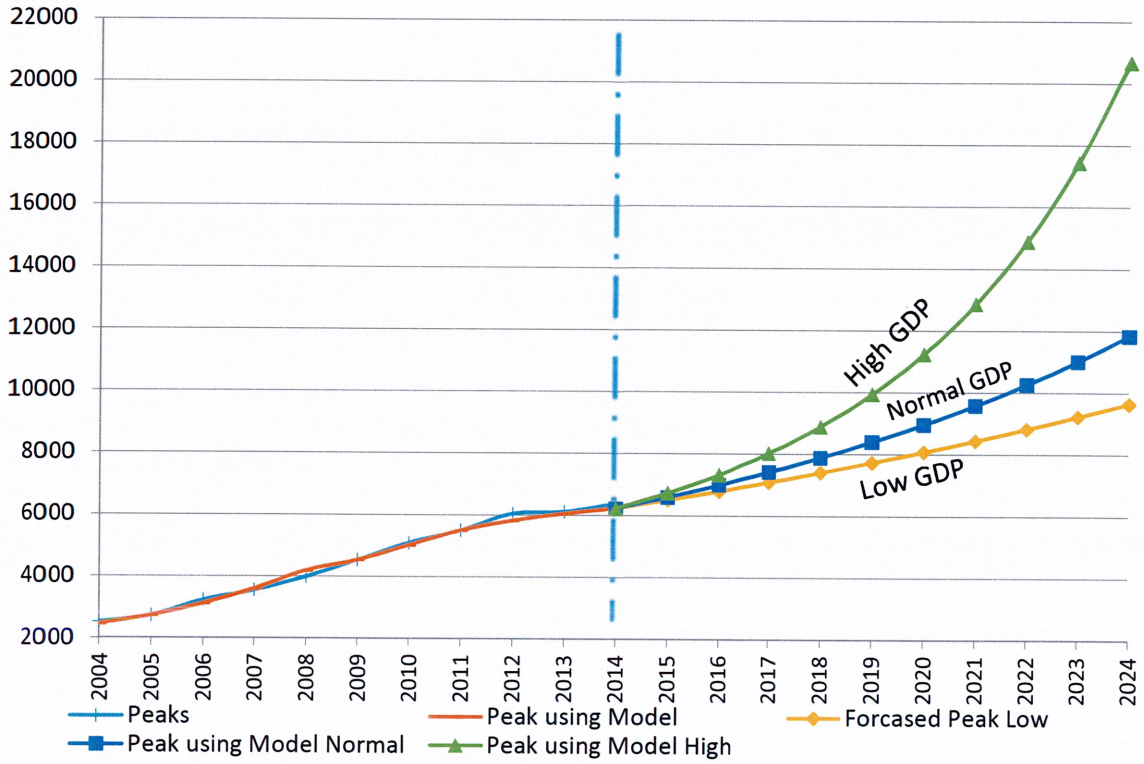


Figure (4-10) Qatar three scenarios of the load forecast for 2014 – 2024

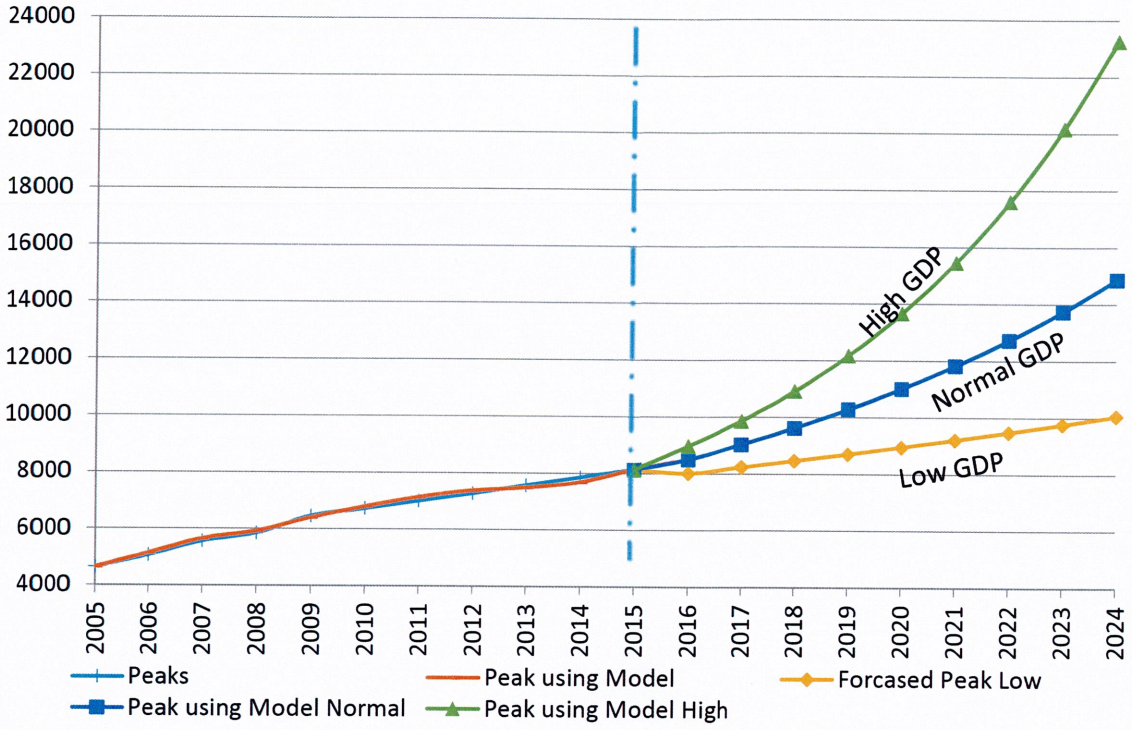


Figure (4-11) UAE three scenarios of the load forecast for 2014 – 2024

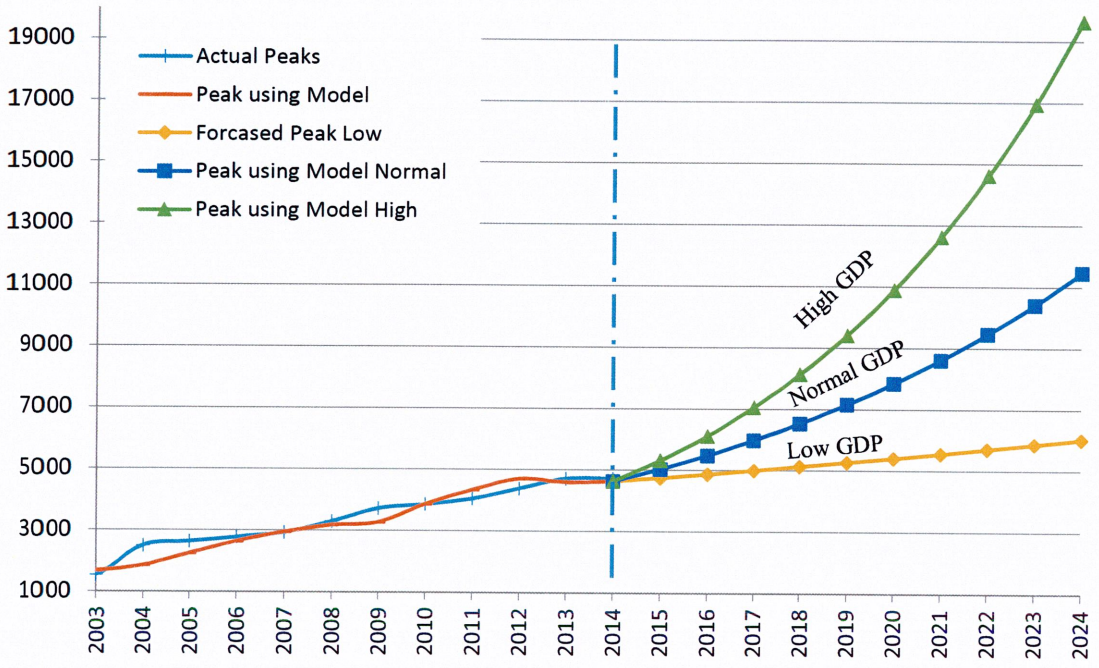


Figure (4-12) Oman three scenarios of load forecast for 2014 – 2024

Table (4-3)
Forecasted Cumulative Growth Rate by GCC Member States

Country	2016 – 2024
Kuwait	8
KSA	6.3
Bahrain	6.6
Qatar	4.6
UAE	8.5
Oman	9.2
Average	**7.2**

Table (4-3) showing the forecasted cumulative growth rate by GCC member states that illustrates result presents Slower Demand Growth Forecasts than expected. Member States' forecasts has lower demand growth due to lower growth in population and GDP as shown in Appendix (A). The data collected from AFESD (2012) and World Bank Data (2015). The calculated Energy growth forecasts illustrated in Figures (4-13) to (4-18).

The results shown in Figures (4-13) to (4-18) present the forecasted peak load with different expected growth rates of GDP in each member state. It is obvious that the growth rates of these states are not similar, because of differences in the economy growth presented in Appendix (A). The variation of the forecasted peak loads clearly indicates the opportunity of having electricity power trade among the six member states, because there will be more electricity demand need to by fulfill. The opportunities will be explained in Chapter 5.

Three scenarios were estimated for member states GDP, which represent high growth, normal growth and low growth. It is intended with these scenarios to forecast the peak load demand for the future. It is apparent that any miss-prediction regarding the future peak load would risk the economic

growth, which is not desired by the decision markers to avoid over or lower investments due to wrong estimation for the growth.

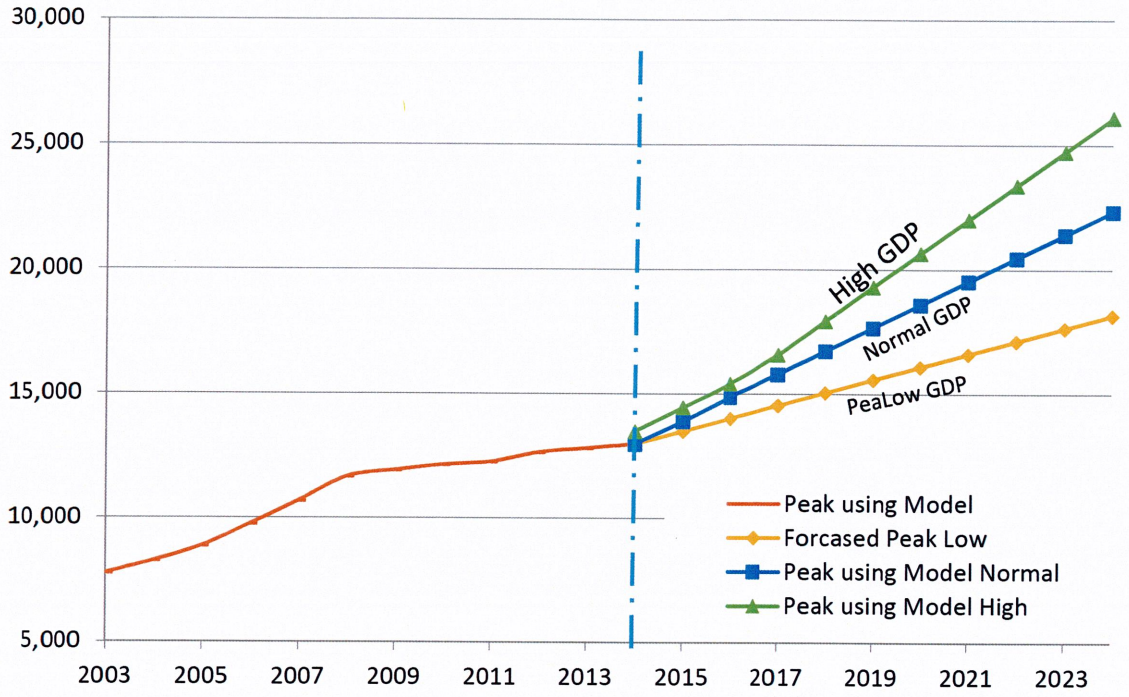


Figure (4-13) Bahrain Three Scenarios of Energy Forecast

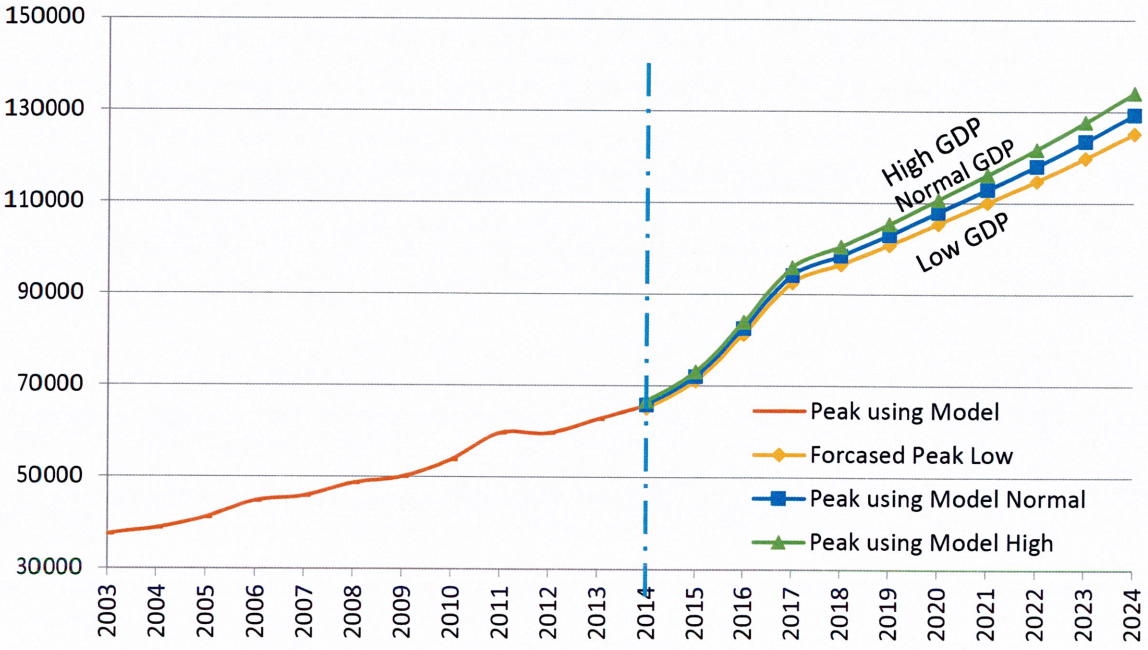


Figure (4-14) Kuwait Three Scenarios of Energy Forecast

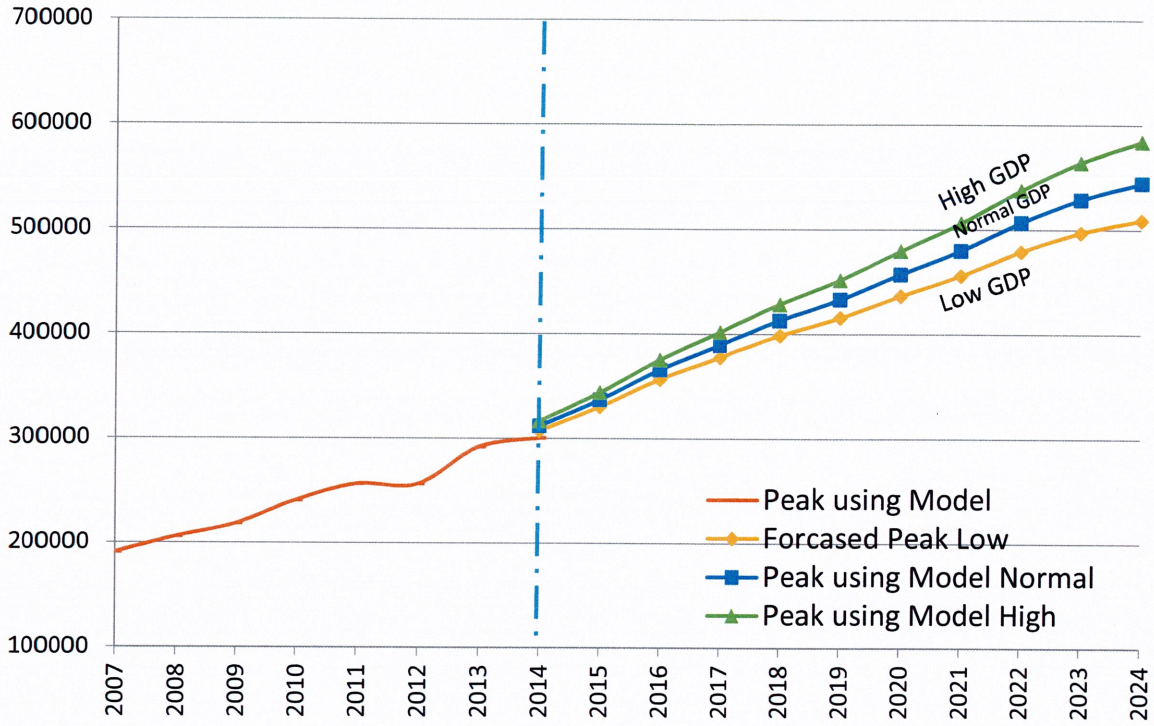


Figure (4-15) Saudi Arabia Three Scenarios of Energy Forecast

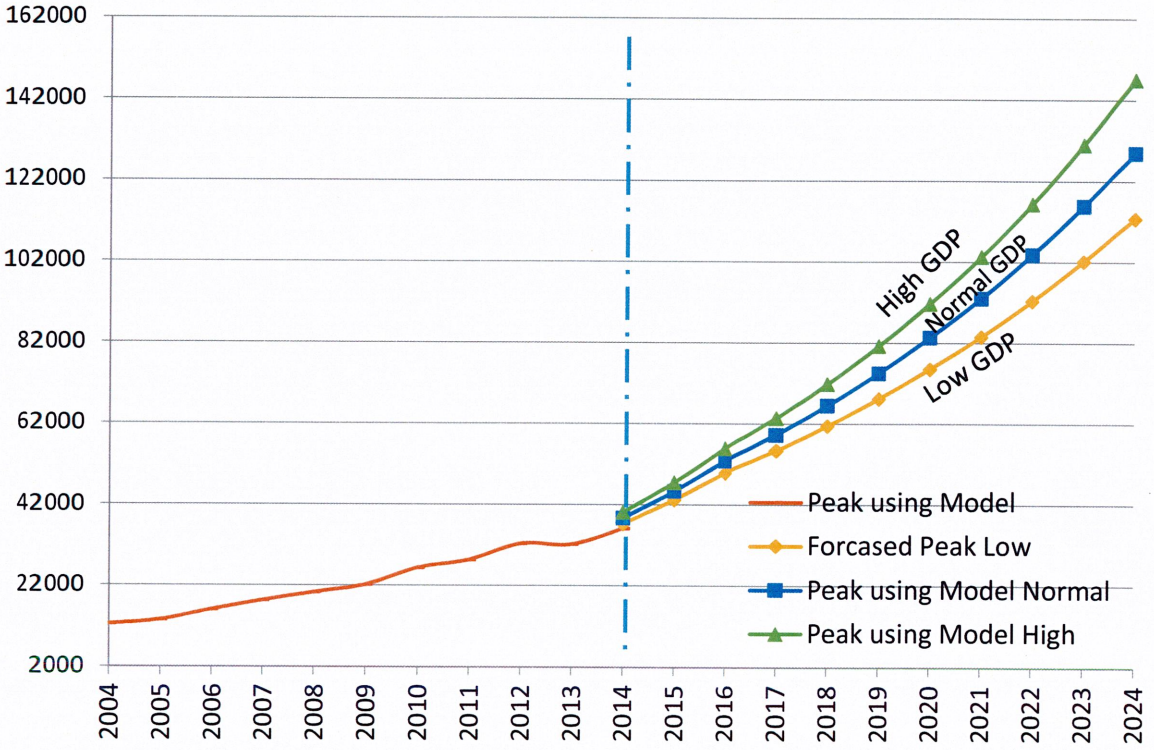


Figure (4-16) Qatar Three Scenarios of Energy Forecast

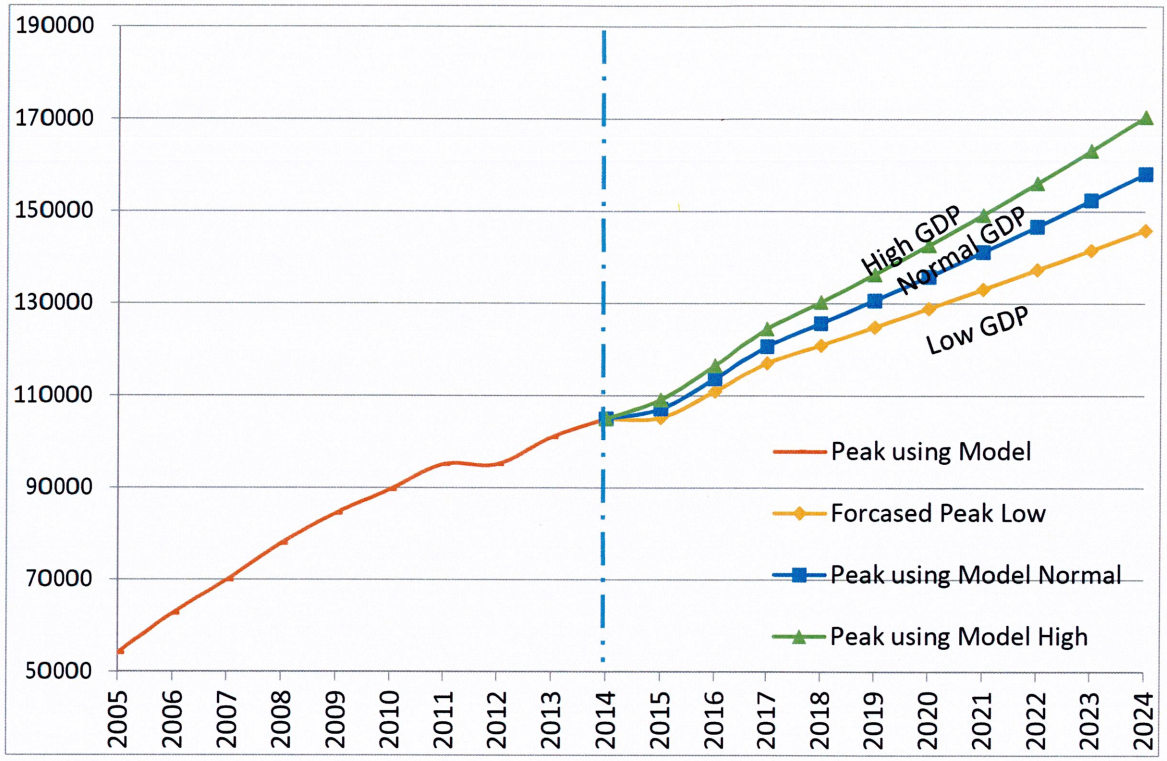


Figure (4-17) UAE Three Scenarios of Energy Forecast

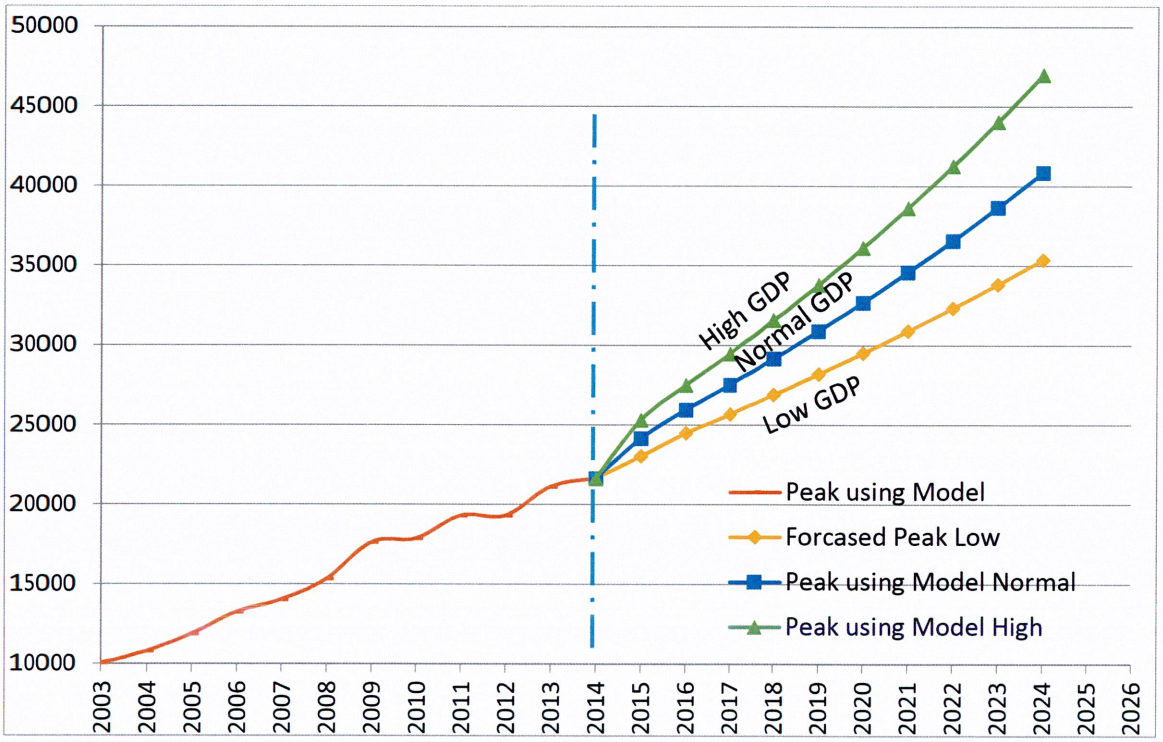


Figure (4-18) Oman Three Scenarios of Energy Forecast

4.6.2 Results of ANFIS for Estimated Peak Load Demand

Figure (4-19) illustrates the four layers connection for three inputs and one output. These four layers represent the Neuro-Fuzzy model, which will used to represent the developed estimated peak load model in this study. It is clear that the results obtained automatically through training of data performed in ANFIS (Adaptive Neuro-Fuzzy Inference System).

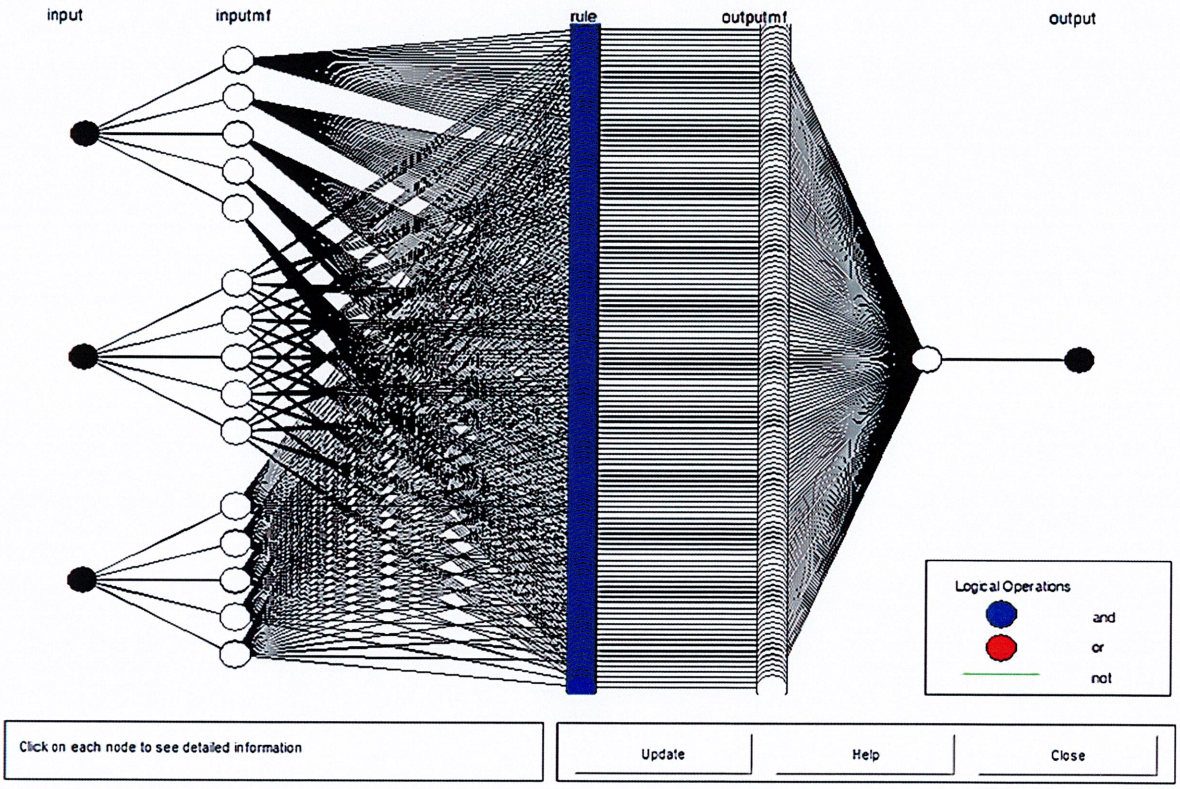


Figure (4-19) ANFIS Structure with three Inputs and One Output

Figure (4-20) shows the proposed model using the Neuro-Fuzzy, where the proposed model is three inputs and one output model. The three inputs are

the year, population and GDP. The output is the peak load for the Kingdom of Bahrain. Therefore, the three inputs used as follows:

1. Input 1: Year.
2. Input 2: Population.
3. Input 3: GDP.

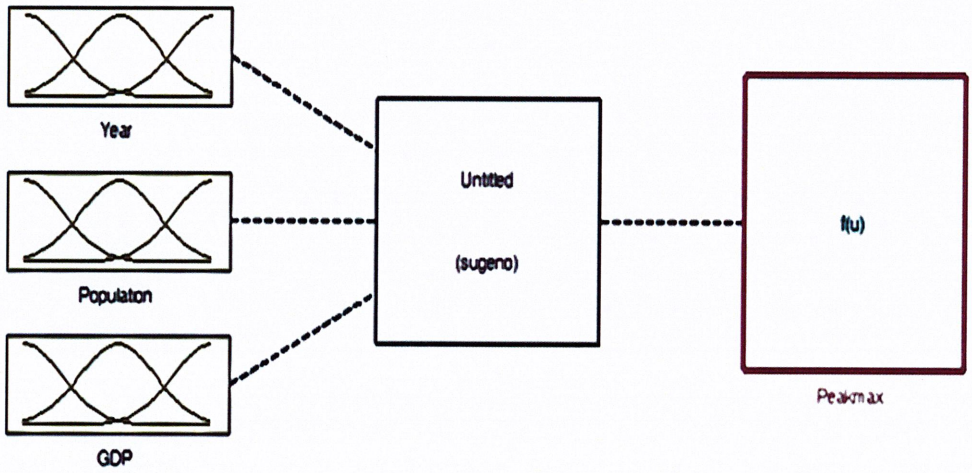


Figure (4-20) Artificial Neuro-Fuzzy Logic Model Using Long Term Load Forecasting

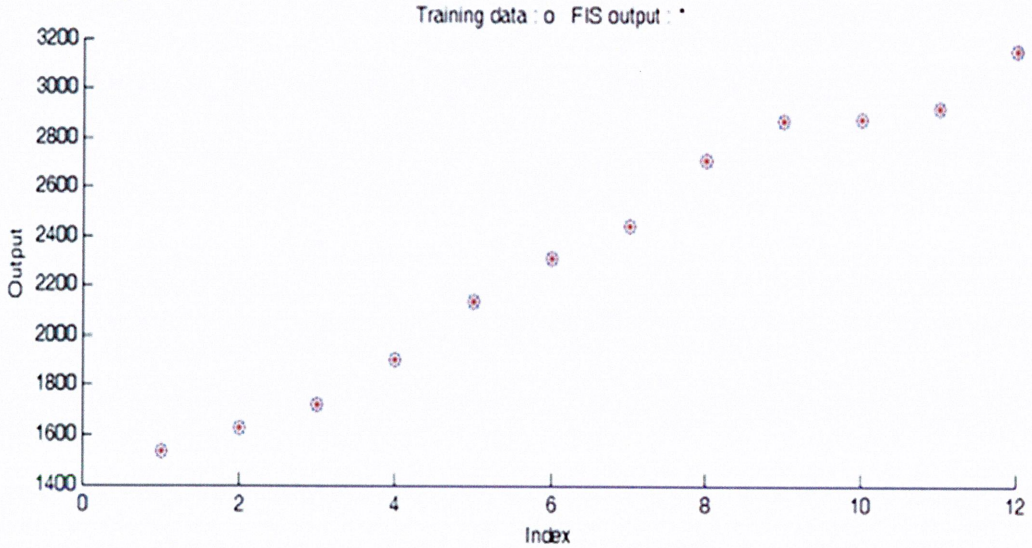


Figure (4-21) Actual Data Used Versus Output of the Neuro-Fuzzy Model

Figure (4-21) illustrates the actual data collected and presented for member states peak demand, where the estimated peak load demand for the coming years generated by Neuro-Fuzzy model.

The output of the given model presents the Neuro-Fuzzy model average results error, which is equal to 0.53% and it is less than the multi regression method, which is almost about 2%. The final membership functions for each input variable is shown in Figure (4-22). It shows the range of the years from 2003 until 2014.

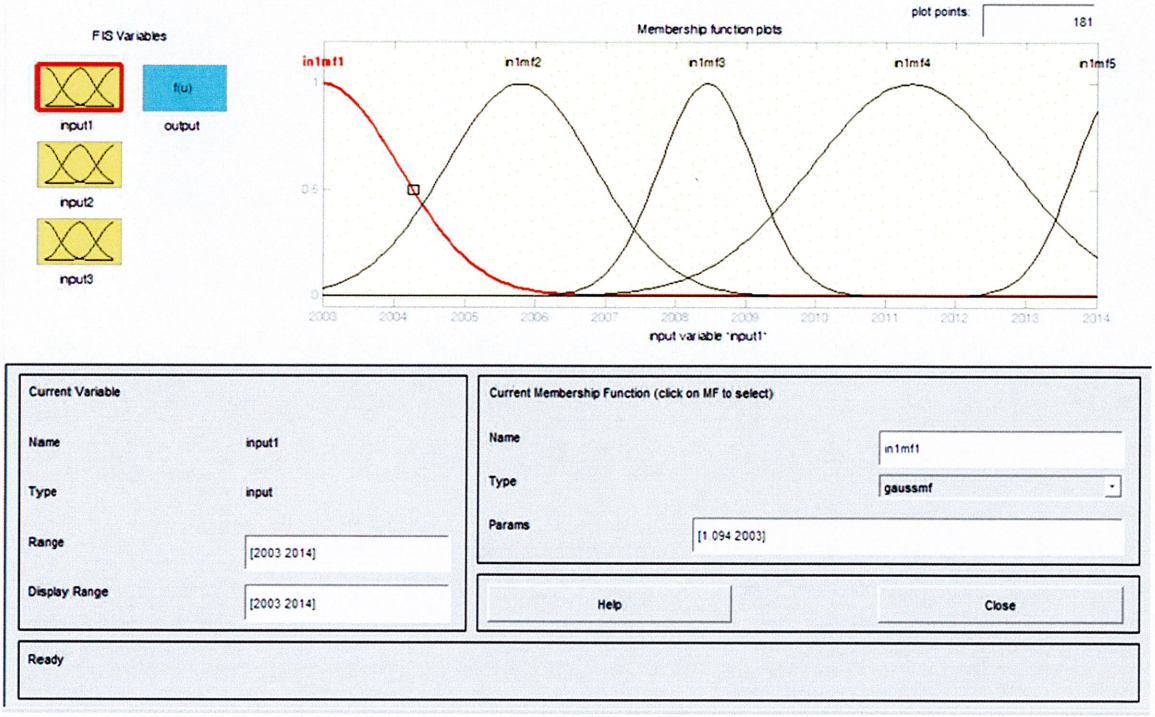
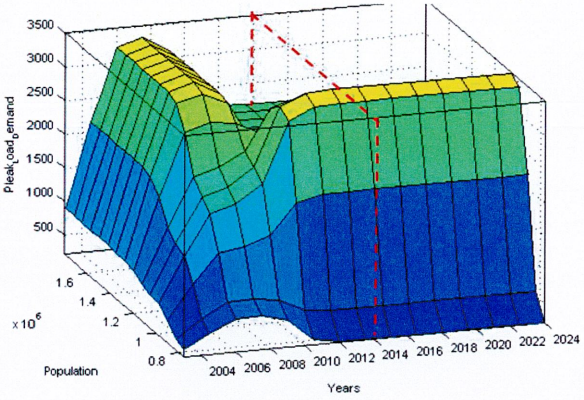


Figure (4-22) Membership Function Used in the Neuro-Fuzzy Logic Model for Long Term Load Forecasting

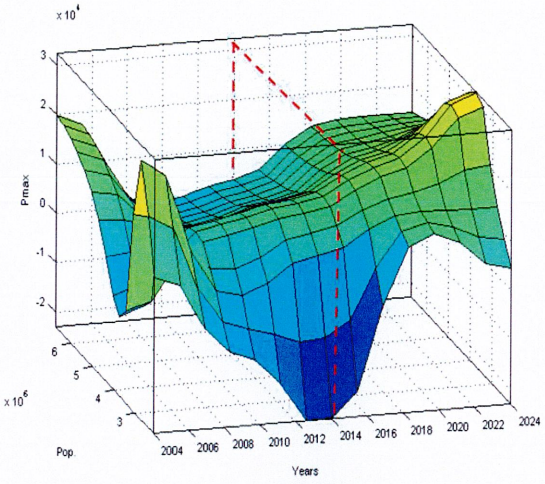
The input-output surface membership function of the maximum peak demand models is presented in Figure (4-23). This means that the number of membership functions chosen as three inputs, where the surface view between the inputs and the output of GCC countries. The input-output shown is a non-linear surface and illustrates how the model will respond to varying values of the year.

The Neuro-Fuzzy is trained on input data as well as the associated target values. The trained data can then make predictions of the load based on the relationships learned during training. A real data case study of the load in GCC was used. After the Neuro-Fuzzy is trained on the input data set, a new data set is coming at its input, and the network provides a forecast of the load for the coming years.

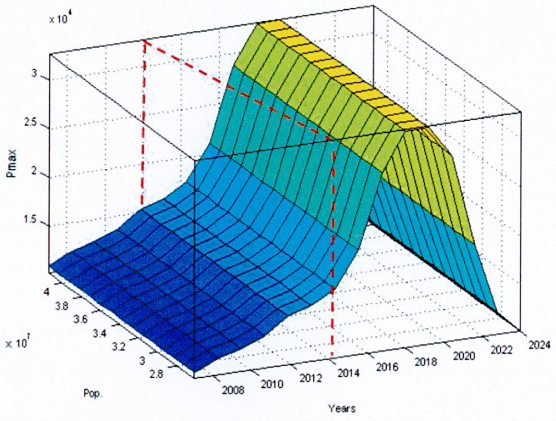
In the present thesis, ANFIS application of a neuro-fuzzy technique used for forecasting the long-term annual peak-load forecasting. The used technique takes into account the uncertainties in the nature of the peak load.



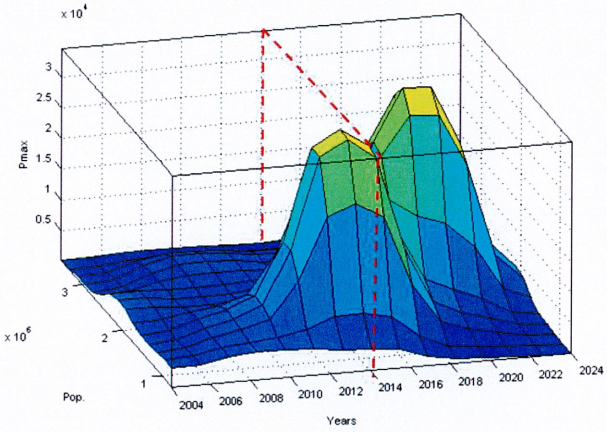
(a) BAH



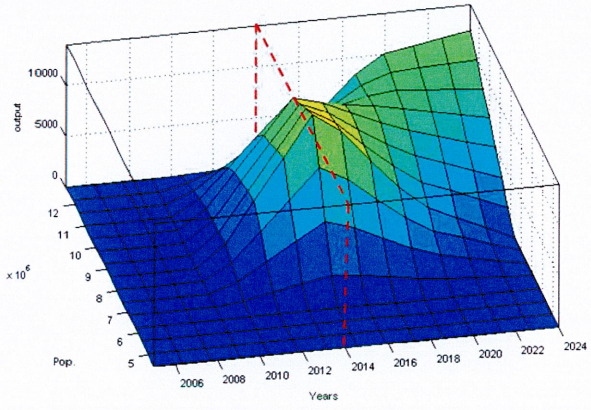
(b) KUW



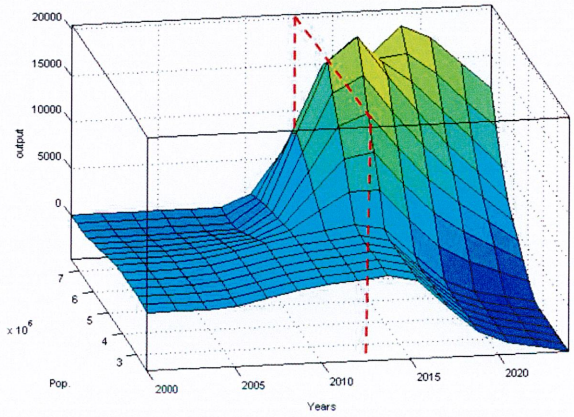
(c) KSA



(d) QAT



(e) UAE



(f) Oman

Figure (4-23) GCC Surface Sketch for the Output of the Neuro-Fuzzy Models

The Net Electricity Generation in the GCC, and the generation and system adequacy forecast, which present the unavailable capacity and reliable available capacity are shown in Figures (4-24) to (4-35). The data collected from AFESD (2012) and World Bank Data (2015).

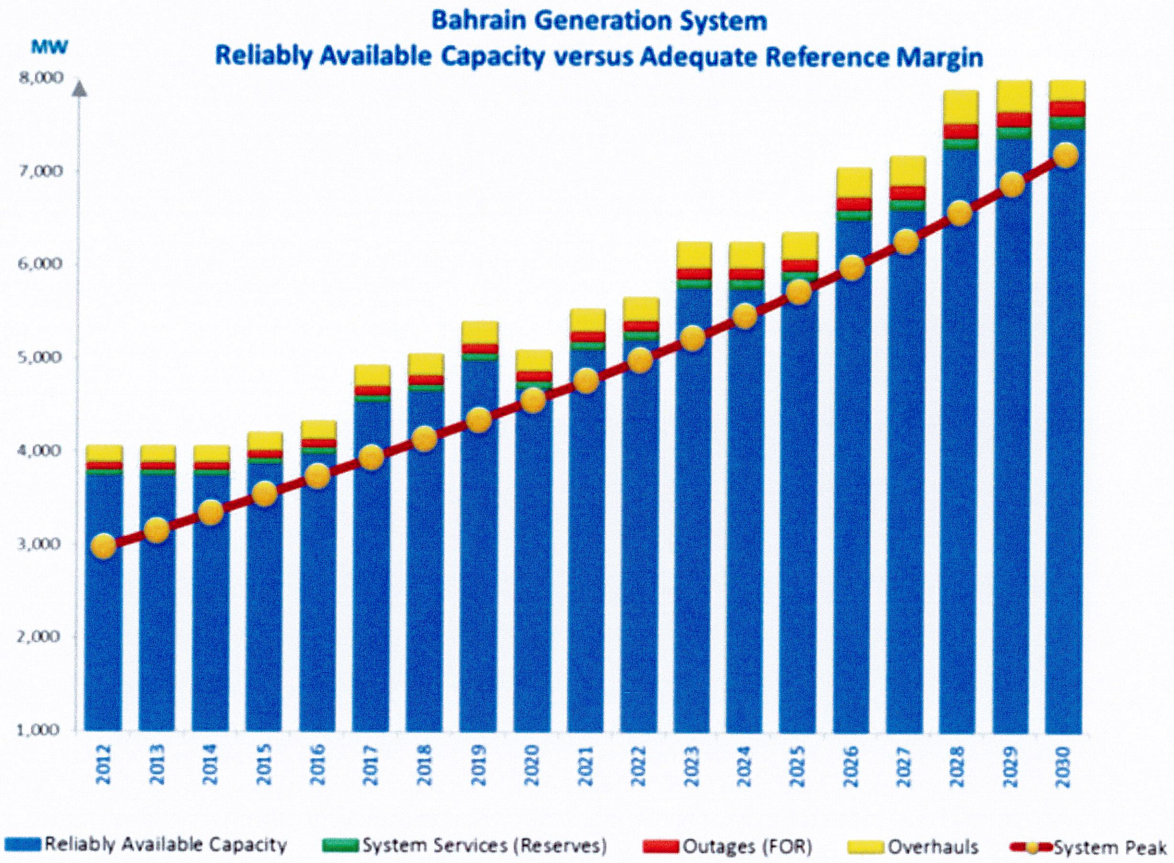


Figure (4-24) Bahrain Net Generating Capacity Forecasting

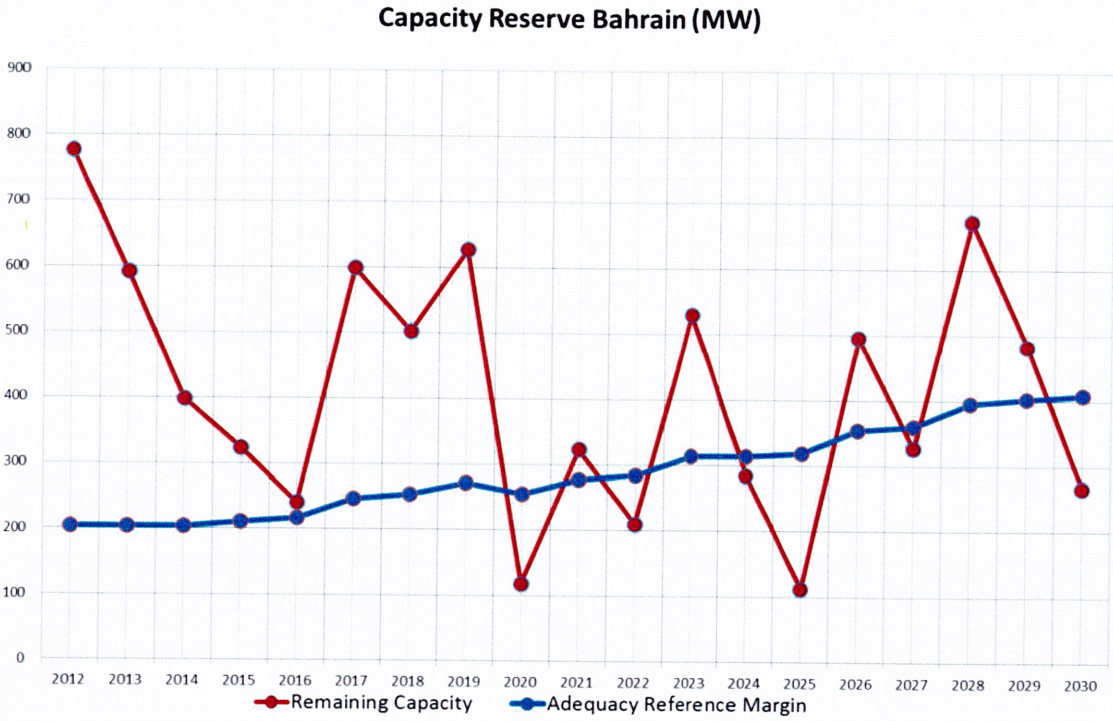


Figure (4-25) Bahrain Generation and System Adequacy Forecast

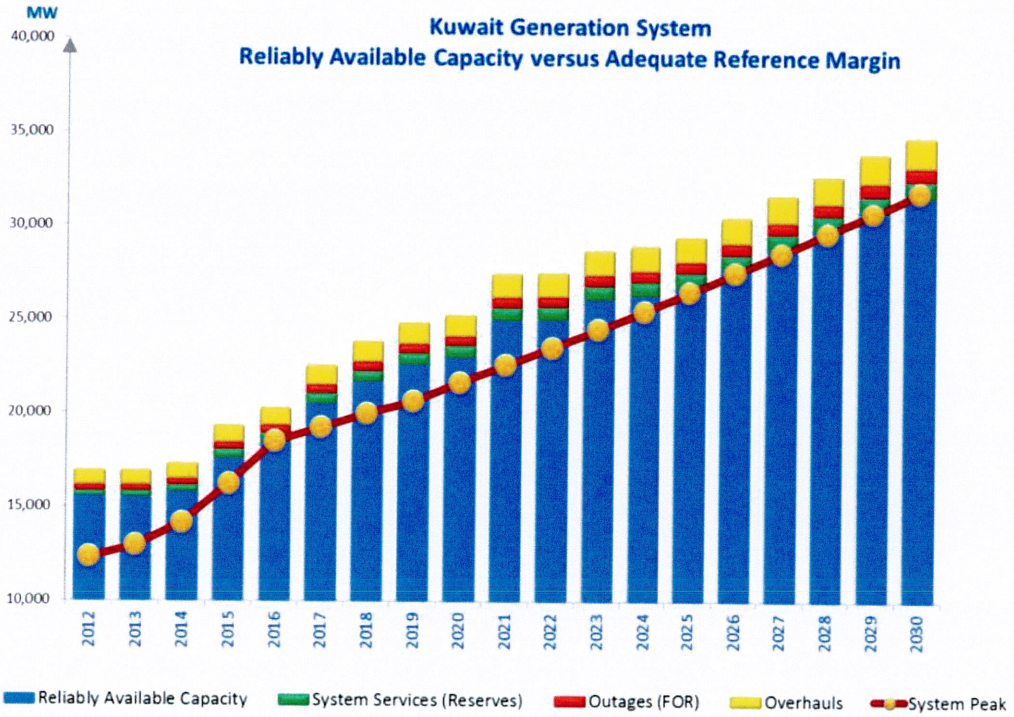


Figure (4-26) Kuwait Estimation of Capacity development

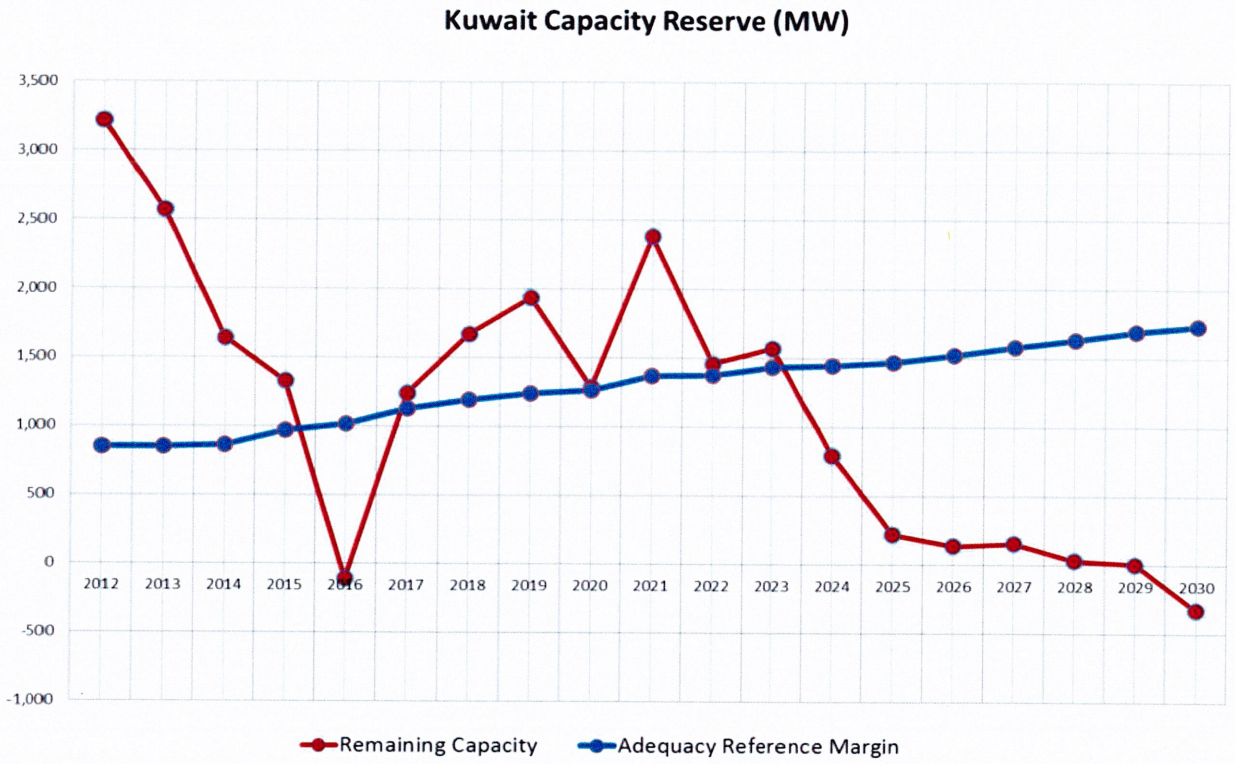


Figure (4-27) Kuwait Generation and System Adequacy Forecast

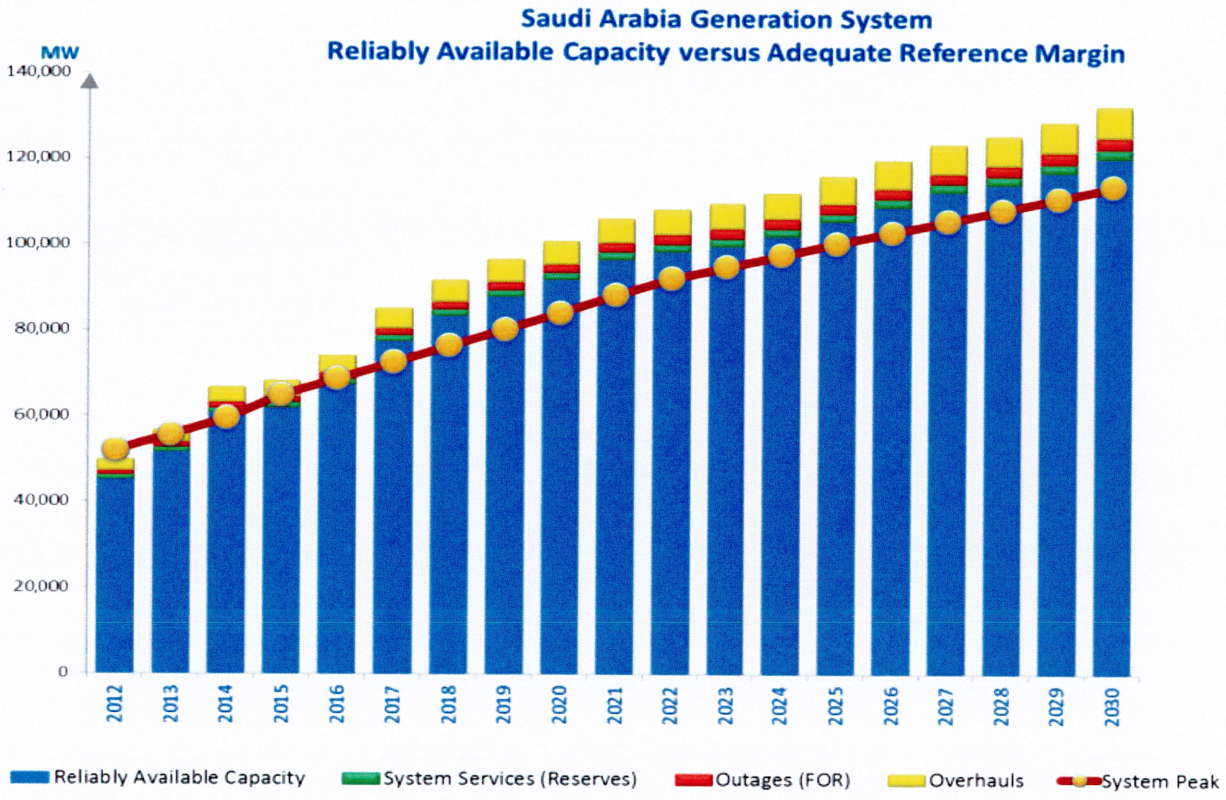


Figure (4-28) KSA Estimation of Capacity development

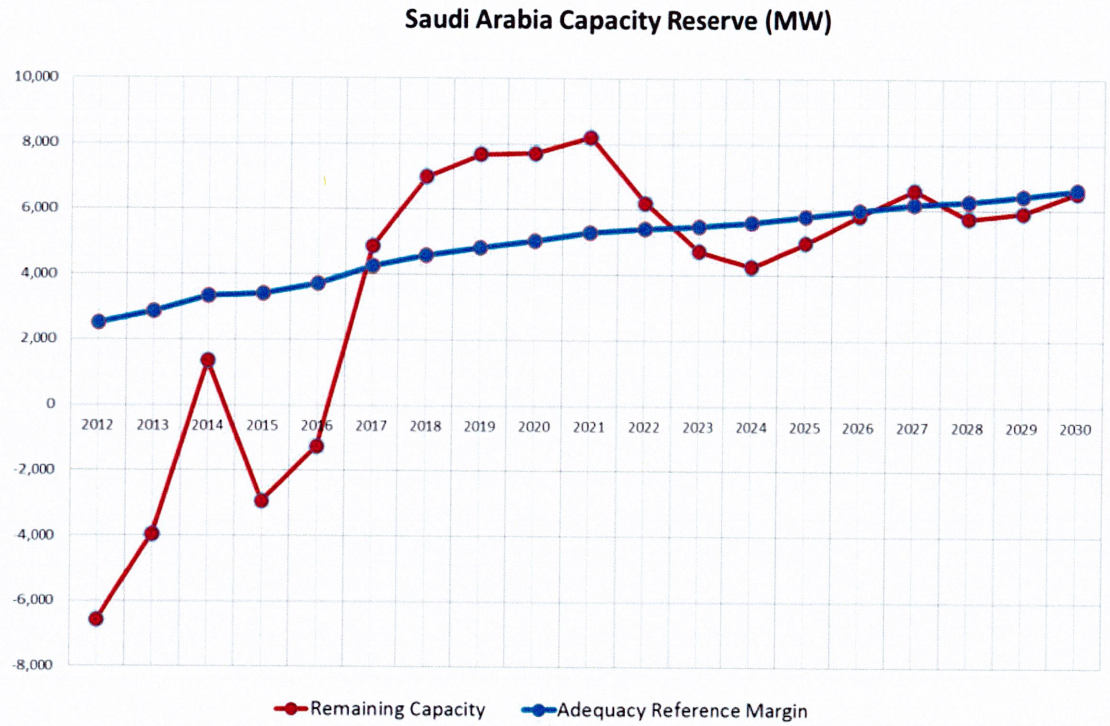


Figure (4-29) KSA Generation and System Adequacy Forecast

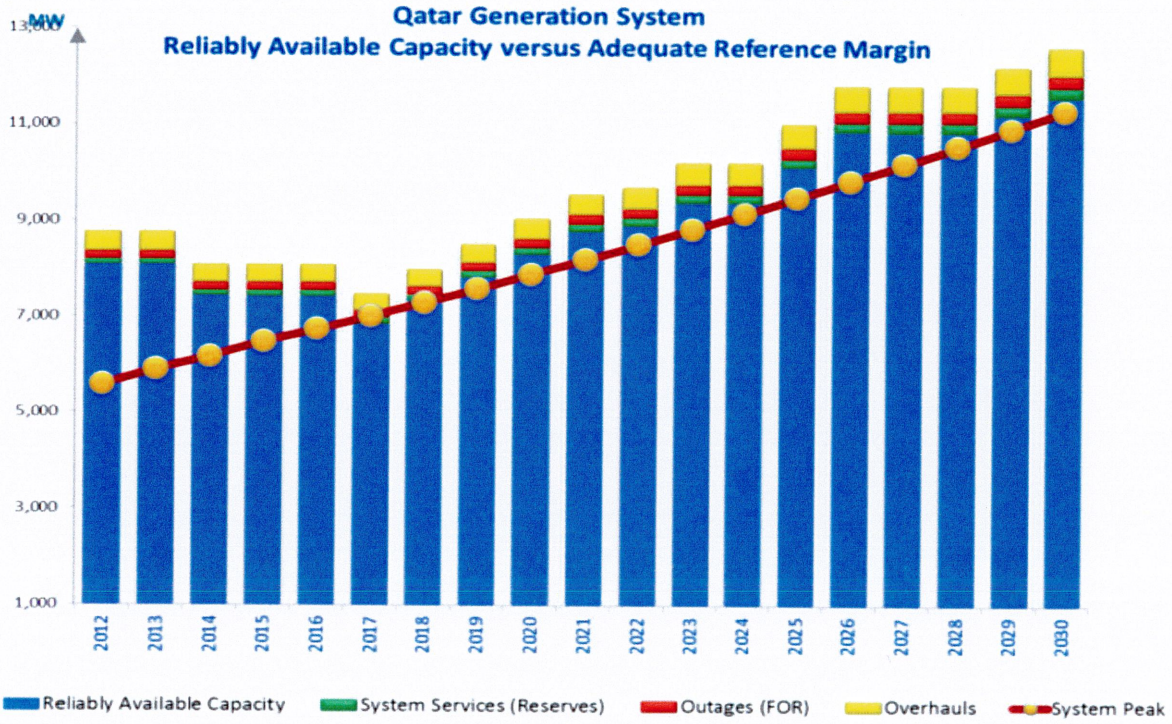


Figure (4-30) Qatar Net Generating Capacity Forecasting

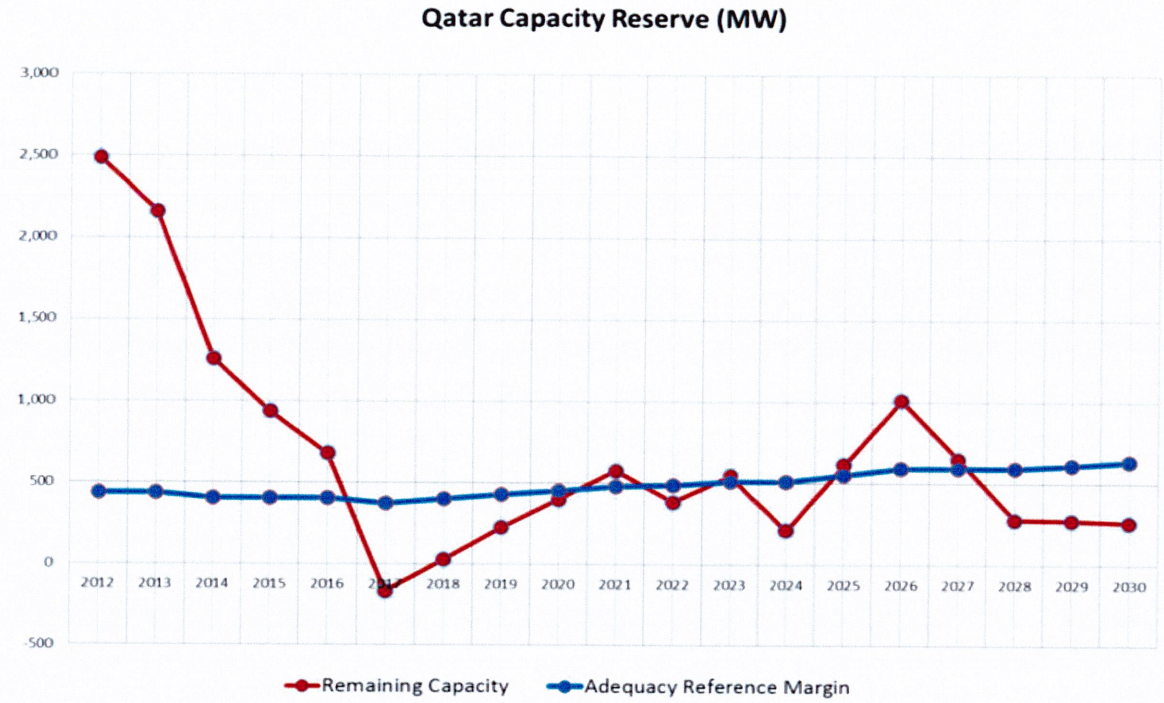


Figure (4-31) Qatar Generation and System Adequacy Forecast

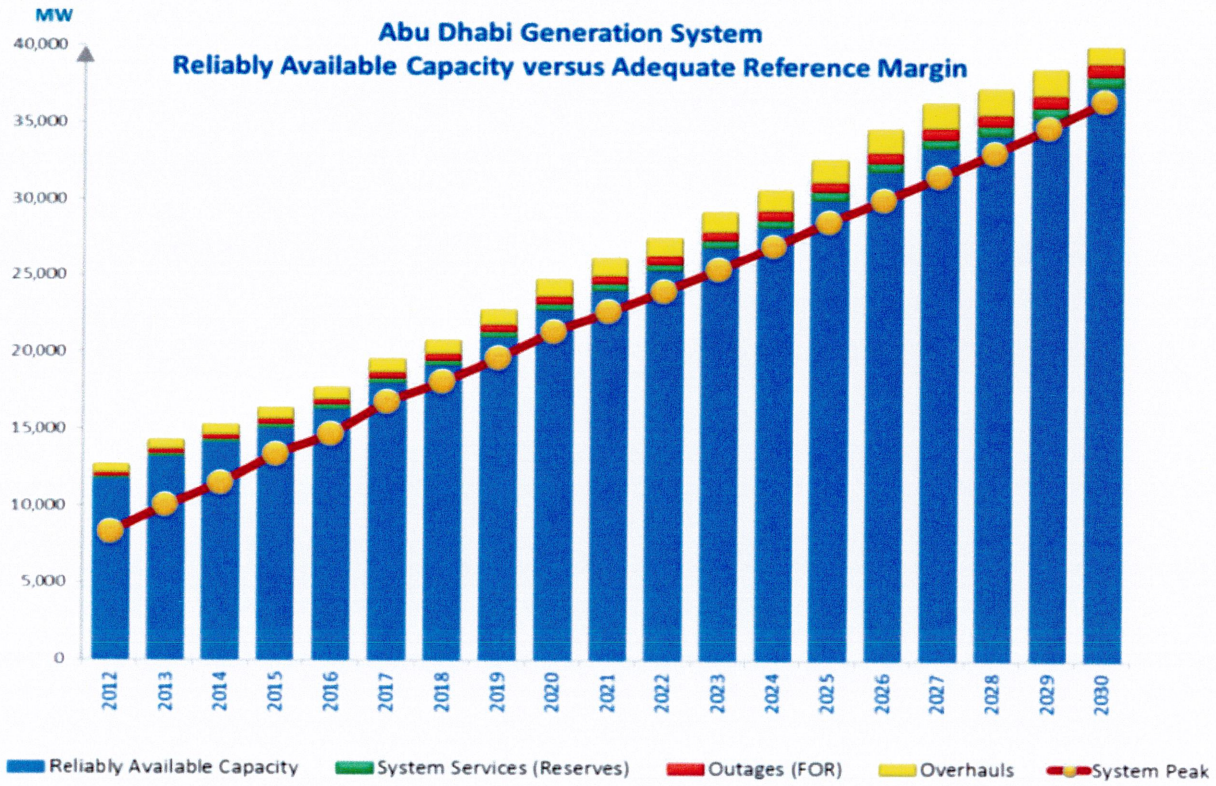


Figure (4-32) UAE Estimation of Capacity development

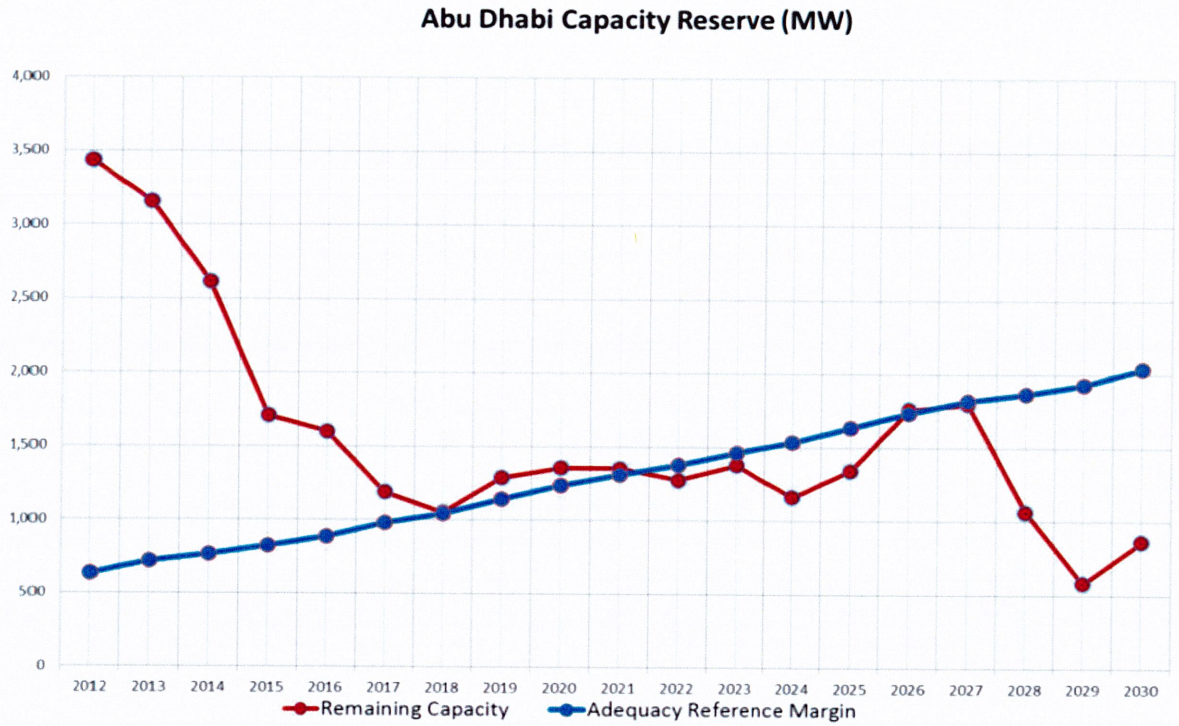


Figure (4-33) UAE Generation and System Adequacy Forecast

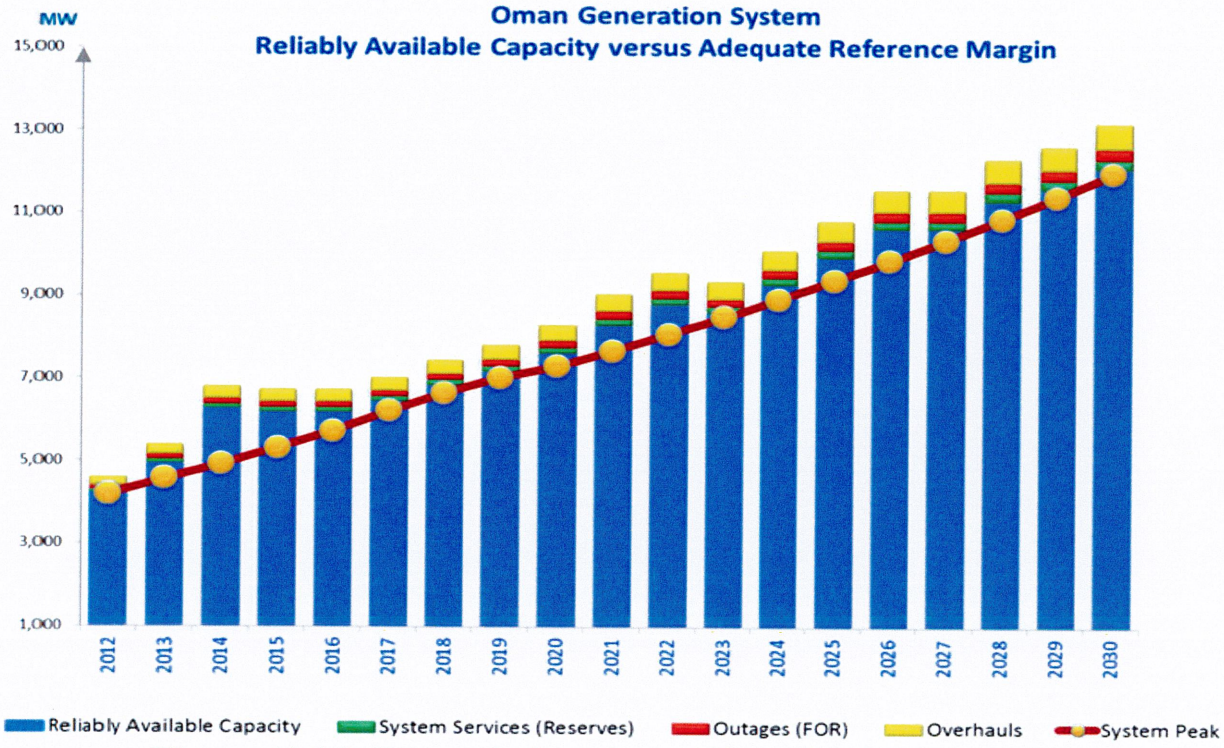


Figure (4-34) Oman Estimation of Capacity development

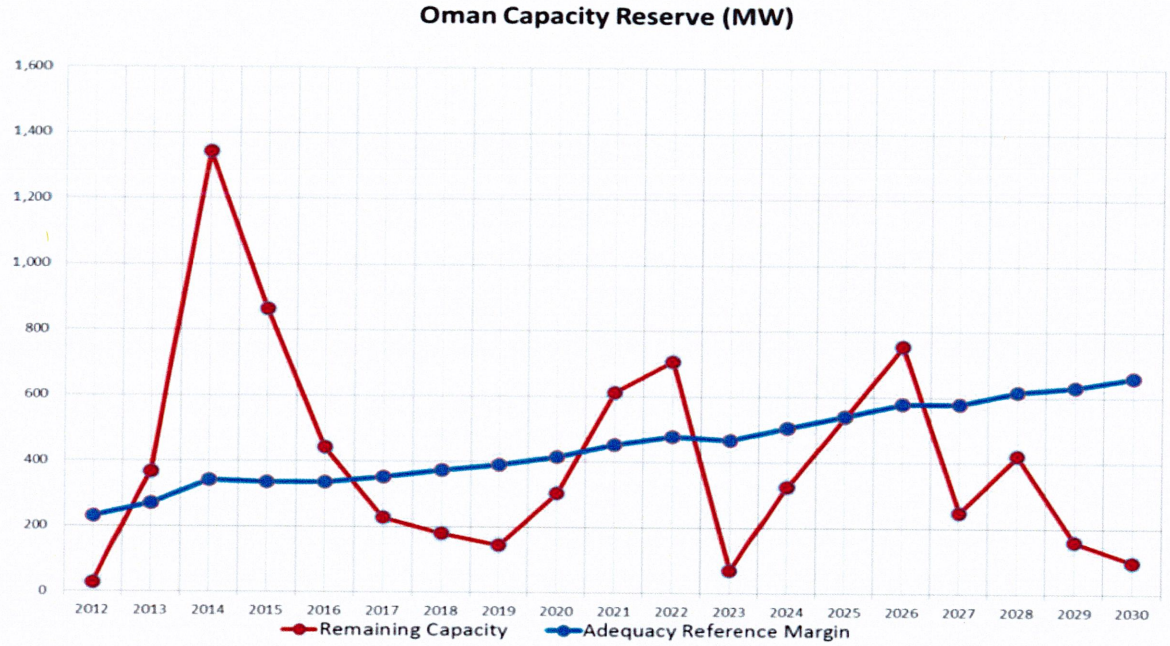


Figure (4-35) Oman Generation and System Adequacy Forecast

It is known fact that forecasting of peak loads is one of the important task for decision markers since they need this information for the planning of periodical operations, energy trading and facility expansion. This is why forecasting of peak load demand constitutes the central and integral process in the electricity sector to take in consideration all generation planning for this purpose; else, the planned generation capacity may end with over or under generation capacity.

The results shown in Figures (4-24) to (4-35) summarize the system adequacy and future capacity development for all member states. In Figures (4-24), (4-26), (4-28), (4-30), (4-32), and (4-34) the growth of network peak, network operations reserve margins and available reliable generation capacity for the planning period are illustrated for Bahrain, Kuwait, KSA, Qatar, UAE and Oman respectively. By making use of these results, the assessment of the

planned generation becomes possible because the assessment of the generation ability match the consumption on the same power system.

Furthermore, with the information given in Figures (4-25), (4-27), (4-29), (4-31), (4-33), and (4-35) for Bahrain, Kuwait, KSA, Qatar, UAE and Oman respectively it is also possible to compare the annual developments of the remaining generation capacity, which provides the information about the system adequacy reference margin. These comparison were presented for the part of net generation capacity that should be kept available at all time to ensure the security of supply during the whole planned period, and to cover the increase of load from the reference time point to the peak load.

4.7 Conclusion

It is known that the Peak load forecasting is one of the important tasks for decision makers in proposing the planning for periodical operations, energy trading and facility expansion in the electricity sector. Peak load demand forecasting is central and integral processes for this purpose.

The model presents Electrical long-term peak load demand forecasting using Multiple Linear Regression and Artificial Neuro-Fuzzy Intelligent System (ANFIS) methods. Both methods have an acceptable average error percentage of the forecasted results. The Multiple Linear Regression method advantages are to have a model with simple equations used to calculate demand forecasting where ANFIS model has more accurate forecasted results. The model type might be selected based on user's requirement like the energy traders or forward planning decision makers.

The multiple linear regression and Neuro-Fuzzy applied in the present thesis to model the peak load for GCC. Both techniques applied, where the average percentage errors calculated from the results obtained and found to be close to 2% and 0.53% in multi linear regression and Neuro-Fuzzy, respectively. The obtained results demonstrate clearly that the obtained models effectively help in finding the estimated future loads and the Neuro-Fuzzy is the most accurate technique compared with the Multi Linear Regression requested by energy traders and decision makers. In addition, the present study indicates the high ability of Neuro-Fuzzy modeling the maximum load.

The system does not require a large number of sample data. The models present the Electrical long term peak load demand forecast using both the Neuro-Fuzzy and Multiple Linear Regression method, which both have an acceptable error percentage.

The results are presented the peak load forecasted, taken into consideration the different expected growth in the GDP of the country. This type of forecasting will give more visibility for the decision makers and energy traders to take the correct decision for planning of the periodical operations, energy trading and facility expansion in the electricity sector.

Both techniques used in the present study to estimate the maximum loads, population and GDP for GCC. These techniques are the exponential and linear modeling uses a software called Graph 4.4.2 as a curve fitting technique. The most suitable one and more realistic in modeling for the study is the linear model, where the minimum percentage error between the estimated and actual values are obtained. For the population, the maximum percentage error is 5.9% using the linear model, but the exponential model

shows 7.1% as a percentage error of the Peak Load the maximum percentage error is 4.7% using the linear model, which shows for the exponential as 6.6%.

For the GDP the maximum percentage error is 12.8% using the linear model, which shows for the exponential as 17.8%. The Neuro-Fuzzy results obtained having 1.15% error for the peal load versus years, 1.07% error for the GDP versus peak load and 0.91% error for population versus peak load. The present thesis discusses simple models for estimating peak loads and an efficient algorithm to calculate the model parameters of each case. It is clear that the input parameters of each model are historical loads, GDP and population data on the GCC. Finally; using most suitable modeling for the three estimated models, which are the Annual Peak Load, Population and GDP are found. These models are so close to the real values.

Chapter 5

Modeling Power Trading Opportunities for GCC Countries

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Modeling Power Trading Opportunities for GCC Countries

5.1 Introduction

This chapter will cover the Market Analysis for all GCC interconnected countries, where market model will be determined to be used for the power trading purpose. The Market Analysis method used to determine the opportunities of power trading during the peak load demand for the interconnected countries and based on the Power Trading Chances between them, where the opportunity model defined and obtained.

Dimensions of market analysis summarized at David A. Aaker (2013) outlined the following dimensions of a market analysis:

1. Market size (current and future)
2. Market trends
3. Market growth rate
4. Market profitability
5. Industry cost structure
6. Distribution channels
7. Key success factors
8. Key success Details

The objective of a market analysis and modeling is to determine the market and market opportunities, defeat, they say that there are no opportunities because GCC countries has a similar load demand pattern and weather condition, both now and in the future. Organizations evaluate the future attractiveness of a market by gaining an understanding of evolving

opportunities and threats as they relate to that organization's own strengths and weaknesses.

5.2 Market Analysis

Generally, Market Operator in the electric system refers to the unit or body that takes the responsibility of the electricity trading transactions. It should provide a trusted platform for trading of electrical transactions. Some electrical transactions included the ancillary services. This kind of platform called the Energy Management Market System (EMMS), which its function is to establish the onset of market liberalization. This could performed by separate of the System Operator, which should be an independent entity as Transmission System Operator (TSO) or Independent System Operator (ISO). In addition, this could be performed to simultaneously achieve the purposes of system reliability and market efficiency through System Operator.

As market defined by the network of contacts between buyers and sellers, who all know the general rules governing the trading. The Market Operator primary role is to manage bids and offers in specific periods. The commodity used for such bids and offers is the electrical energy, capacity, ancillary services and transmission rights, where the period of time starts from tens of years covers a long term contract, or for one year, one month, multiple days (or longer) ahead to Day Ahead. Some Market Operator extends this role into hours, half or quarter hours ahead. Figure (5-1) shows the matching deals role between Supply and Demand for Market Operators.



Figure (5-1) Matching Deals role for Market operators

Market Operator is the entity that manages the electricity marketplace to provide an efficient trading platform for transacting electric energy and ancillary services. This managing function is usually established at the onset of market liberalization, and performed by either an independent organization such as the transmission system operator, or an entity controlled by the system operator to simultaneously achieve both objectives of system reliability and market efficiency.

Over the years, with the increases of demand, security requirement, and to involve the private sector in the electricity industry, such trend has spread over most regions in Europe, Australia and North America, and selected countries in Asia and Africa. Therefore, the electricity market size has grown bigger, with fewer markets, and adoption of common or harmonized market rules and the role of Market Operator developed because of market development or Market Regulation development. Because of that, merging

and coupling the Markets have been the main items on the agenda of regulators in certain parts of the world.

This chapter covers the context of Market Operations and regional electricity trade, including the benefits of developing and implementing Regional Electricity Markets (REMs). The challenges and lessons learned from this history and experience gained from the previous formation of Electricity Markets attempts to create REMs in the GCC region. In addition, the present chapter ended with a discussion of the requirements for National and Regional Market Development in the gulf countries. In addition, the historical development of Regional Electricity Market Operators will be tabulated at the end of the chapter and summarize the experience of market integration, which is listed. This experience used later in this thesis for the suggested Market Model for the Regional Electricity Market in the GCC region, and the experience gained will help in assessment of the proposed Market Operator for the GCC region.

5.2.1 The Regional Electricity Market Operators

It's well known that the Market is the place where buyers and sellers met and exchange their commodities. In electricity, utilities the commodities used are the electrons in quantity of kWh or MWh.

Power Market based on game theory application, which applied in electricity market modeling and analysis. Singh (1999) published the *Tutorial on Game Theory Applications in Electric Power Systems* IEEE Power Engineering Society, which become a landmark for the application of electricity market modeling and analysis.

There are mainly two types of electricity markets. The pool, or spot market, which is the electricity market and based on the principle of centralized power dispatch, and bilateral forward markets.

5.2.2 Market size, Trends and Growth

The market size defined through the capacity of the machine available and the demand potential. The history of market volume presented in section (2.5.3). The quantities given in technical terms, which is GW or MW for power capacities and the time is in hours. Qualitative measuring mostly uses the sales turnover as an indicator. The market price used in GCCIA interconnection is the US Dollar per MWh.

The volume is dependent on two procurement parties and their ordinary demand in the coming summers. Furthermore, the market volume either measured in quantities and time zone the energy required. The time zone classified into two categories, which are either peak time of off peak time.

The Market volume right for summer 2015 is about 144GWh for a member state, where for summer 2016 is 144GWh for one member state and 1756.8GWh for another member state.

All member states are willing to utilize the interconnector to gain more benefits, by start trading between each other.

The market still under construction and the growth of the market measured after initiating the market.

5.2.3 Market Profitability

The benefit calculation explored and calculated in section (2.6.1), where the calculation shows a saving of 735 Million USD, besides additional benefits achieved by selling the Barrel of Crude Oil used to generate 10.5TWh in the Crude Oil market. The amount of Crude Oil saved from this operation depends on generators heat rate of the machine used by the imported party.

Countries around the world are increasingly pursuing and benefitting from the integration of national electricity markets into larger regional power markets to provide reliable, affordable electricity to consumers. Increased cooperation in the trade of power among countries can bring numerous benefits, including:

- Increased energy security
- Improved reliability
- Access to resources
- More efficient and effective use of infrastructure
- Economies of scale in investments
- Facilitation of financing for new investments
- Increased energy efficiency
- Greater renewable energy penetration
- Reduced environmental impact
- Reduced cost of supply for consumers

5.2.4 Industry Cost Structure

The Industrial Cost Price will be calculated and described in details in Chapter 6. Al-Ebrahim et al (2010) present in section (2.2.1) the cost in the

merit order form for all machines connected to the system and illustrated through Figure (2-1) to Figure (2-5). This calculation includes the fix and variable cost of the generation units and international fuel price.

5.2.5 Distribution channels and challenges

The distribution channels as agreed by the General Agreement is the Transmission System Operators (TSO's) and procurement parties. At the same time, many regional electricity market (REM) development efforts around the world are facing challenges that slow progress and reduce the benefits of regional integration. It is important to understand these challenges when designing a strategy for increased trade among Arab countries. The challenges include:

- Difficulty in aligning national and regional investment decisions
- Differences in regulatory environments between countries
- Limited scope of regional institutions
- Limited financing
- Changes in political framework
- Concerns about national sovereignty and energy independence

5.2.6 Key Success Factors

The key success factors are mainly the expected benefits and saving which is about 735 Million USD, where this could be achieved by addressing the mentioned obstacles in section (2.4) and it will be discuss in the present chapter in section (5.3).

Regardless of the type of regional trade, there needs to be a legal, regulatory, and governance structure in place conducive to international trade, even if the trade is the only bilateral between two countries. The participating countries must have the political will to relinquish a portion of their energy supply responsibilities to the greater good of the region.

In term of having an effective market with participation from market players, the countries should liberalize the electricity utilities to be more active and participate in the targeted market. The most common stages to build electrical market in national level through unbundle system mentioned by Al-Muhawesh (2007) and it's listed as follows:-

- Rules established by the government, regulator, or owners.
- Reform the utility or utilities.
- Privatization.
- Unbundling or separating the three main components (Generation, Transmission, and Distribution).
- Allowing IPP to participate in building capacity.
- Allowing bulk customers to choose their suppliers.
- Establishing ISO, RTO, PX, or a combination of two or all of them.
- Allowing all customers to purchase energy from any supplier in a complete competitive market.

5.3 Results and Observation from the diversity between the M.S's Peak load

The peak time for the Gulf countries comes in the summer time where it is a very long period. Therefore, the data classified into two categories.

The first category related to the week, where the peak recorded and the second category is the time of peak during the day.

Table (5-1) observes the peak load values and the time occurrence, Humidity and temperature for five member states and the peak of the GCC together during six years starting from 2009.

Table (5-1) Peak Load Data for Years 2009-2012

Item	PEAK DATA FOR YEAR					
	2009	2009	2009	2009	2009	2009
	GCC	KSA	KUW	BAH	QAT	UAE
Date	24/8/09	24/8/09	28/6/09	24/8/09	24/8/09	17/8/09
Time	15:00	15:15	14:30	15:00	14:40	19:34
Load	28672	11739	9960	2438	4535	6255
Humidity	N/A	6	4	63	18	63
Temper.	N/A	44	48	40	45	37
	2010	2010	2010	2010	2010	2010
Date	14/8/10	28/8/10	15/6/10	25/8/10	14/7/10	29/8/10
Time	14:00	16:05	14:30	14:58	13:55	16:41
Load	30421	12965	10890	2708	5090	6885
Humidity	N/A	59	4	41	14	17
Temper.	N/A	41	51	41.5	49	38
	2011	2011	2011	2011	2011	2011
Date	4/8/11	4/8/11	27/7/11	7/8/11	1/8/11	15/8/11
Time	14:41	14:41	14:32	16:04	13:49	16:41
Load	39861	13423	11285	2812	5367	7849
Humidity	N/A	47	6	57	29	42
Temper.	N/A	40	50	37	41	39
	2012	2012	2012	2012	2012	2012
Date	1/8/2012	04/08/2012	1/8/12	23/7/12	6/8/12	6/8/12
Time	15:39	14:59	13:44	14:38	14:32	15:39
Load	42950	14388	11956	2880	6243	8525
Humidity	N/A	99	7	24	50	40
Temper.	N/A	28	50	44	45	14
	2013	2013	2013	2013	2013	2013
Date	17/7/2013	16/7/2013	17/7/2013	4/9/2013	18/7/2013	22/7/2013
Time	15:43	16:24	15:19	14:39	14:05	15:58
Load	44266	15333	12078	2917	6012	8873
Humidity	53190	18500	12988	3086	6384	12372
Temper.	3780	265	951	255	391	1271
	2014	2014	2014	2014	2014	2014
Date	11/6/2014	31/8/2014	11/6/2014	25/8/2014	7/9/2014	21/7/2014
Time	14:31	13:47	14:30	14:46	15:15	15:29
Load	52489	17198	12410	3152	6740	9236
Humidity	61116	21948	13446	3535	7042	13376
Temper.	3682	496	1036	437	302	1362

The radar graph shown in Figure (5-2) observes the first category where the peak load for the six member states occurred in different week numbers. Kuwait and Oman peak load occurrence varied in between week number 22 and week number 31. The total period for the recorded peak load found in Kuwait and Oman in the ninth and eighth weeks, respectively. This gives a large of range of peak occurrence during the months of July and August. Qatar Peaks occurred in the weeks between week number 28 and 37. This was a range of 8 weeks from the mid of July to the end of August.

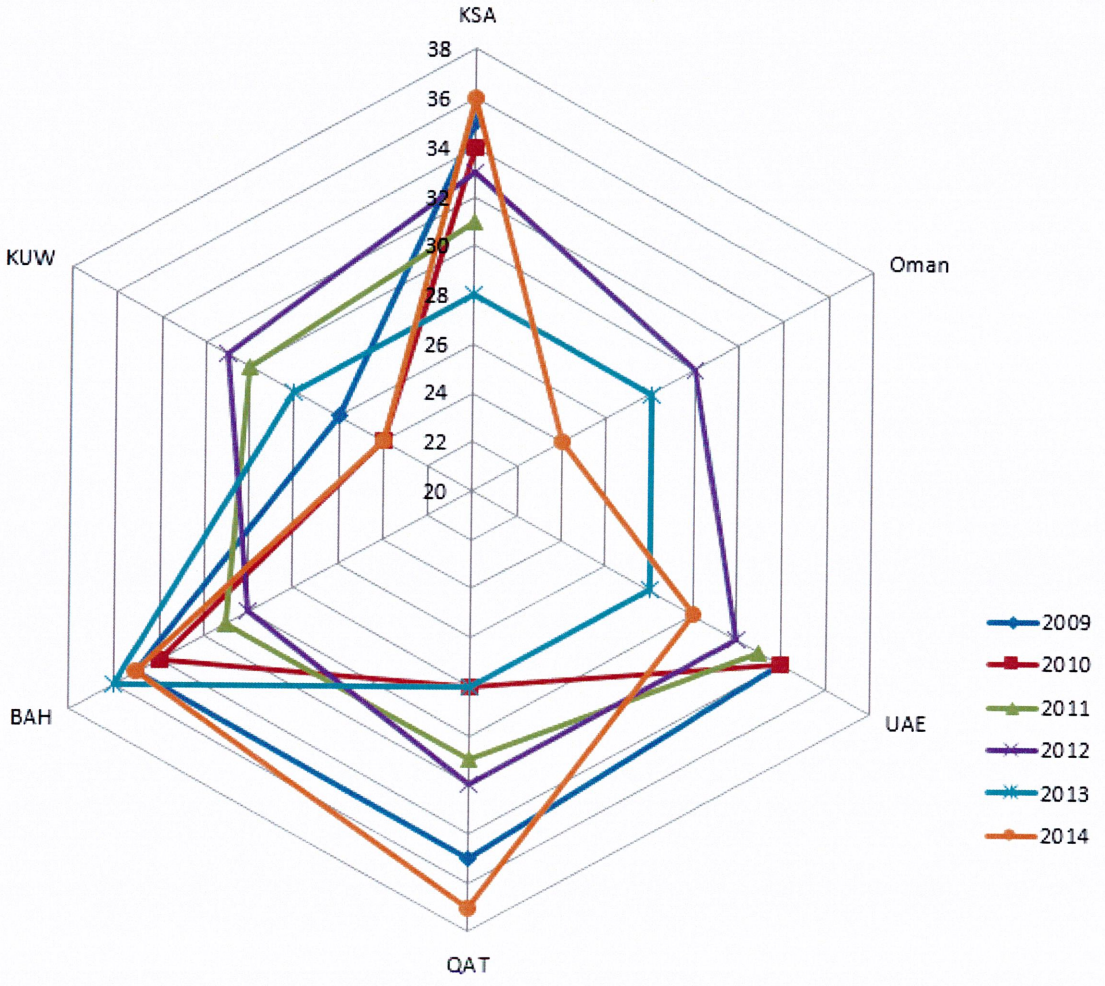


Figure (5-2) Comparison of the week Peak Load recorded last 5 years.

Bahrain peaks were found less than Qatar, where peaks by three weeks. The peaks in Bahrain occurred in the weeks from 30 and 36. This was a range of 6 weeks from the end of July to the end of August. The peak load in Saudi Arabia occurred in the weeks between week number 28 and 36. This is a range of two month, which was in August. The peaks never recorded out of the month August. UAE peaks found in the weeks between week number 28 and 34. These peaks are accord in July and August. These data correlated base with time of occurrences and the week of occurrences and observed in the model shown in Table (5-2).

Table (5-2) observed the weeks where the peaks recorded in the member states during the last six years. It shows differences in the range of weeks and weeks numbers where peaks recorded. These differences give the chances of having a power trading between numbers of member states.

Table (5-2) Week Ahead Opportunity Model

Week No.	24	25	26	27	28	29	30	31	32	33	34	35	36	37
OMN														
KUW														
QAT														
BAH														
KSA														
UAE														

The data observed in Figure (5-3) illustrates time recorded for the peak load of the six member states. The radar graph observes the differences in peak load during the day. The time of the peak load recorded for the six

member states found at noontime except the record peak of UAE in the year 2009, which occurred at nighttime.

The peak load varied in Kuwait MS between 13:30Hrs and 14:30Hrs. Kuwait has a short range for peak not exceeding one hour and not exceeding the time of 14:30hrs. Qatar peaks occurred in times from 13:30Hrs and 14:44Hrs. Qatar has the same range of Kuwait peak time. Bahrain and KSA peaks occurred in times both range starts from 14:30Hrs and ends 16:04Hrs and 16:24Hrs respectively. Therefore, both Bahrain and KSA peaks come after Kuwait and Qatar peaks, where Qatar peak happened in the same time of Bahrain peak "two minutes difference". Oman peak load period was during 14hrs.

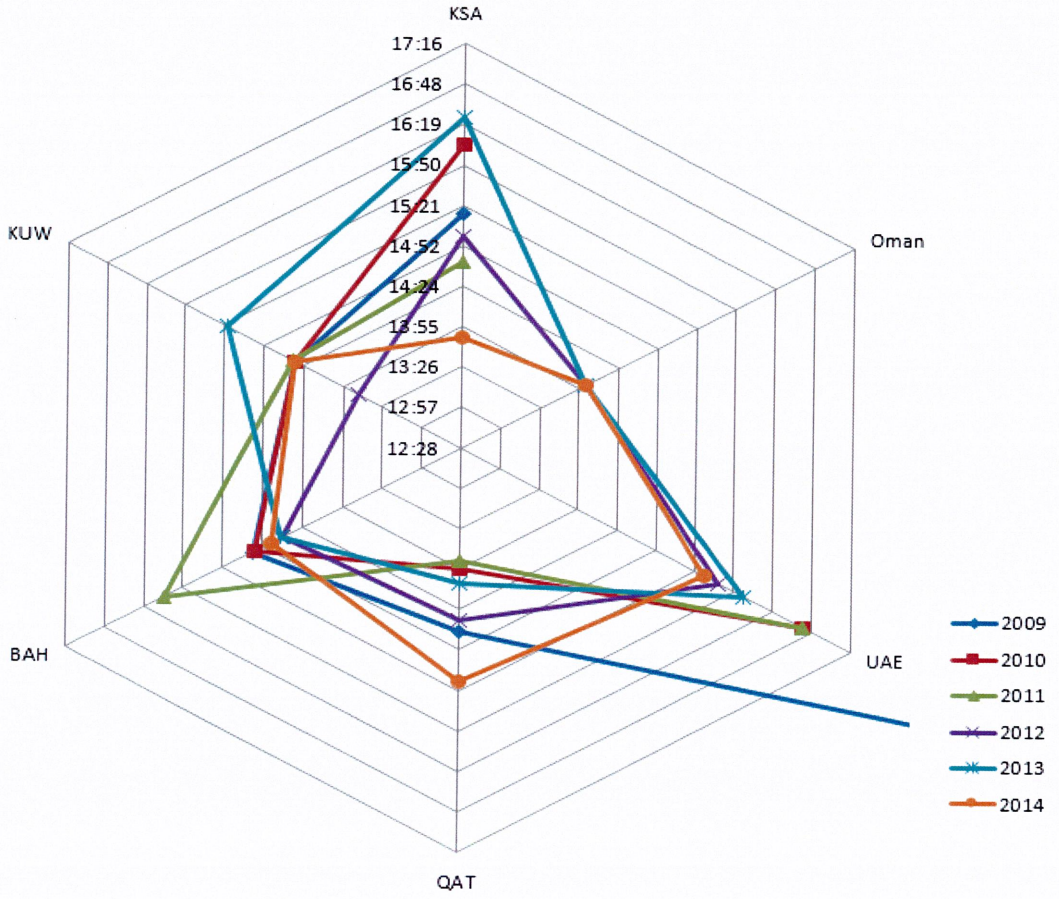


Figure (5-3) Comparison of the time of the Peak Load recorded in the last 6 years.

The peak load in Saudi Arabia occurred in times from 14:41Hrs and 16:05Hrs. This is the same range of Bahrain peak time. KSA peak comes after Kuwait and Qatar peaks. UAE peaks occurred in times from 15:34Hrs and 16:41Hrs. Its peaks come after Kuwait and Qatar peaks and some time comes after Bahrain and / or KSA peak time. These data correlated base with time of occurrences and the week of occurrences and observed in model shown in Table (5-3).

Table (5-3) Day Ahead Opportunity Model

Week No.	13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30
OMN								
KUW								
QAT								
BAH								
KSA								
UAE								

5.4 Opportunities in the Spot Market

Generally, the results shown in the Table (5-3) presents opportunities for all member states to have power trading between each other for long term power trading contract like monthly contracts or in the day ahead market. These opportunities found as follows:

1. Oman or Kuwait can make a power trading with UAE because their peaks are not coming in the same week periods.
2. Oman or Kuwait can make a power trading with Bahrain, and/ or KSA but they should be careful in week number 31.
3. Qatar can make a power trading with Kuwait or Oman if Qatar peak come after week 31, or it can make a power trading with Bahrain, KSA and UAE if the peak comes before week number 31.
4. Bahrain, KSA and UAE should look for the second category to check the possibilities of power trading between each other in the spot market.

On the other hand, the results shown in Table (5-3) shows the range of time where the peaks recorded in the member states interconnected during 2009 to 2014. It observed that there are differences in peak load occurrence during the day, which will give more opportunities of having spot power trading between the interconnected countries. These opportunities found as follows:

1. Oman has a peak load during 1400Hrs hours, so they can make trading before this time or after this time.
2. Kuwait and Qatar have a similar time range of peak load during the day where Bahrain and KSA also have a similar time range of peak

load during the day, where there are minor opportunities for trading among them in the spot market.

3. Kuwait and/or Qatar can both of them make a spot power trading for the peak time during the peak time of the day with the UAE.
4. Kuwait and/or Qatar can both of them make a spot power trading for the peak time during the peak time of the day with Bahrain or KSA member states during the peak time of the day.
5. There is less of the opportunity of having a spot trading between UAE and KSA or Bahrain in period of 15:00Hrs to 16:00Hrs where they have good opportunities in the rest of the time.

5.5 Conclusion

Since the GCC interconnected, the opportunities of spot market did not study in details to find the possibilities of power trading in Spot Market and Day Ahead Market.

Therefore, Member State makes some power trading contracts based of long-term forecasts of power required to meet the peak demand. The most expensive power is the power at peak time, which transferred through the cross-border to support other member states and to save additional cost of using oil/gas fuel to meet the peak demand of electrical energy.

The results observed that all member states have the opportunity for power trading in a short-term contract market like monthly contracts or Day Ahead Market. In addition, all member states have the opportunity for power trading in the spot market. Each member state should check the opportunities based on the given methodology.

Chapter 6

Generation Cost Modeling and Machine Reliability for GCC Countries

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Chapter 6

Generation Cost Modeling and Machines Reliability for GCC Countries

6.1 Introduction

This chapter covers the overall cost of the Generation units with a suggested Model for GCC countries, and Machines Reliability for the interconnected machines and switching of the machine during switching the supplier. The generating units should interact with the market rule and market model. This chapter will cover an introduction for different types of generating technology; the factors that drive the power plant cost; the financial analysis methodology and key assumption; and estimates of power plant overall cost.

Generally, the load demand challenged momently by generation units meeting the demand, changes in customers' requirements in business and residential activities which interact with the weather condition as shown in the previous chapter. Kaplan (2010) classify the generation types in his book into three categories to meet load demand in the system, which are the base load, intermediate load and peak load generating units. McHugh (2008) classifies the generation types in his Technical Paper into four types as follows:

a) Plants that use intermittent resources such as wind and solar provide a relatively uncertain (stochastic) level of output in a trading interval, but have zero fuel costs and so are typically the lowest SRMC plants. This is particularly likely to be the case where environmental and

technological regulations such as renewable energy certificates, tradable pollution permits, and/or carbon taxes are significant.

b) Base load plants have low variable costs, but high startup and shutdown costs, and have a relatively limited capability to ramp output up or down to follow the load.

c) Mid-merit or load following units is normally medium cost plants, both in terms of variable cost, startup cost and shutdown cost, and are quite effective at adjusting (ramping) output up or down to cover reasonably rapid changes in demand.

d) Peaking plants, mostly based on gas turbine technology. These units are very effective at following load and can be started up and shut down quickly and cheaply. However, they are usually the highest variable cost plants in a portfolio, particularly when distillate used as the fuel input.

These types of generation usually dispatched to cover the daily load curve as shown in Figure (6-1).

6.2 Generator Cost Function and Operating Characteristics

The physical generating units should be freely participate in the Electricity Market based on offer prices submitted by Generation Companies. Earlier the generating units dispatched economically to meet system load illustrated in Figure (6-1), where in the liberalized market the generators dispatched base on winner in the bids for the next transection. Generating energy for thermal unit depend on many parameters, which are as follows:

1- Heat Rate
2- Capacity
3- Fuel type
4- Generation allocation
5- Variable O&M
6- Fixed O&M
7- Forced Outage
8- Maintenance Rate
9- Start Up Costs
10- Type of generation (Non Cycling, Must Run)
11- Life cycle of the unit
12- Emission Price Units
13- Risk Outage

The machines used in GCC countries are combustible fuel unit types that were used mainly oil and gas available in the region.

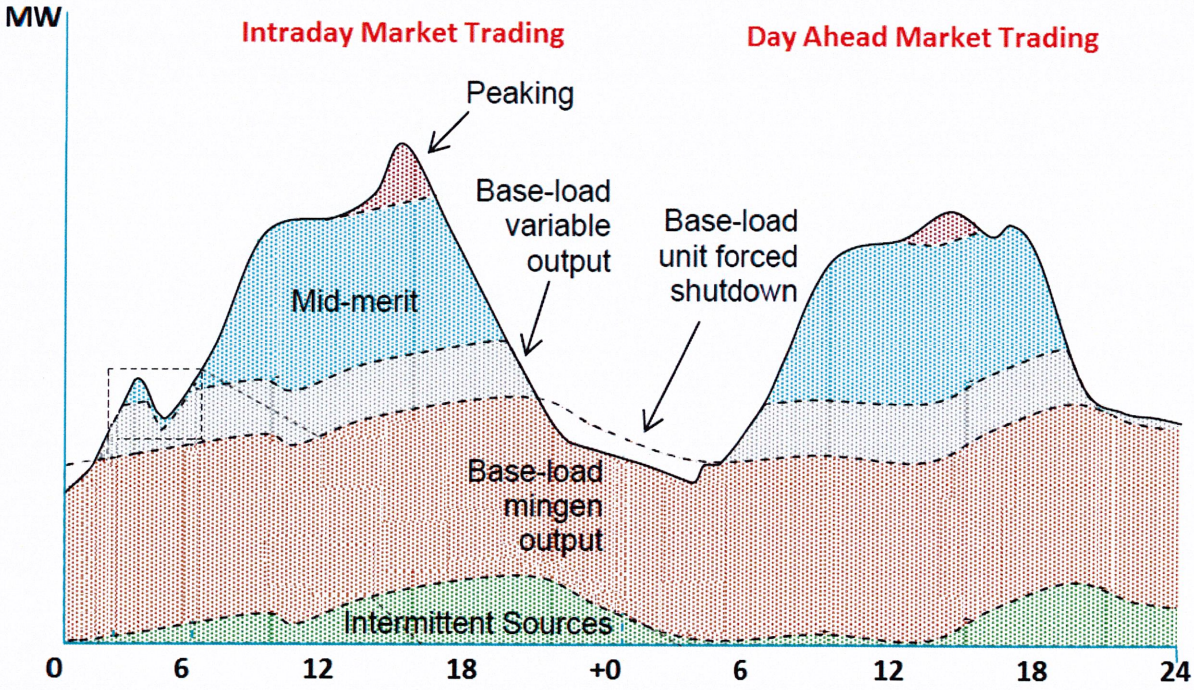


Figure (6-1) Daily Load Curve

The key driver for such type of variable cost generating units is the efficiency of converting fuel to electricity, and measured by the machine's Heat Rate, which is the amount of fuel used in British Thermal Units (BTU) required to generate one Kilowatt-hour of electrical energy. Table (6-1) used

to convert amounts of fuel used from one shape to another. Generator variable cost is directly proportional to the machine Heat Rate where generator efficiency is inversely proportional to the machine Heat Rate. The Heat Rates are not applicable to the non-combustible fuel unit types like nuclear and non-biomass renewable plants.

Heat Rate = BTUs / kWh (6-1)

The utilization of generating unit called the capacity factor is the ratio of amount of electrical power produced during the period.

Capacity factor = Generation capacity (MW) x 8760 Hours (year) (6-2)

It is very important to use the correct units in every stage of calculating the cost of generating electricity and the production cost of the machine due to a different set of units, which are used, from the used fuel for power station until the electricity generated from the generator. The present example shows the cost of generating electricity from the rented diesel generator, where it has quoted at $10 per gallon of diesel fuel used, and consumes one 55-gallon (Gal) barrel of fuel per 1-hour (h) running period. Therefore, the rental cost of the diesel generator for a 24-h running period is as follows:

Cost = $ rate per hour × quantity of hours of operation (6-3)

$$\frac{Cost}{Hour} = \frac{\$10}{gal} \times \frac{55gal}{barrel} \times \frac{1barrel}{hour} = \$550$$

$$Cost = \$\, rate\ per\ hour \times quantity\ of\ hours\ of\ operation$$

$$= \frac{\$550}{h} \times 24\ h\ of\ operation = \$13200$$

Table (6-1) Energy Conversions for Markets International

Energy Conversion Table

Select Calorific Values

			FROM
Natural Gas (btu/cf)		1,040	
Crude Oil (toe/tonne)		1.0415	
Coal (toe/tonne)		0.6460	
kilowatt/hours	kWh	1	
megawatt/hours	MWh	1	
gigawatt/hours	GWh	1	
terawatt/hours	TWh	1	
therms	th	1	
decatherms	mmbtu	1	
million therms	mm.th	1	
kilojoule	kJ	1	
gigajoule	GJ	1	
petajoule	PJ	1	
kilocalorie	kcal	1	
gigacalorie	Gcal	1	
petacalorie	Pcal	1	
cubic foot (natural gas)	ft³	1	
thousand cubic feet	thou.ft³	1	
million cubic feet	m.ft³	1	
billion cubic feet	bcf	1	
trillion cubic feet	tcf	1	
cubic meter (natural gas)	m³	1	
thousand cubic meters	thou.m³	1	
million cubic meters	mcm	1	
billion cubic meters	bcm	1	
barrel oil equivalent	boe	1	
million barrels oil equiv	mm.boe	1	
tonne oil equivalent	toe	1	
million tonnes oil equiv	mm.toe	1	
tonne of coal equivalent	tce	1	
million tonne coil equiv	mm.tce	1	
tonne LNG	tonne LNG	1	
million tonnes LNG	mm.tonne LNG	1	

therms			joules			calorie			cubic foot of NG					cubic meters of NG				rrel of oil equival		tonne of oil equivalent		nne of coal equivale		tonne of LNG	
therm	mmbtu	mm.therm	kJ	GJ	PJ	kcal	Gcal	Pcal	ft³	thou.ft³	m.ft³	bcf	tcf	m³	thou.m³	mcm	bcm	boe	mboe	toe	mtoe	tce	mtoe	tonne	mtoe
	1x10⁴	1x10⁴	1x10³	1x10⁹	1x10¹⁵	1x10³	1x10⁹	1x10¹⁵		1x10³	1x10⁶	1x10⁹	1x10¹²		1x10³	1x10⁶	1x10⁹		1x10⁶		1x10⁶		1x10⁶		1x10⁶
0.0341	0.003412	3.41E-08	3,600	0.0036	3.6E-09	860	0.0009	8.60E-10	3.28	0.0033	3.28E-06	3.28E-09	3.28E-12	0.093	9.29E-05	9.29E-08	9.29E-11	0.00061	6.14E-10	8.60E-05	8.60E-11	0.000133	1.33E-10	0.000066	6.62E-11
34.12	3.41	3.41E-05	3,600,000	3.6	3.60E-06	859,845	0.8598	8.60E-07	3,281	3.28	0.0033	3.28E-06	3.28E-09	93	0.093	9.29E-05	9.29E-08	0.61418	6.14E-07	0.086	8.60E-08	0.133	1.33E-07	0.066	6.62E-08
34,120	3,412	0.0341	3.60E+09	3,600	0.0036	8.60E+08	860	8.60E-04	3,280,769	3,281	3.28	0.0033	3.28E-06	92,913	93	0.093	9.29E-05	614	6.14E-04	86	8.60E-05	133	0.000133	66	0.000066
3.41E+07	3,411,999	34.12	3.60E+12	3,600,000	3.6	8.60E+11	859,845	0.8598	3.28E+09	3,280,769	3,281	3.28	0.0033	9.29E+07	92,913	93	0.093	614,175	0.61	85,985	0.086	133,103	0.133	66,180	0.066
1	0.1	1.0E-06	105,519	0.1055	1.06E-07	25,202	0.0252	2.52E-08	96.2	0.0962	9.62E-05	9.62E-08	9.62E-11	2.72	0.0027	2.72E-06	2.72E-09	0.018	1.80E-08	0.0025	2.52E-09	0.004	3.90E-09	0.0019	1.94E-09
10	1	1.0E-05	1,055,192	1.0552	1.06E-06	252,016	0.2520	2.52E-07	962	0.962	9.62E-04	9.62E-07	9.62E-10	27.23	0.0272	2.72E-05	2.72E-08	0.180	1.80E-07	0.0252	2.52E-08	0.04	3.90E-08	0.019	1.94E-08
1,000,000	100,000	1	1.06E+11	105,519	0.1055	2.52E+10	25,202	0.0252	9.62E+07	96,154	96.2	0.0962	9.62E-05	2.72E+06	2,723	2.72	0.0027	18,001	0.018	2,520	0.0025	3,901	0.004	1,940	0.002
9.48E-06	9.48E-07	9.48E-12	1	1.0E-06	1.0E-12	0.2388	2.39E-07	2.39E-13	0.0009	9.11E-07	9.11E-10	9.11E-13	9.11E-16	2.58E-05	2.58E-08	2.58E-11	2.58E-14	1.71E-07	1.71E-13	2.39E-08	2.39E-14	3.70E-08	3.70E-14	1.84E-08	1.84E-14
9.48	0.9477	9.48E-06	1,000,000	1	1.0E-06	238,834	0.2388	2.39E-07	911	0.91	0.0009	9.11E-07	9.11E-10	25.81	0.0258	2.58E-05	2.58E-08	0.171	1.71E-07	0.0239	2.39E-08	0.037	3.70E-08	0.018	1.84E-08
9,476,952	947,695	9.48	1.00E+12	1,000,000	1	2.39E+11	238,834	0.2388	9.11E+08	911,411	911	0.9114	9.11E-04	2.58E+07	25,812	25.81	0.0258	170,596	0.171	23,883	0.0239	36,971	0.037	18,382	0.018
3.97E-05	3.97E-06	3.97E-11	4.19	4.19E-06	4.19E-12	1	1.0E-06	1.0E-12	0.0038	3.82E-06	3.82E-09	3.82E-12	3.82E-15	0.0001	1.08E-07	1.08E-10	1.08E-13	7.14E-07	7.14E-13	1.00E-07	1.00E-13	1.55E-07	1.55E-13	7.70E-08	7.70E-14
39.68	3.968	3.97E-05	4,187,000	4.1870	4.1870E-06	1.00E+06	1	1.0E-06	3,816	3.82	0.0038	3.82E-06	3.82E-09	108.06	0.1081	1.08E-04	1.08E-07	0.71	7.14E-07	0.1	1.00E-07	0.155	1.55E-07	0.077	7.70E-08
3.97E+07	3,968,000	39.68	4.19E+12	4,187,000	4.1870	1.00E+12	1.00E+06	1	3.82E+09	3,815,629	3,816	3.82	0.0038	1.08E+08	108,061	108.06	0.1081	714,286	0.714	100,000	0.1	154,799	0.155	76,967	0.077
0.0104	1.04E-03	1.04E-08	1,097	0.0011	1.10E-09	262	2.62E-04	2.62E-10	1	0.001	1.00E-06	1.00E-09	1E-12	0.02832	2.83E-05	2.832E-08	2.832E-11	0.00019	1.89E-10	2.62E-05	2.62E-11	0.000041	4.06E-11	0.00002	2.02E-11
10.4	1.04	1.04E-05	1,097,200	1.10	1.10E-06	262,080	0.2621	2.62E-07	1,000	1	0.001	1.00E-06	1.00E-09	28.32	0.02832	2.83E-05	2.832E-08	0.189	1.89E-07	0.026	2.62E-08	0.041	4.06E-08	0.020	2.02E-08
10,400	1,040	0.0104	1.10E+09	1,097	0.0011	2.62E+08	262	2.62E-04	1,000,000	1,000	1	0.001	1.00E-06	28,320	28.32	0.02832	2.83E-05	189	0.00019	26.2	2.62E-05	41	0.000041	20	0.000020
10,400,000	1,040,000	10.40	1.10E+12	1,097,200	1.10	2.62E+11	262,080	0.2621	1.00E+09	1,000,000	1,000	1	0.001	2.83E+07	28,320	28.32	0.02832	188,646	0.189	26,210	0.026	40,572	0.041	20,173	0.020
1.04E+10	1.04E+09	10,400	1.10E+15	1.10E+09	1,097	2.62E+14	2.62E+08	262	1.00E+12	1.00E+09	1,000,000	1,000.0	1	2.83E+10	2.83E+07	28,320	28.32	1.89E+08	189	2.62E+07	26.2	40,572,256	41	20,172,779	20
0.3672	0.0367	3.67E-07	38,742	0.0387	3.87E-08	9,254	0.0093	9.25E-09	35.31	0.03531	3.53E-05	3.5E-08	3.53E-11	1	0.001	1.00E-06	1.00E-09	0.0067	6.66E-09	0.0009	9.25E-10	0.0014	1.43E-09	0.00071	7.12E-10
367	36.72	3.67E-04	38,742,132	38.74	3.87E-05	9,254,045	9.25	9.25E-06	35,310	35.31	0.03531	3.53E-05	3.53E-08	1,000	1	0.001	1.00E-06	6.66	6.66E-06	0.9255	9.25E-07	1.4	1.43E-06	0.712	7.12E-07
367,224	36,722	0.3672	3.87E+10	3.87E+04	0.0387	9.25E+09	9,254	0.0093	3.53E+07	35,310	35.31	0.03531	3.53E-05	1,000,000	1,000	1	0.001	6,661	0.0067	925	0.0009	1,433	0.0014	712	0.0007
3.67E+08	3.67E+07	367	3.87E+13	3.87E+07	38.74	9.25E+12	9.25E+06	9.25	3.53E+10	3.53E+07	35,310	35.31	0.03531	1.00E+09	1.00E+06	1,000	1	6,661,074	6.66	925,464	0.93	1,432,606	1.4	712,301	0.7
55	5.51	5.51E-05	5,817,255	5.82	5.82E-06	1,389,361	1.39	1.39E-06	5,301	5.30	0.0053	5.30E-06	5.30E-09	150	0.15	1.50E-04	1.50E-07	1	1.0E-06	0.139	1.39E-07	0.22	2.15E-07	0.11	1.07E-07
5.51E+07	5,512,984	55	5.82E+12	5,817,255	5.82	1.39E+12	1,389,361	1.39	5.30E+09	5,300,947	5,301	5.30	0.0053	1.50E+08	150,126	150	0.15	1,000,000	1	138,936	0.139	215,071	0.22	106,935	0.11
397	39.68	3.97E-04	4.19E+07	41.87	4.19E-05	10,000,000	10	1.00E-05	38,154	38.15	0.0382	3.82E-05	3.82E-08	1,081	1.08	1.08E-03	1.08E-06	7.14	7.14E-06	1	1.0E-06	1.55	1.55E-06	0.77	7.70E-07
3.97E+08	39,681,895	397	4.19E+13	41,870,000	41.87	1.00E+13	10,000,000	10	3.82E+10	38,153,846	38,154	38.15	0.0382	1.08E+09	1,080,539	1,081	1.08	7,142,857	7.14	1,000,000	1	1,547,988	1.55	769,669	0.77
256	25.63	2.56E-04	27,048,020	27.05	2.70E-05	6,460,000	6.46	6.46E-06	24,647	24.65	0.0246	2.46E-05	2.46E-08	698	0.70	6.98E-04	6.98E-07	4.65	4.65E-06	0.65	6.46E-07	1	1.0E-06	0.50	4.97E-07
2.56E+08	25,633,280	256	2.70E+13	27,048,020	27.05	6.46E+12	6,460,000	6.46	2.46E+10	24,647,385	24,647	24.65	0.0246	6.98E+08	698,028	698	0.70	4,649,620	4.65	646,000	0.65	1,000,000	1	497,206	0.50
516	51.55	5.16E-04	54,400,000	54.40	5.44E-05	12,392,596	13	1.30E-05	49,572	49.57	0.05	4.96E-05	4.96E-08	1,404	1.40	0.0014	1.40E-06	9.35	9.35E-06	1.30	1.0E-06	2.01	2.01E-06	1	1.0E-06
5.16E+08	51,554,621	516	5.44E+13	54,400,000	54.40	1.30E+13	12,992,596	13	4.96E+10	49,571,751	49,572	49.57	0.05	1.40E+09	1,403,901	1,404	1.40	9,351,490	9.35	1,299,260	1	2,011,238	2.01	1,000,000	1

6.3 Cost of Electricity Generation

Usually, if there were a plan for units entering service on January 1, 2015, the cost analysis for construction would be start three to seven years earlier base on the technology of generation targeted. Then the units incorporate with small projected changes from the study analysis and cost and performance for selected technologies.

6.3.1 Cost Trend of Electricity Generation

Kaplan (2010) presents in his book "Power Plant Characteristics and Costs" power project costs were analyzed and estimated base case results illustrated in Figure (6-2) and Figure (6-3).The range of prices for Nuclear Project Cost is between $1500 and $3000, where for Pulverized Coal Project Cost is between $1200 and $2500. Figure (6-4) illustrates the Combined Cycle Project Cost, which its cost start from $500, and reached $1500. Generally, the cost of Combined Cycle Project is less than the other type of generation technology.

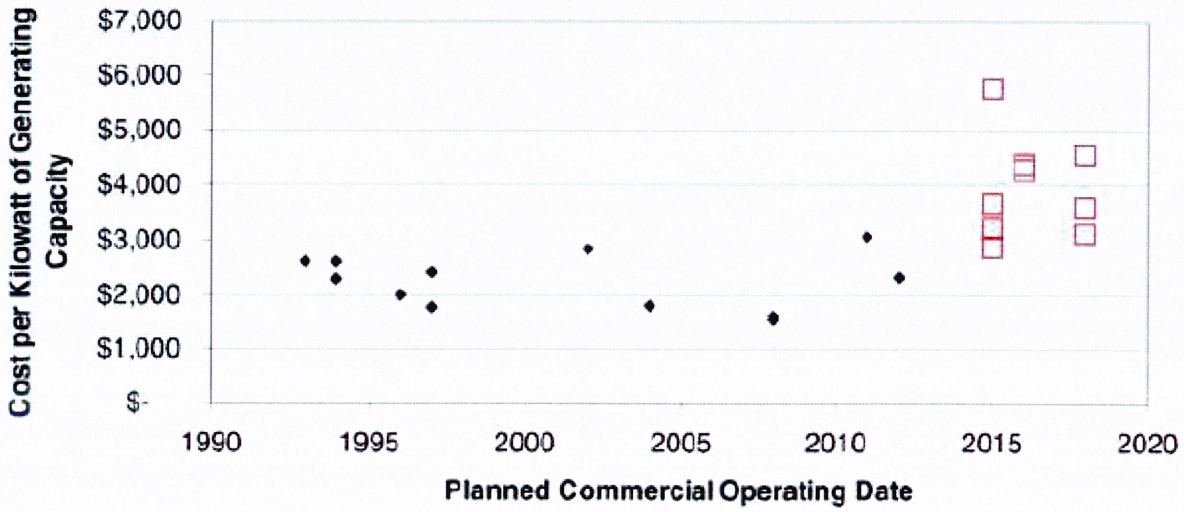


Figure (6-2) Nuclear Project Cost Trends

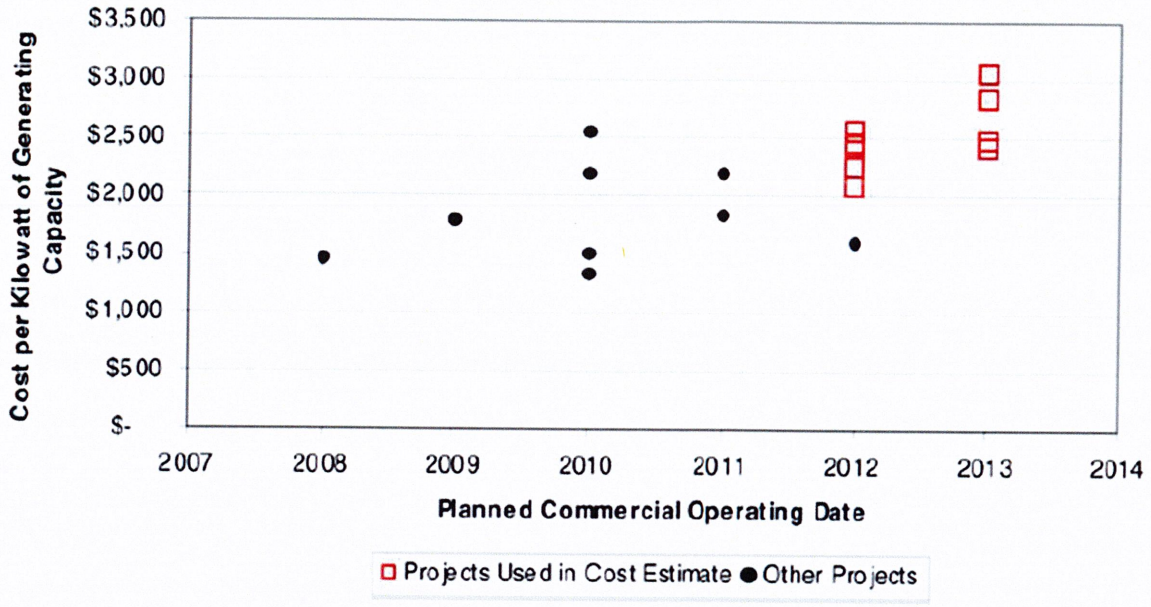


Figure (6-3) Pulverized Coal Project Cost Trends

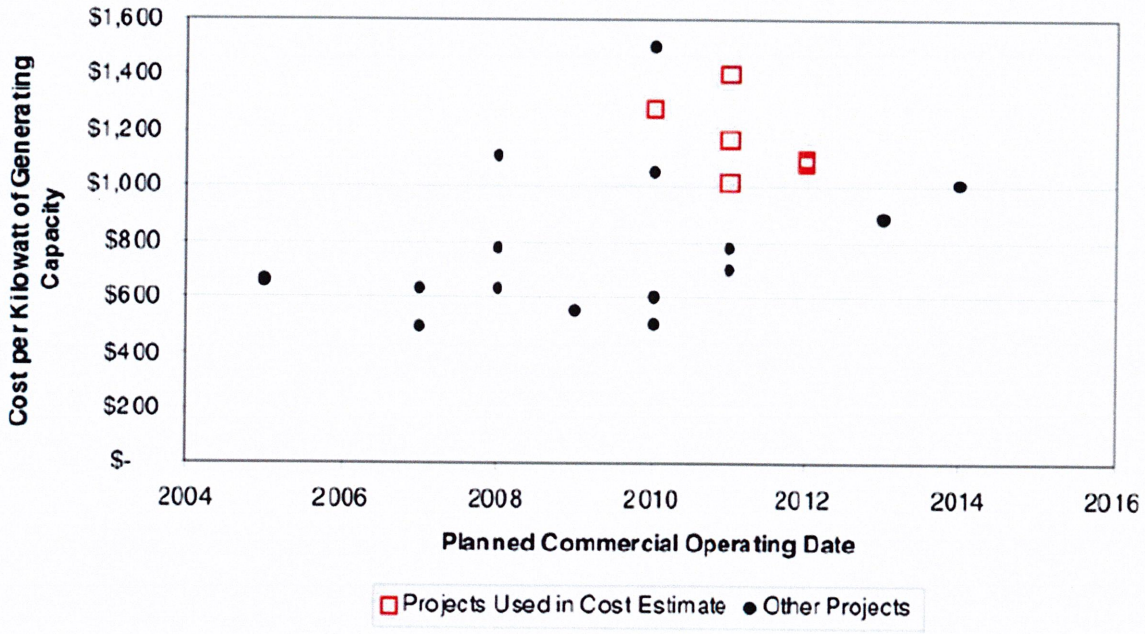


Figure (6-4) Combined Cycle Project Cost Trends

The Levelized cost of electricity generation (LCOE) is the ratio of the Net Present Value of total capital and operating costs of a particular plant to the

net present value of the net electricity generated by that plant over its operating life. The equation for that is as follows:

LCOE = TOTC / NPVEG (6-4)

LCOE: Levelized cost of electricity generation,
TOTC: Net Present Value (NPV) of total costs (capital and operating)
NPVEG: NPV of net electricity generation (MWh)

$$TOTC = \sum \frac{TC_n}{(1+r)^n} \quad (6\text{-}5)$$

TOTC: Net Present Value (NPV) of total costs (capital and operating)
TC_n: Total costs for power in operating year (n) (capital and operating costs)
G_n: Net Generation in operation year (n)
n : operating year
r : Annual discount rate (10% real)
l : Operating life of plant

$$NPVG = \sum \frac{G_n}{(1+r)^n}, \quad n=1 \quad (6\text{-}6)$$

A joint study carried by IEA/NEA Secretariat (2010) to calculate the Levelized costs of electricity (LCOE) for base-load power generation presented in Figure (6-5) and Figure (6-6). The most important assumptions concern the real discount rates, 5% and 10%, also keeping with tradition, fuel prices and, for the first time, a carbon price of USD 30 per ton of CO_2.

Two important conclusions come up from this study shown in Figure (6-5) and Figure (6-6). First, in the low discount rate case, more capital-intensive, low-carbon technologies such as nuclear energy are the most competitive solution compared with coal-fired plants without carbon capture and natural gas-fired combined cycle plants for base load generation.

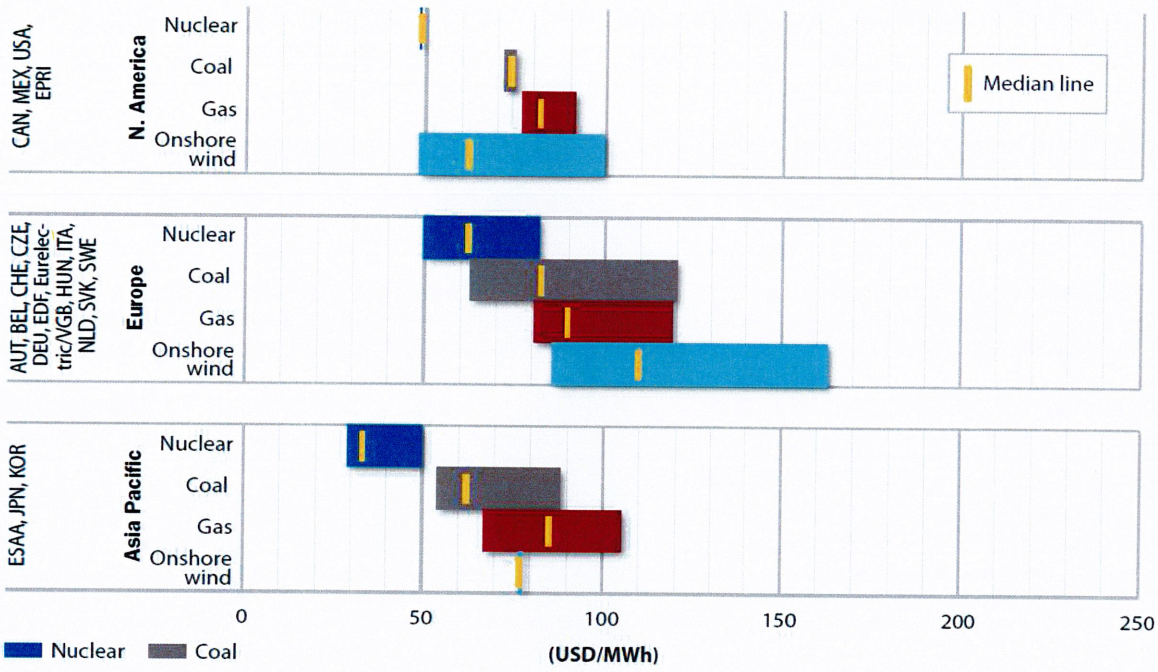


Figure (6-5) Regional ranges of the Levelized Cost of Electricity different types of power plants (at 5% discounted rate)

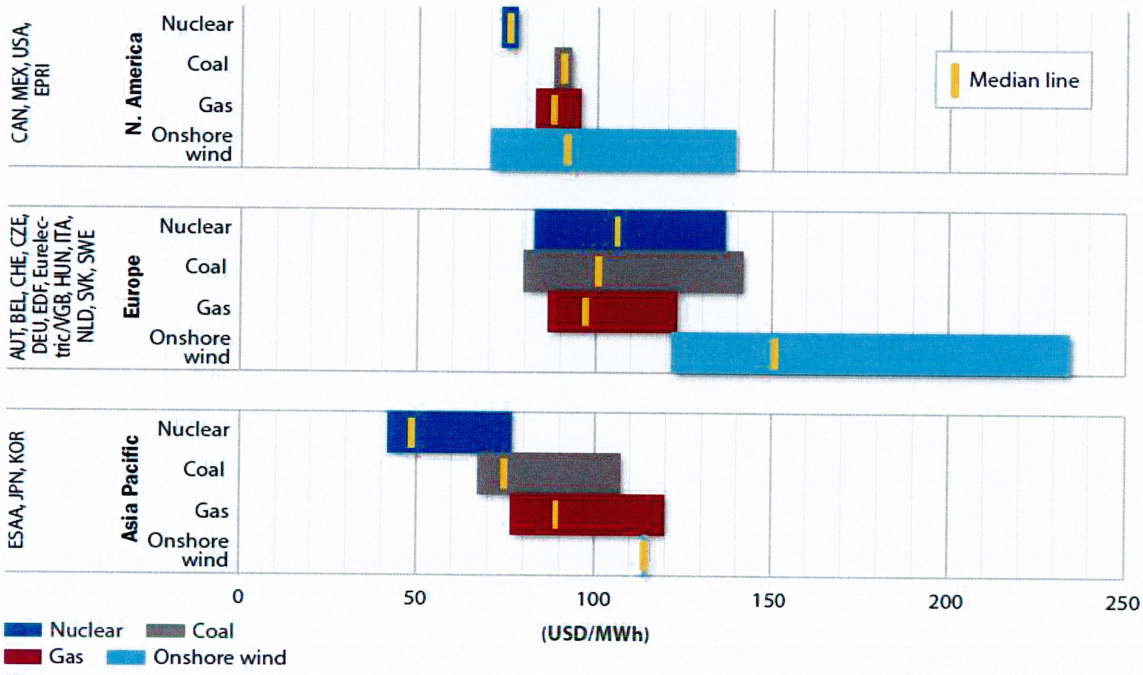


Figure (6-6) Regional ranges of the Levelized Cost of Electricity different types of power plants (at 10% discounted rate)

Second, in the high discount rate case, coal without carbon capture equipment, followed by coal with carbon capture equipment, and gas-fired combined cycle turbines (CCGTs), are the cheapest sources of electricity. Since the available resources in the Gulf region is oil and gas, the CCGTs become one of the most recommended power generation in the gulf region.

6.3.2 Electricity Market Model

The European Electricity Market Model EMMA as explained in EMMA (2014), which minimizes total system cost of the interconnected Northwestern European power system. Total system cost consist of the capital costs, fuel and CO_2 costs, and other fixed and variable costs, of generation, transmission, and storage assets. It represents partial equilibrium model of the wholesale electricity market, that determines optimal or equilibrium yearly generation, transmission and storage capacity, hourly traded generation and hourly market-clearing prices for each market zone. The Model deals with eleven discrete technologies with continuous capacity, where in GCC region there are mainly two types. Therefore, the total system cost consists of three parameter, which are fixed, variable and transmission costs as illustrated in the coming equations.

The GCC Multi Zone Border to Border Regional Electricity Market Model MZBBREM is an arithmetical formalized dispatch of the GCC interconnected power systems that has been proposed to be implemented in their region. MZBBREM model is used AURORAxmp that used in many regions in the world like USA and Europe as mentioned by Foley (2010). It is proposed to address a range of obstacles toward creating an Electricity Market Model for GCC countries avoiding repetition unsuccessful experience in creating a

Regional Electricity Market. It presents a semi-balance economic model of the wholesale electricity marketplace. It determines maximum welfare benefits for the interlinked resources.

a) Overview

The AURORAxmp (AURURA extensible modelling power) Electric Market Model is comprehensive and reliable electricity market forecasting tool available. It endows the user to produce electric market price forecasts, value and uncertainty analyses, and automated system optimization. All that backed by one of the finest databases available.

AURORAxmp software is used in Generation Planning / Utility Budgeting which helps in integrated resource planning, budget projections and detailed generator analysis. Even though, it helps in the Market Assessment and Strategy. This means it concentrates on price forecasting at zones in GCC, market design and policy analysis, and scenario based and probabilistic treatment of the inputs. Likewise, it helps as trading support software. AURORAxmp assessing production cost impacts and used in infrastructure studies.

Industry professionals developed AURORAxmp to model a dynamic and volatile marketplace. AURORAxmp combines state-of-the-art technology, industry experience, and a user-friendly interface.

Captured from Member states feedback and meetings, issues and concerns on the subject of power trading will be treated as official stance and will be handled as part of the proposed approach towards producing a local energy market in the area. The findings are formulated into tangible and

acceptable proceedings that the member countries could be embraced as part of their development plan for the area to assure that it would fit within the targets of their imaginations.

b) Total system costs

The entire system costs are as follows:

$$Cost\ (\frac{\$}{\text{MW}}) = r \times q \tag{6-7}$$

Where r is the dollar rate per hour, and q is quantity of hours of operation.

Unit Assumptions calculation for the quantity, size (MW).

1. Total System Costs

The heat rates are not applicable to the non-combustible fuel unit types like nuclear and non-biomass renewable plants.

$$H = BTUs / kWh \tag{6-8}$$

where H is the heat rate.

The GCC model minimizes total system costs for GCC interconnected system "C". In this case, the GCC model will be in respect to a large number of decision variables and technical constraints.

$$C = \sum_{r,i} \left(C^{fix}_{r,i}\right) + \sum_{r,i,t} \left(C^{var}_{t,r,i}\right) + \sum_{r,rr} \left(C^{trans}_{r,rr}\right) \tag{6-9}$$

Where the fixed generation costs are $^{fix}_{r,i}$, the variable generation costs are $C^{var}_{t,r,i}$, and the transmission costs are $C^{trans}_{r,rr}$, over all time steps t, regions r, and generation technologies i.

From the economic point view, total cost of production consists of the fix costs and the variable costs. The fix cost consists of capital investment, fix operation and maintenance, depreciation costs and Insurance costs.

The following equations formulated from Figure (6-7) for all units generation cost components as follows:

$$\text{Unit Generation Cost } g(c) = \sum_{r,i} \left(C^{fix}_{r,i}\right) + \sum_{r,i,t} \left(C^{var}_{t,r,i}\right) \quad (6\text{-}10)$$

$$g(c) = \sum_{r,i} \text{Insurance Costs (IC)} + \sum_{r,i} \text{Depreciation Costs (DC)} + \sum_{r,i} \text{Capital Inv. Profit. (CIP)} + \sum_{r,i} \text{Fixed O\&M Costs (FOMC)} + \sum_{r,i,t} \left(C^{var}_{t,r,i}\right) \quad (6\text{-}11)$$

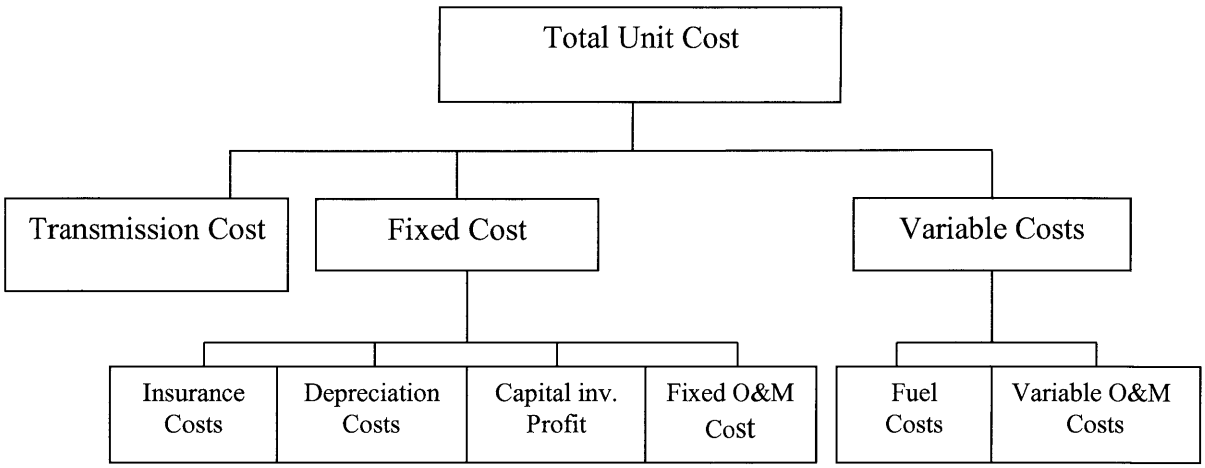


Figure (6-7) Unit Generation Cost Components

Figure (6-8) illustrates the results of economic calculations. In these calculations both variable and fixed costs for equipment's are considered which presents opportunities of savings in the case fuel cost fluctuates in the fuel market. The fixed and variable costs are shown in the same figure with their total costs. It shows the generation units cost component using cost plus method for each generation unit, and shows different values for the fixed and variable cost for each generator.

Furthermore, it is also possible to determine what sort of opportunities is available for each generation plant of the network in terms of supply and its price. These differences show different costs of generation units, which can offer different prices. Machines that has lower operation costs can offer better prices for the market.

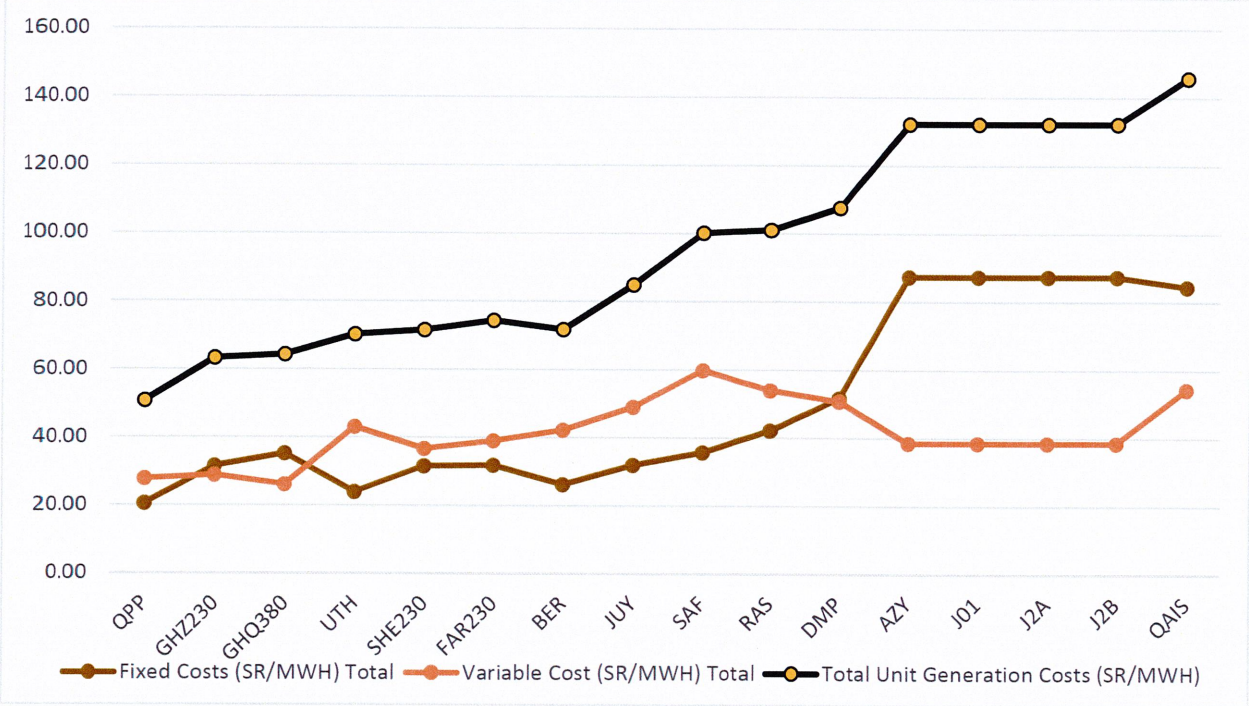


Figure (6-8) Unit Generation Cost Components using Cost-Plus method.

The unit generation cost equations formulated is as follows

$$C_{g,i} = \sum_{r,i}[C^{fix}_{r,i} + C^{var}_{r,i}] \text{ x } RF \qquad (6\text{-}12)$$

Where $C^{gen}_{r,i}$ is generation cost, $C^{fix}_{r,i}$ is generation fix cost, $C^{var}_{r,i}$ generation variable cost RF is the risk factor.

There are other Fix Costs FC which can be formulated as follows:

$$C^{fix}_{r,i} = \sum Insurance\ Costs\ (IC) + \sum Depreciation\ Costs\ (DC) + \sum Capital\ Inv.Profit.\ (CIP) + \sum Fixed\ O\&M\ Costs\ (FOMC) \qquad (6\text{-}13)$$

and;

$$C^{var}_{t,r,i} = \sum Fuel\ Cost + \sum Variable\ O\&M\ Cost \quad (6\text{-}14)$$

Equation (6-15), which was used in the AURORA software, calculate the GCC model minimizes total system costs for GCC interconnected system "C". In this case, the GCC model will be in respect to a large number of decision variables and technical constraints.

$$C = \sum_{r,i} \left(C^{fix}_{r,i} + FC_{r,i}\right) + \sum_{r,i,t} \left(C^{var}_{t,r,i}\right) + \sum_{r,rr} \left(C^{trans}_{r,rr}\right) \quad (6\text{-}15)$$

Where $C^{fix}_{r,i}$ is the fixed generation costs, $C^{var}_{t,r,i}$ is the variable generation costs, and $C^{trans}_{r,rr}$ is the transmission costs, over all time steps t, regions r , and generation technologies i.

2. Supply and Demand

The fundamental constraint of the mannequin is the energy balance. The power demand is the required to be converged. For the demand of electrical energy, data were collected and modelled for all member states in Chapter 4. LTLF forecasting using Multiple Linear Regression method is applied in all member countries. Likewise, the energy was calculated and calculated for all member countries. The effects of the LTPF Model presets an acceptable degree of mean errors. Figure (6-9) presents the Market Price where both load demand curve and generation supply interact. This could be represented in the equation (6-16).

$$\sum Supply\ (\text{MW}) = \sum Demand\ (\text{MW}) \quad (6\text{-}16)$$

$$\therefore \sum Supply = \sum BAH + \sum KSA + \sum KUW + \sum QAT + \sum UAE + \sum OMN$$

Market Price at each region is at the value when generation quantities are equal to demand, as shown in equation (6-17) and illustrated in Figure (6-9)

$$Market\ Price = \frac{\sum Member\ State}{\sum_{r,rr}\left(C^{trans}_{r,rr}\right)} \quad (6\text{-}17)$$

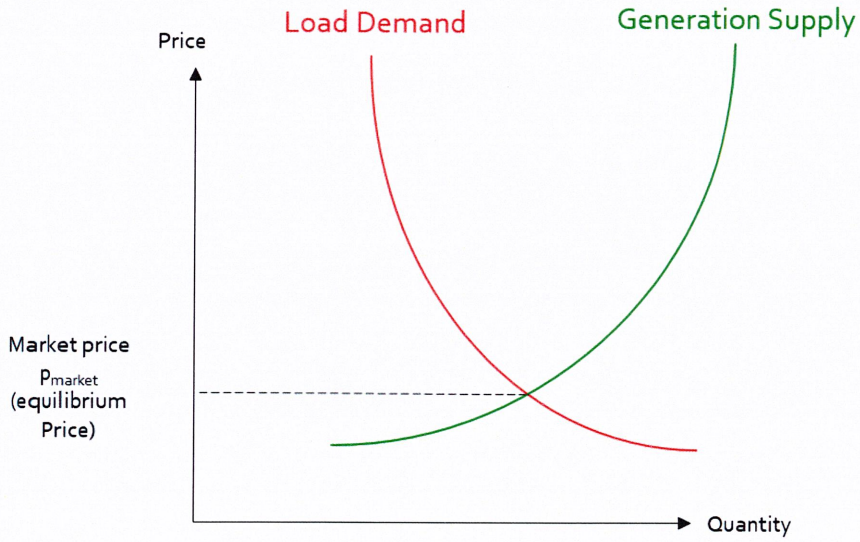


Figure (6-9) Equilibrium Market Price

3. Power System Inflexibilities

The model is standing on energy balance, where low numbers of generation technology, the net transfer capacity present and system losses are the inflexibilities available items in the organization. There is nothing to be done considering the available generation technology, where it is suggested to member nations to throw more diversity of generation technology in this regards.

Applying the equation (6-9) presents the inflexibilities in the third portion of the equivalence. Thus, the net transfer capacity was estimated.

$$\sum_{r,rr}\left(C^{\,trans}_{r,rr}\right)=\sum_{t,r,i}\left(\hat{x}^{\,inv}_{r,rr}\cdot \emptyset_{\,r,rr}\cdot C^{\,NTC}\right) \qquad (6\text{-}18)$$

where transmission costs are a function of additional interconnector capacity $\hat{x}^{\,inv}_{r,rr}$, distance between markets $\emptyset_{\,r,rr}$, specific annualized NTC investment costs per MW and km $C^{\,NTC}$.

It's agreed between member states that they will consider 2% transmission losses due to the distance between markets. Therefore, $\emptyset_{\,r,rr}$ is a fix number equal to 1.02.

4. Flexibility Options

The model has some of the major flexibility, which are:

- The NTC values are calculated from the interconnection control center, and no need to collect information from interconnected states.
- Units commit based on the value created over an operating period.
- Using a pre-forecast of prices, economic value is determined based on units' minimum uptime and minimum downtime.
- Iterates to a solution of consistent prices and resource operation
- Committed units run at minimum (or maximum) capacity depending on the value in each hour of operation.

5. Alternative Problem Formulation

The cost minimization can be formulated using AURORA that is the figure of the product from EPIS. KEMA Consulting (2003) depicts the software as follows:

It is a comprehensive, detailed Wholesale Price Forecast (Electricity Market Simulation) software system with strong doubt analysis ability. The general algorithm of this product summarized as follows:

- AURORA builds a resource stack for each country.
- The marginal unit is set up in each area given the native demand.
- Given transmission costs, losses and constraints, economic power flows are defined. This is answered by considering equivalent pipelines between areas rather than actual transmission lines.
- Small sets of the most economic flows are allowed to require home.
- The clearing price is found in each area given native load and imports and exports.
- Using genetic algorithm techniques, considers the likely benefits of moving power in markets; steps 3 through 5 are repeated until no significant benefits can be obtained by additional power flows on pipelines. This product specifically utilizes a unit commitment package in the market-modelling module.

6. Model Limitations/Shortcoming

Any model has limitations, some of these limitations as presented KEMA Consulting (2003) are as follows:

1- Transmissions are modeled in pipelines shape. That will represent the following:

a. Lack of detailed reliability and congestion assessment for internal to the area assessment situations.
b. It will prevent realistic satisfaction of requirements for bottleneck identification between states.
c. The real, physical modelling and analysis of actual transmission lines is required to product results expected by the evaluation.

2- The part of the whole organization to multi areas that might prevent realistic inter-area market simulation. The assessment tool needs to be flexible to consider any desired field or sub-area for the psychoanalysts. This can be a major area of enhancement if this merchandise is selected for the subject area. One means of defeating this problem could be to encourage this provider in partnering with a powerful flow provider. Deficiency of a power flow. This subsystem is required for determination of real time operation of generators, load current, imbalance prices and congestion management costs. It is also the subsystem that identifies the congestion. Not receiving an optimal power flow block the assessment of congestion and bottlenecks and also nodal price forecast.

7. Time Series Input Data

The data are used in the model collected from time series information from the organization and data presented in the published document from the member countries. The data compiled for every hour, and scalar data.

Each member states electricity demand is described using hourly data. The annual available historical information are used for the available time series.

The database structure in these areas is flexible enough to be subdivided or combined together. This product is capable of hourly chronological simulation for:

- Transmission constrained for dispatch at different zone
- Economically optimized commitment for unit at each hour
- Both fundamental or non-fundamental based pricing

System derives these constraints from the generation costing input information such as must-run units and minimum down time for production units.

8. Other Input Data

Fixed and variable generation costs are considered as supported data for building the model. Major input data into the model are fuel prices, variable operation and sustenance costs, and startup costs obtained from international fuel prices as reported in the present chapter.

The available generation data are taken. Short, medium, and long term frameworks are analytical concepts that never apply perfectly to a real world state of affairs. The short term is confined by the factor of time. The short term leads to plan any extension of the power plant is needed for the future to be tallied to the existing content.

The generation scaling method has been adopted for all previous studies so far, though the parameters were updated accordingly in each instance. The following standard parameters were used for the recently concluded in Tables (6-2) and (6-3), which represent also the investment payment schemes for new units.

The information gathered for the GDP and population in the region from the World Bank database, where the data used presented in Appendix A. The data amassed from the World Bank because it is a trust data for all member countries. World Bank headquarter in the GCC region is situated at Riyadh in the Kingdom of Saudi Arabia. More interaction done with World Bank through number of conferences where we invite Dr. Maria from World Bank to participate with speech in the Fourth Power Trading Forum held at Abu Dhabi and organized by GCCIA on 17 December 2015.

Table (6-2) Generic Data for New and Existing Units Specification

	ST-FO	GT-DO/NG	CC-NG
Typical size [MW]	600	57	632
Investment cost [USD/kW]	2133	1485	1733
Net Heat Rate [MJ/KWh]	9.93	12.34	6.28
Life Time [y]	35	25	30
FOR [%]	6	9	8
Planned unavailability [weeks/y]	6	4	6
Variable O&M cost [USD/MWh]	1.64	4.4	2.72
Fixed O&M cost [USD/kW y]	11.2	12	10
Loading Gradient [MW/min]	4	10	5
Technical minimum [%]	50	33	50

Table (6-3)
Generic Data for New and Existing Units of Year Commissioning

Type	Year of commissioning			
	-3	-2	-1	0
CC	0%	35%	40%	25%
ST	9%	32%	32%	27%
GT	0%	35%	35%	30%

The reliability data and analysis were described in section (6.6.1) shows the reliability index for the interconnected region.

9. Exogenous vs. Endogenous Capital Stock

The GCC Interconnection Authority (GCCIA) is a joint stock company subscribed by the six (6) Gulf States, whose Articles of Association and Bylaws were approved by Royal Decree No. M/21 on July 29, 2001. Their joint stock shares are owned by the governments creates these entities. Each governments has its own assets and shares in the governments. They have their own policies in regard existing generation and transmission infrastructure. The details in this perspective looks like a black box and not described publicly, where each member state has its own policies within their jurisdiction.

10.Modelling Balancing Costs

For balancing the costs, the Power Energy Trading Agreement parties agree to make the balancing of cost through GCCIA. GCCIA should balance any costs between PETA Parties and send the invoices in this regards. The Governments in the GCC countries have also a General Agreement, which described the role and responsibilities of reach party. PETA described the model of balancing the energy and cost.

There are also two committees were formed to follow, check and modify the modelling and the balancing cost procedures. Operations committee releases its first version of Billing and Invoice Procedure in 2013, which describes the detailed steps in balancing the costs.

c) Assessing Electricity Market Integration

The Gulf Countries Council members' electrical networks were connected through a 400 kV backbone that span from south of Kuwait till the north of Abu Dhabi. Built for the principal role of emergency support, the project spanned to create a raw source of industry in the region, which is power trading between the member states through the interconnector. This new industry is nevertheless in its path towards adoption and due date.

AURORAxmp produces both short-term and long-term price forecasts for all major market zones. It simulates supply and demand on an hourly basis to provide electricity price forecasts. It aids in counting both on-peak and of for peak pricing of the interconnection system.

Creating an electrical market is part of the process of maturation in this industry in the GCC area. Optimization of the grid capacity has not touched unless a market created. Obstacles and challenges were accepted into consideration to make the power trading between member countries.

Through proper observations of power trading activities that has taken place in 2010 and 2011 between member states using the GCC Interconnector, the courses and circumstances would be reviewed against the typical and standard power trading practices from around the world. The NTC of interconnection before expanding the network is tabulated in Table (6-4).

Table (6-4) NTC Capacity Margin values for the Interconnection Before expanding the network

From	To					Max Export
	Kuwait	KSA	Bahrain	Qatar	UAE	
Kuwait	-	358	358	358	358	358
KSA	317	-	405	419	850	850
Bahrain	317	519	-	419	519	519
Qatar	317	572	405	-	572	572
UAE	317	772	405	419	-	1,007
Max Import	317	850	405	419	1,326	-

Figure (6-10) shows the results of the self-sufficiency scenario for member states. There is no power exchanges recorded between MS's since 2012 as presented in Figure (3-26). It is clear from Figure (6-10) which illustrates the peak load demands for all GCC countries; Bahrain has the lowest peak load size. The longest peak load belongs to Saudi Arabia. Oman's peak load size is larger than Bahrain and UAE's peak load size is larger than Oman but lower than Kuwait. In this self-sufficiency scenario, it is assumed that all member states have steady growth.

Networks Scenarios considers imports and exports

The security Including Networks scenario considers imports and exports to calculate the capacity margin are presented in the Table (6-5). It present the expansion in network capacity that contributes to security of supply.

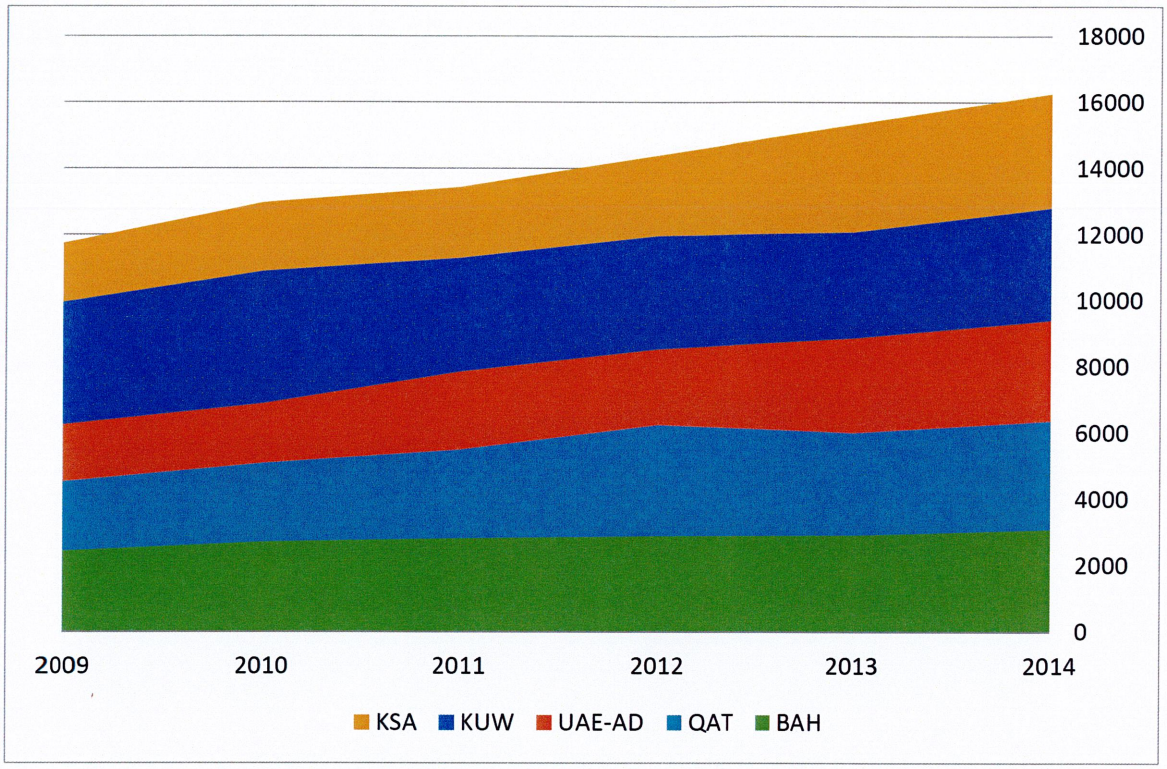


Figure (6-10) Self-sufficient Peak Load Demand in GCC (MW)

The expansion in the network was due to export, import for casted besides the security and reliability reasons, but since large incident recorded in the interconnected system more energy demand from the interconnection to secure the member states requirement during the incidents. The Net Transfer Capacity NTC of the interconnection after expanding the network during 2014 and 2015 tabulated in Table (6-5). The NTC values were presented in Table (6-5) are higher than the NTC values found in Table (6-4) because the UAE, Qatar and Kuwait connection were upgraded to curry more energy. The amount of power could be transfer were increases between member states after network upgrade.

Table (6-5) NTC Capacity Margin Values for the Interconnection After Expanding Network

From	To					Max Export
	Kuwait	KSA	Bahrain	Qatar	UAE	
Kuwait	-	1,235	998	1,235	1,235	1,235
KSA	1,235	-	998	1,280	1,280	1,320
Bahrain	998	998	-	998	998	998
Qatar	1,200	1,200	998	-	1,200	1,200
UAE	1,200	1,200	998	1,240	-	1,240
Max Import	1,235	1,320	998	1,280	1,960	-

Import and Export Opportunities Scenario

Savings in avoided transmission construction within countries achieved by reducing the amount of generation capacity required in each of GCC countries. Figure (6-11) shows the Import and Export opportunities scenario using the network capacity of the interconnection constraints. Figure (6-11) presents three years forecasted imports and exports opportunity scenario outputs. More explanation and analyses will be presented in section 6.4 with example.

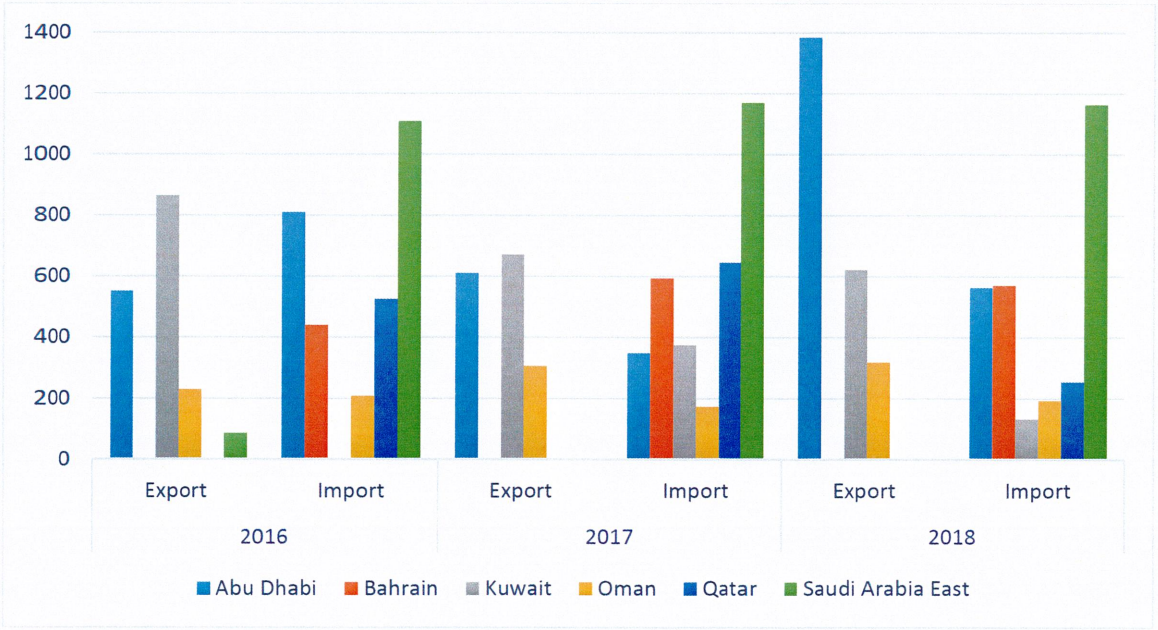


Figure (6-11) Import and Export Opportunities scenario outputs (MW)

Free Market Scenario

In case of developing the market and free Market comes in place, the network expanding may take place according to both economics and security of supply reasons presented early. Figure (6-12) shows the amount of money that member state can gain it through the saving captured from trading in the capacity during the free market system. The outcome from the free market scenario shows an opportunity of availability of high saving gained, by taken in consideration according to electricity trading imports and exports.

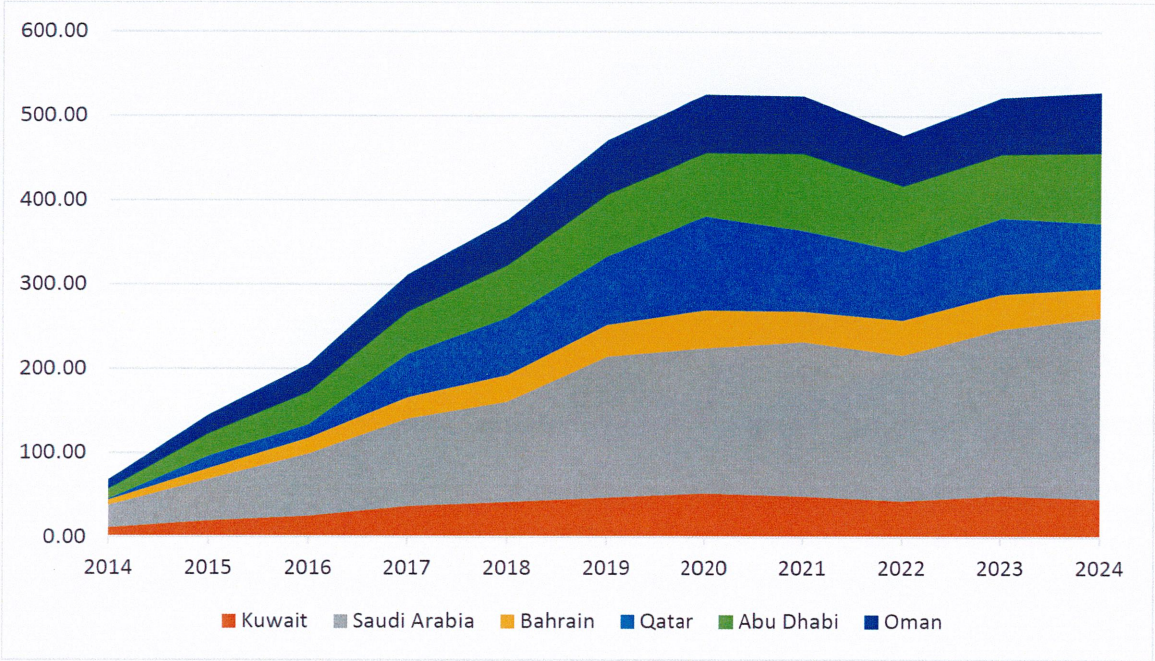


Figure (6-12) Monetary Savings in Capacity Free Market (US$ million)

6.3.3 Average Generation Cost for CCGT's and OCGT's in GCC

In regard calculating average generation cost for CCGT's and OCGT's in GCC, the assumptions on costs and various technical characteristics to avoid the inconsistencies between the size of OCGT and steam units within CCGT plants for the new entrant CCGT and GTs based on the following method:

- The average capacity of the gas turbine component is used in existing CCGT plants (196.3 MW), based on data collected from GCC Member States.
- Calculate the ratio of steam turbine to gas turbine capacity implied by the assumed heat rates for new entrant CCGT and OCGT's, assuming each CCGT is comprised of two gas turbines and one steam turbine;
- Finally, we multiplied the above ratio by the average gas turbine capacity and added this to our OCGT unit size assumptions, to give an estimate of the unit size of a CCGT.

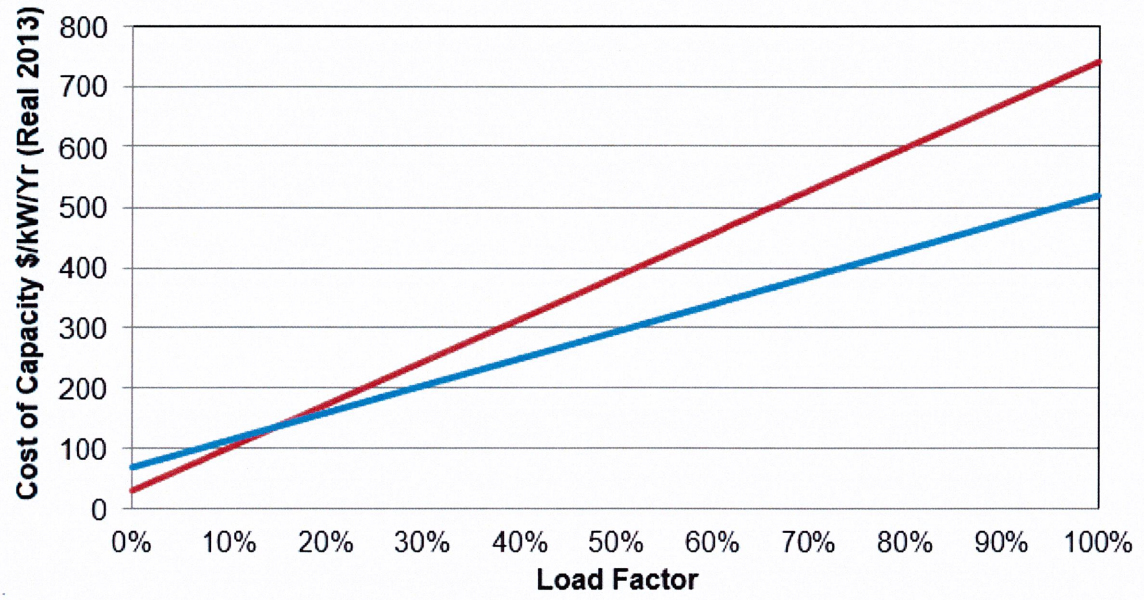
The data for both CCGT and OCGT's is as illustrated in Table (6-6a) and Table (6-6b), respectively. The generation cost calculated from these tables is illustrated in below depicts the screening curves for our new entrant CCGT and OCGT plants and presented in Figure (6-13). It shows that the CCGT cost dropped after operating the generators more that 20% of its load factor. OCGT machines are more expensive in operation except if the load factor very low.

Table (6-6a) Generation Cost for CCGT Assumptions, Vakhtang et al (2014)

	Qatar	Bahrain	Oman H-Class	Oman F-Class	Abu Dhabi	KSA	Average Ass.
Size (MW)	2700*	630	555.7	438	800	199	887
Investment Cost (USD/kW)	969.2	900.0	708.7	743.3	950.0	632.5	817
HHV Net Heat Rate (Btu/kWh)	-	7,300	6,300	6,439	7,331	6,385	6751
Life Time (Years)	25	25	30	30	30	25	27.5
FOR (%)	-	4	3	3	3	-	3.25
Planned Outages (Weeks/year)	0.2	2.0	2.1	2.1	1.8	-	1.64
Variable O&M Cost (USD/kWh)	0.00314	0.00160	0.00200	0.00200	0.00330	-	0.0024
Fixed O&M Cost (USD/kW)	2.5	11.0	15.7	15.7	10 – 13	-	11.38
Mean Time to Repair (Hours)	-	-	72	72	72	-	72

Table (6-6b) New Entrant OCGT Assumptions, Vakhtang et al (2014)

	Bahrain	Oman	Abu Dhabi	KSA	Average Ass.
Size (MW)	200.0	280.6	660.0	155.0	248.6
Investment Cost (USD/kW)	700.0	548.5	680.0	892.0	503.6
Net Heat Rate (Btu/kWh)	10,417	9,450	10,600	10,275	10,430
Life Time (Years)	25.0	25.0	25.0	25.0	25
FOR (%)	7	3	3	-	4.3
Planned Outages (Weeks/year)	1.0	2.1	1.3	-	1.5
Variable O&M cost (USD/kWh)	0.00160	0.00240	0.01300	-	0.00157
Fixed O&M Cost (USD/kW)	14.0	16.0	4.5 – 5.5	-	12
Mean Time to Repair (Hours)	-	48	72	-	60



Vakhtang et al (2014)

Figure (6-13) New Entrant OCGT and CCGT Screening Curves

The Fuel prices applied to simulations in 2015 to calculate the production cost price for the interconnected countries estimated based on value of gas in exporting countries presented in Figure (6-14). The results of the international benchmarks fuel prices approach presented in Table (6-7). This approach is used because there is no fuel price index for the region. The differences in the fuel cost between GCC countries are due to the distance and logistics affecting the price by the difference of transportation as presented by Vakhtang et al (2014).

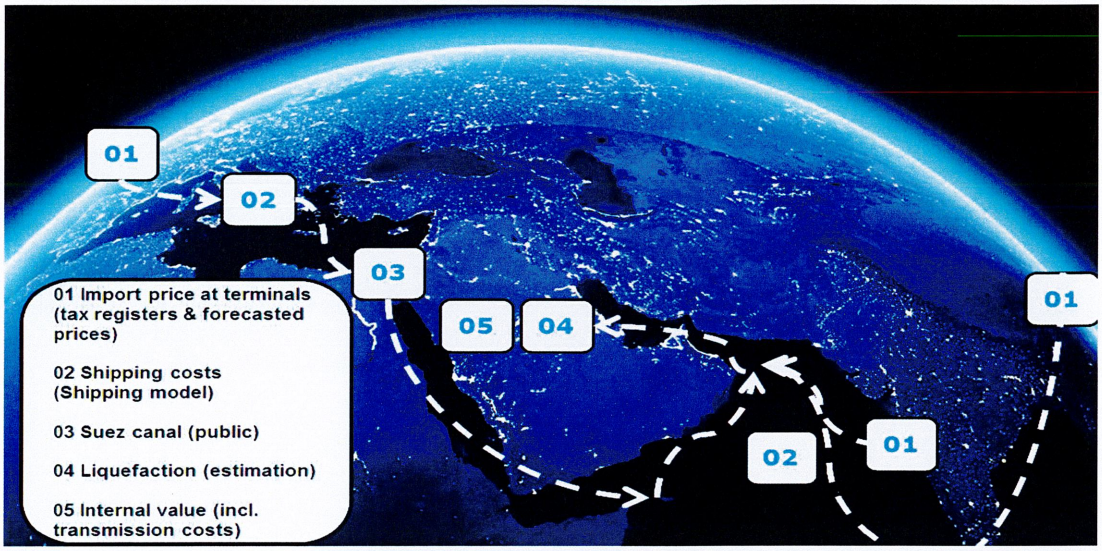


Figure (6-14) Methodology Approached to Identify the Fuel Price Regional, Vakhtang et al (2014)

Table (6-7) Fuel Prices for GCC Region in year 2015, Vakhtang et al (2014)

Fuel Prices	NG	HFO	LFO	LCO	DS
	USD/Mbtu	USD/kg	USD/kg	USD/kg	USD/kg
Bahrain	12.36	0.43	0.51	0.60	0.86
Kuwait	12.52	0.43	0.51	0.60	0.86
Oman	9.22	0.43	0.51	0.60	0.86
Qatar	9.22	0.43	0.51	0.60	0.86
Saudi Arabia	9.22	0.43	0.48	0.50	0.89
UAE Abu Dhabi	10.13	0.43	0.51	0.60	0.86

6.3.4 Base and Peak Load Generation Cost in GCC

In this section, the steps taken to calculate the generation unit price with taken in consideration more variables like the Heat Rate and unit type used are presented. The heat-rate is not a fixed number from a single machine in all-operating range of the machine. Its operating point value during the base load is at minimum. In another term, the machine has the most efficient point at base load operating point as appears in Stoft (2002). The unit type, which represent the design and technology used, to generate an energy for different types presented in section (6.1).

The size of the intermittent type of generation in GCC countries is negligible. REN21/ISEP (2013) observe that the GCC countries targets for their RES integration. Bahrain target is 5% by 2020, Kuwait targets are 1% electricity generation by 2015, where they are looking for 10% integration by 2020, and 15% integration by 2030. Oman target is 10% of electricity generation by 2020. Saudi Arabia targets are 50% of electricity from non-hydrocarbon resources by 2032, where 54GW from renewable (of which: 41GW from PV and CSP, 9GW wind, 3GW waste-to-energy, 1GW geothermal), and 17.6GW from nuclear. UAE targets found in both Dubai and Abu Dhabi. Dubai target is 15% of electricity by 2030, where Abu Dhabi target is 7% of electricity generation capacity by 2020.

A full calculation model and results to compute the generation cost of a generator is as illustrated in both Table (6-8) and Table (6-9). The systematic calculation that classified into 22 steps placed in self-explanatory way to give the reader easier way to understand the method used to calculate the generation cost for electricity units.

The calculation for the Nominal Levelized Fixed Cost for Generated Unit, which called the Cost of New Enter (CONE) for unit generation, presented in Table (6-8). The results generated for two values of gas fired fuel cost. The CONE value not affected by the fuel price if the other parameter kept same.

Unit Generation Cost of the same unit used presented in Table (6-9). The unit generation cost affected directly by the fuel price of the market. Therefore, it is important to take in consideration the fuel price in operating the machine.

Table (6-8) Nominal Levelized Fixed Cost for Generated Unit, Vakhtang et al (2014)

Unit Assumptions	Peak Period	Baseload	Peak Period	Baseload	Remarks
(1) Size (MW), Make and Model	230	345	230	345	
(2) Turn-key construction costs ($/kW)	$1,000	$1,200	$1,000	$1,200	Including, for example, site procurement, engineering, procurement and construction, finance and legal costs, transmission interconnection costs, owner engineering, project mobilization, spares costs, mobilization and contingency costs
(3) Fixed annual O&M ($/kW)	$10	$20	$10	$20	Including, for example, O&M salary and benefit costs, transmission charges, etc.
(4) Annual Administrative & General Expenses ($/kW)	$5	$5	$5	$5	Including, for example, insurance, administrative overhead, etc.
(5) Expected service life (years)	30	30	30	30	It should be as per contract with the IPP or the company going to construct the generation unit
(6) Annual Estimated hours of operation	3,000	6,000	3,000	6,000	
(7) Net Heat Rate (BTU/kWh)	10,500	7,000	10,500	7,000	Net Heat Rate level for the peak and base load periods as measured by electricity output metered at station gate.
(8) Fuel Type and current cost of primary fuel for unit ($/mmBTU)	$5.00000	$5.00000	$12.00000	$12.00000	Natural Gas cost using US Dollar per mmBTU.
(9) Fuel cost ($/kWh)	$0.05250	$0.03500	$0.12600	$0.08400	Fuel Cost per unit = Heat Rate x Fuel type
(10) Non-fuel variable O&M ($/kWh)	$0.00200	$0.00200	$0.00200	$0.00200	Fix cost operation and maintenance per unit
(11) Nominal Levelized Fixed Cost of Typical generator	119.51	152.23	119.51	152.23	

Table (6-9) Unit Generation Cost for the given case

Unit Assumptions	Peak Period	Baseload	Peak Period	Baseload	Remarks
(11) Nominal Levelized Fixed Cost of Typical Highest-Cost Unit in Period	119.51	152.23	119.51	152.23	
(12) Unit's Expected Annual Hours of Operation	3,000	6,000	3,000	6,000	
(13) Annual Fixed Cost per kWh	$0.03980	$0.02540	$0.03980	$0.02540	
(14) Unit's Fuel Cost per kWh	$0.05250	$0.03500	$0.12600	$0.08400	
(15) Unit's Variable O&M cost per kWh	$0.00200	$0.00200	$0.00200	$0.00200	
(16) Cash Working Capital Requirement per kWh	$0.00463	$0.00315	$0.01088	$0.00731	
(17) Revenue Requirement for Cash Working Capital	$0.00047	$0.00032	$0.00110	$0.00074	The model used is cost plus method for this type of contract.
(18) Total Variable Cost per kWh	$0.05960	$0.04046	$0.13998	$0.09405	
(19) Total Fixed and Variable Cost per kWh	$0.09940	$0.06586	$0.17978	$0.11945	
(20) Total Fixed Cost per MWh	$39.80	$25.40000	$39.80000	$25.40000	
(21) Total Variable Cost per MWh	$59.60	$40.46170	$139.97562	$94.04612	
(22) Total Fixed and Variable Cost per MWh	$99.40	$65.86	$179.78	$119.45	

6.4 Results of Production Cost Calculation for the GCC

In regard of calculating the production cost calculation for the unit generation used in the GCC countries, the PROMO and AURORA xmp v12.0 software Sanya (2011) used to deal with high amount of data used for each generator in all member state units. The methodology used is similar to the methodology used in section (6.3.2). From the given methodology the validation for the used model to find the production cost price for the machines in the six interconnected countries are as shown in Figures (6-15) to (6-28).

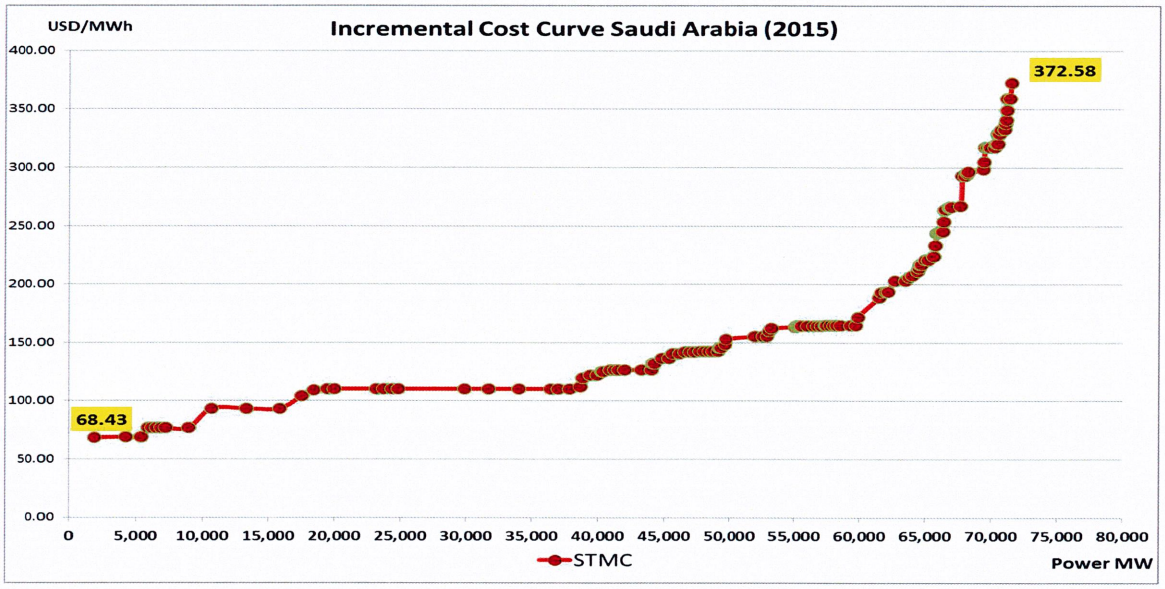


Figure (6-15) Incremental Cost Curve Saudi Arabia Using International Fuel Price

The fuel prices, used for calculating the energy production cost are the international fuel price and uniform fuel prices. These results represent the supply cost of the product or commodity in the regional electricity market. The results presented for all member states and for all member states. Saudi Arabia production cost in 2015 for Generation System has a Maximum Capacity of 67,612 MW, Minimum operational cost equal to $68per MWh and maximum operational cost equal to $373per MWh using international fuel prices is as presented in Figure (6-15). The results of production cost using uniform fuel

prices, which presented in Figure (6-15), is lower than that of the international fuel prices. This presents clearly amount of subsidies in fuel prices at the eastern side of KSA. Most of generation unit prices in the eastern region of KSA is less than $90 per MWh. The most expensive machine reaches to $150 per MWh.

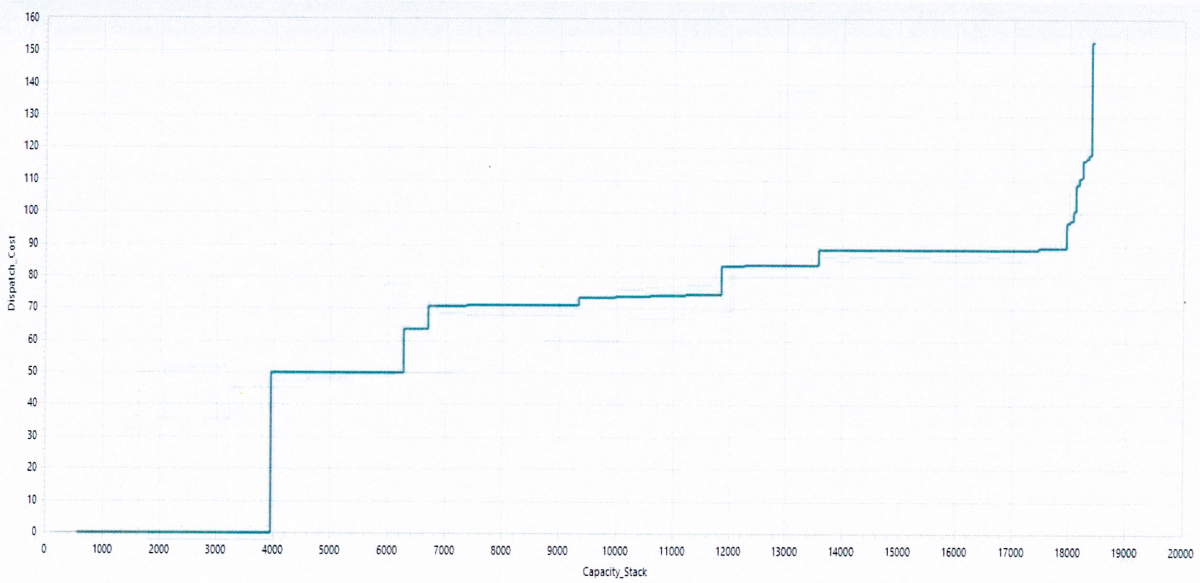


Figure (6-16) Incremental Cost Curve Saudi Arabia using uniform fuel price

Kuwait production Cost in 2015 for Generation System with maximum capacity equal to 19,729 MW, minimum operational cost equal to$50 and $95.89 per MWh, and maximum operational cost equal to $140 and $281per MWh for contract and international fuel price, respectively. The results illustrated in Figure (6-17) and Figure (6-18).

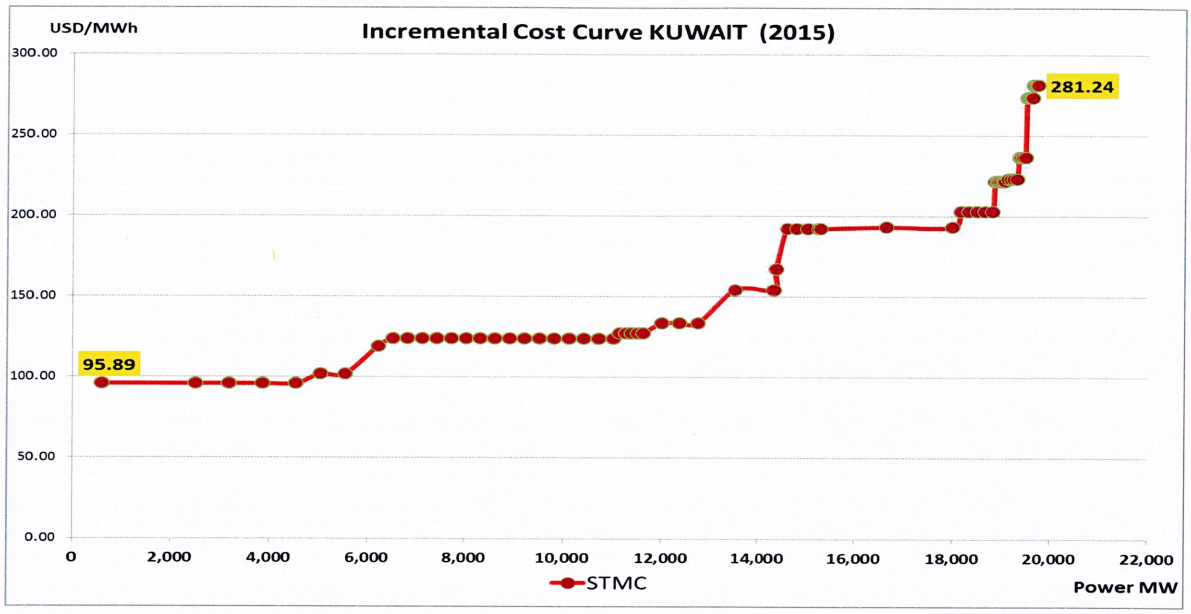


Figure (6-17) Incremental Cost Curve for Kuwait using international fuel price

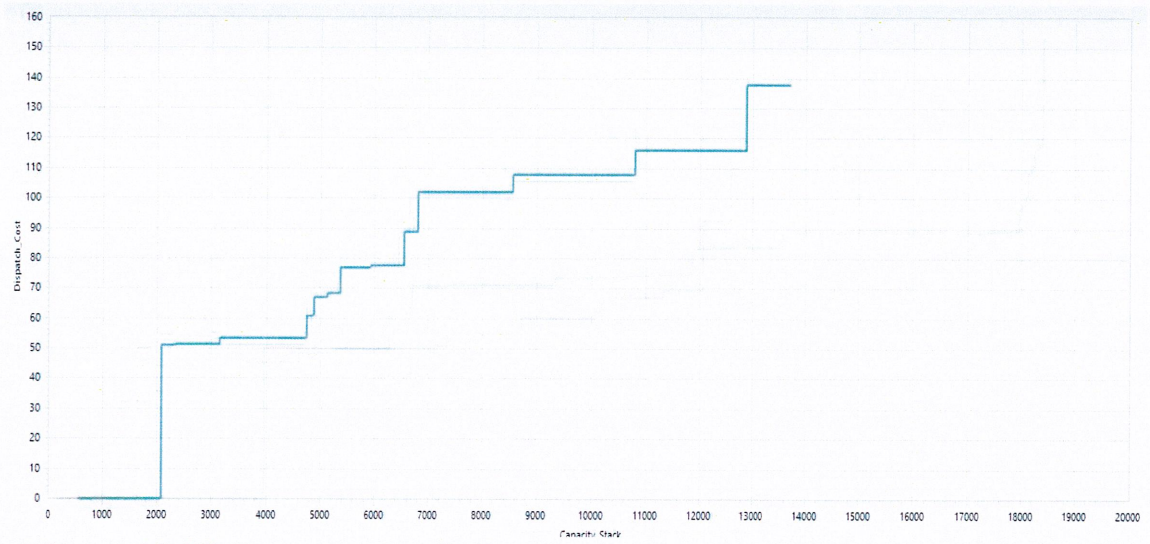


Figure (6-18) Incremental Cost Curve for Kuwait using uniform fuel price

Bahrain Generation System, which has maximum capacity 6,316 MW, minimum operational cost $50 and $82.51 per MWh, and Maximum operational cost equal to $114 and $179 per MWh for uniform and international fuel prices, respectively. The results illustrated in Figure (6-19) and Figure (6-20).

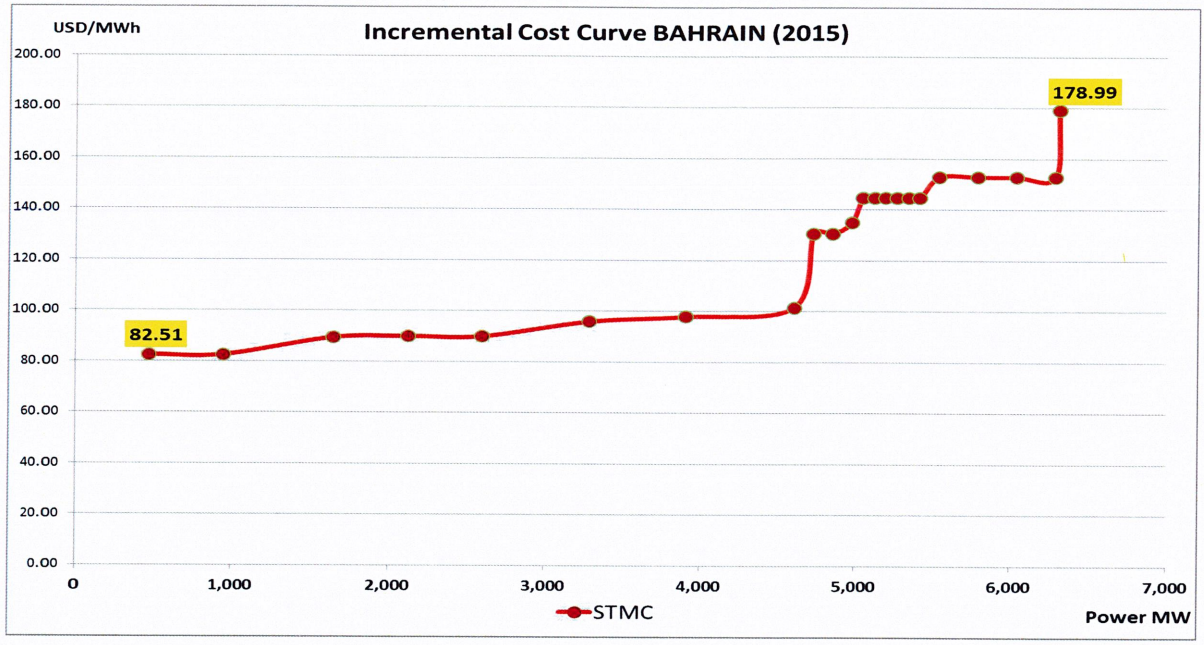


Figure (6-19) Incremental Cost Curve for Bahrain using international fuel price

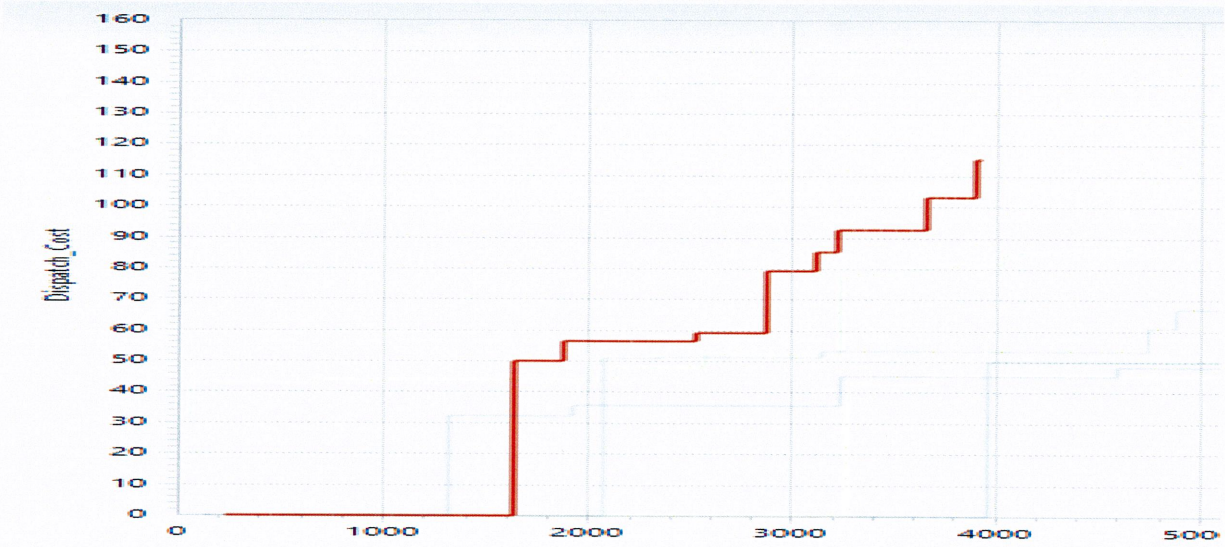


Figure (6-20) Incremental Cost Curve for Bahrain using uniform fuel price

Qatar Generation System, which has a maximum capacity of 7,100 MW, minimum operational cost $42 and $66per MWh, and maximum operational, cost $89 and $110.85 per MWh for the uniform and international fuel prices. The results presented in Figure (6-21) and Figure (6-22).

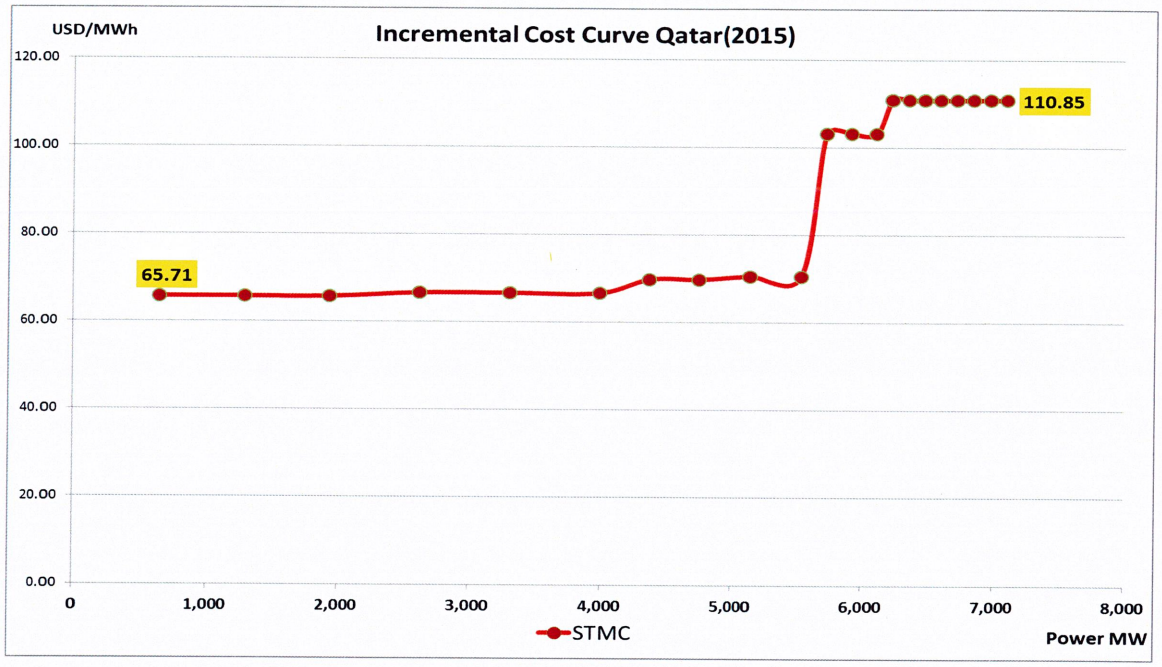


Figure (6-21) Incremental Cost Curve for Qatar using international fuel price

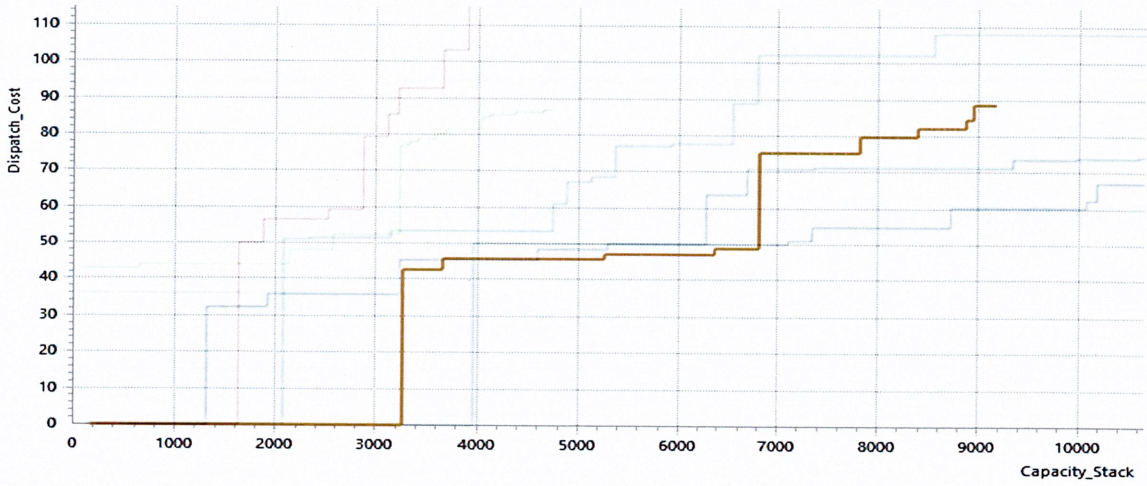


Figure (6-22) Incremental Cost Curve for Qatar using uniform fuel price

UAE Abu Dhabi Generation System, which has maximum capacity 25,080 MW, minimum operational cost $33 and $74 per MWh, and Maximum operational cost $88 and $124.5 per MWh for the uniform and international fuel prices, respectively. The results presented in Figure (6-23) and Figure (6-24).

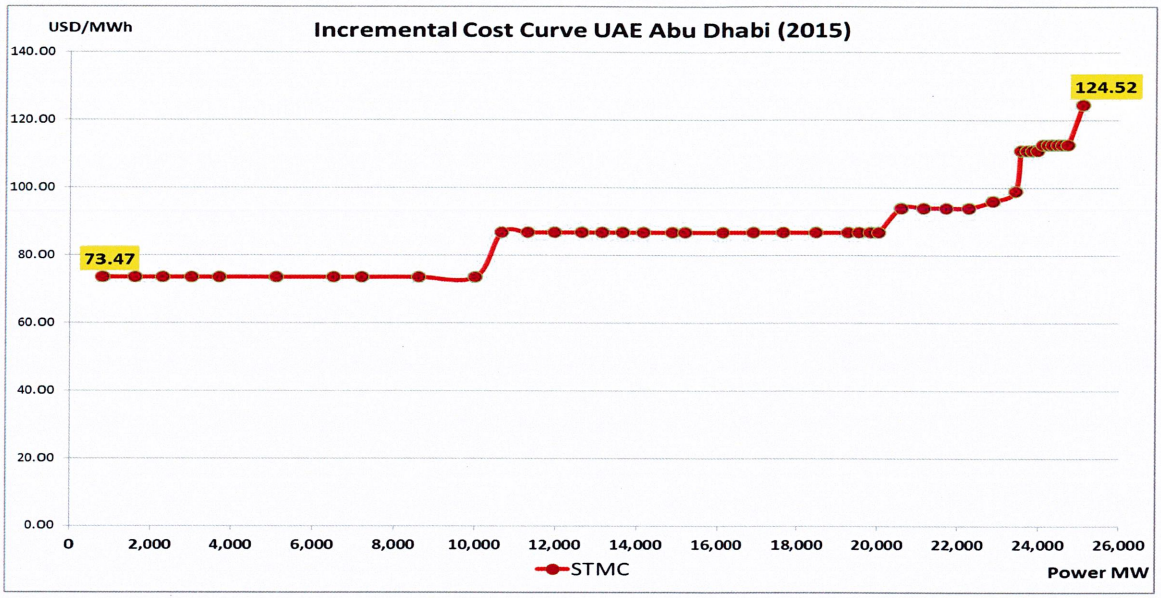


Figure (6-23) Incremental Cost Curve for UAE using international fuel price

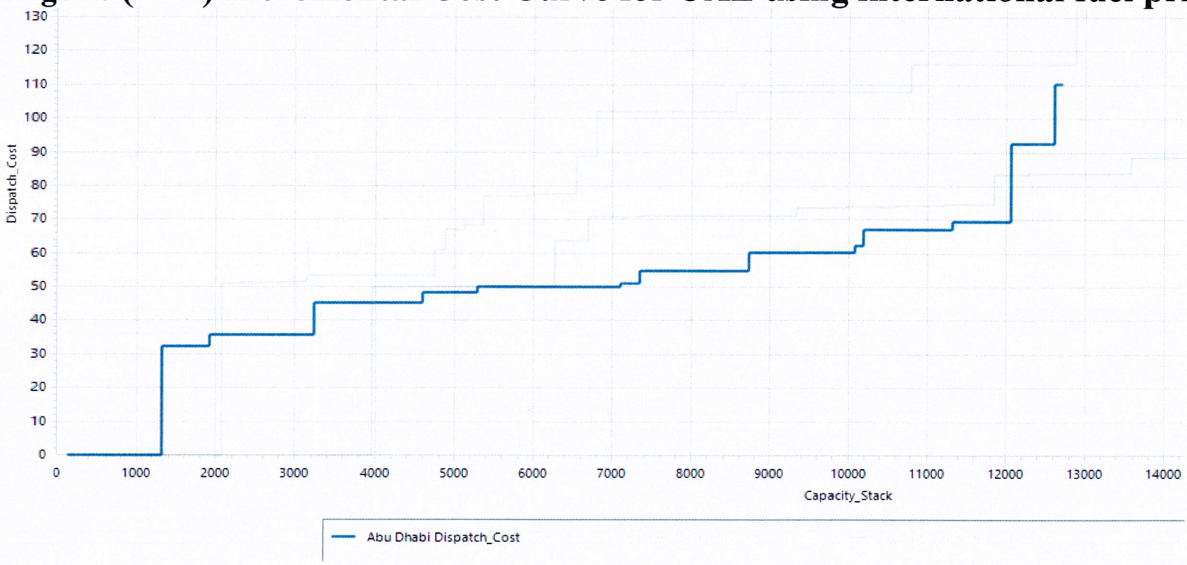


Figure (6-24) Incremental Cost Curve for UAE using uniform fuel price

Oman Generation System, which has a maximum capacity 8,657 MW, minimum operational cost $32 and $39 per MWh, and Maximum operational, cost $88 and $115 per MWh for the uniform and international fuel prices. The results presented in Figure (6-25) and Figure (6-26).

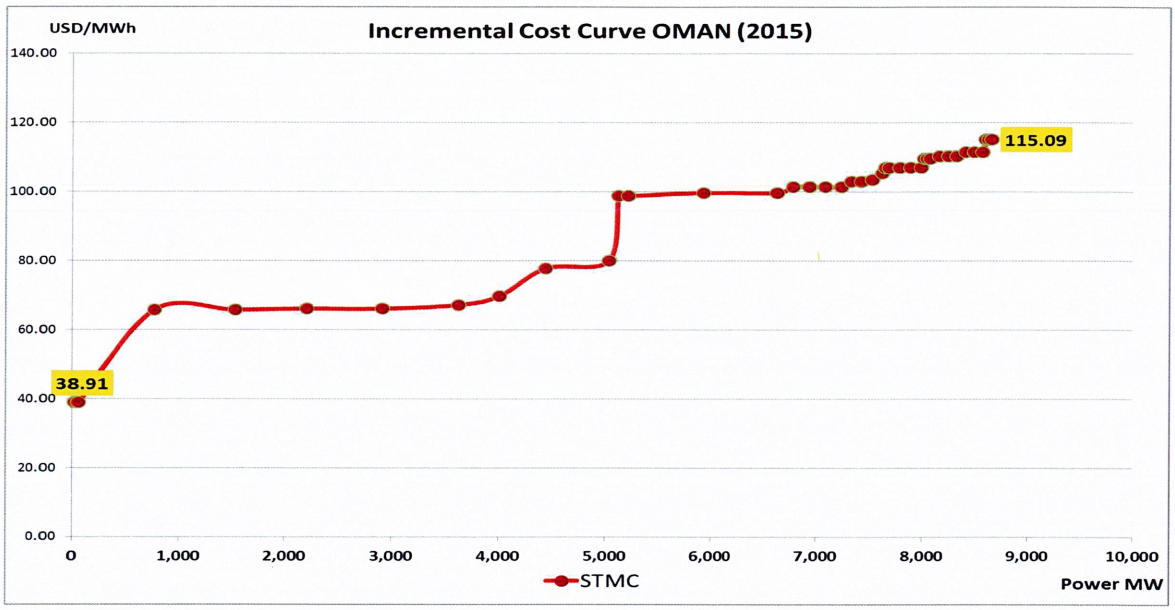


Figure (6-25) Incremental Cost Curve for Oman using international fuel price

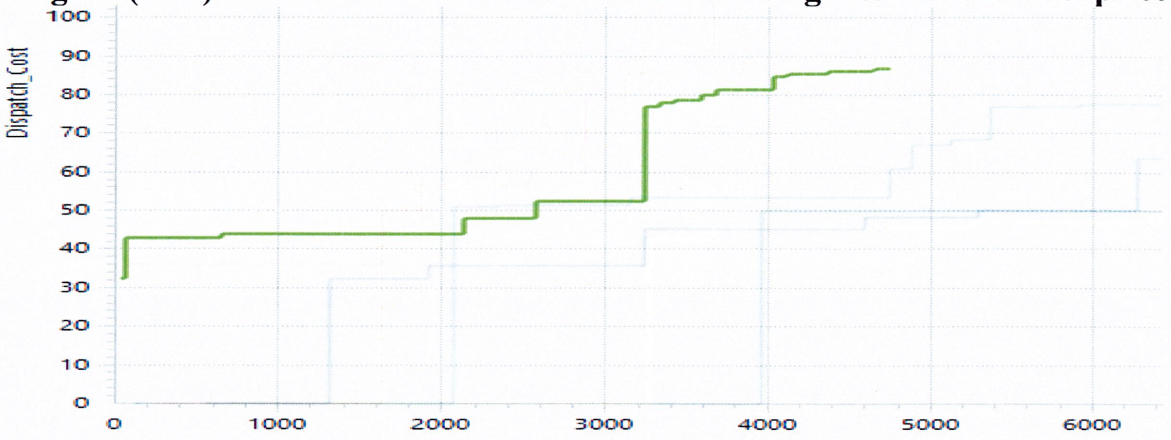


Figure (6-26) Incremental Cost Curve for Oman using uniform fuel prices

The GCCIA Countries production cost with maximum capacity of 138,350 MW presented in Figure (6-27) and Figure (6-28). The range of production cost varied from member states to another. An example showing how trading scenario take place between GCC countries from the available data are presented in Figure (6-29) to Figure (6-34), which covers peak and off peak periods. The incremental cost curves used in Figure (6-28) implemented for this example. The results attained from the software AURORA are presented in Figures (6-29) to (6-34). Figures (6-29) and (6-30) present the MS's daily generation cost during the winter and summer periods. The variation in

demand lead to a variation in unit cost prices. One MS can imports the energy from the MS that has lower energy prices.

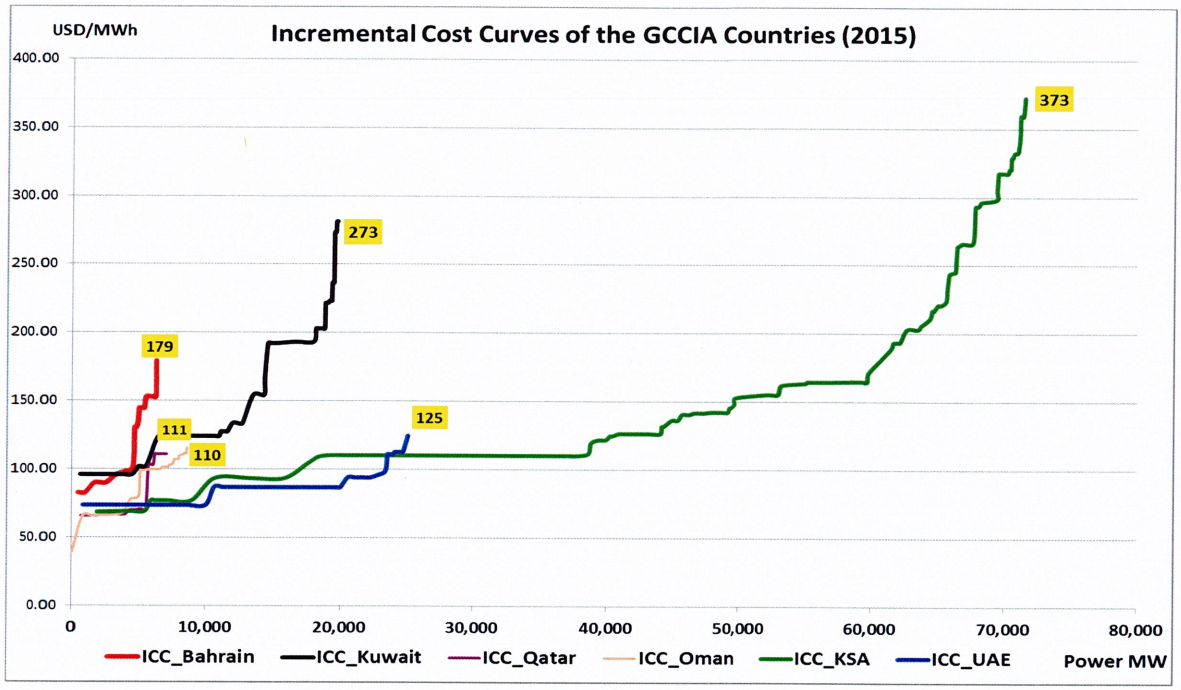


Figure (6-27) Incremental Cost Curves of the GCCIA Countries using international fuel price

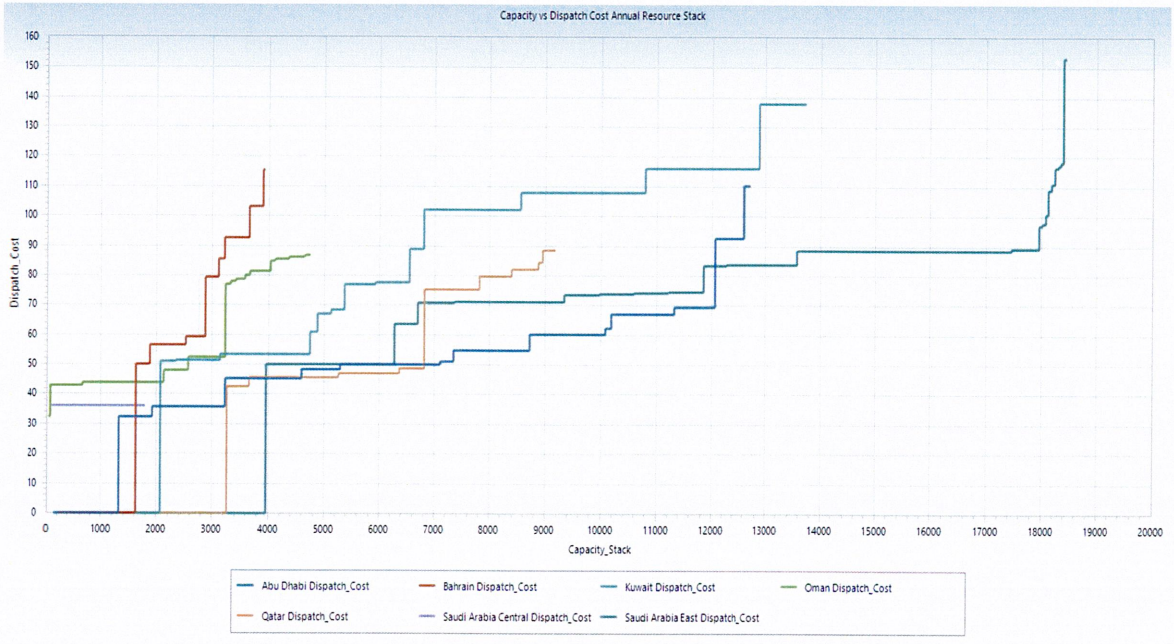


Figure (6-28) Incremental Cost Curves of the GCCIA Countries (2015) using uniform fuel prices

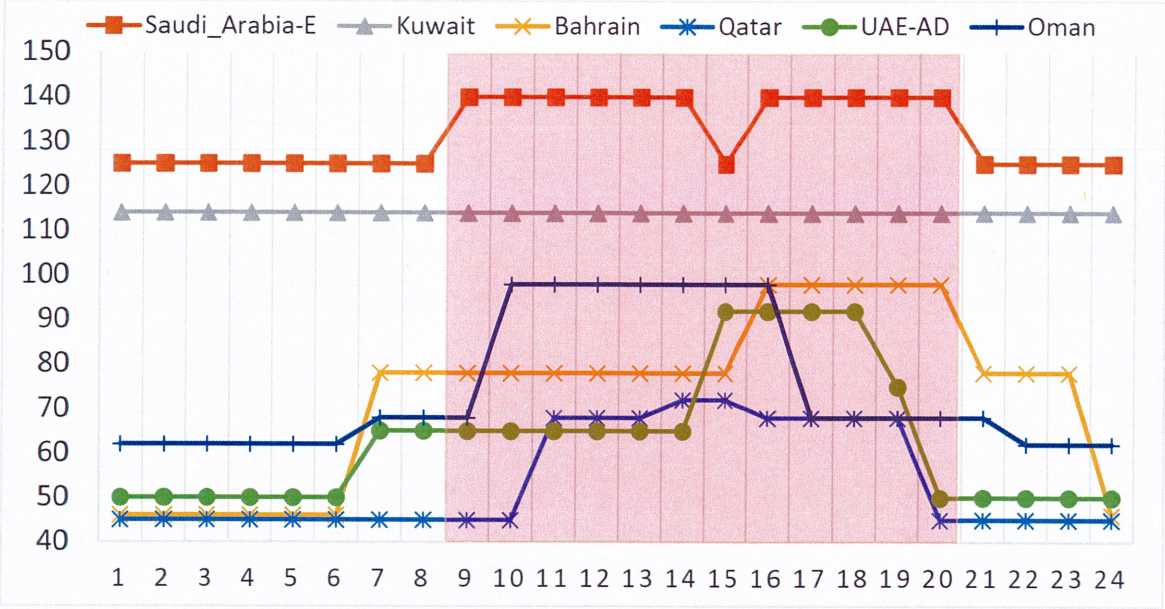


Figure (6-29) Trading opportunities During Winter

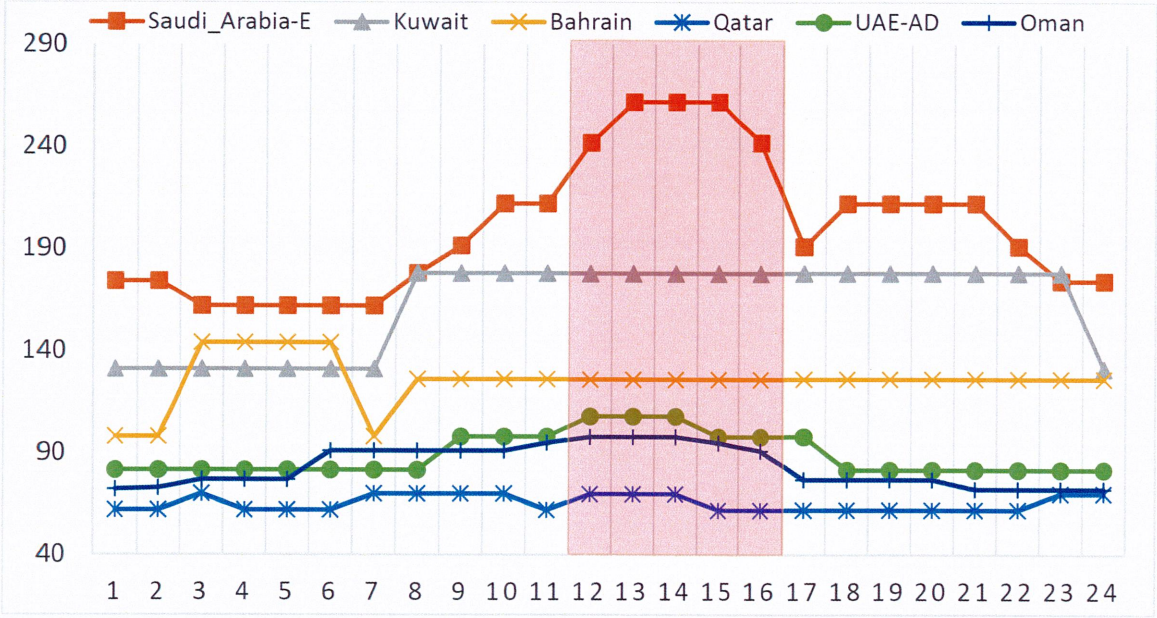


Figure (6-30) Trading opportunities During Summer

Among these Figures (6-31) to (6-34) show snapshots of trading examples. The energy flow from lower cost member states such as Bahrain and Qatar to the higher costs states such as Kuwait and UAE as shown in Figure (6-31). Similarly, Figure (6-32) illustrates the flow of the electricity from Kuwait, Bahrain and Qatar to KSA and UAE.

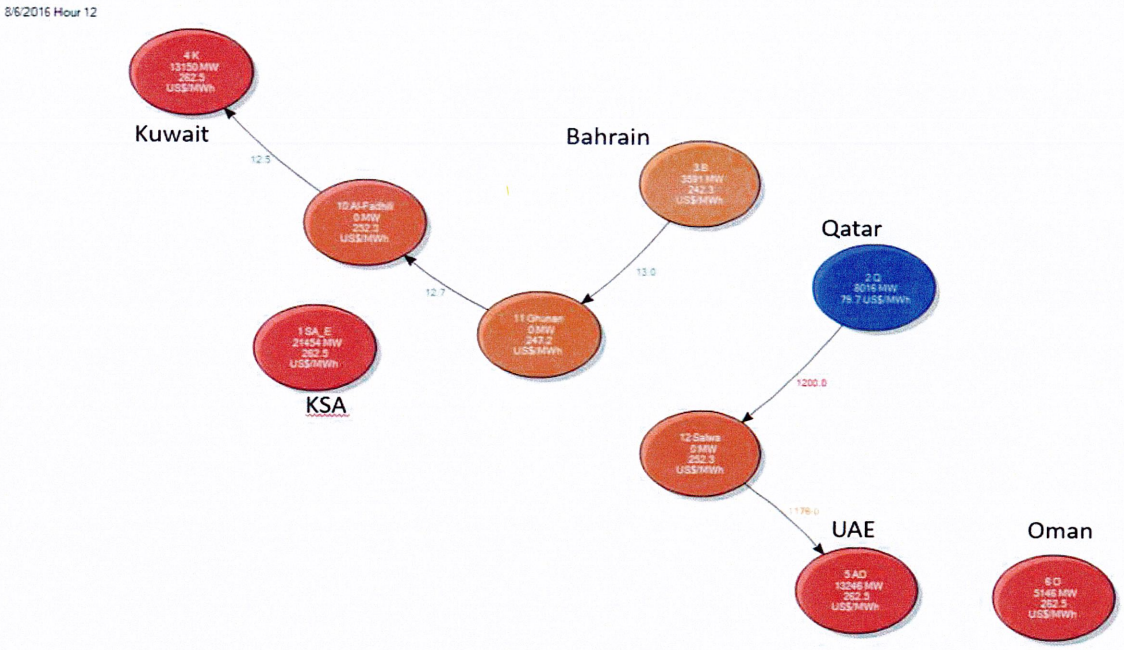


Figure (6-31) Trading Example at Summer Peak 6 Aug. 2016 12:00hrs

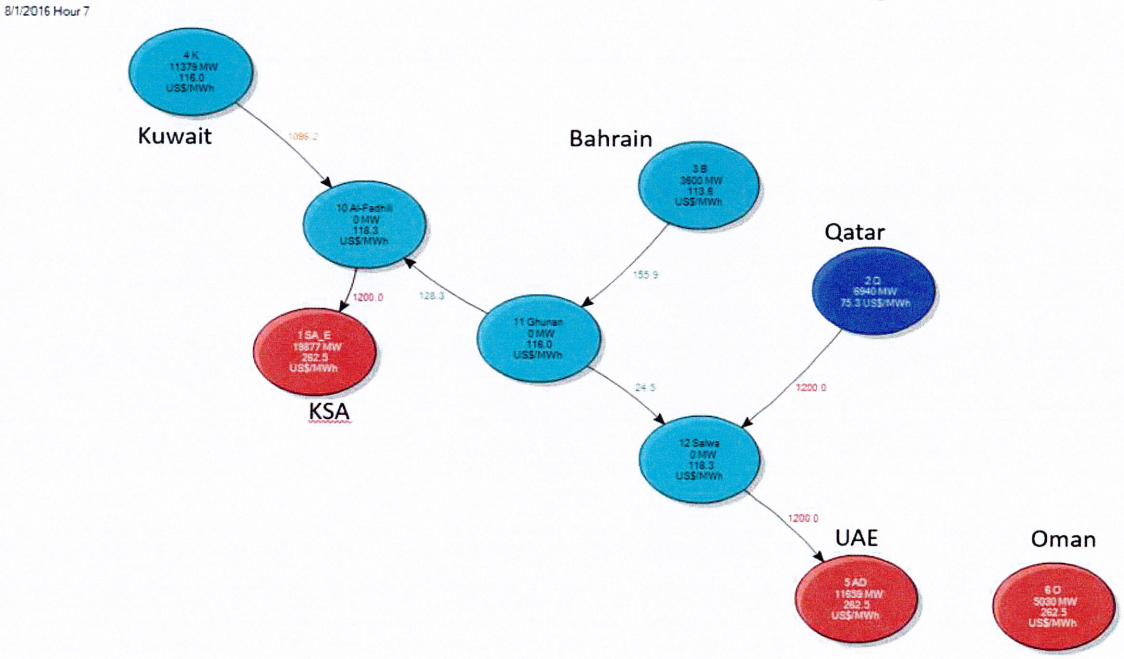


Figure (6-32) Trading Example at summer off Peak at 3 Aug 2016, 7:00hrs

Another trading examples are presented in figures (6-33) and (6-34) for the cases of winter peak demand and off peak demand. It is noticed that the energy flow is self-sufficient during these periods from lower to the higher cost regions, which are KSA and UAE. This represents the normal behavior of the

power trade markets, which usually purchase the electricity from lower price zone and sell it to the higher price zone.

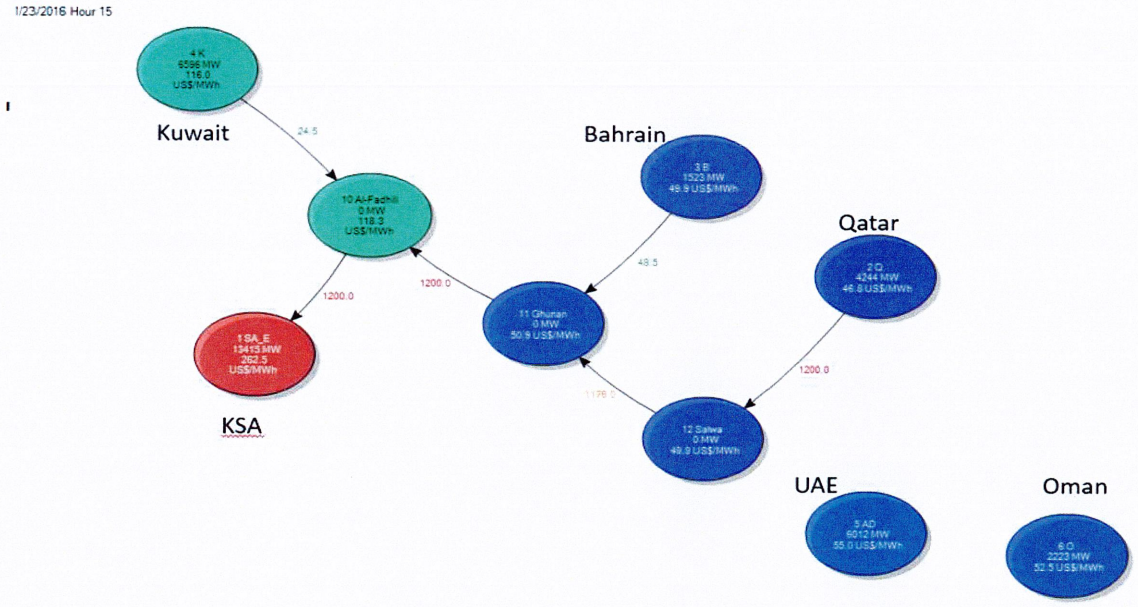


Figure (6-33) Trading Example at winter Peak 23 Jan 2016 15:00hrs

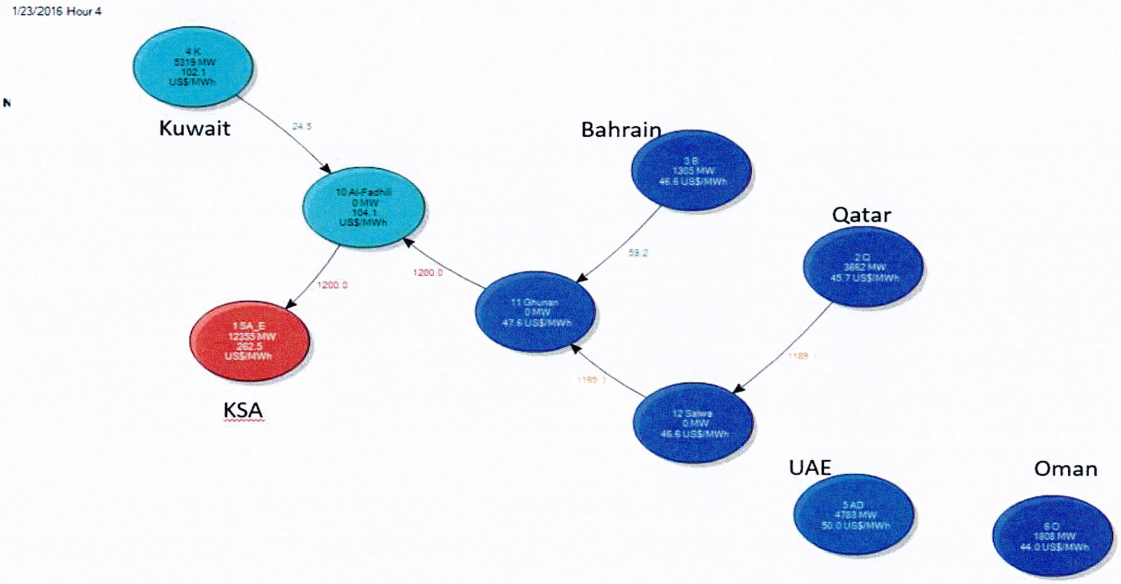


Figure (6-34) Trading Example at winter off Peak 23 Jan 2016 4:00hrs

The production cost were summarized in Table (6-10) using uniform prices and international fuel prices. The uniform prices means the average prices for the different periods of both minimum and maximum. There are differences in

energy prices between member states as presented in the table. The range difference between members states were around $10 to $100 per MWh. The capacity available for trade between member states is 10.5TWh during the year. The expected saving and benefits for the traded parties estimated to be equal to $105 Million to $1050 Million yearly for the traded parties.

The actual prices for the member states changing during the day as shown in Figures (6-29) and (6-30). Both Figures (6-29) and (6-30) show the trading opportunities during winter and summer, respectively. The range of market prices of the GCC country during high and load demand season presented in Tables (6-11a) and (6-11b). These results collected from the output of AURORA software.

Figures (6-31) to (6-34) illustrating the trading examples at peak and off-peak for the GCC. The trading will take place between the GCC based on their need. As an example, consider Figure (6-31) which illustrates the mode of power trade at summer. It is found that the starting of the arrow from Bahrain and ended in KSA will show the power transfer from Bahrain to KSA. This means that the beginning of the arrow is the starting point (has extra power and can sell the power), where the ended point (needs power) shows the country that need to buy the power.

Table (6-10) Production Cost using Uniform and International fuel prices

	Uniform		International Prices	
Country	**Min**	**Max**	**Min**	**Max**
Bahrain	$50	$114	$83	$179
Kuwait	$50	$140	$96	$281
Oman	$32	$88	$39	$115
Qatar	$42	$89	$66	$111
Saudi Arabia	$50	$153	$68	$373
UAE	$33	$88	$74	$125

Table (6-11a) GCC Market Prices during High Demand Season

Electricity Market	Max Marginal Price	Minimum Marginal Price	Average Marginal Price	Standard Deviation of MP
High Load Season	USD/MWh	USD/MWh	USD/MWh	USD/MWh
Bahrain	178.99	97.70	139.56	17.87
Kuwait	202.89	119.12	147.80	15.80
Oman	115.09	115.09	115.09	0.00
Qatar	110.85	110.85	110.85	0.00
Saudi Arabia	193.73	111.87	153.37	16.83
UAE Abu Dhabi	124.52	112.63	124.27	1.70

Table (6-11b) GCC Market Prices during Low Demand Season

Electricity Market	Max Marginal Price	Minimum Marginal Price	Average Marginal Price	Standard Deviation of MP
Low Load Season	USD/MWh	USD/MWh	USD/MWh	USD/MWh
Bahrain	97.70	89.86	97.18	1.11
Kuwait	154.34	95.89	111.69	16.78
Oman	115.09	79.89	106.43	11.26
Qatar	110.85	70.52	100.24	14.36
Saudi Arabia	164.84	93.21	114.64	17.78
UAE Abu Dhabi	124.52	86.67	103.67	13.43

6.5 Benefits Calculations

6.5.1 GCC Value of Lost Load

Provision of different types of support to the GCC countries electrical networks is the emergency support is the main reason behind the original planning of the GCC Interconnector since the early 1980s. Maintaining dynamic stability, system reliability and high operational security are the sought-after traits behind the establishment of the Interconnector.

Since the commissioning of the GCC Interconnector on 17Feb 2009, the GCC Interconnector have faced and overcome over 1200 system contingencies until 2015, which ranged from minor to major incidents. Some of these incidents may lead to isolation mode for some member states, and probable load shedding schemes would have operated. Resulting in loss of load and probable system collapse if not remedied quickly has the major concern for the electricity utilities in the member states.

Some incidents which are recorded and shared with the member states range from small gas-turbine generation units as large as a whole power station with a full load, approaching peak time. Thankfully, due to the dynamic nature of the GCC Interconnected network, the system inertia and the variant fuel mix, so far no registered case of load shedding took place in the GCC countries.

To quantify and illustrate the value of the benefit received from the Interconnector, a globally recognized methodology of determining value of the actual loss of load used. This value represented through the avoided loss of load through the emergency support received between the member states through the Interconnector known as VoLL (Value of Lost Load).

VoLL is the maximum price of the supply of electricity demand is worth. Such as to reflect its cost to consumers during an electricity outage. The quantity of VoLL can estimated by dividing national Gross Domestic Product (GDP) by the total annual national energy consumption.

VoLL = Gross Domestic Product / Total Annual energy consumption (6-19)

The Gross Domestic Product GDP of the GCC member state countries taken from the Emirates NBD Report (2013) "GCC Quarterly Jan 2013". The Emirates NBD (2013) illustrates the GDP for GCC countries that used to

evaluate the estimated VoLL of each member state. The GDP data of the year 2012 for the GCC countries used to evaluate the VoLL for each country in the GCC region. Table (6-12) displays the value of VoLL in each of the GCC member states according to its GDP in the year 2012, as follows:

Table (6-12) VoLL Estimation calculation in 2012

Country	GDP 2012 (US$ billion)	Energy Demand (GWh)	Estimated VOLL ($/MWh)
UAE	338.9	83,000	4083
Bahrain	29	11,000	2636
Saudi Arabia	669.7	211,100	3172
Qatar	173.3	18,800	9218
Kuwait	160.7	49,300	3260
Oman	72.6	11,400	6368
GCC Total	**1444.2**	**384,600**	**3755**

Table (6-12) illustrates the total Number of Frequency Incidents for member states in the year 2012. The total number of incidents in all member states in the year 2012 found 255 incidents. It classified into three types of incidents, which are generation loss, demand loss and combined incidents. Most incidents recorded in the generation loss category.

Table (6-13) Total Number of Frequency Incidents for year 2012

PARTY	Total Number of Frequency Incidents		
	Generation	Demand	Combined
Bahrain	**20**	**2**	**0**
Kuwait	**78**	**5**	**1**
Oman	**27**	**1**	**1**
Qatar	**22**	**1**	**2**
Saudi Arabia	**7**	**0**	**0**
UAE	**80**	**6**	**1**
Total	**234**	**15**	**5**

The Evaluation of emergency support for the Member State in the year 2012 done based on the actual energy imported during the above emergencies recorded on GCCIA system. The amount of energy recorded for those

emergencies accumulated for each member state and counted as the amount of energy used for emergency support for each interconnected member state in 2012. By using the calculated VoLL value combined with the actual emergency support in year 2012 for the GCC countries, the estimated value of support calculated as shown in Table (6-14).

The estimated benefits from year 2012, 2013 and 2014 support received by the GCC member state economic benefits of emergency support are $18.88, $17.60 and $19.48 million US dollars respectively. Such benefit would maintained provided the member states continue to maintain the required minimum level of operating reserve to ensure system versatility and dynamic response towards sudden contingencies and loss of generation.

Table (6-14) Estimated Value of Emergency Support for GCC Countries in 2012-2014

Country	Imported Energy in 2012 (MWHr)	Estimated VOLL ($/MWHr)	Estimated Value of Support (US$ Mil)	Imported Energy in 2013 (MWHr)	Estimated VOLL ($/MWHr)	Estimated Value of Support (US$ Mil)	Imported Energy During incedents 2014 (MWHr)	Estimated VOLL ($/MWHr)	Estimated Value of Support (US$ Mil)
UAE	1248.9	4083	**$5.10**	1784	4083	**$7.28**	941.4	4,962	**$4.67**
Bahrain	675.76	2636	**$1.78**	162	2636	**$0.43**	1634	1,989	**$3.25**
Saudi Arabia	482.44	3172	**$1.53**	1258.8	3172	**$3.99**	2573.1	3,058	**$7.87**
Qatar	869	9218	**$8.01**	200	9218	**$1.84**	111	6,354	**$0.71**
Kuwait	754	3260	**$2.46**	1243	3260	**$4.05**	648.8	4,597	**$2.98**
Oman	Not recorded	6368	**Not Calculated**	Not recorded	6368	**Not Calculated**	366.9	3,922	**Not Calculated**
Total			**$18.88**			**$17.60**			**$19.48**

However, it noted that the member states maintain receiving emergency support through the GCC Interconnector and still save money while reducing the operating reserve of the online and operating generation in each member state. This feature will detailed in a later part of this report.

6.5.2 Power Trade and Inadvertent Power Exchanges:

In global power markets, the availability of the grid capacity is essential to ensure proper conductance of power trade activities and resolving of energy

imbalances between different parties. The first form is the scheduled power exchanges between two or more parties across the Interconnector. The same can be arranged through power trade contracts, either monetary of in-kind trading. The resolve of imbalances sorted between the member states through GCCIA coordination and scheduling to maintain fair access and usage of the available energy floating on the grid.

The availability of multiple products for power trading such as scheduled energy exchanges, procurement of Operating Reserve and procurement of the Installed Capacity Reserve has given the member states more margins to guarantee the security and supply to their own demand at time of need. Such products also support the establishment of a GCC power market, through the Interconnector, when such products are being used and depended on to meet system demand and grid obligations. Such benefit unquantified since the received value depends on the member states involvement and integration of the power-trading concept as a source of national income for the country as well as its choice to depend on it to reduce dependency on imported and expensive fuels. Such benefit can be realized when the member states start trading on the economic benefit to reduce operating and maintenance costs, as well as reduce carbon emissions to the environment.

The second form of power exchanges is the inadvertent power flows across the Interconnector. Since there are six member states connected through a single grid, each electrical system tends to act and react to power flows across the grid in its own behavior and manner. Thus, unscheduled exchanges occur frequently during every minute or so as part of the initial nature of electricity. Although the member states to try its best to maintain control of its tie-line moderation and system frequency, yet such exchanges are bound to occur from time to time across the year.

To quantify the received value from receiving inadvertent power exchanges across the GCC Interconnector based on the average cost of energy, estimated at each member state's valued cost of electricity. The same estimated through the World Bank Report on Arab Interconnection Study in 2012.

The amount of the Annual Energy Exchange supported to Member States in the last four years illustrated in Figure (6-35). It compares the amount of

energy between these member states. The cost of the Energy Exchange support evaluated by multiplying this support to the average cost in each MS as shown in Table (6-15).

Table (6-15) Average cost of Electricity in year 2012

Cost/Country	Bahrain	KSA	Kuwait	Qatar	UAE
Average Cost of Electricity ($/MW)	$75	$137	$147	$67	$86

Table (6-16) displays the volume of received unscheduled energy exchanges between the GCC member states in the years from 2009 to 2014. It can be quantify and estimate the received benefit of receiving inadvertent power exchanges through the GCC Interconnector for each member states, based on imported energy.

Thus, it viewed that although unscheduled energy exchanges not compensated in monetary base, yet their worth still considered valuable and beneficial to the Member States when calculated in relation to the estimated cost of electricity at their side.

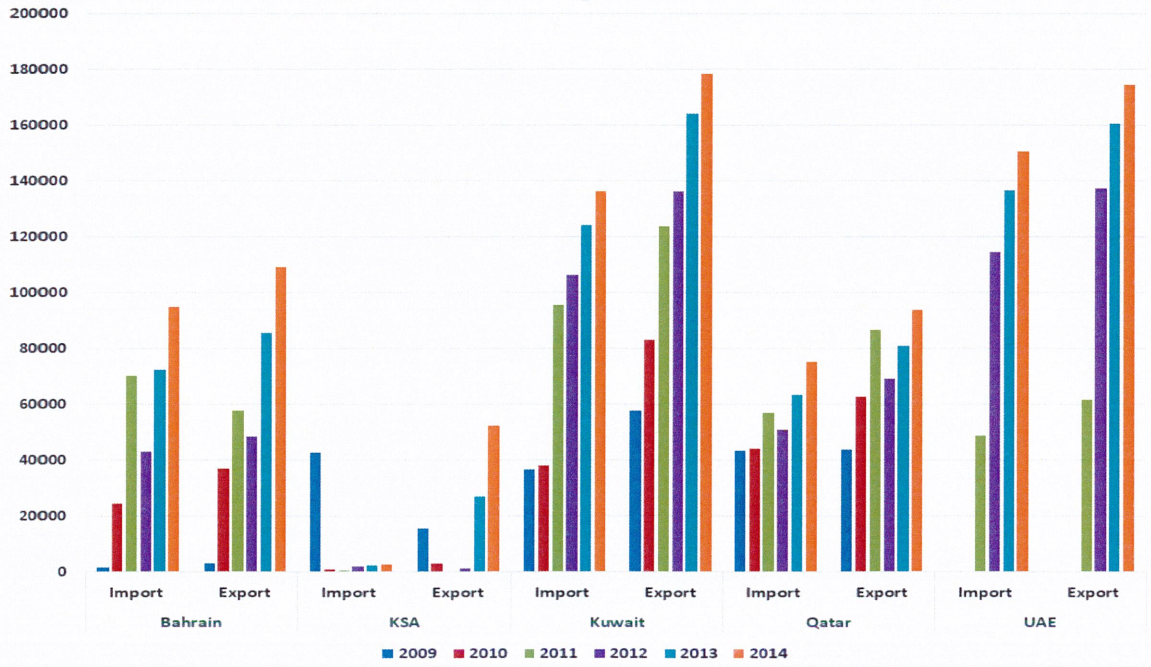


Figure (6-35) Annual Energy Exchange (MWh) in the Years (2009-2014)

Table (6-16) Energy Exchanges Between the GCC Countries During the Years 2009-2014

Annual Energy Exchange (MWh)										
MWh										
	Bahrain		KSA		Kuwait		Qatar		UAE	
Year	Import	Export	Import	Export	Import	Export	Import	Export	Import	Export
2009	1517	3000	42754	15606	36788	57786	43565	43733	0	0
2010	24535	36926	988	3108	38160	82874	44015	62667	0	0
2011	70302	57644	527	215	95584	123603	56901	86719	48944	61640
2012	43033	48263	2087	1269	106292	136203	50826	68959	114521	137445
2013	72364	85608	2352.5	26845	124061	164057	63592	80883	136499	160633
2014	94841	108943	2618	52421	136397	178348	75097	93656	150667	174588

Benefits of the interconnector were illustrated in the Figures (6-35) to (6-42). It represents the benefits of the sharing installed capacity resources, the spinning reserve, and the emergency support during incidents. The benefits of the energy exchange were represented in Figure (6-36). The bar chart shown in Figure (6-36) illustrates the cumulative value of cost reduction for all member states on yearly bases. The estimated value of energy imported was around $32.4, $40.5 and $45.5 Million dollars in the years 2012, 2013 and 2014 respectively as shown in Table (6-17). Member states energy forecasted prices illustrated in Figure (6-38).

Accordingly, the savings reach US$ 5.66 billion for the period 2014 to 2038 as shown in Figure (6-39). In addition to above quantified benefits, we provide qualitative descriptions of a number of other benefits brought by the interconnector, including economies of scale derived from building large shared generation units, better integration of renewables and nuclear generation like UAE and reductions in frequency management costs. We use international fuel price forecasts as a benchmark for estimating the savings in fuel costs.

Benefits of Sharing Spinning Reserves during years 2014 to 2038 were presented in Figure (6-42). More results illustrated in Figures (6-37) to (6-42).

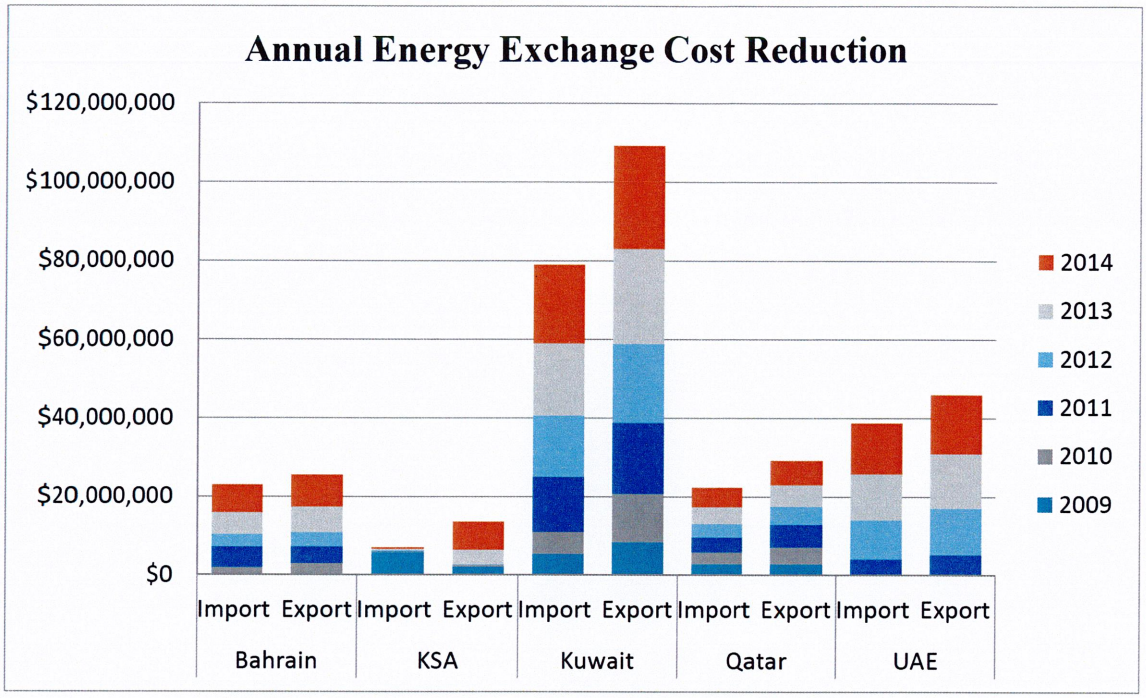


Figure (6-36) Perceived Value of Energy Exchanges during the years 2009-2014

Table (6-17) Annual Energy Exchange Cost Reduction

Annual Energy Exchange Cost Reduction $												
	Bahrain		KSA		Kuwait		Qatar		UAE		MS's Import Million $ Benifits	MS's Exports Million $ Benifits
Year	Import	Export	Import	Export	Import	Export	Import	Export	Import	Export		
2009	$113,775	$225,000	$5,857,298	$2,138,022	$5,407,836	$8,494,542	$2,918,855	$2,930,111	$0	$0	$14.298	$13.788
2010	$1,840,125	$2,769,450	$135,356	$425,796	$5,609,520	$12,182,478	$2,949,005	$4,198,689	$0	$0	$10.534	$19.576
2011	$5,272,650	$4,323,300	$72,199	$29,455	$14,050,848	$18,169,641	$3,812,367	$5,810,173	$4,209,184	$5,301,040	$27.417	$33.634
2012	$3,227,475	$3,619,725	$285,919	$173,853	$15,624,924	$20,021,841	$3,405,342	$4,620,253	$9,848,806	$11,820,270	$32.392	$40.256
2013	$5,427,300	$6,420,600	$322,293	$3,677,765	$18,236,967	$24,116,379	$4,260,664	$5,419,161	$11,738,914	$13,814,438	$39.986	$53.448
2014	$7,113,075	$8,170,725	$358,666	$7,181,677	$20,050,359	$26,217,156	$5,031,499	$6,274,952	$12,957,362	$15,014,568	$45.511	$62.859
Total	$22,994,400	$25,528,800	$7,031,731	$13,626,568	$78,980,454	$109,202,037	$22,377,732	$29,253,339	$38,754,266	$45,950,316	$170.139	$223.561

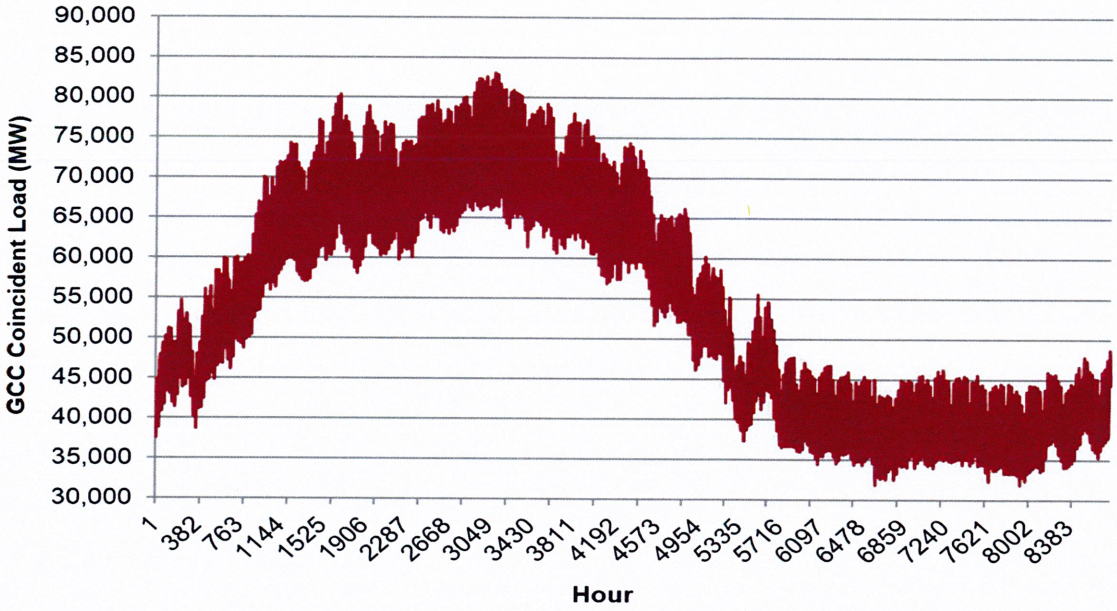


Figure (6-37) Load Curve demand for the GCC countries during 2013

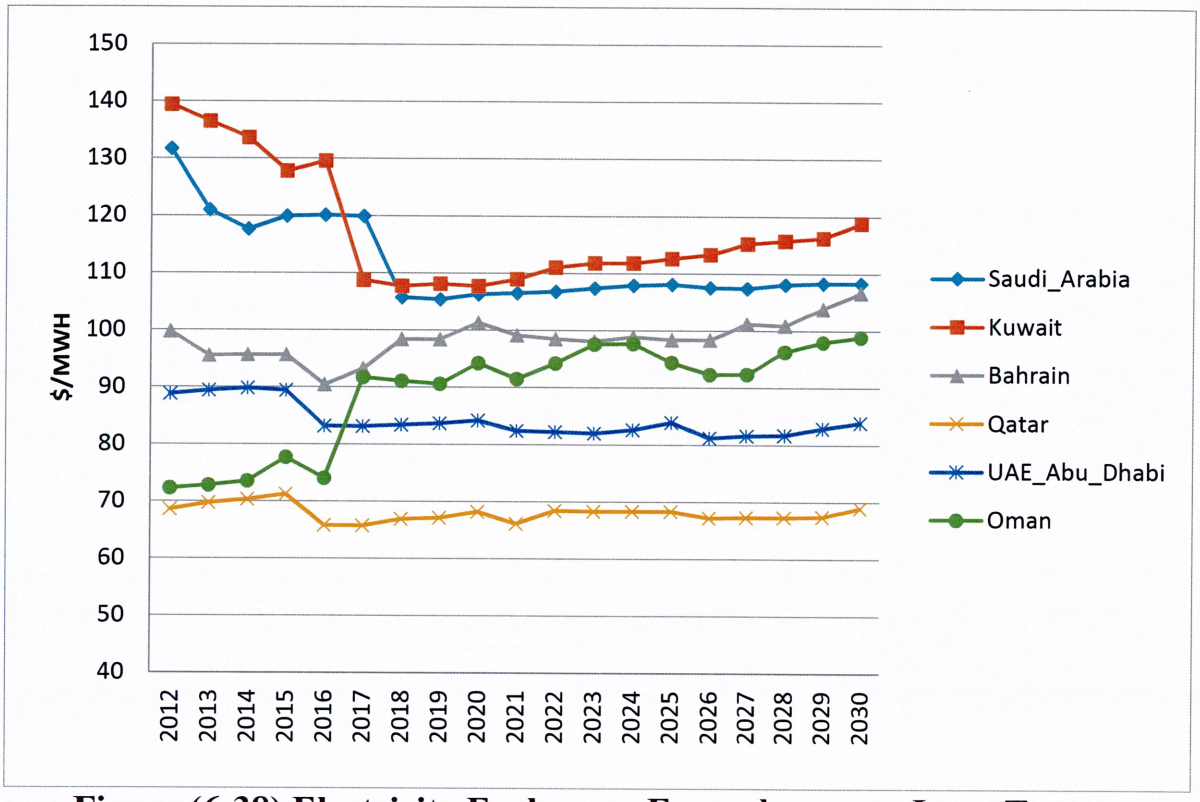


Figure (6-38) Electricity Exchanges Example among Long Term Average Specific Cost of Electricity

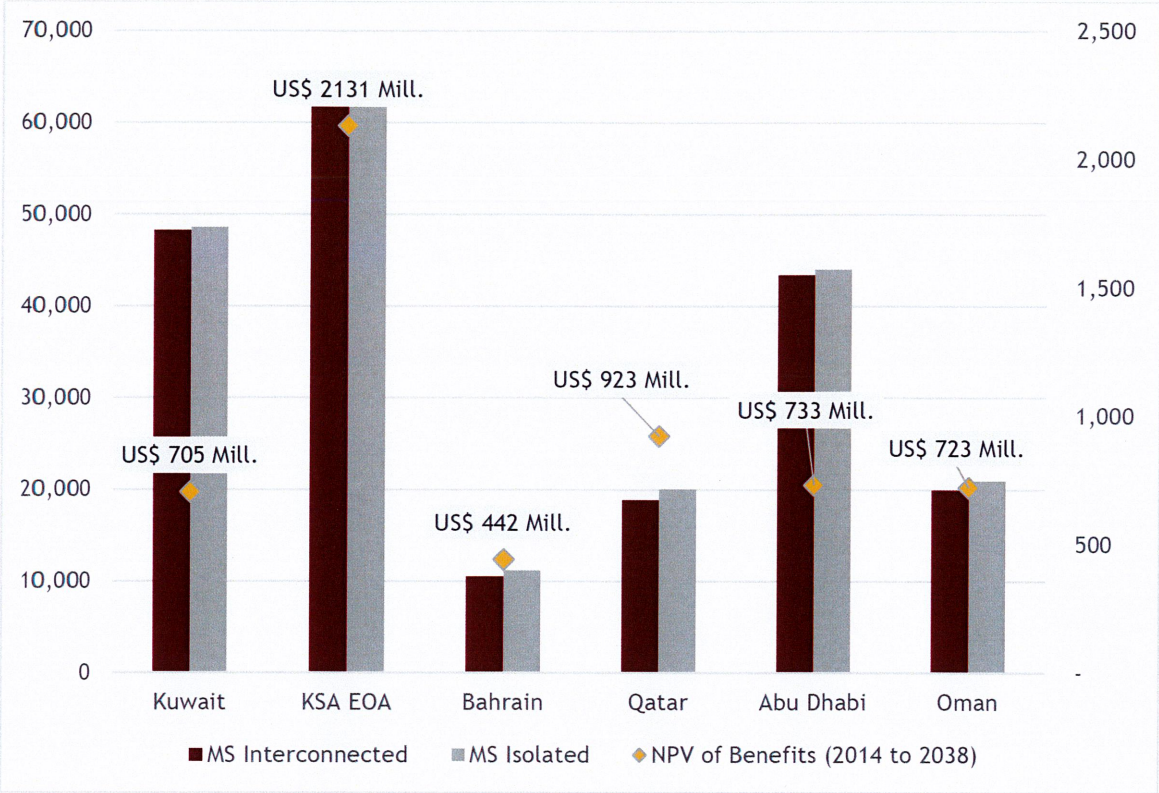


Figure (6-39) Installed Capacity Savings

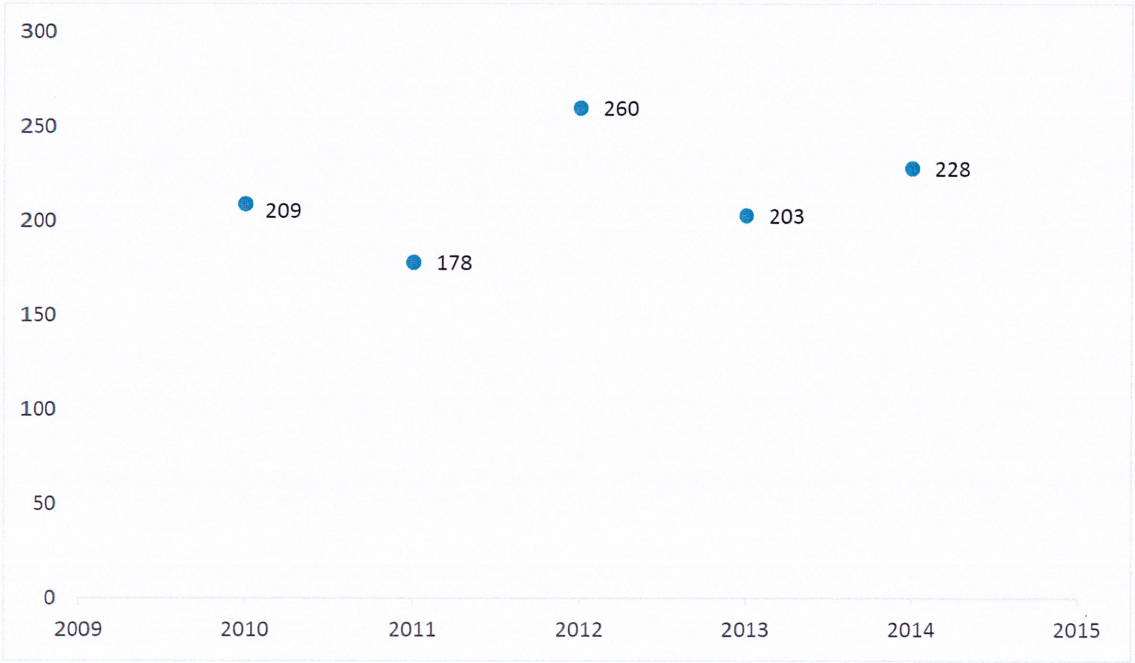


Figure (6-40) Number of Incidents in the GCC countries

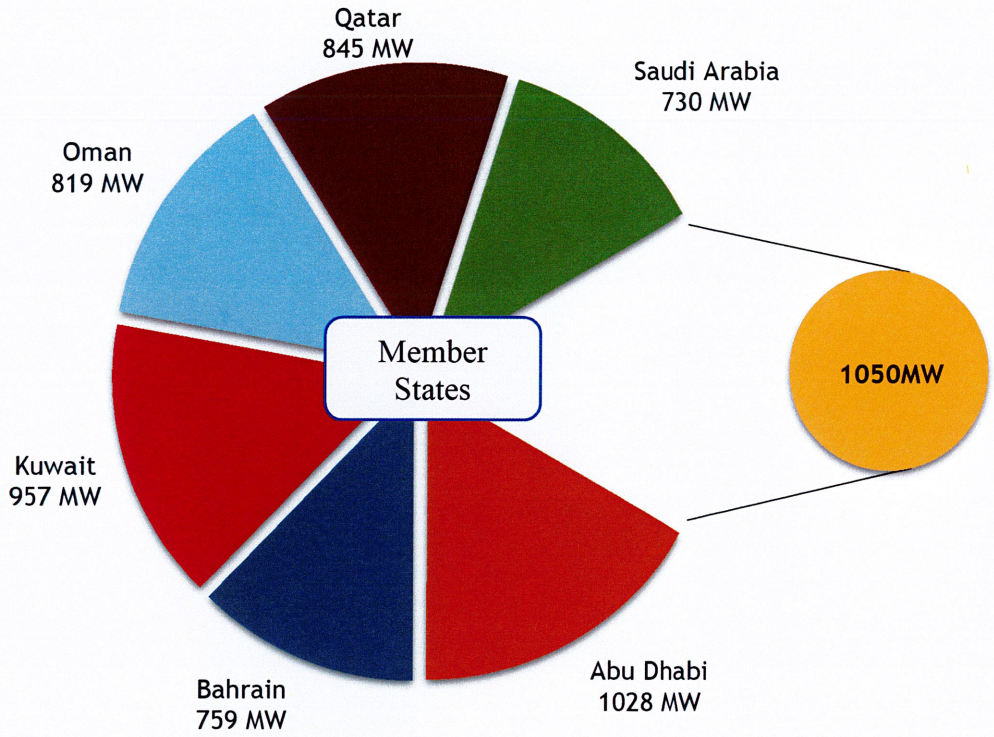


Figure (6-41) Spinning Reserve Requirement (2014)

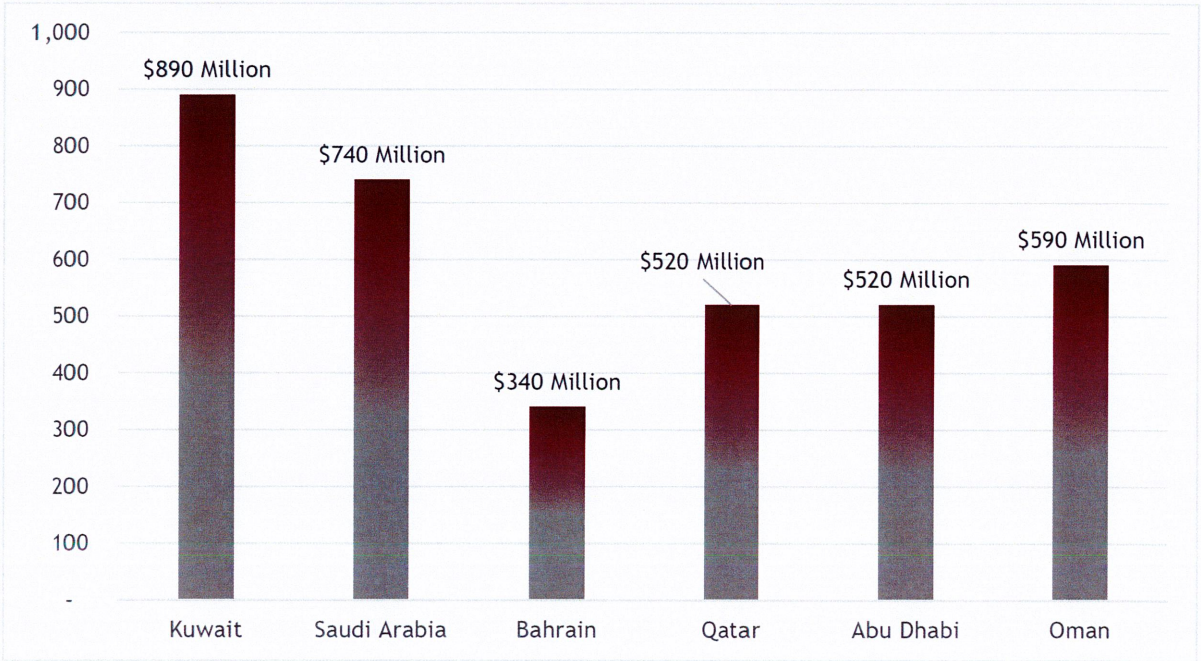


Figure (6-42) Benefits of Sharing Spinning Reserves (2014 to 2038)

6.6 System Reliability during the Trading

One of Electricity Market Reform objectives is to make sure of system security for the electricity supply. The Capacity Market used to protect demand users from losing the electricity supply or facing electricity shortages causes curtailment in load demand.

6.6.1 Elements Used to Set Reliability Standard

There are a number of elements used to set a reliability standard to measure the security of supply, where the most common elements listed as follows:

1- De-rated Capacity margin: it measures the excess supply above peak demand. It means the adjustment of supply taking in account availability of plants, and it is a measure of the average or mean;
2- Loss of Load Expectation (LOLE): represents the amount of time not meeting the demand and measured in hours per year. This is a probabilistic approach where the actual amount will vary depending on the measured periods that the demand load not met. For example, The Republic of Ireland targets an LOLE of 8 hours per year; France targets the same standard of 3 hours per year, the Netherlands 4 hours per year, and GCCIA 5 hours per year.

The methodology shown in Figure (6-43) used to determine the LOLE for the GCCIA interconnection. The AURORAxmp software used to calculate the LOLE target, which is 5hrs/year. Monte Carlo simulation of outages used to obtain acceptable results for the LOLE, which needs about 1000 iterations for the present model. The target of 5 hours per year achieved.

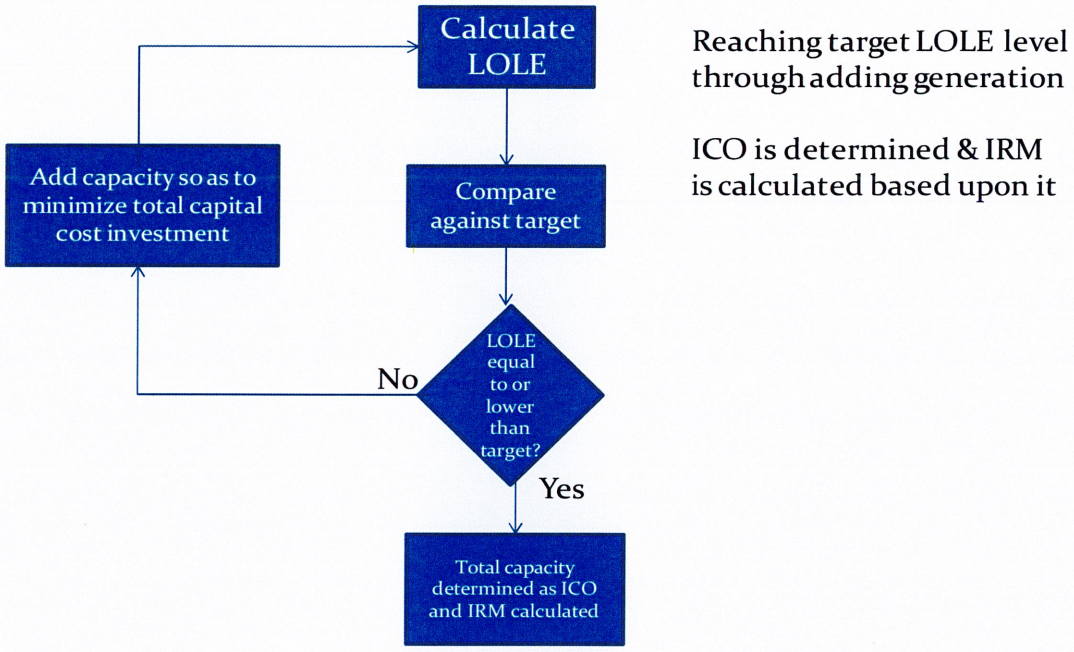


Figure (6-43) Methodology used to calculate the LOLE for the GCC interconnected systems

3- Expected Energy Unserved (EEU): It is the amount of electricity demand expected not meet by supply in the current year.

4- The transient state-probabilities of the machines is one of important reliability inquiries. The data required for doing a model for System operates at full capacity, System fails or System operates at less than full capacity due to generator outages.

Forced Outage Modeling Using the Frequency/Duration Method

Forced outage refers to a generator failure event, including the time required to complete the repair. AURORAxmp accommodates several methods of modeling forced outages; including a deterministic de-rate method and a stochastic method. This EPIC Inc. (2016) article explores some

modeling considerations with the use of the stochastic frequency/duration method.

In AURORAxmp, the frequency/duration outage method applied by selecting Outage method equal to Frequency duration option in the Resource folder of Run Setup. The parameters considered in the frequency/duration method are those found in the following columns of the Resources, Force outage, Mean Repair Time, Risk Outage and Risk Resource Link (optional). The value specified in the Forced Outage column is the expected forced outage rate (FOR) or the percent of hours in the course of a fixed time period that a unit is down on a forced outage. The value in the Mean Repair Time column is the mean time to repair (MTTR) or the average amount of time, in hours, that it would take to complete the repair after a unit has failed.

Mean Time to Failure

AURORAxmp uses the FOR and MTTR values to obtain another value called the Mean Time to Failure or MTTF. The MTTF describes the mean or average elapsed time, in hours, between forced outage events.

In the Figure (6-44), the parameters m_1, m_2 and m_3 are the random period of time during the year when a given unit is in operation. The parameters r_1 and r_2 are the random period of time when the same unit is down for repair.

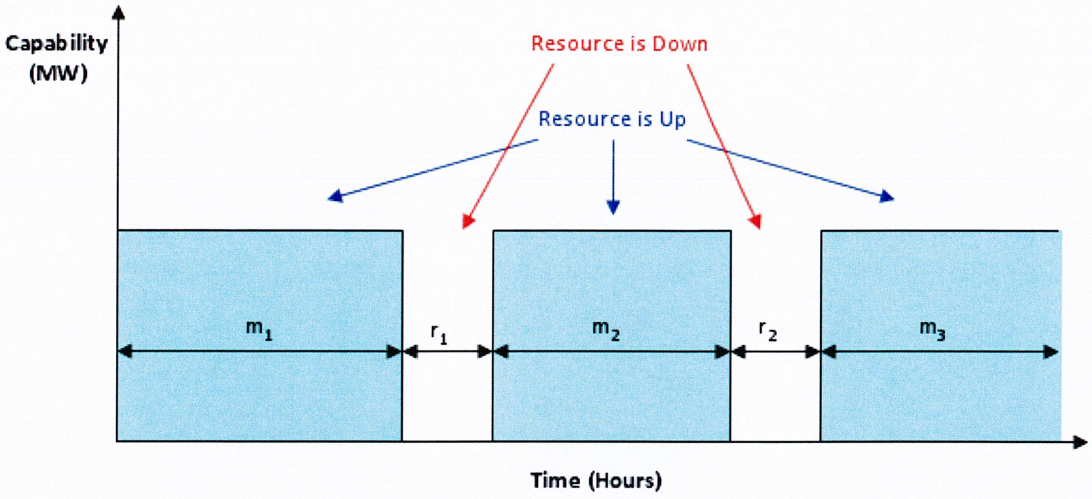


Figure (6-44) Resource Outage Figure

From the above figure, we observe the expected values as follows:

$$m = \frac{m_1+m_2+m_3}{3} = E[m_1 + m_2 + m_3] = MTTF \qquad (6\text{-}20)$$

and

$$r = \frac{r_1+r_2}{2} = E[r_1 + r_2] = MTTR \qquad (6\text{-}21)$$

Using equations (6-20) and (6-21), we can now show that the expected forced outage rate is related to the MTTR and MTTF as follows:

$$FOR = E\left[\frac{r_1 + r_2}{m_1 + m_2 + m_3 + r_1 + r_2}\right] = \frac{E[r_1 + r_2]}{E[m_1 + m_2 + m_3] + E[r_1 + r_2]}$$

$$FOR = \frac{MTTR}{MTTR+MTTR} \qquad (6\text{-}22)$$

By rearranging equation (6-22), we get the following equation, which used to compute the MTTF based on the user specified expected FOR and MTTR.

$$MTTF = MTTR\left[\frac{1}{FOR} - 1\right] \qquad (6\text{-}23)$$

There are a large number of combinations of values that can be specified for MTTR and FOR. As will be discussed below, however, certain combinations of MTTR and FOR will require increased sampling or specification of a longer study period in order to have the reported expected FOR closely approximate the input FOR parameter. Table (6-18) shows the resulting MTTF when the MTTR is assumed to be equal to 48 hours.

Table (6-18): MTTF resulting from a variety of FOR and MTTR of 48 hours

FOR (% of time down on outage)	MTTR (hours down once failed)	MTTF (hours between failures)	Example
0.001%	48	4,799,952	i.e. never fails
1.0%	48	4,752	i.e. once/6-7 months
5.0%	48	912	i.e. once/month
10.0%	48	432	
15.0%	48	272	
20.0%	48	192	i.e. once/week
50.0%	48	48	i.e. every two days
65.0%	48	25.8	i.e. every day
99.0%	48	0.5	i.e. always fails
100.0%	48	-	i.e. always fails

Introducing Uncertainty into the Formulation

Given a single parameter, namely the MTTF, and two states (operable and non-operable), AURORAxmp introduces uncertainty into the formulation

via the exponential distribution. The exponential distribution function is a single parameter distribution, with the mean consisting of the inverse of the MTTF (λ=1/MTTF). Its probability density function is given by:

$$f(x,\lambda) = \lambda e^{-\lambda x} \quad , x \geq 0, \quad \lambda > 0. \tag{6-24}$$

Figure (6-45) below illustrates the exponential cumulative distribution function (CDF) shown in equation (6-24) and probability density function (PDF) for the time to failure with MTTF=432 (FOR=10%, MTTR=48).

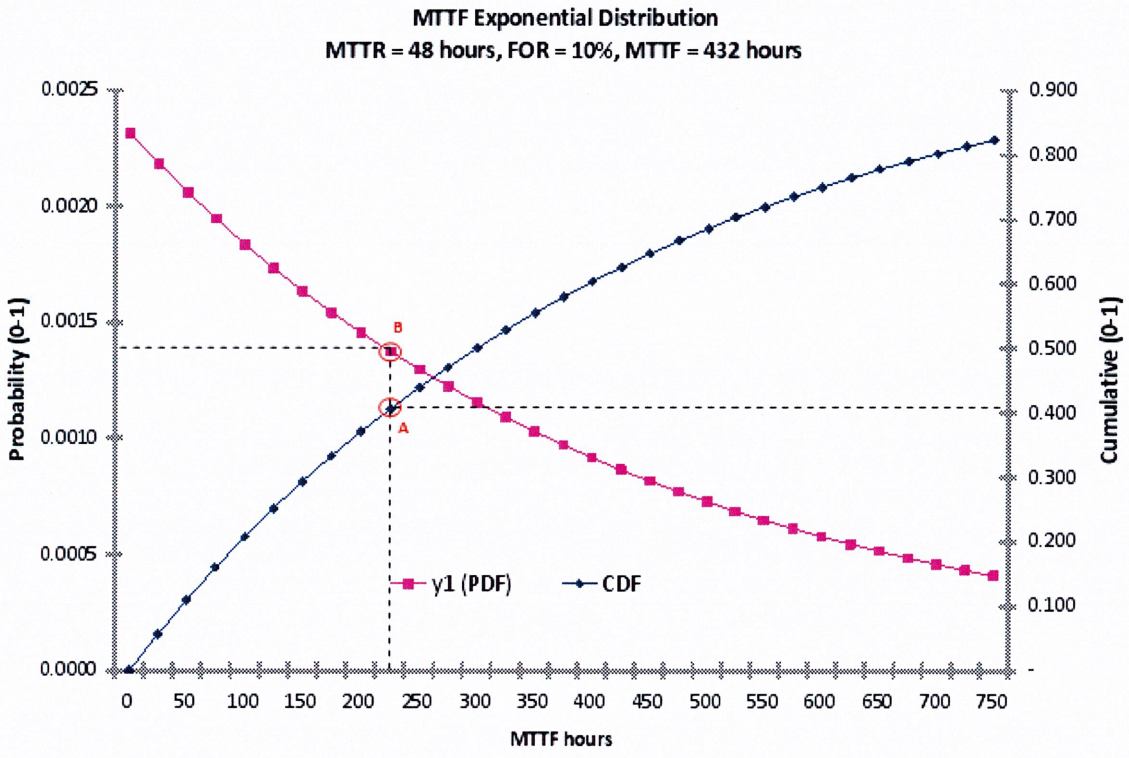


Figure (6-45) Exponential Distribution (MTTF=432)

The CDF in Figure (6-45) shows the probability that the operating hours between outages will be less than or equal to the corresponding value on x-

axis. As an example, at point A, the probability that the continuous operating hours since the last outage will be less than or equal to 225 is 40.6.

Generation Scaling for LOLE

The LOLE of the system is calculated and compared against the quarry. If the calculated LOLE is higher than the target, then new generation is added to the system and the LOLE is recalculated. If it is even higher than the target LOLE then more generation is added. The procedure is iterated until the calculated LOLE becomes equal to or lower than the target LOLE. The amount of generation presented in the system becomes the ICO and is accordingly applied to calculate the IRM at that level. The additional of a new generation that will trade with the overall generation expansion plan where the capital costs are minimized. Standard generation capacities, technology, fuel, characteristics and capital costs are accepted. The flow chart presented in Figure (6-43) illustrates the LOLE.

Generation System Reliability Indices

Probabilistic methods can provide more meaningful information to be used in design and resource in planning and allocation (Prada 1999, pp.14). Both the analytical methods and Monte Carlo simulation approaches can be use for probabilistic evaluation as follows:

- The analytical methods:
    - represent the system by mathematical models, and
    - use direct analytical solutions to evaluate reliability indices from the model.
- The Monte Carlo simulation methods:

- Estimating the reliability indices through simulating the actual random behavior of the system.

Figure (6-46) shows categorizing and typical reliability indices used in power system evaluations.

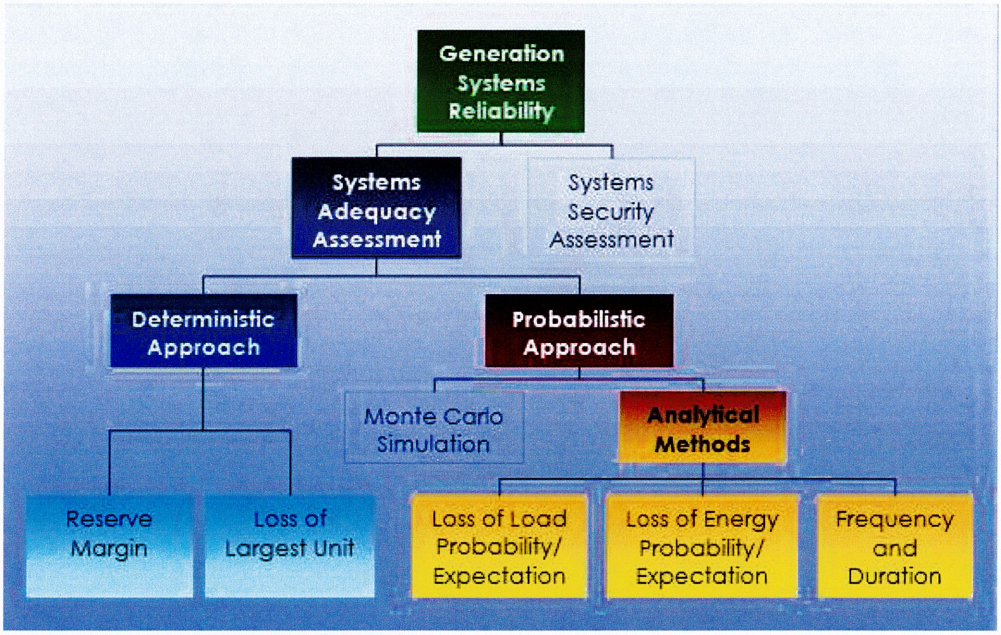


Figure (6-46) Generation System Reliability Assessment Indices Category

The reliability indices results for GCC are presented in Table (6-19), where equation (6-25) is used to calculate the LOLP.

$$LOEE = \sum_j P_j t_j \qquad (6\text{-}25)$$

where p_j probability of capacity outage t_j percentage of time.

$$LOLF(occ./year) = \sum_{j\varepsilon S}(F_j - f_j) \qquad (6\text{-}26)$$

where F_j is the frequency of departing system state j and f_j is the portion of F_j which corresponds to not going through the boundary wall between the loss-of-load state set and the no-loss-of-load state set.

$$LOLP = \sum_j P[C_A = C_j] \cdot P[L > C_j] = \sum_j \frac{p_j \cdot t_j}{100} \quad (6\text{-}27)$$

where P the probability of L expected load, C_A available generation capacity, C_j remaining generation capacity, p_j probability of capacity outage t_j percentage of time when the load exceeds C_j.

$$LOLE = LOLP \cdot T \quad (6\text{-}28)$$

where $T = 8760$ hours.

$$LOLD\ (hr/disturbance) = \frac{LOLE}{LOLF} \quad (6\text{-}29)$$

Table (6-19) Reliability Indices for GCC

Reliability Indices	Value
LOEE, Loss of Energy Expectation	18000 MWh
LOLF, Loss of Load Frequency	4.3%
LOLP, Loss of Load Probability	0.0181
LOLD, Loss of Load Duration	4.977 hrs/year

In a power system, the adequacy of the generating capacity is normally improved by the interconnected countries. At present time, it appears that the loss of load probability is calculated for evaluating the adequacy of a given network. As well, it is well known that the frequency and duration deals with both of the loss of load frequency and loss of load duration, which were calculated for the GCC interconnected network. The frequency of the losses of load is 4.3% with the probability of 0.0181. Maximum loss of load duration allowed by GCC countries is 5 hours a year. Also, the loss of energy expectation is an expected value rather than a probability. The LOEE were calculated and found equal to 1800 MWh for the interconnection. The following indices "LOEE, LOLF, LOLP and LOLD" are summarized in Table

(6-19). The result determined in this study for the GCC countries is 4.977hrs/year, which is within the acceptable limit.

6.6.2 Modeling for the Machines during Switching

This section will study the transient state probabilities of the machines and LOLE for the GCC interconnected network. The machines from the TVA power generating units used instead of the GCC countries machine due to unavailability of data for the machine during the three states. The TVA power generating were calculated by Laplace Transforms entitle using MATLAB Simulink 7.10 package to obtain the same results. For each model, the three-state probabilities of the TVA models derived. Each model considered as 3-state model, where its equations obtained using the curve fitting technique and Neuro-Fuzzy techniques. The results indicated that the transient – state probabilities are almost identical for both techniques. Most of each state – probabilities model formulated so far mainly employ transient state modeling to estimate the transient probability values of the TVA model.

The Tennessee Valley Authority TVA (2013) is a corporation owned by the United States Government. The TVA provides electricity for 9 million people in parts of seven southeastern states. The TVA receives no taxpayer money and makes no profits. It should highlighted that TVA renewed its vision to help lead the Tennessee Valley region and the nation toward a cleaner and more secure energy future. Now, TVA considered as new green power providers program contributors to TVA's expanding renewable energy. As of 1 March 2012, there are 47.5 MW of solar capacity operational today TVA (2013).

In Biggerstaff et al (1969), they presented a method showing the Markov process to determine the state probabilities of generating units as functions of time. In their study, they considered four three-state TVA models. These three states restricted to three; where the first is operating at full capability, the other is operating at less than the full capability due to component outages (known as directed state) and the last then forced out. The state probability functions calculated using the Laplace Transforms. The initial probabilities considered for the operation at full capability to be unity and the other two states are zeros.

Chen et al (2013) in their paper the used the genetic algorithm (GA) which employed to estimate the battery model parameters including the diffusion capacitance in real time using measurement of current and voltage of the battery. The conclusion made from the simulation and experiment results for their research.

Kim et al (2013) in their paper carries on their study of the dynamic characteristics of a solar cell that rarely found. In their study, an AC impedance model of a solar cell module developed using impedance Spectroscopy and it then used for evaluating the effects of the ripple current generated by a single-phase inverter. In Qamber et al (1994) they re-derived the Laplace Transforms again, because they found that Biggerstaff et al (1969) failed to detect a mathematical flaw.

Qamber et al (1994) derive the three state general formulas for both steady state and transient probabilities. The formulas derived in Qamber et al (1994) paper, where it can be applied to any Markov model and is independent of matrix manipulations.

Yan et al (2013) in their paper presented a hybrid midterm electricity market clearing price forecasting model combining both squares support vector machine and auto-regressive moving average with external input modules. The proposed model in their study showed improved forecasting accuracy compared to a forecasting model using a single least squares support vector machine.

6.6.3 Modeling and Methodology

The curve-fitting technique used to develop the models for four 3-state models for the generators to get the three models of each generator for the TVA system. Each model of generator has three-states. Each model of the 3-state TVA models can be represents by the Figure (6-47). These three-state models for the TVA models considered as follows:

S_1: System operates at full capacity and defined as Up-State

S_2: System fails, where no power generated and known as Down-State

S_3: System operates at less than full capacity due to generator outages and known as De-Rated State.

As a Markov model, Figure (6-47) represented in the following Matrix form:

$$\begin{bmatrix} -(a+b) & c & d \\ a & -(c+e) & f \\ b & e & -(d+f) \end{bmatrix} \qquad (6\text{-}30)$$

Where the symbols a, b, c, d, e and f are the transition rates of each TVA four models. These transition rates for the four TVA models extracted from Biggerstaff et al (1969) and given in Table (6-20).

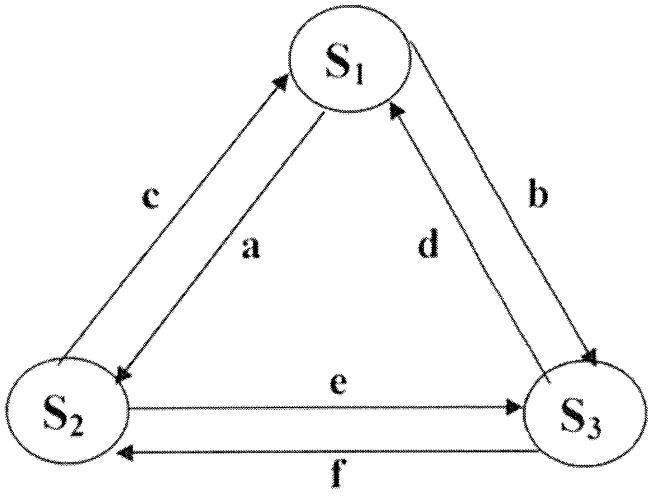


Figure (6-47) Three-State TVA Diagram Model

Table (6-20) Transition Rates of the Four TVA Models

TVA Model	Transition Rates (per hour)					
	a	b	c	d	e	f
1	0.0003	0.0010	0.0225	0.0350	0.0008	0.0004
2	0.0006	0.0050	0.0400	0.1000	0.0004	0.0004
3	0.0005	0.0002	0.0240	0.0430	0.0001	0.0001
4	0.0010	0.0006	0.0200	0.1000	0.0002	0.0020

The general formulas of state – probabilities for each 3-State TVA model formed as a differential equation, which is the rate of change of each state-probability with the rate of change of the time. The general equations are:

$$dP_1(t)/dt = -(a+b)\,P_1(t) + c\,P_2(t) + d\,P_3(t) \quad (6\text{-}31)$$

$$dP_2(t)/dt = a\,P_1(t) - (c+e)\,P_2(t) + f\,P_3(t) \quad (6\text{-}32)$$

$$dP_3(t)/dt = b\,P_1(t) + e\,P_2(t) - (d+f)\,P_3(t) \quad (6\text{-}33)$$

The three equations (6-31), (6-32) and (6-33) are solved to calculate the transient probabilities solutions.

6.6.4 Results and Discussions

As mentioned earlier, there are many methods used to calculate the transient probabilities. One of which is the Laplace Transforms method that obtains the transient state probabilities of the 3-State TVA models given in Qamber et al (1994). The initial probabilities for each model are P_1 (0) =one, P_2 (0) =zero and P_3 (0) =zero. The results obtained for the four TVA models summarized and listed in Tables (6-21) to (6-24). The availability of each model is represented by the summation of the individual probabilities of the Up and De-rated States.

Table (6-21) TVA1 Model, Transient probabilities using Laplace Transforms

Time (hour)	P_1 (t)	P_2 (t)	P_3 (t)
0	1.00000	0.00000	0.00000
5	0.99403	0.00141	0.00455
10	0.98896	0.00267	0.00837
15	0.98465	0.00380	0.01155
20	0.98102	0.00479	0.01419
25	0.97793	0.00568	0.01639
30	0.97530	0.00647	0.01823
35	0.97306	0.00718	0.01976
40	0.97116	0.00780	0.02104
45	0.96954	0.00836	0.02210
50	0.96816	0.00885	0.02298
55	0.96699	0.00929	0.02372
60	0.96598	0.00968	0.02433
65	0.96512	0.01003	0.02485
70	0.96438	0.01034	0.02527
75	0.96375	0.01062	0.02563
80	0.96321	0.01086	0.02593
85	0.96274	0.01108	0.02618
90	0.96234	0.01128	0.02638
95	0.96200	0.01145	0.02655
100	0.96170	0.01160	0.02670
105	0.96145	0.01174	0.02681
110	0.96123	0.01186	0.02691
115	0.96104	0.01197	0.02700
120	0.96087	0.01206	0.02706

Table (6-22) TVA2 Model, Transient probabilities using Laplace Transforms

Time (hour)	P_1 (t)	P_2 (t)	P_3 (t)
0	1.00000	0.00000	0.00000
3	0.98547	0.00169	0.01284
6	0.97464	0.00318	0.02219
9	0.96653	0.00449	0.02898
12	0.96043	0.00564	0.03392
15	0.95583	0.00666	0.03751
18	0.95232	0.00757	0.04011
21	0.94964	0.00836	0.04200
24	0.94757	0.00906	0.04337
27	0.94595	0.00968	0.04436
30	0.94469	0.01023	0.04508
33	0.94369	0.01071	0.04560
36	0.94289	0.01114	0.04597
39	0.94225	0.01152	0.04623
42	0.94173	0.01185	0.04642
45	0.94130	0.01215	0.04655
48	0.94094	0.01241	0.04665
51	0.94065	0.01264	0.04671
54	0.94039	0.01285	0.04676
57	0.94018	0.01303	0.04679
60	0.94000	0.01319	0.04681

Table (6-23) TVA3 Model, Transient probabilities using Laplace Transforms

Time (hour)	P_1 (t)	P_2 (t)	P_3 (t)
0	1.00000	0.00000	0.00000
5	0.99677	0.00234	0.00089
10	0.99397	0.00442	0.00162
15	0.99154	0.00626	0.00220
20	0.98945	0.00788	0.00267
25	0.98764	0.00932	0.00304
30	0.98608	0.01058	0.00334
35	0.98471	0.01170	0.00359
40	0.98353	0.01269	0.00378
45	0.98249	0.01357	0.00394
50	0.98159	0.01434	0.00407
55	0.98081	0.01503	0.00417
60	0.98012	0.01563	0.00425
65	0.97952	0.01617	0.00431
70	0.97900	0.01664	0.00436
75	0.97854	0.01705	0.00440
80	0.97814	0.01742	0.00444
85	0.97778	0.01775	0.00447
90	0.97747	0.01804	0.00449
95	0.97719	0.01830	0.00451
100	0.97695	0.01852	0.00452
105	0.97674	0.01872	0.00454
110	0.97655	0.01890	0.00454
115	0.97639	0.01906	0.00455
120	0.97625	0.01920	0.00456

Table (6-24) TVA4 Model, Transient probabilities using Laplace Transforms

Time (hour)	$P_1(t)$	$P_2(t)$	$P_3(t)$
0	1.00000	0.00000	0.00000
5	0.99292	0.00474	0.00233
10	0.98724	0.00903	0.00374
15	0.98255	0.01288	0.00456
20	0.97859	0.01635	0.00506
25	0.97518	0.01948	0.00534
30	0.97220	0.02229	0.00551
35	0.96957	0.02482	0.00561
40	0.96725	0.02709	0.00566
45	0.96517	0.02914	0.00569
50	0.96331	0.03098	0.00571
55	0.96165	0.03263	0.00571
60	0.96016	0.03412	0.00572
65	0.95882	0.03546	0.00572
70	0.95763	0.03667	0.00571
75	0.95655	0.03775	0.00570
80	0.95558	0.03872	0.00570
85	0.95471	0.03960	0.00569
90	0.95392	0.04039	0.00570
95	0.95321	0.04110	0.00570
100	0.95257	0.04173	0.00570
105	0.95200	0.04231	0.00570
110	0.95148	0.04282	0.00569
115	0.95102	0.04328	0.00569
120	0.95061	0.04370	0.00569
125	0.95023	0.04408	0.00569
130	0.94989	0.04442	0.00569
135	0.94959	0.04472	0.00569
140	0.94932	0.04499	0.00569
145	0.94908	0.04524	0.00568
150	0.94886	0.04546	0.00568
155	0.94867	0.04565	0.00568
160	0.94849	0.04583	0.00567

The curve fitting modulation in the MATLAB package used to obtain the models of the 3-state four TVA models after reproducing the results using the (L. T.). The result used to calculate by the Laplace Transforms values, which observed in Tables (6-21) to (6-24), to obtain the following equations:

TVA1:

P1(T)= –2.174E-12 T5 +9.791*10-10 T4– 1.878E-7 T3 + 2.017E-5 T2 – 0.001284 T +1 (6-34)

P2(T)=1.64*10-13 T5– 9.269*10-11 T4+ 2.318E-8 T3 – 3.382*10-6 T2+0.0002988T - 5.001*10-7 (6-35)

P3(T)=(1.979E-12) T5– (8.788E-10)T4 + 1.64E-7 T3– 1.678*10-5 T2 + 0.0009856 T+ 1.551*10-5 (6-36)

TVA2:

P1(T)= –3.323*E-10 T5 + 6.705*10-8 T4 – 5.446*10-6 T3 + 0.0002302T2 – 0.005381T +0.9999 (6-37)

P2(T)= 5.134E-12 T5 – 1.347E-9 T4 + 1.646E-7 T3 – 1.244E-5 T2 + 0.000598 T+ 2.012E-6 (6-38)

P3(T)= 3.279*10-10 T5 – 6.582E-8 T4 + 5.288E-6 T3 – 0.0002179 T2+ 0.004784 T + 0.0001414 (6-39)

TVA3:

P1(T)= –8.916*10-13 T5 + 4.168*10-10 T4 – 8.413E-8 T3 + 9.747*10-6 T2 – 0.0006915T +1 (6-40)

P2(T)= 3.796E-13 T5 – 1.922E-10 T4 + 4.4E-8 T3 – 5.98E-6 T2 +0.0004975 T – 2.558E-7 (6-41)

P3(T)= 5.547E-13 T5 – 2.36*10-10 T4 + 4.12E-8 T3 – 3.808E-6 T2 + 0.0001946 T + 5.983E-6 (6-42)

TVA4:

P1(T)= –1.932E12 T5 + 9.656E-10 T4 – 1.935*10-7 T3 + 2.088E-5 T2– 0.001396 T+ 0.9996 (6-43)

P2(T)= 3.225E-13 T5– 2.118E-10 T4+ 6.099E-8 T3– 1.009*10-5 T2+ 0.0009961 T + 7.443E-6 (6-44)

$P_3(t)=1.608*10^{-12}\ t^5 – 7.529*e^{-10}\ t^4 + 1.324e^{-7}\ t^3 – 1.078*10^{-5}\ t^2 + 0.0003998t + 0.0003752$ (6-45)

Based on the above models for the 3-State four TVA models using the MATLAB, the results (Using the same interval of time for each model) are calculated and plotted with the existed data (results calculated using the Laplace Transforms) for TVA models. The plotted results are shown in Figures (6-48) to (6-51), which represent the 3-state four TVA models.

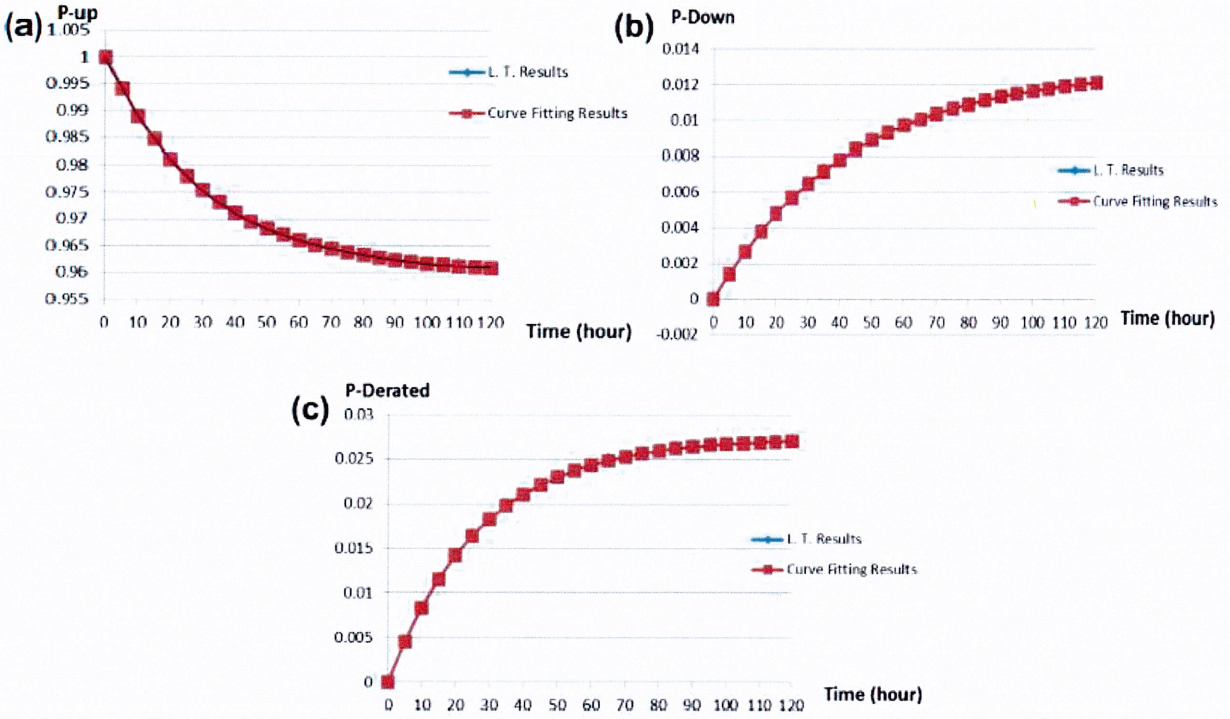


Figure (6-48)(a) TVA1 results, P-up, (b) TVA 1 results, P-down, (c) TVA 1 results, P- De-rated.

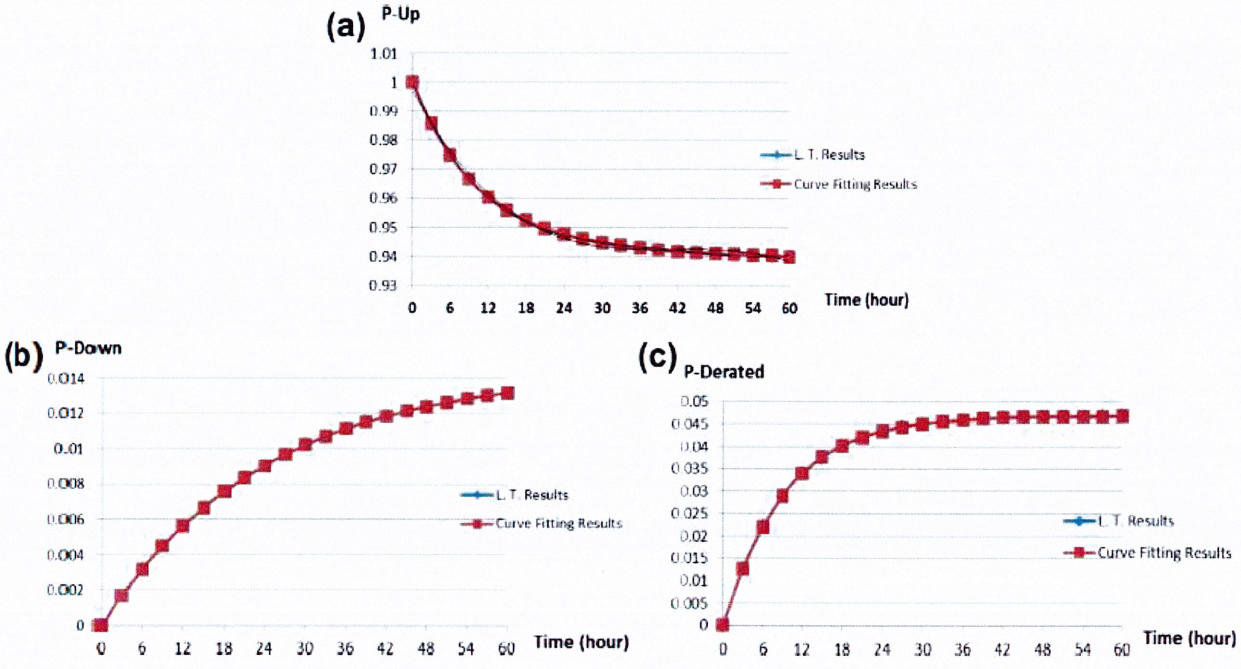


Figure (6-49) (a) TVA 2 results, P-up, (b) TVA 2 results, P-down (c) TVA 2 results, P- De-rated.

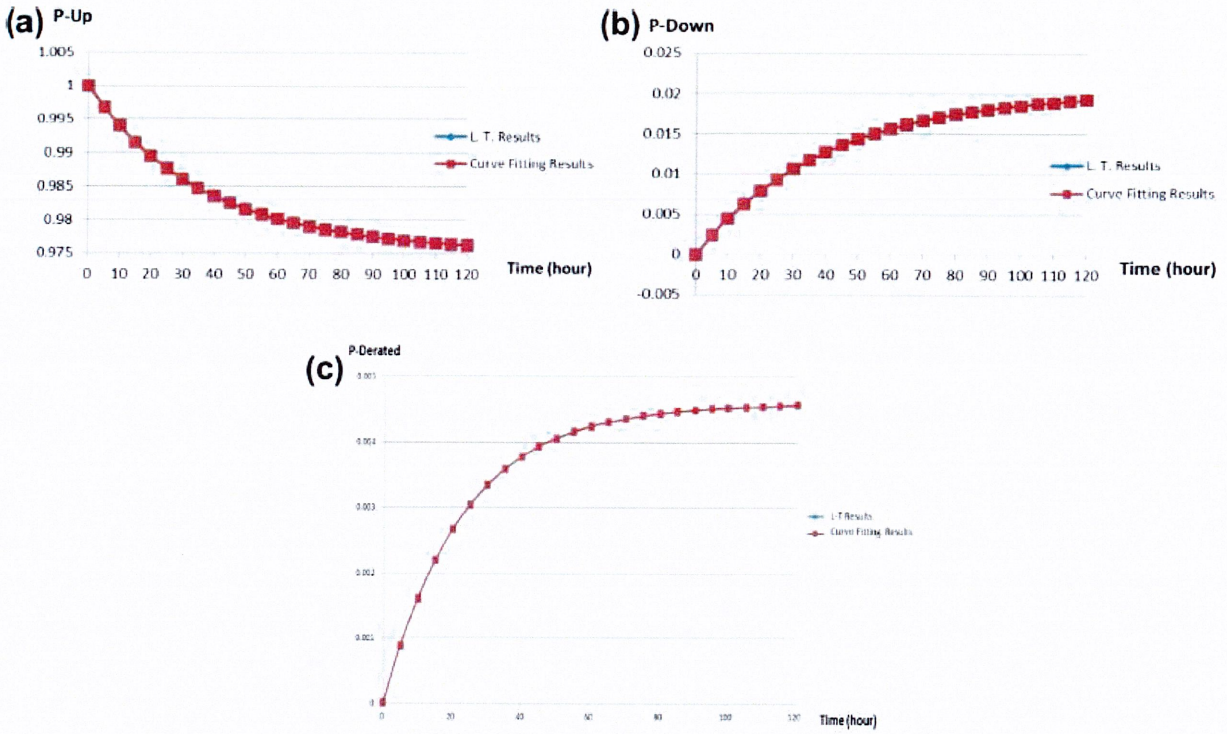


Figure (6-50) (a) TVA 3 results, P-up, (b) TVA 3 results, P-down (c) TVA 3 results, P- De-rated.

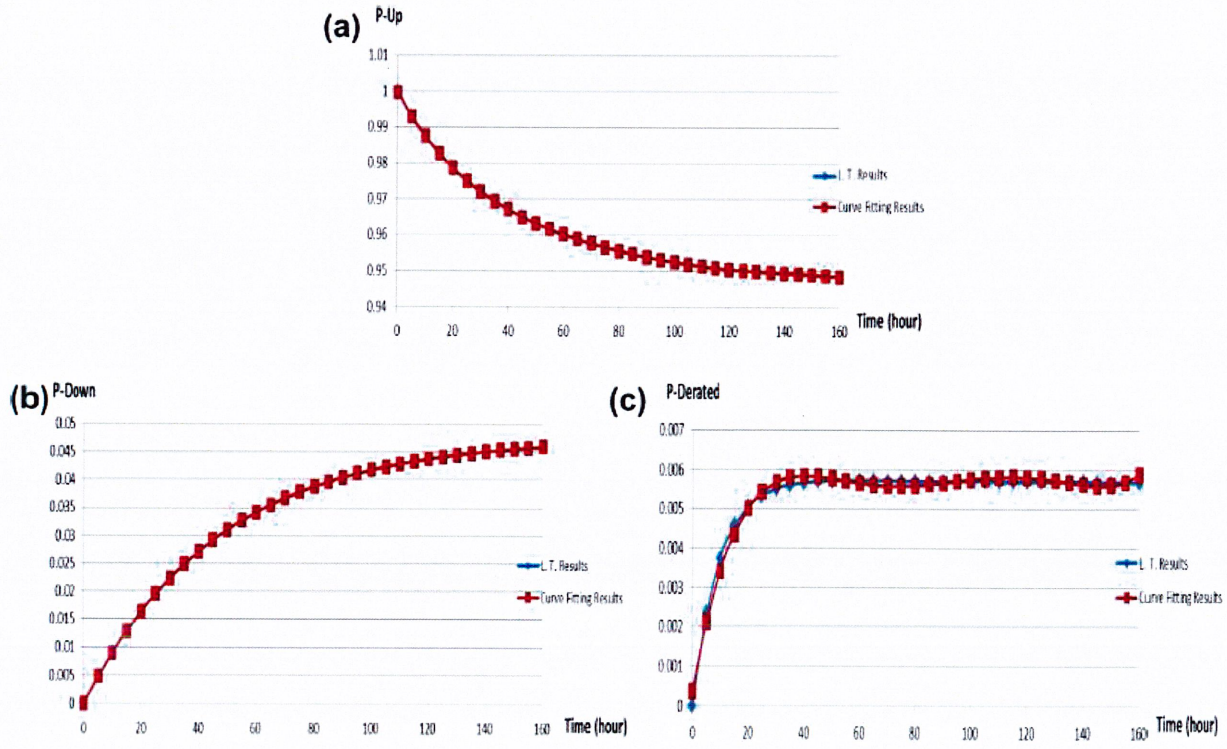


Figure (6-51) (a) TVA 4 results, P-up, (b) TVA 4 results, P-down (c) TVA 4 results, P- De-rated.

6.6.5 Modeling using Neuro-Fuzzy

The Neuro-fuzzy system has a combination of advantages of the neural networks and fuzzy logic. Carpenter et al (1993) noted that neural networks have two main benefits. First, they are capable of learning non-linear mappings of numerical data. Second, they perform parallel computation. However, the operation of neural networks has also many weaknesses. Therefore, it is very hard to understand the meaning of weights, and the incorporation of prior knowledge into the system is usually impossible. Fuzzy logic uses human understandable linguistic terms to express the knowledge of the system. This makes possible a close interaction between the system and human operator, which is a very desirable property.

Therefore, the aim of Neuro-fuzzy systems is to combine collectively the benefits of both approaches. Simply, the operation of the system expressed as linguistic fuzzy expressions and learning schemes of neural networks used to learn the system.

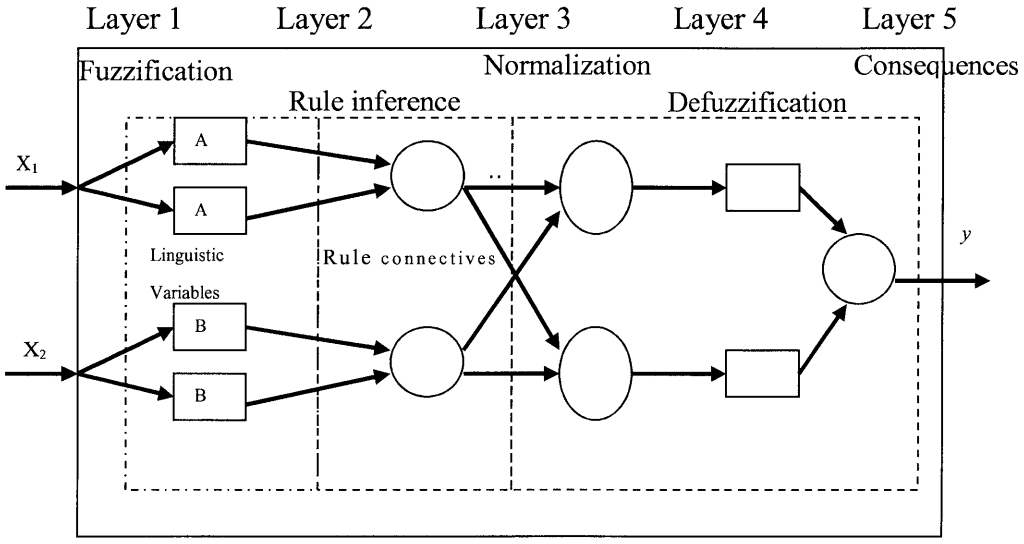


Figure (6-52) A Neural Fuzzy Inference System

In addition, Neuro-fuzzy systems allow incorporation of both numerical and linguistic data into the system. The Neuro-fuzzy system is also capable of extracting fuzzy knowledge from numerical data.

The general model for the Neuro-fuzzy system shown in Figure (6-52), which illustrates the five-layer connection for two inputs and one output. These five layers represent the Neuro-Fuzzy model, which used to represent the TVA model used above.

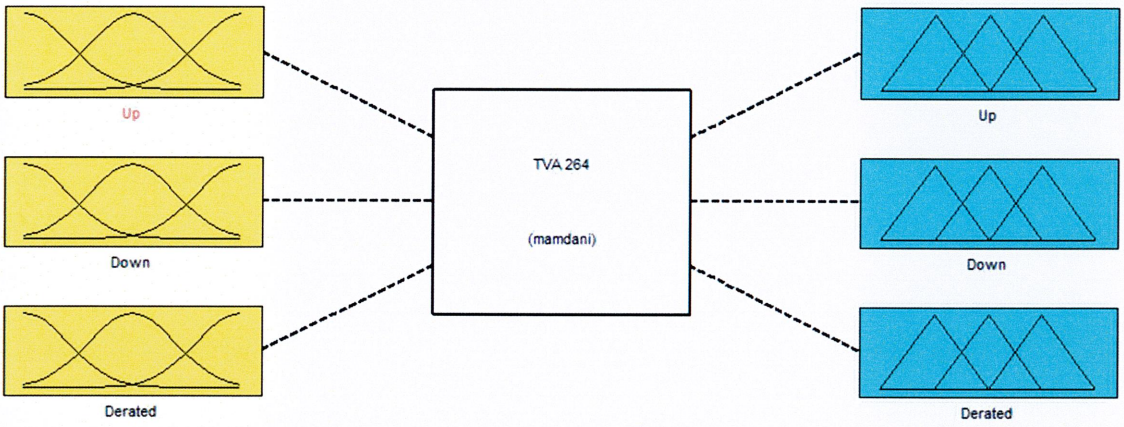


Figure (6-53) The Neuro-Fuzzy Inference System for the TVA model

The proposed model using the Neuro-Fuzzy is three inputs and three-output model as shown in Figure (6-53). The number of member states used for this model is either 6-member states to represent the Higher and Lower limits of each state of the TVA model or 9-member states to represent the Higher, Average and Lower limit of each state of the TVA model. The plotted results illustrated in Figures (6-54) to (6-57), which represent the 3-state four TVA models using the Neuro-Fuzzy method.

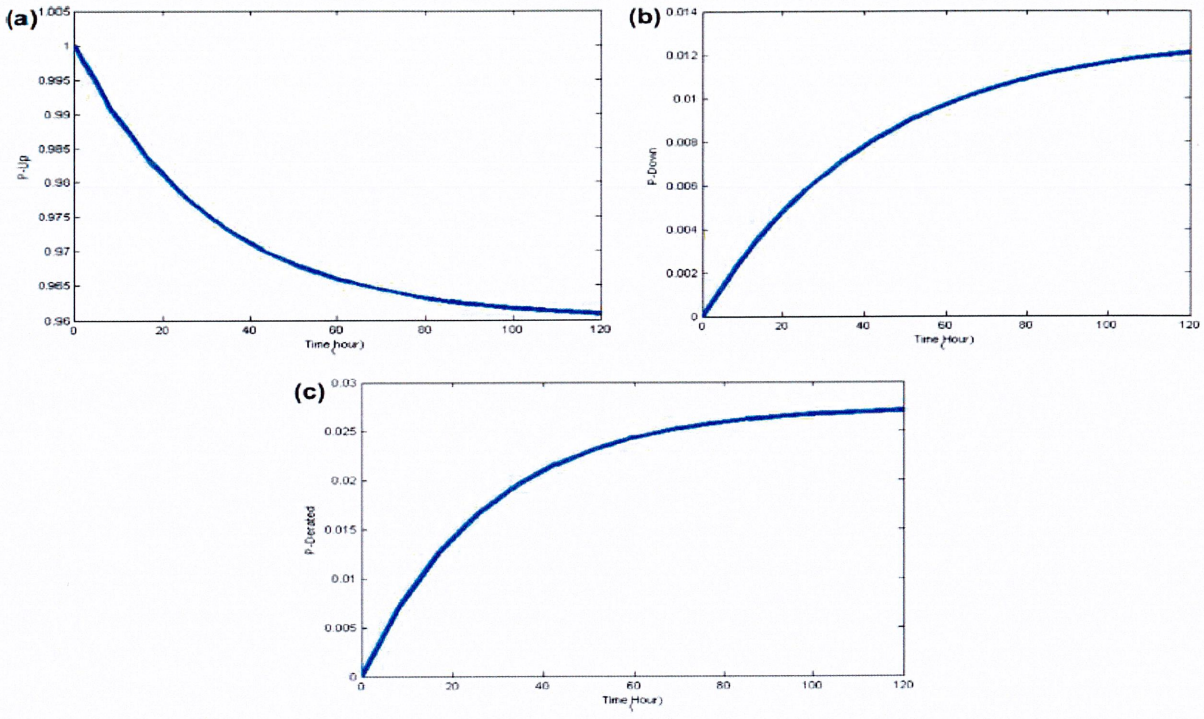


Figure (6-54) (a) TVA 1 results, P264-Up, (b) TVA 1 results, P264-Down, (c) TVA 1 results, P264-derated.

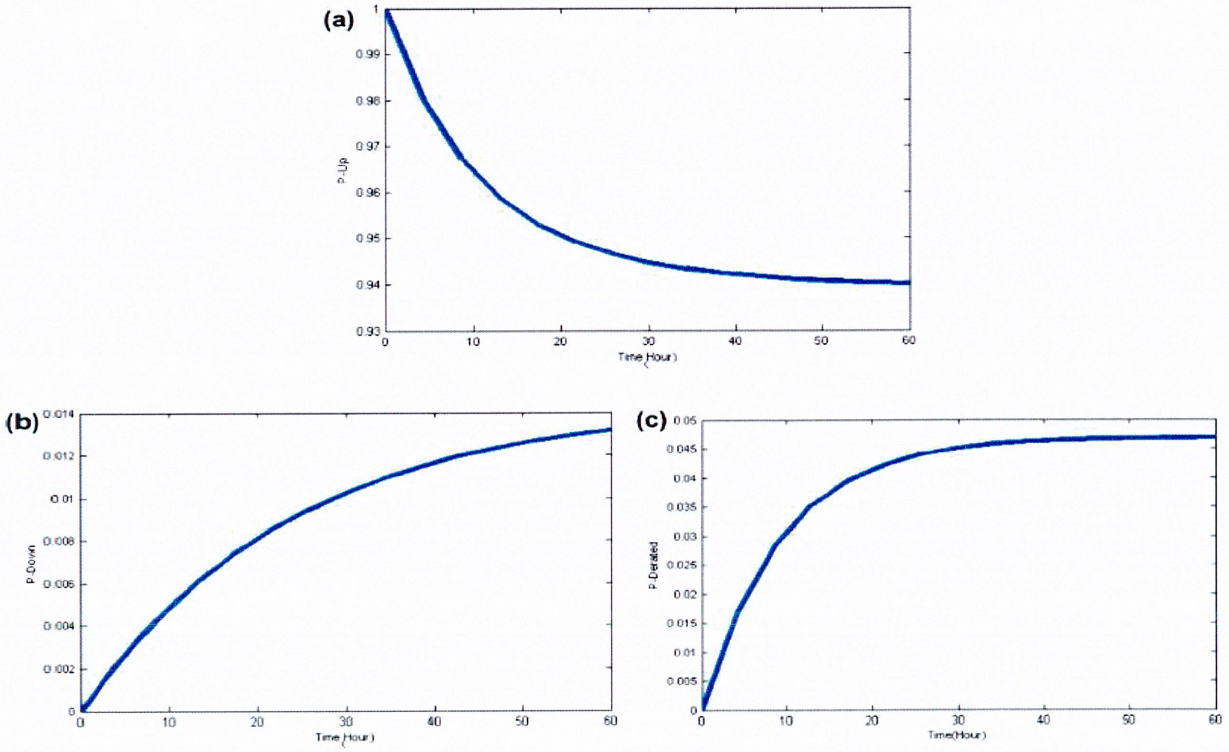


Figure (6-55) (a) TVA 2 results P267-Up, (b) TVA 2 results, P267-down (c) TVA 2 results P267-derated.

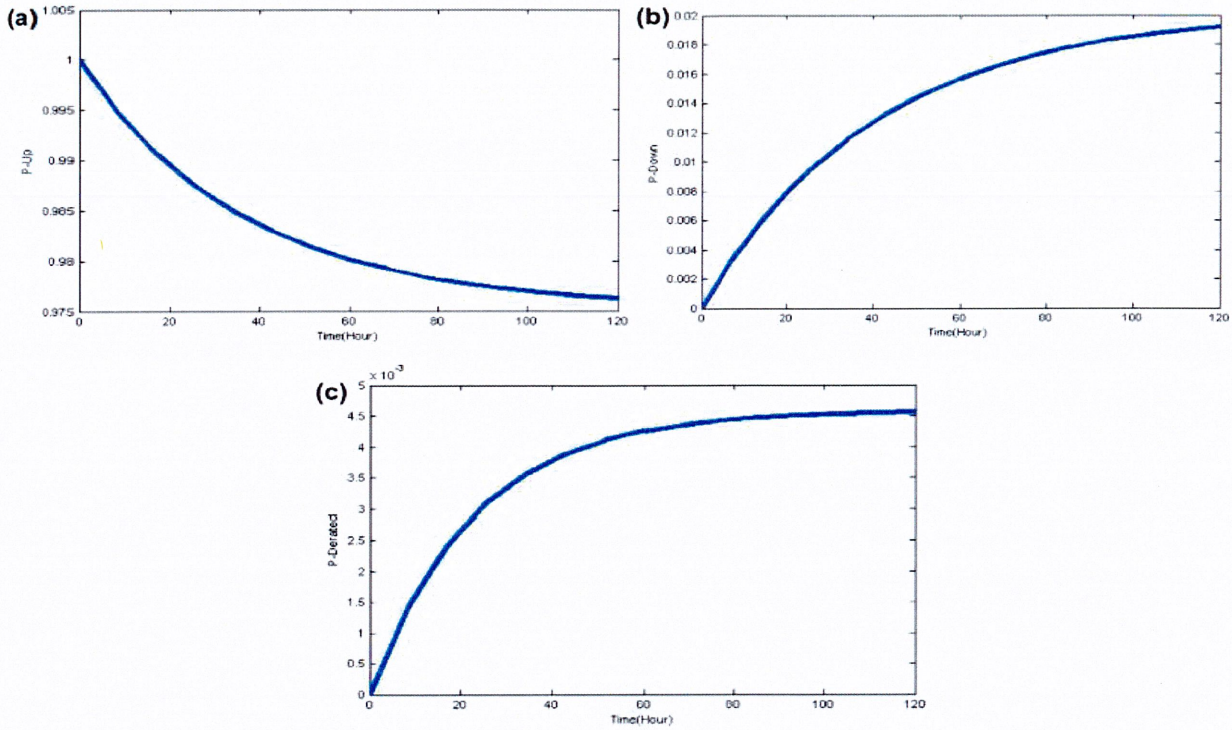


Figure (6-56) (a) TVA 3 results P270-Up, (b) TVA 3 results P270-down, (c) TVA 3 results P270-derated.

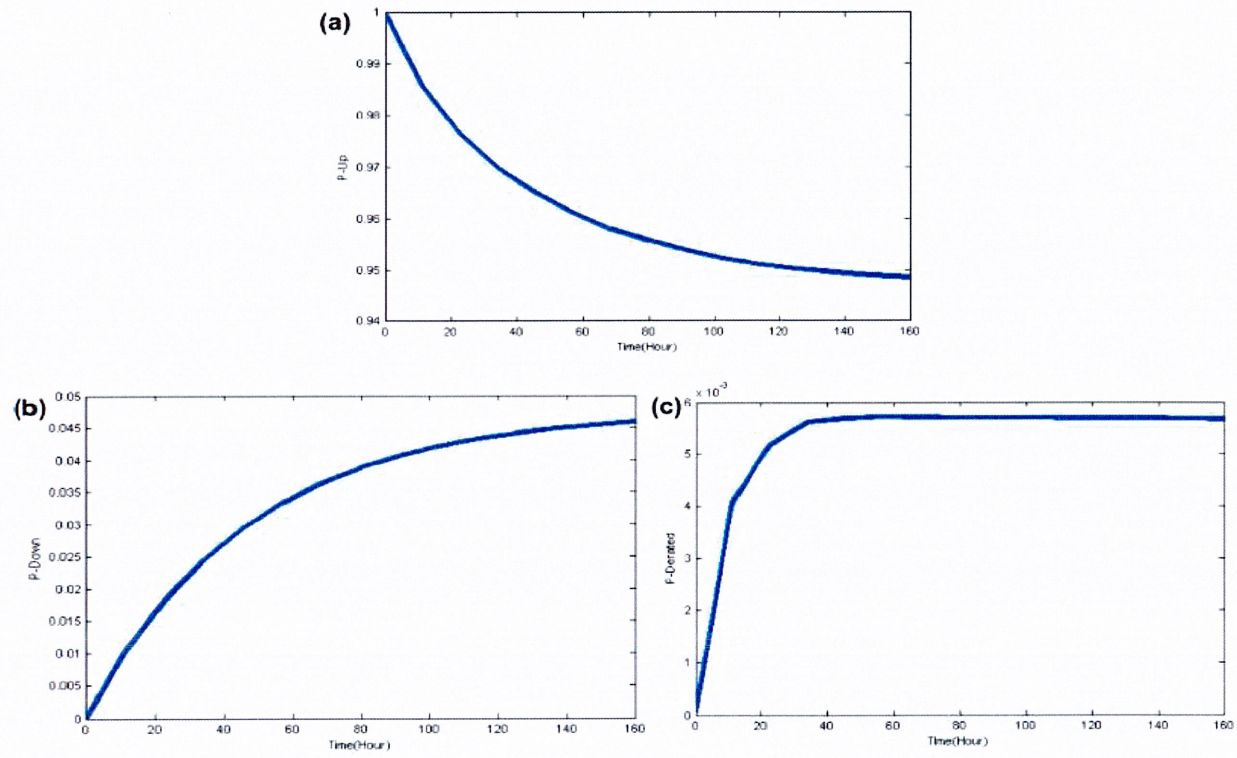


Figure (6-57) (a) TVA 4 results P273-Up, (b) TVA 4 Results P273-down, (c) TVA 4 results P273-derated.

6.7 Conclusions:

The production cost differentials between the member states creates opportunities for energy trading among GCC Countries. Referring to production, Costs between Member States calculated and presented in Table (6-9) using Uniform Prices and International fuel prices. There is difference between member states in in range of $10 to $100 per MWh. The capacity available for trading between member states is 10.5TWh during the year. The expected saving and benefits for the traded parties estimated to be equal to $105 Million to $1050 Million yearly for the traded parties. The estimated value of energy imported by member states are around $32.4, $40.5 and $45.5 Million dollars in the years 2012, 2013 and 2014 respectively as shown in Table (6-17). The estimated benefits from VoLL in years 2012, 2013 and 2014 due to support received in emergency support are $18.88, $17.60 and $19.48 million US dollars respectively. More results obtained by AURORA zonal prices, trading examples and benefits for the interconnection illustrated earlier in the present chapter.

The results of the feasibility of electrical energy trading among the GCC carried out through Electricity Market Simulator shown in this chapter. The results obtained by calculating the optimal operation schedule of the interconnected system, where related hourly Market Prices presented referring to the year 2015 for the high load season, and the low load season. If the power transfer in an interconnector reaches the limit (NTC), the zones of electricity market de-coupled with different market prices.

Two techniques applied in this chapter to model the three-state probabilities of the four TVA models. These techniques are the curve fitting

technique and the Neuro-Fuzzy technique. The average percentage error calculated from the results of these two models found 0.04% and 0.005% of the curve-fitting model and the Neuro-Fuzzy model, respectively. Through the obtained results, it found that the results from both models used are very similar to the results obtained by the Laplace Transforms.

The ANFIS model has advantages more than the curve-fitting model. The ANFIS model has more accurate resulted than the curve-fitting model. It is an average error percentage is ten times less than the curve-fitting model.

The target of 5 hours per year for the LOLE for the interconnected member states is calculated and found within the given limit of LOLE based on the methodology used to determine the LOLE for the GCCIA interconnection.

Chapter 7

Conclusions and Recommendation for Future

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Chapter 7

Conclusions and Recommendation for Future

7.1 Conclusion

This thesis is applied study covers modeling of GCC Electric Power Markets, Market Machines Reliability, Market Demand Forecasting, Benefits evaluation for energy exchanges and the Market Model for Trading Opportunities. This study deals with actual barriers to initiating the GCC Regional Electricity Market. It concluded that there is the number of barriers holding the traded parties in starting to participate in this Regional Market, where the uniform prices "subsided prices" was the main obstacle toward agree and fare price for the buyers and sellers.

The GCC Regional Market setup and structure based on GA and PETA. The targeted market base on member states and analysis of different markets worldwide is to have a voluntary market with optionally having one zone or multi-zonal prices.

Five objectives were targeted in this research, which are as follows:

1- Study readiness of the GCC Regional Electricity Market and recommend a Regional Market Model to be implemented for GCC countries.

2- The second objective is to create Model for Member States Electricity Demand.

3- The third objective is to explore the trading potential between these six nations and to create the Trading Opportunity Model for the interconnected countries.

4- The fourth objective is to identify the marginal cost for the energy generated by member states base on international fuel prices.
5- The fifth objective is to create the reliability model and examine the reliability for the switching machine, calculate LOLE for the interconnected networks.

It could be seen that to establish a new industrial growth in the oil-rich region, multiple angles and issues such as local politics, industrial reform and adoption of new global trends are some of the main points that need to be taken in consideration and addressed. The economic reason could be used as a driver for initiating a Regional Electricity Market based on the forecasted benefits calculated in chapter 6.

From the experience gained from different markets in the worldwide, GCCIA has the similar condition of SIEPAC in initiating the interconnection but it is border to border connection. The suggested steps for the GCC member states is initiating National Electricity Market and support the development to initiate Electricity Markets at KSA, UAE and Oman. Therefore, the Multi Zone Border to Border Regional Market Model with the ancillary services market is the recommended Regional Market Model as transition Model toward one voluntary Regional Electricity Market with ancillary services. The Market setup will be similar to Markets Model illustrated in Figure (2-21). GCC Market coupling proposed to be done when any member states start their National Electricity Market.

The GCC Interconnected Authority shall take the role in participating in development National and development of the Regional Electricity Market.

REM could develop from the freeze state of market "Trading base on energy need" toward voluntarily market participant as shown in Figure (2-21) by addressing the main barriers presented in section 2.4. The largest barriers in the Business Model are the energy subsidies that found in all GCC countries from generation sector to customer sector, which can be solved by moving the subsidies from the generation sector to the consumer sector. The suggested solution for the regulatory level barrier in national level is creating regional regulatory body to harmonize the rules and regulation needed to develop the REM. The suggested solution for the physical barriers is to increase number of market players by involving Dubai, Sharjah, and Northern Emirates networks in the power market as individual market player.

The economic benefit is a market driver for developing the market model GCC countries, which reach to billions of dollars yearly. After analyzing all member states it found the way of activating the regional market between the member states by shifting the Cooperative shape into competitive level of the electricity utilities to achieve better utilize for GCC resources to reflect accurate prices, enable demand-side response, and correct investment signals.

The REM shall introduce Intraday Market beside the Day Ahead Market to utilize the opportunities presented in both week ahead and day ahead Power Trading Opportunity Model for the interconnected countries, illustrated in Table (5-2) and Table (5-3) respectively. The Radar Opportunity Model is a new idea to present the demand and present the opportunity in different electricity market demand as presented in Figures

(5-2) and (5-3). It used by member state to monitor the trading opportunities for the Intraday, day ahead and next week trading.

Load demand is one of the main elements to present market opportunity and to identify the load forecasting for each market. Therefore, the forecasted load demands Model to prepare for a long-term contract between member states. Furthermore, the STLF and MTLF Models shall develop for the forming a deal for the same forecasted demand.

The tariff of the energy calculated economically and physically based on fixed and variable cost of the generating units. The production cost differentials between the member states creates opportunities for energy trading among GCC Countries. Referring to production costs between Member States calculated and presented in Table (6-10) using Uniform/shallow Prices and International fuel prices. There is difference between member states in the range of $10 to $100 per MWh. The capacity available for trade between member states is 10.5TWh during the year. The expected saving and benefits of the traded parties estimated to be equal to $105 Million to $1050 Million yearly for the traded parties.

The prices offered are based on the total costs of energy, which is equal to the agree tariff, where some member states using the cost plus model to identify the prices. It's suggested for member states think about offering prices based on next the dollar returning the fixed cost of the generated unit, which called the Marginal Cost Price. The next step for member states is to focus in returning operational cost and part of their fixed cost. This by itself is a good start to gain benefits from the regional trading.

In addition, the estimated benefits from VoLL in years 2012, 2013 and 2014 due to support received in emergency support are $18.88, $17.60 and $19.48 million US dollars respectively recorded in Table (6-14). The estimated benefits from the energy imported by member states are around $32.4, $40.0 and $45.5 Million dollars in the years 2012, 2013 and 2014 respectively as shown in Table (6-17).

The peak load forecasting is one of the important tasks for decision makers in proposing the planning for periodical operations, energy trading and facility expansion in the electricity sector. Peak load demand forecasting is central and integral processes for this purpose.

The results from the model for LTLF in Chapter 4 presents the forecasted load demand in considering the different expected growth in the GDP of the country. This will give more visibility to the market participate in the opportunities and also helps the decision makers to take the correct decision for planning of the periodical operations, energy trading and facility expansion in the electricity sector.

7.2 Recommendations for Regional Electricity Market Development

In order to create liberalized GCC Regional Power Market and preparation for coupling future local markets, the mentioned challenges in Chapter 3 need to address in a politically acceptable approach that would be within the member state's interest, to be economically beneficial, support the future strategies and does not require extreme modifications in the current set-up.

The following actions recommended for establishment of the national electrical power market in the GCC countries, which is part of the movement towards the development of the REM:

1. Create the Multi Zone Border to Border Regional Market Model.
2. Shift governmental subsidies shown in Figure (3-25) to the eligible costumers only and build the balanced economic model with a level of sustainability.
3. National support for power sector development in its current structural configuration shown in Figure (3-27).
4. Develop the National Regulatory toward allowance different types of market players to participate in the Regional Electricity forming a competitive Multinational Wholesale Model as shown in Figure (3-28 a and b).
5. Create a Regional Regulatory to develop the National Regulation toward allowance the generation companies participate in the Regional Electricity Market forming a Multinational Wholesale Model for Single buyer and Generation Companies as shown in Figure (3-28 a and b).
6. Adoption and integration of alternative energy resources.
7. Access to additional market participants and variety in providing services.
8. Alignment of local regulations to support and promote power trading.
9. Accounting for the Interconnector in local system operations and generation expansion plans.
10. Support of academic research and awareness towards the benefits of power trading and its effects on the welfare of the nations.

11. Increase the competition between the players by open the REM to the investors.

7.3 Possible Future Research

There is a wide area for future researches of studies, which consist of a number of themes and subject. The future researches are as follows:

1- The Regulatory Model to be used for the GCC REM: GCC Regional Regulatory is one of hot subject in this region. There are a variety number of Regulatory Model and setup could be study for the Regional Markets. Each Model has its own reasons to initiate the market and objective to achieve. These different types of Regulatory Model could be having similar target and objectives with GCC REM. The study recommended checking the applicable Model for the GCC REM. The outcome of the study is to find the most suitable Regulatory framework, objective and targets for the GCC REM. The outcome of the study could end with creating a unique type of Regional Regulatory Model to be proposed to address the GCC REM base on applied Regional Market Model used.

2- Studying the mechanism suggested for Auction and Market Price for the GCC REM: A detail study to allocate the most suggested models for the Auction and the methodology used to clear auction. The market price should be studied and the forecasted Market Price to be Model uses price indicator for this market.

3- Studying connecting the GCC REM to another regional market, which helps in activating the GCC REM: One of the biggest opportunities is to study connecting this market

4- Six individual studies for each of the member state recommended further studies to find out electricity market model for each of them.
5- Develop STLF and MTLF Models for GCC countries helping in the forming a deal for the same forecasted demand.

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Appendix (A)

GCC Historical Socioeconomic Data

The appendix shows the socioeconomic data for GCC collected for the LTLF study as follows:

Table (A-1) Bahrain Historical Socioeconomic Data

Year	Population		GDP	
	Number	Growth rate (%)	US$	Growth rate (%)
1990	493,000		$4,229,787,379	
1991	507,000	3%	$4,616,223,404	10%
1992	516,458	2%	$4,751,063,830	9%
1993	530,225	3%	$5,200,265,957	3%
1994	544,366	3%	$5,567,553,457	17%
1995	558,879	3%	$5,849,467,819	5%
1996	573,792	3%	$6,101,861,436	4%
1997	589,115	3%	$6,349,202,394	4%
1998	604,842	3%	$6,183,776,596	-3%
1999	620,989	3%	$6,621,010,372	7%
2000	637,582	3%	$9,062,906,915	37%
2001	661,317	4%	$8,976,207,713	-1%
2002	710,554	7%	$9,632,155,053	7%
2003	764,519	8%	$11,074,822,074	15%
2004	823,744	8%	$13,150,166,755	19%
2005	888,824	8%	$15,968,726,862	21%
2006	960,425	8%	$18,505,053,191	16%
2007	1,039,297	8%	$21,730,000,000	17%
2008	1,103,496	6%	$25,710,877,660	18%
2009	1,178,415	7%	$22,938,218,085	-11%
2010	1,228,543	4%	$25,713,271,277	12%
2011	1,195,020	-3%	$29,044,069,149	13%
2012	1,234,900	3%	$30,756,462,766	5%
2013	1,274,800	3%	$32,897,606,383	8%
2014	1,316,500	3%	$33,851,063,830	6%

Table (A-2) Kuwait Historical Socioeconomic Data

Year	Population		GDP	
	Number	Growth rate (%)	US$	Growth rate (%)
1990	2,058,832		$18,427,778,571	
1991	2,007,110	-3%	$11,008,793,176	-40%
1992	1,914,590	-5%	$19,858,555,215	80%
1993	1,822,071	-5%	$23,941,391,391	21%
1994	1,729,551	-5%	$24,848,483,838	4%
1995	1,637,031	-5%	$27,191,689,008	9%
1996	1,637,906	0%	$31,493,987,642	16%
1997	1,686,256	3%	$30,354,434,553	-4%
1998	1,766,247	5%	$25,941,929,462	-15%
1999	1,853,152	5%	$30,121,879,435	16%
2000	1,929,470	4%	$37,711,864,407	25%
2001	1,990,022	3%	$34,890,772,742	-7%
2002	2,042,215	3%	$38,137,545,245	9%
2003	2,095,993	3%	$47,875,838,926	26%
2004	2,166,344	3%	$59,440,108,585	24%
2005	2,263,604	4%	$80,797,945,205	36%
2006	2,389,498	6%	$101,550,654,721	26%
2007	2,538,591	6%	$114,641,097,818	13%
2008	2,705,290	7%	$147,395,833,333	29%
2009	2,881,243	7%	$105,899,930,507	-28%
2010	3,059,473	6%	$115,419,050,942	9%
2011	3,239,181	6%	$154,027,536,232	33%
2012	3,419,581	6%	$174,070,025,009	13%
2013	3,593,689	5%	$174,161,495,063	0%
2014	3,753,121	4%	$163,612,438,510	-6%

Table (A-3) KSA Historical Socioeconomic Data

Year	Population		GDP	
	Number	Growth rate (%)	US$	Growth rate (%)
1990	16,361,453	3%	$116,778,107,707	22%
1991	16,890,555	3%	$131,335,914,553	12%
1992	17,398,523	3%	$136,304,138,852	4%
1993	17,890,529	3%	$132,151,401,869	-3%
1994	18,373,412	3%	$134,327,102,804	2%
1995	18,853,670	3%	$142,457,676,903	6%
1996	19,331,311	3%	$157,743,124,166	11%
1997	19,809,633	2%	$164,993,858,478	5%
1998	20,302,193	2%	$145,772,800,000	-12%
1999	20,825,955	3%	$160,957,066,667	10%
2000	21,392,273	3%	$188,441,866,667	17%
2001	22,007,937	3%	$183,012,266,667	-3%
2002	22,668,102	3%	$188,551,200,000	3%
2003	23,357,887	3%	$214,572,800,000	14%
2004	24,055,573	3%	$258,742,133,333	21%
2005	24,745,230	3%	$328,459,608,764	27%
2006	25,419,994	3%	$376,900,133,511	15%
2007	26,083,522	3%	$415,964,509,673	10%
2008	26,742,842	3%	$519,796,800,000	25%
2009	27,409,491	2%	$429,097,866,667	-17%
2010	28,090,647	2%	$526,811,466,667	23%
2011	28,788,438	2%	$669,506,666,667	27%
2012	29,496,047	2%	$733,955,733,333	10%
2013	30,201,051	2%	$744,335,733,333	1%
2014	30,886,545	2%	$746,248,533,333	0%

Table (A-4) Qatar Historical Socioeconomic Data

Year	Population		GDP	
	Number	Growth rate (%)	US$	Growth rate (%)
1990	476,478	3%	$7,360,439,211	13%
1991	485,114	2%	$6,883,516,484	-6%
1992	489,668	1%	$7,646,153,984	11%
1993	492,120	1%	$7,156,593,654	-6%
1994	495,179	1%	$7,374,450,769	3%
1995	501,019	1%	$8,137,911,978	10%
1996	511,864	2%	$9,059,340,385	11%
1997	528,213	3%	$11,297,802,115	25%
1998	548,618	4%	$10,255,495,027	-9%
1999	570,643	4%	$12,393,131,868	21%
2000	593,453	4%	$17,759,890,110	43%
2001	613,720	3%	$17,538,461,538	-1%
2002	634,388	3%	$19,363,736,264	10%
2003	668,165	5%	$23,533,791,209	22%
2004	732,096	10%	$31,734,065,934	35%
2005	836,924	14%	$44,530,494,505	40%
2006	988,448	18%	$60,882,142,857	37%
2007	1,178,955	19%	$79,712,087,912	31%
2008	1,388,962	18%	$115,270,054,945	45%
2009	1,591,151	15%	$97,798,351,648	-15%
2010	1,765,513	11%	$125,122,306,346	28%
2011	1,905,437	8%	$169,804,735,989	36%
2012	2,015,624	6%	$190,289,835,165	12%
2013	2,101,288	4%	$201,885,439,560	6%
2014	2,172,065	3%	$210,109,065,934	4%

Table (A-5) UAE Historical Socioeconomic Data

Year	Population		GDP	
	Number	Growth rate (%)	US$	Growth rate (%)
1990	1,811,458	6%	$50,701,443,696	22%
1991	1,913,190	6%	$51,552,165,622	2%
1992	2,019,014	6%	$54,239,171,888	5%
1993	2,127,863	5%	$55,625,170,253	3%
1994	2,238,281	5%	$59,305,093,980	7%
1995	2,350,192	5%	$65,743,666,576	11%
1996	2,467,726	5%	$73,571,233,996	12%
1997	2,595,220	5%	$78,839,008,445	7%
1998	2,733,770	5%	$75,674,336,283	-4%
1999	2,884,188	6%	$84,445,473,111	12%
2000	3,050,128	6%	$104,337,372,362	24%
2001	3,217,865	5%	$103,311,640,572	-1%
2002	3,394,060	5%	$109,816,201,498	6%
2003	3,625,798	7%	$124,346,358,067	13%
2004	3,975,945	10%	$147,824,370,320	19%
2005	4,481,976	13%	$180,617,018,380	22%
2006	5,171,255	15%	$222,105,922,396	23%
2007	6,010,100	16%	$257,916,133,424	16%
2008	6,900,142	15%	$315,474,615,739	22%
2009	7,705,423	12%	$253,547,358,747	-20%
2010	8,329,453	8%	$286,049,336,038	13%
2011	8,734,722	5%	$348,526,072,158	22%
2012	8,952,542	2%	$373,429,543,907	7%
2013	9,039,978	1%	$387,192,103,472	4%
2014	9,086,139	1%	$399,451,327,434	3%

Table (A-6) Oman Historical Socioeconomic Data

Year	Population		GDP	
	Number	Growth rate (%)	US$	Growth rate (%)
1990	1,812,159		$11,685,045,608	
1991	1,892,345	4%	$11,341,482,445	-3%
1992	1,979,914	5%	$12,452,275,683	10%
1993	2,066,264	4%	$12,493,107,932	0%
1994	2,139,539	4%	$12,918,855,657	3%
1995	2,191,864	2%	$13,802,600,780	7%
1996	2,219,768	1%	$15,277,763,329	11%
1997	2,227,596	0%	$15,837,451,235	4%
1998	2,224,922	0%	$14,085,373,212	-11%
1999	2,225,481	0%	$15,710,148,244	12%
2000	2,239,403	1%	$19,507,412,224	24%
2001	2,272,547	1%	$19,452,015,605	0%
2002	2,323,203	2%	$20,142,782,835	4%
2003	2,385,075	3%	$21,633,810,143	7%
2004	2,448,194	3%	$24,763,589,077	14%
2005	2,506,891	2%	$31,081,924,577	26%
2006	2,553,376	2%	$37,215,864,759	20%
2007	2,593,750	2%	$42,085,305,592	13%
2008	2,652,281	2%	$45,905,331,599	9%
2009	2,762,073	4%	$48,388,296,489	5%
2010	2,943,747	7%	$58,641,352,406	21%
2011	3,210,003	9%	$67,937,581,274	16%
2012	3,545,192	10%	$76,341,482,445	12%
2013	3,906,912	10%	$78,182,574,772	2%
2014	4,236,057	8%	$81,796,618,986	5%

الملخص: أطار صناعة السوق الإقليمية للكهرباء خلال مرحلة الانشاء لتحسين موارد الطاقة وموثوقية شبكات الكهرباء في دول مجلس التعاون

هذا بحث تطبيقي لإنشاء سوق إقليمية لتجارة الطاقة الكهربائية يهدف لتحسين استخدام الموارد على أسس اقتصادية. وستغطي هذه الأطروحة الوحدات الرئيسة المطلوبة لبناء سوق إقليمية للكهرباء في دول مجلس التعاون الخليجي، وهي مكملة لدراسة المهاوش للسوق السعودية بإضافة بقية دول مجلس التعاون.

فالدول تعمل جاهدة في مرحلة ما بعد ربط شبكاتها الكهربائية ورفع مستوى أمن واستقرار الشبكات والحصول على الدعم اللازم في حالات الطوارئ إلى الاستفادة من الرابط الكهربائي بشكل تجاري واقتصادي. لذلك فإن الطريق للوصول إلى سوق إقليمية للكهرباء تحتاج إلى ثلاث خطوات رئيسة. الخطوة الأولى هي تقييم استعداد البلدان المترابطة نحو سوق تجارة الطاقة. والثانية هي تشكيل وتحديد النموذج التجاري المقترح من خلال التجارب العالمية في اسواق الكهرباء الإقليمية. والثالثة هي تحديد أوجه القصور للوصول إلى السوق الإقليمية، ووضع المقترحات والتوصيات نحوها. فتمت دراسة الدول وأوضحت بشكل موضوعي مستوى تطور دول المجلس نحو تفكيك قطاع الكهرباء إلى مؤسسات تلعب أدوار محددة في سوق تجارة الطاقة. وكذلك تم دراسة الأسواق الإقليمية واقترح النموذج المناسب. وتلي ذلك تقديم المقترحات والتوصيات لتطوير النموذج المعمول به في القطاع الكهربائي في دول المجلس والمشغّل للسوق.

أن السوق تعتمد في أساسها على عرض وحدات التوليد في الخليج والطلب المتوقع للكهرباء. لذلك تم دراسة أحمال دول مجلس التعاون لدول الخليج العربية، وعمل نموذج للأحمال باستخدام طريقتي متعددة الانحدار والبرمجة اللغوية العصبية (Multi-Regression وANFIS)، وذلك لمعرفة الطلب المستقبلي على الطاقة. واستخدمت الاحمال المتوقعة لدراسة الفرص التجارية المحتملة. كما تم عمل نموذج لفرص تبادل وتجارة الطاقة في أوقات الذروة بين دول مجلس التعاون لتحديد الصفقات البينية المتوقعة واوقاتها وحجم التداول المتوقع. إلى جانب ذلك تم دراسة الفوائد المتوقعة من تلك الصفقات والتي ستكون المحفز الرئيسي للسوق.

ولمعرفة أسعار السوق للطاقة فقد تم احتساب تكلفة الإنتاج باستخدام برنامجي AURORA وPROMO واستعرض بعدها نطاق أسعار الطاقة. وباستخدام الاحمال المتوقعة والاسعار فقد تم احتساب الفوائد والتوفير المتوقعة للصفقات التجارية المستقبلية. إلى جانب ذلك تم احتساب حجم وفورات الدول من عمليات تباد الطاقة الغير مجدولة، وقيمة الطاقة المفقودة VoLL.

كما تم دراسة موثوقية النظام خلال عمليات تغيير المنتج للطاقة وأوضحت نتائج الدراسة أن موثوقية نظام السوق عالية خلال عملياتها باستخدام طريقتي لابلاس ترانسفورمز والبرمجة اللغوية العصبية ANFIS. كما أظهرت نتائج دراسة الموثوقية المتعلقة بالفاقد المتوقع للأحمال (LOLE) باستخدام برنامج أورورا وطريقة مونتي كارلو بأن المتوقع فقده يقل عن خمس ساعات في السنة كما هو معتمد لدول مجلس التعاون.

وبذلك تم عمل النموذج المقترح للسوق الإقليمية للكهرباء واحتساب أسعار انتاج الطاقة والكميات المتوفرة في الدول، واحتساب المتوقع من الاحمال، وعمل نموذج للطلب المتوقع، وتم احتساب الفوائد المتوقعة من العمليات التجارية وقياس موثوقيتها في هذه الدراسة. وأكدت الدراسة على جدوى انشاء سوق تجارة الطاقة بين دول مجلس التعاون بموثوقية وجدوى اقتصادية، كما اقترحت عدد من التوصيات التي ستساهم في بناء السوق التجارية المشتركة لدول مجلس التعاون.

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أطار صناعة السوق الإقليمية للكهرباء خلال مرحلة الانشاء لتحسين موارد الطاقة وموثوقية شبكات الكهرباء في دول مجلس التعاون

أطروحة مقدمة كجزء من متطلبات الحصول على درجة الدكتوراه

في الهندسة (الهندسة الكهربائية)

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