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SAUDI ELECTRICITY SUPPLY INDUSTRY FRAMEWORK DURING TRANSITION PERIOD IN THE DEREGULATION PROCESS

Thesis
Submitted in Fulfillment of the Degree of
Doctor of Philosophy in Electrical Engineering

By

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Under the Supervision of
Prof. Isa Salman Qamber

June 2007

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بسم الله الرحمن الرحيم

In the name of Allah the most Compassionate

And the most Merciful

رسالة الدكتوراه في الهندسة الكهربائية

الإطار العام لصناعة الكهرباء بالسعودية خلال الفترة الانتقالية لعملية إعادة التنظيم

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Tareq A. Al-Muhawesh
2007

إهداء

إلى أبي وألف رحمة على أمي

Dedication

To my Father, Abdullah, and my late Mother, Norah.



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First, and foremost, praise is due to Allah Almighty, in whom I believe and depend on. My deepest appreciation goes to my wife Samia and my children Abdullah, Abdullatif, Norah, Mohammed and "Affari" for their understanding and patience throughout my studies. I would like to thank my sisters and brothers for their love and support.

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ABSTRACT

Governments all over the world, in the recent past, are seriously adapting and implementing privatization through restructuring or deregulating the electrical industry. The reasons behind deregulation differ from one country to another. However, the paramount reason is to avoid uncertainty of the future. This uncertainty is due to expected tremendous load demand growth, depletion of natural resources, and negative environment impact. Other reasons could be seeking competition, inefficiency of the existing electrical utilities, avoiding subsidies from government's budget, possibility of getting power cheaper elsewhere.

Since deregulation process has already started in Saudi Arabia, management and staffs of Saudi Electricity Company (SEC) are recommended to work together to form an efficient industry framework. The efficient design is required to *keep prices down and satisfy the future expected high demands without the need of financial support while keeping in mind environment protection and reliable & safe power supply to customers.*

This study proposes a framework for SEC which should encourage power system expansion in the right direction.

Three main questions arise during the course of this study:-

- Where will be SEC future generation expansion?
- What is the future shape of Saudi electricity supply industry?
- Which is cheaper to transmit electricity or fuel from one province to another province?*

Answering any of the above questions which needs gathering of information and forming a complete optimization model and testing it, is by it self a complete thesis.

This study started by giving a brief about Saudi Arabia electricity industry. It gives SEC data at year 2005 including some of the current practices and parameters. The ongoing deregulation activities by SEC are also explained.

---

* This is verbally recommended by Prof. Abdullah Al-Shehry (Faculty of King Fahad University of Petroleum & Minerals and V.P. of Saudi Regulatory Authority)

The most popular market models are reviewed and more attention is given to the participants as the critical links in any deregulated system. As a result, SEC framework is proposed, including the pricing methods and trading techniques.

The complete linear model of the MW LP-Based OPF which is used to know the future generation potential areas in any utility is proposed. The study also explains the available power flow optimizing tools. As well, ELD is considered through the study as the basic optimization tool to dispatch the power system.

The model established through the study is applied to the eastern province of Saudi Arabia. Case studies are investigated to know the potential generation areas and finally the results are analyzed.

Finally, it is concluded by the summary findings and discussing the directions of possible future researches.

ABBREVIATIONS

ATC	*Available Transfer Capability*
ASP	*Ancillary Services Price*
BL	*Business Line*
CBM	*Capacity Benefit Margin*
CCC	*Customer Call Center*
CMS	*Congestion Management System*
CSC	*Customer Service Company*
CSP	*Customer Service Providers*
CTA	*Consolidated Transmission Area*
DISTCO	*Distribution Company*
DLR	*Dynamic Line Rating*
DSP	*Distribution Service Price*
DTA	*Developing Transmission Area*
ECRA	*Saudi Electricity & Co-generation Regulatory Authority*
ELD	*Economic Load Dispatch*
ERP	*Enterprise Resource Planning*
ESI	*Electricity Supply Industry*
ETC	*Existing Transmission Commitments*
EUP	*End User Prices*
FACTS	*Flexible AC Transmission System*
FERC	*Federal Energy Regulatory Commission in USA*
GEC	*General Electricity Corporation*
GENCO	*Generation Company*
GRIDCO	*Grid owning Company*
IOU	*Investor Owner Utility*
IPP	*Independent Power Producers*

IWPP	*Independent Water and Power Producers*
ISO	*Independent System Operator*
LINDO	*Linear Interactive & Discrete Optimizer (powerful tool for solving linear programming problems)*
LP	*Linear Programming*
LR	*Lagrange Relaxation*
MO	*Market Operator*
NCM	*Nodal Congestion Management*
NEM	*National Electricity Market in Australia*
NEMMCO	*National Electricity Market Management Company in Australia*
NGC	*National Grid Company in England & Wales*
OA	*Operating Area*
OASIS	*Open Access Same Time Information System*
OPF	*Optimal Power Flow*
PES	*Public Electricity Suppliers in UK*
PSP	*Power Service Providers*
PP	*Power Pool*
PPI	*Process Planning Improvement*
PURPA	*Public Utilities Regulatory Policy Act in USA*
PX	*Power Exchanger*
REC	*Regional Electricity Company*
RI	*Regulatory Institute*
RIA	*Refined Immune Algorithm*
RP	*Regulation Price*
RSP	*Retailing Service Price*
RTO	*Regional Transmission Organization*
SA	*Settlement Administrator*

SAP	*Systems Applications and Products*
SC	*Schedule Coordinator*
SCADA	*Supervisory Control And Data Acquisition*
SCUC	*Security Constrained Unit Commitment*
SEC	*Saudi Electricity Company*
SED	*Saudi Electricity Distribution*
SENG	*Saudi Electricity National Grid*
SESI	*Saudi Arabia Electricity Supply Industry*
SESOM	*Saudi Electricity System Operation and Marketing*
SLA	*Service Level Agreement*
SMP	*System Marginal Price*
SR	*Saudi Riyal (1 $ = 3.761 SR)*
SWCC	*Saline Water Conversion Corporation*
TCM	*Transmission Congestion Management*
TOP	*Trading Outside the Pool*
TP	*Transmission Provider*
TQM	*Total Quality Management*
TRANSCO	*Transmission Company*
TRM	*Transmission Reliability Margin*
TSP	*Transmission Service Price*
TTC	*Total Transfer Capability*
UC	*Unit Commitment*
UDC	*Utility Distribution 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 capacity of generators, voltage control and black start capability. [5]

ARAMCO is the only oil company in Saudi Arabia.

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 price of electricity.[25]

Contract for Differences is a type of bilateral contract where a seller (generator or retailer) is to be paid 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. [5]

Distribution Companies manage and maintain the electricity distribution network including technical support, assets management, planning services, financial support, and operating & maintaining of all distribution network (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 generation 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.

Hedge "is a transaction that may consist of cash instruments or derivatives and is used to offset risks associated with certain positions by establishing opposing positions. Hedge is defined as a position or combination of positions, which could reduce some types of risk. An example of a hedge is the purchase or sale of futures contracts to reduce the interest rate risk by offsetting cash market transactions at a later date. ***Hedging*** is the process of reducing uncertainty of future price movements."[38]

Independent Power Producer (IPP) is a power plant that owns and operates one or more generators 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.

LINDO is a powerful tool for solving linear programming problems. More details are illustrated in Appendix 3.

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

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

Market Network Service Providers (MNSP's) are network service providers who provide market service.

Market Rules are the operational rules sited by the regulator to be mandatory to 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."[5]

Postage-stamp pricing is a simple charge for transmission per kWh or for peak kW: it treats generation and consumption as being at a single point and ignores costs of transmission due to line losses and congestion. [3]

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. [38]

Sensitivity Range is a command in LINDO software to display the sensitivity analysis of the currently installed solution of the model in memory. More details are illustrated in Appendix 3.

Settlement Administrator (SA) or Schedule Coordinator (SC) is the entity responsible for the settlements among market participants. It could be joined with the system operator or market operator under one entity or it could be separated.

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. [36]

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 is to be considered as the trade price for all transactions in the given period. [36]

Tagging is a mechanism for scheduling the physical transfer of power between control areas, also, called TIS (Transaction Information System). [38]

Transmission Network Service Providers (TNSP's) operate the high voltage networks in the NEM that transmit electricity from generating units to distribution grids and some customers. [26]

LIST OF SYMBOLS

P_{gi}	The real power in MW generated by a power plant at bus i.
P_{li}	The real power in MW delivered to a load from bus i.
P_{dij}	The real power in MW delivered from bus i to bus j.
C_{gi}	Unit Generation cost of producing one MWH of energy at bus i.
C_{ij}	Unit cost of wheeling one MWH from bus i to bus j.
n	Set of all bus indices.
N_{ij}	No. of circuits between bus i and bus j.
P_{gi}^{min}	Minimum real power output at generation bus i.
P_{gi}^{max}	Maximum real power output at generation bus i.
CL_{ij}	Line capacity limit of MW's between bus i and bus j

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1. INTRODUCTION

1.1 Deregulation History

Since the start of utilizing the electric energy in its basic shape, until today, the way in delivering energy to customers has gone through various stages according to the needs, capability, knowledge, technology, and rules. Starting without regulators until it is found necessary to have regulators govern the small utilities before more than a century ago. Then, vertically integrated utilities became the most popular practice all over the world with little differences in detailed practices. Despite those differences, typically, such utilities own three major business lines namely generation, transmission and distribution covering a specific geographic area. Such utility is self dependent in all aspects from technical support to auxiliary services and billings. However, some of utilities are getting financial support (subsidy) from their governments to avoid high bills on customers. [38]

Due to various reasons and needs, as explained in the previous paragraph, restructuring of electric industry had started in different countries all over the world since 80th until now and it passes through so many stages which differ according to the utility set up. But the most common stages can be listed as follows:-

- Rule to be 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's to participate in generation.
- Allowing bulk customers to choose their suppliers.
- Establishing ISO or RTO or PX or a combination of two or all of them.
- Allowing all customers to purchase energy from any supplier in a complete competitive market.

Each country has its own time table in going through some or all of the above listed stages in addition to other detailed steps suiting the uniqueness of the industry.

Table 1.1 lists the deregulation process calendar which could give a brief idea about the electrical energy industry movement toward competitive market.

From the calendar, we can conclude that deregulation in electric industry was initiated in the 80th in Chile and spread all over the world with rapid movements in 1996 toward competition market and it will continue until solid outputs from experiences approve its failure or give support to perfect models to overcome all drawbacks from the system. [3]

Table 1.1 Deregulating Process Calendar [3, 4, 5, 6, 28, 36, 38, 39]	
Year	**Action toward a competitive market**
1978	Public Utilities Regulatory Policy Act (PURPA) initiated the deregulation policy in USA by allowing IPP's to enter to the market.
1982	Start of restructuring in Chile which is also considered as the first country in the world had adapted the competitive market through deregulation. Chile action encouraged other South American countries like: Argentina, Bolivia, Colombia, Peru, and Brazil to adapt the same system.
1989	England and Wales initiated the deregulation policy in UK.
1990	- England and Wales started privatization and introduced competition in the industry. - Norway initiated the deregulation policy.
1991	Australia initiated the deregulation policy.
1992	- Energy Policy Act mandated the electric utility to become deregulated in USA. - IPP's are allowed to enter in the electric industry of Thailand.
1993	European Community allows bulk customers to purchase from any supplier in the community.
1995	IPP's are allowed to enter in the electric industry of Japan.
1996	- FERC in USA issued a rule for transmission open access. - ISO was established in USA (California, Texas, and Midwest). - NEMMCO was established in Australia. - Alberta in Canada started introduced competition in the industry. - Bangladesh initiated the deregulation policy. - New Zealand wholesale market started. - European Union Council initiated the deregulation policy. - Norway and Sweden introduced competition in the industry.
1998	- England and Wales allow all customers to purchase from any supplier. - Germany allows all customers to purchase from any supplier. - Spain and Netherlands introduced competition in the industry. - California allows bulk customers to purchase from any supplier. - The National Electricity Market (NEM) in Australia was started.
1999	- FERC issued a rule for Regional Transmission Organization (RTO) in USA. - European Union, Alberta in Canada, and Pennsylvania in USA allow all customers to purchase from any supplier. - Korean electricity reform was initiated.
2000	- Japan allows bulk customers to purchase from any supplier. - Thailand approved the proposed plan for the reform. - Saudi Arabia issues a rule to start SEC as a first step toward deregulating the industry.
2001	- Separation of generation assets from the Korean Power Company.
2002	- California allows all customers to purchase from any supplier. - Ontario in Canada introduced competition in the industry.
2003	- SEC is reformed with the three main components working separately from technical aspect but still financially linked. - Thailand power pool was established. - Japan amended their reform Act to go for full retail competition in 2007.

1.2 Why to Deregulate?

Even though, many of electric utilities around the world are either deregulated or in the transition period toward deregulation, some others are still worried about the negative impacts which could happen from opening the market and reducing the regularities.

In order to help any utility to decide either to deregulate or not, it should be aware of the following facts:-

- It is wrong to conclude that privatization is needed in all cases.
- Each utility has its own characteristics which affect the decision.
- The country culture, rules, and size of industry where the utility exists has major effect in the decision.
- The system parameters and the location have another effect.
- Small market cannot be put in competition.[7]
- The following list gives some reasons to support the deregulation decision which could be applicable to a good number of utilities in the world.

WHY TO DEREGULATE?
Avoiding subsidies from government's budget. [27]
Shifting from monopoly market will lead to more fair prices for each service.
Efficient power plants are expected to be built by IPP's to compete with the market which will reduce the cost. [34]
Innovations and renewable energy will find better atmosphere. [23]
Inefficiency of the existing electrical utilities.
Uncertainty of the future due to expected tremendous load demand growth, depletion of resources, negative environment impact.
Privatization will force the companies' management to be more toward increasing shareholders investments.
"International energy company concept – a company whose focus is becoming more global and more multi-purpose" [5].
Cost reduction due to competition.
Fuel supply stability.
Improve customer services.

Despite the above positive points, still some difficulties may face the deregulating process which could be solved or avoided or reduced by extra efforts and practices:-

- Electricity markets transactions complexity and data availability due to different parties involved which need sophisticated information technology with open access to every one all the time. [3]
- Due to the fact that energy can not be stored, up to nowadays technology, balancing supply with demand on real time between parties is a must which is a real challenge to the system operator. Any shortcomings could lead to partial or total blackout compared to a busy tone in communication service or using the stored gas when we have gas supply shortages. [28]
- Chance for mishandling of network by the Transmission Provider (TP) to increase profits being a natural monopoly company. In other words, we can say that the TRANSCO has natural monopoly characteristics. So, it is advised to overcome the misusage problem by establishing ISO to be independent from transmission network owner.
- Market power could be forced by some of the service providers and control the prices rather than to be controlled by the market prices. So, a very well established market is needed with corrective tools and supported by a well stated rules by regulatory to eliminate the market power negative effect.

1.3 Saudi Arabia Power History [39]

Geographically, Saudi Arabia is divided into four main operating areas namely: Central Operating Area (COA), Eastern Operating Area (EOA), Western Operating Area (WOA), and Southern Operating Area (SOA) as shown in Figure1.1. The reason for such divisions was due to very long distances between these areas.

Ten electrical companies were serving the whole country independently, in addition to the General Electricity Corporation (GEC) which was responsible for the northern area of Saudi Arabia.

In year 2000, all the companies and the GEC were joined together to form the Saudi Electric Company (SEC) which is considered a vertically integrated utility owning generation, transmission and distribution over the whole kingdom. Each Operating Area has a control center that performs operation and maintenance of a specific area. The temporary organization was setup as in Figure 1.2.

From 2002 to 2004 restructuring of the organization was carried out to be as per activities as shown in Figure 1.3 as a preliminary step for separation in the future.

Chapter 2 will give more detailed data about SEC and its latest practices along with ongoing activities toward deregulation and future plans.

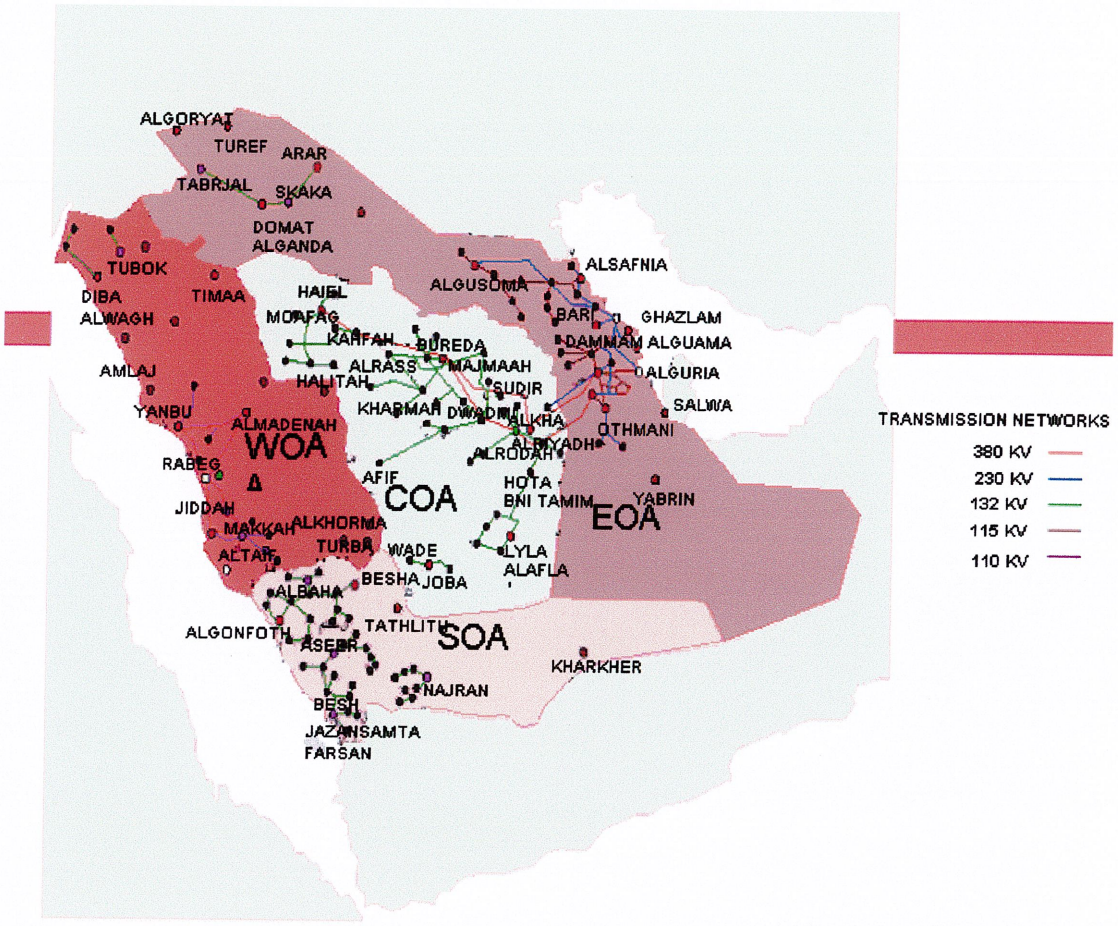


Figure 1.1
Saudi Arabia Map (Geographical Area and Transmission Network)

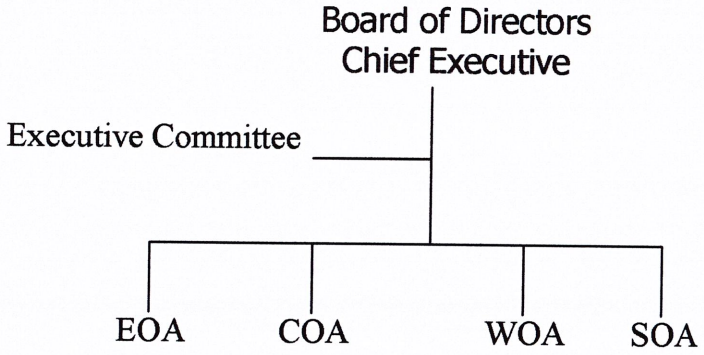


Figure 1.2
SEC at year 2000

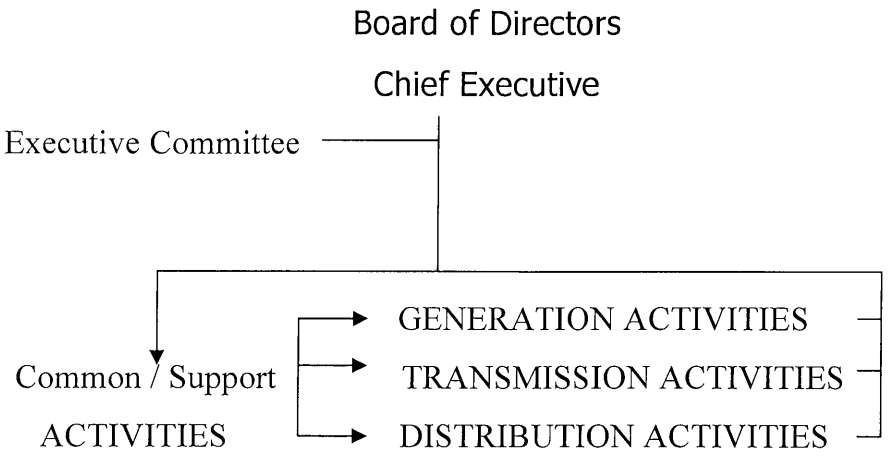


Figure 1.3

Restructure SEC Organization as per Activities

1.4 Literature Survey

To provide a good review of different opinions and to know the limitations of previous studies in the electric industry deregulating process; this section will summarize each reference according to its order in the bibliography.

Chapter 2, Chapter 3, and most of Chapter 5 of this study are actually a literature review for this study.

Jeffrey Hein in his master thesis in reference [1] proposed a new model for the entire United States' electrical industry to resolve most of the problems associated with the restructuring efforts at the time of his thesis. Chapter 4 of our study has the same direction of Mr. Hein but with different framework suitable for Saudi Arabia electrical industry uniqueness and requirements.

A good comparison between AC and DC power flow models is carried out by the authors of reference 2 which concluded that DC models are good approximation for AC models with less complications and it is advisable to replace them in the market type studies but not in the operational studies. This conclusion encourage us in this study to propose the MW LP-based OPF to be used for market studies such as finding the future generation potential areas.

As per reference [3] the transmission is a very complicated issue in the deregulation process due to the need of reliable interconnected system either with one path or with parallel paths for short distances or long distances. The question will be raised who pays for what portion from the overall cost? The book's author analyzed different pricing methods like: Flat Fee Method, Postage Stamp, MW–Mile, and Contract Path Method. The advantages vs. the disadvantages of those methods are discussed. Also, the author addressed the problem of transmission congestion due to the intendancy of buying from the cheapest generated power even if it is very far. This can be controlled by means of: Planning, Price incentives, and Congestion Management. The book's author believes that this is the time of deregulation. Though he has no solid results from practices all over the world, he is speculating that the deregulation will promote competition and cause reduction of costs, increase reliability, and increase availability of more energy services.

Reference [4] looks to the problem from different angle. Instead of giving attention to the cost techniques only, he suggests technical solutions like discussing the static compensator to solve the congestion problems. Other example is the idea of converting the existing generator to synchronous condenser to avoid high cost of adding generation capacity. The book's author discusses the transmission transfer capacity and encourages the utilization of Capacity Benefit Margin (CBM) technique to ensure access to generation from interconnected systems for meeting the required reliability and reducing the generated capacity. Dynamic Line Rating (DLR) is explained as an important and an effective in increasing transmission capacity with preference to the technique of Tension

Monitoring because the way it rates the line based on actual clearance and allows the operation of the line near to its design parameters. The book also, calls for modern teaching methods to encounter the deregulation matters to be included in the graduate education level which encourage utilities to hire employees with master degrees.

Reference [5] believes that advancement in technologies allow small producers to compete with others in a win-win atmosphere. The author considers three types of markets: Completely Market Driven atmosphere, Transitional Market, and Embryonic Free Market. International case studies with problems and solutions are addressed in this book. The author Lio says "The market should dictate when new generation is needed and where it is located." The author also, presented analytical tools for the modeling of the competitive power market and its analysis, presented issues related to transmission open access, and presented the application of Flexible AC Transmission System (FACTS) to utilize the capability of the system. Lio said "The explosion in the use of information technology has seen the introduction of computer-base work management systems, assets management systems, and control systems to manage system operation."

Reference [6] discusses most of the topics of the previous book but with more emphasis on the transmission level and power quality without case studies which make it more toward generalization. So, it is not advised to use the book as troubleshooter, on the other hand it can be taught in the universities due to the generality and being dealt with basic techniques.

Robertson reported that "market forces aren't doing enough to encourage the construction of extra generation to guard against shortages."[7]
In the same article, he points out a very logical conclusion "*small population make it hard to open the market, because there aren't enough customers to attract power companies.*"

In Plano, people knowing that they are paying the old prices for the product which becomes cheaper. "*The January deregulation was accompanied by a state mandate for a 6-percent reduction in electricity rates, anticipated to save an average of $4 a month for customers. But the Legisture also authorized fuel factor adjustments to be made twice a year by the companies to respond to fluctuations in natural gas prices.*"[8]

In Columbia, Wendy the writer of article [9] is referring to an official report that "*recommended splitting B.C. Hydro into separate generating, transmitting and distribution divisions and moving to "market" pricing that it said could lead to increase of 30 percent for residential customers and up to 60 percent for industrial customers.*"

[10-17] are selected articles on the subject where most of them are strongly against deregulation due to any drawback in the implementation experienced in their countries. Others are realizing this point relating the drawback to specific reasons and proposing some solutions.

"*Instead of abandoning deregulation, California should find a way to inject real competition into the market*" [10]

"*If all the troubled companies shut up shop tomorrow, the UK could end up some 10,000 MW short of what it needs during winter weeks. A California-style brown-out is not out of question*" [11]

"*Partial deregulation doesn't work, "he said "and deregulation without some sort of government structure doesn't work, either.*" [12]

"*it should be no surprise that Dynegy is seeking a return to its past as an energy generating and transporting company as the owner of a utility*" [13]

"Texas-New Mexico Power and Light Co. have donated the electricity required to decorate Bogotá's downtown area for the holidays. "he said "But energy deregulation changed all that. The City Council was told that the power company could not give away electricity." [14]

"There was nothing to be gained by deregulation here, because South Dakota already had some of the lowest electric rates in the country." [15]

"The chairman of the state Assembly Energy Company released a report Friedy charging that the state's energy deregulation policy has put New Yorkers at risk."[16]

*"Last year being the first time for cities to deal with deregulation, the city of Midland entered into a one-year contract with TXU Electric to serve the city's electric needs. The one-year contract was made because of an uncertain market."[*17]

Even though, those articles are seeking tangible proves and or scientific analysis, still can expose opinions and events which can lead to the correct direction and effective decisions. So, it worth full to analyze and study the concerns to end up with the best implementation of deregulation process.

The electric power consumption in Saudi Arabia is growing at annual rate of 07% compared to the world rate of more than 03% as in reference [18].

Dr. Lee & Dr. Heydt in reference 19 provide a procedure to give the right signals to suppliers & consumers to balance the power quality with its related costs.

Saudi Arabia is implementing a new hierarchy in the Saudi Electric Company (SEC) by 2003. This is reported as the first step of joining all Saudi Arabia under one company, the second step will be releasing generation business to private sector. [20]

Another factor which is indirectly related to deregulation through the optimization of load transfer for better utilization of transmission capability is the future plan of interconnecting gulf network expected to take place on year 2006 as per [21]. Until the time of releasing this study, the interconnection is under construction but not yet operated which means the schedule is expected to be delayed for some time.

Article [22] listed eleven lessons learned from California crises. The author concluded that deregulation process is not out of dangers in terms of generation shortage or grid congestion. He called also for greater regulatory resources.

Ref. [23] proposed a Refined Immune Algorithm (RIA) as a decision tool to perform the optimal generation expansion planning in a deregulated industry. Despite the traditional generation planning methodologies (linear & non-linear programming, etc...), a new algorithm based on artificial intelligence have been developed combined with Tabu search list to avoid invalid searches.

Security Constrained Unit Commitment (SCUC) is used by ref. [24] to calculate the optimal unit commitment with flexible operation conditions. The proposed algorithm covers both the generating units and the network flow constraints. The article's authors emphasize the importance of fuel diversity to minimize the cost satisfying other constraints like system parameter and environmental effects.

Even though ref. [25] had been reported for Japan's electrical restructuring purposes, it can be a good reference for other countries after tailoring it to its unique characteristics. The analysis and the comparison of the restructuring processes in several countries give the reader the main guidelines in forming electricity market structure. This reference was a good base for this study in proposing the Saudi electrical supply industry framework.

It is worthwhile to conduct comparative analyses of electricity reform in a group of countries with some common features. This has been done by ref. [26] which compared OECD Pacific countries in terms of reform policies, legislative process, market structure, and market design. Those countries namely: Australia, Japan, NewZeland, and Korea are all electrically isolated from other countries. Such common feature which is also valid for Saudi Arabia makes the report a good source of experiences to learn from.

Ref. [27] analyzes California crises and links it directly with the price capping in curtail prices and deregulating the wholesale price which make it high enough not to encourage new comers into the market.

Advice from the author of article [28] to Japan is to avoid a wait-and-see approach to deregulation due to the fact that electricity is so fundamental service in our daily life, however, he expects Japan to be very slow in deregulation process affected by California crisis.

Article [29] proposed a model based on game theory in new partially regulated environment to clarify the mechanism of power trading in determining the electricity price and transaction volume, where multiple utility companies and two IPP's negotiate their sales prices with a given set of large customers in the deregulated environment.

Game theory is a useful tool for analysis of effective power market as concluded in article [30] where two test systems were used to demonstrate the approach.

Dr. Richard Schuler with his Economics background conclude on ref. [31] that the market clearing prices are inversely related to the number of generating firms bidding to enter a single market. Also, the author briefly summarizes the effect of transmission constraints on the clearing price as it is considered to be additional charges to generation costs.

Ref. [32] recommended a securitization tool to be used to recover the stranded costs which are generated in the transition period from regulated to a competitive market. The article reported that securitization has a unique advantage of reducing the level of stranded costs while recovering it.

Changes in the value relevance of book value and earnings in response to deregulation are tested in ref. [33] by examining changes in coefficient magnitudes and incremental explanatory power for 9 years. Book value founded to be decreasing while earnings increasing.

Transmission Congestion Management's (TCM) role in power operation was emphasized by ref. [34] especially in a deregulated industry. Lower prices of larger generators under competitive market could direct the power flow to cause transmission congestion. The paper analyzed TCM types including NCM and ZCM. It concluded that different types of TCM to be adapted depending on the uniqueness of the industry and the stage of the restructuring process.

Acceptable limits of non participation to the load frequency control problem are called for in ref. [35] to allow any unit to enter to the system in any deregulated industry.

As per ref. [36], simple marginal prices are not covering startup and other generation costs needed to satisfy market participants. The same reference proposed Lagrange Relaxation (LR) based method to cover generators' costs at all times. After running sample system, the article concluded that demand elasticity has impact on prices and profits at peak hours.

The author of ref. [37] calls for immediate researches to design an efficient industry, edible, and resistant to market power. Also calls for enhancement of customer services and enhancement of operational techniques.

Reference [38] discussed most of the key issues in deregulation and its models with more emphasis on pricing, congestion management, tagging, energy trading, hedging, and stranded costs. The book also, gives full illustration about OASIS Functions. The author gave the following link between RTO & ISO "RTO could act as an ISO (non-profit institution), stand-alone transmission companies (for-profit TRANSCO), hybrids or any other form that could accomplish the aims of Order No. 2000. The flexibility in determining the future structure of RTOs is one of the appealing advantages of the final rule."

The information used from ref. [39] is purely from what is published only in the annual reports of SEC to avoid any conflict of interest since this study is reported by an engineer in SEC which I am proud of.

The last three references [40, 41, and 42] are the latest presentations related directly to the study subject presented to SEC management and outside seminars. These presentations are proposing the future framework of Saudi Arabia Electrical Industry (SESI).

1.5 Thesis Objectives

Saudi Arabia is undergoing deregulation of the electrical industry to introduce and increase competition among the power providers at the wholesale generation level and they may be encouraged to go further to the customers' level by giving them the right to choose their suppliers. So, the timing of this work gave an advantage to the researcher to:-

- Monitor the real steps taken by SEC in the deregulating process.
- Analyzing the pioneers' practices in the world in market structure of the electrical industry.
- Start from where others end in selecting the participants and the interface points.
- Avoid wrong practices in the decisions taken for separating system operator from transmission owners or not.
- Be clearer about what problems to be solved.

This study has two objectives; the first one which is minor in electrical engineering field and it is to be studied in more details by economists. This objective is to give the most suitable framework of energy market and specifying the interface points among parties. This work will give a proposed framework for SEC which should encourage power system expansion in the right direction. The methodology will depend on:-

- Other experiences.
- Knowledge of the real situations and constrains.
- Knowledge of religion and culture.

Even though, the market framework will depend on the pricing method as well as the network configuration and constraints. This part will not be completely covered in this work and it is to be left to economists. The absence of realism will make it hard for economists also to ensure any conclusion related to the market power which will be a good future research after deregulation take place in Saudi Arabia.

The second objective is to establish a tool to be used to know the future generation potential areas in any utility by achieving the following:-

- Linear Programming to be used in order to get the optimal location of future generation.
- To build a MW LP-Based OPF (using LINDO).
- To test the model by applying it to a real eastern province system in SEC.
- To run the model to different scenarios to know the potential generation areas.
- To analyze the results and give recommendations.

Beside the above listed objectives, this study will recommend some of related future studies.

2 SAUDI ELECTRICITY COMPANY

Utility Data [39]

SEC is the only utility in the kingdom of Saudi Arabia providing electricity to customers. It is a vertically integrated utility owning generation, transmission, distribution and General Services like: Facilities (office services), Industrial Security, Transportation, Finance, Information Technology (IT), Materials, and Human Resources.

By the year 2005, SEC had around 29000 employee serving all business lines mentioned above for the final service which is providing a reliable and safe energy to almost 4.7 million customers in the four operating areas distributed as shown in Figure 2.1.

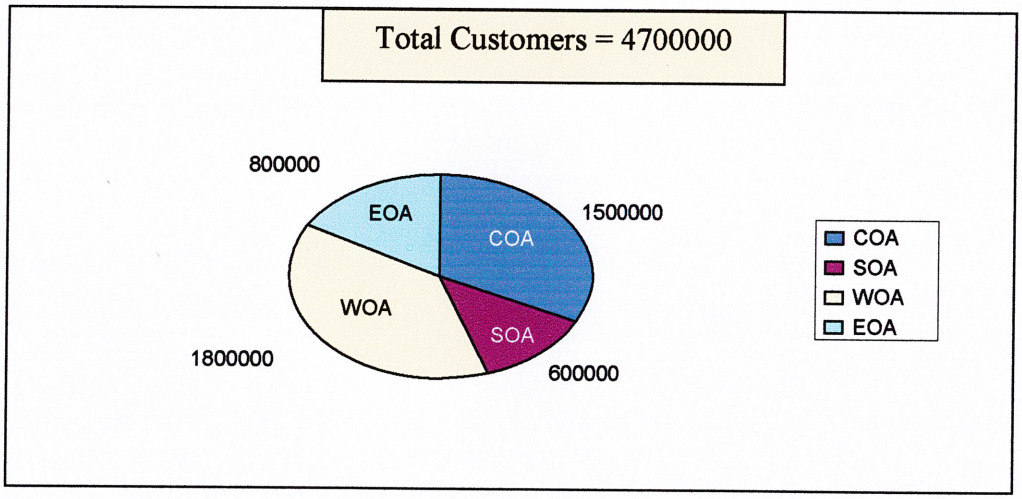


Figure 2.1
No. of Customers per Operating Area (year 2005)

2.1.1 Main Business Lines

Distribution business line is responsible for customer service, the low voltage network (127/220/380 V), and the medium voltage network less than 110 KV (13.8/69 KV).

Distribution B.L. is also responsible for isolated power plants up to the capacity of 20 MW.

Transmission business line is responsible for the network with voltages 110 KV and above, taking care of their customers at their level. Transmission also provides support to the operations & maintenance groups in the Operating Areas (OA) during load shedding and emergency restoration activities. In addition, transmission B.L is providing system protection and control. System planning in transmission B.L. is providing load forecasts and demand management planning to distribution B.L. Figure 2.2 gives the power system capacity in terms of grid stations and transformers.

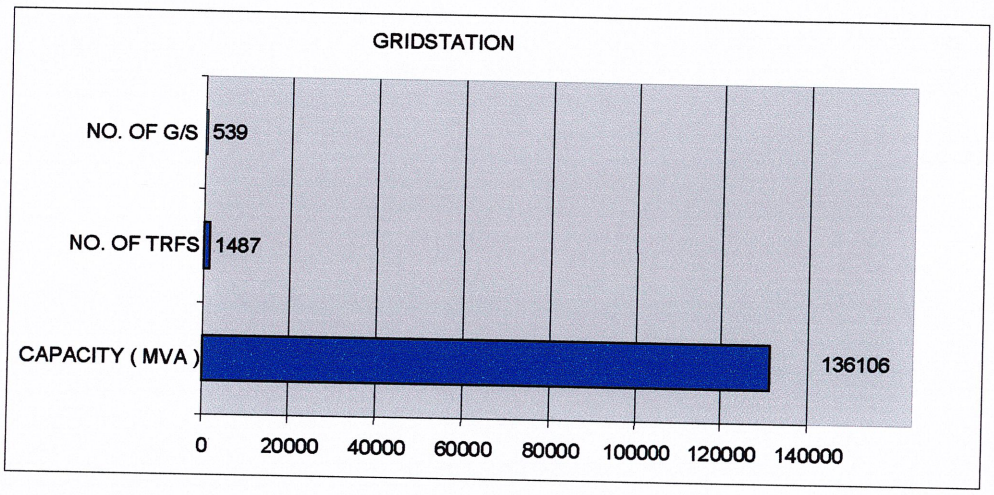


Figure 2.2
SEC Grid stations and Capacity as per 2005

Optimized supply arrangements are curried out by the system operator under transmission B.L. for a total load of more than 30000 MW distributed among operating areas as per type of the network (consolidated or isolated) as shown in Figure 2.3.

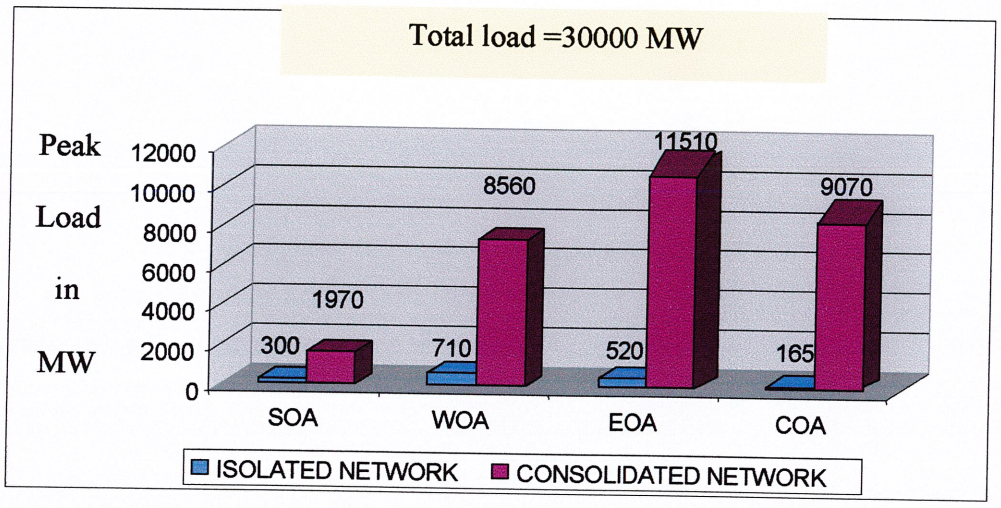


Figure 2.3
Operating Areas Peak Load (MW) in 2005 as per Type of Network

The areas from transmission B.L. view are divided according to the network expansion status. Consolidated Transmission Area (CTA) covering EOA and COA areas is already inter-connected. The rest of the country is under development and is called the Developing Transmission Area (DTA) which is under ongoing projects to be connected. The transmission lines of these two areas can be seen clearly in Figure 1.1 in Chapter 1.

Generation B.L. is responsible for all power plants in the country including any isolated power plants with capacity greater than 20 MW. The total generation capacity in Saudi Arabia reaches to 33400 MW (year 2005) distributed among the areas as illustrated in Figure2.4.

The power plants in SEC are steam power plants, gas power plants, combined, and diesel power plants. The sharing of the 150000 GWH generated energy as per unit type is shown in Figure 2.5.

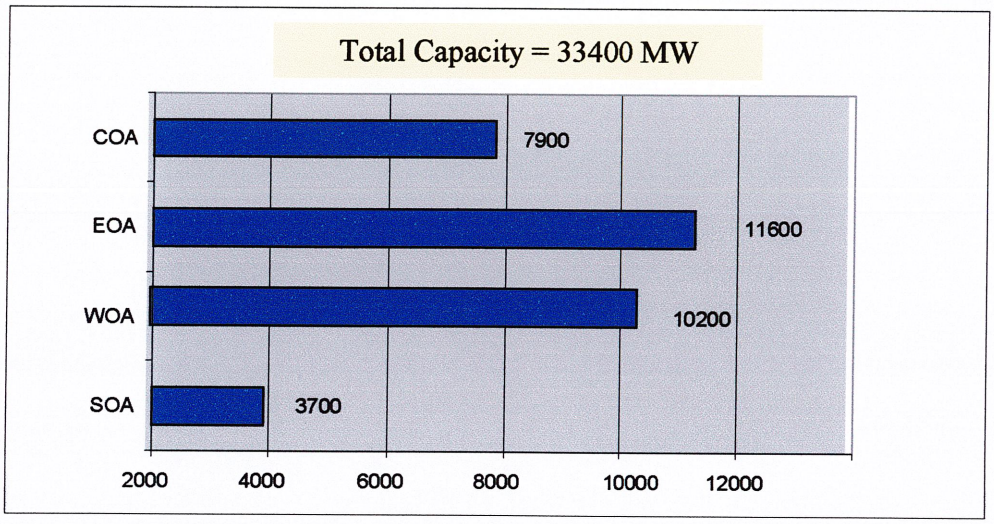


Figure 2.4
Actual Generation Capacity (MW) in 2005 in Saudi Arabia

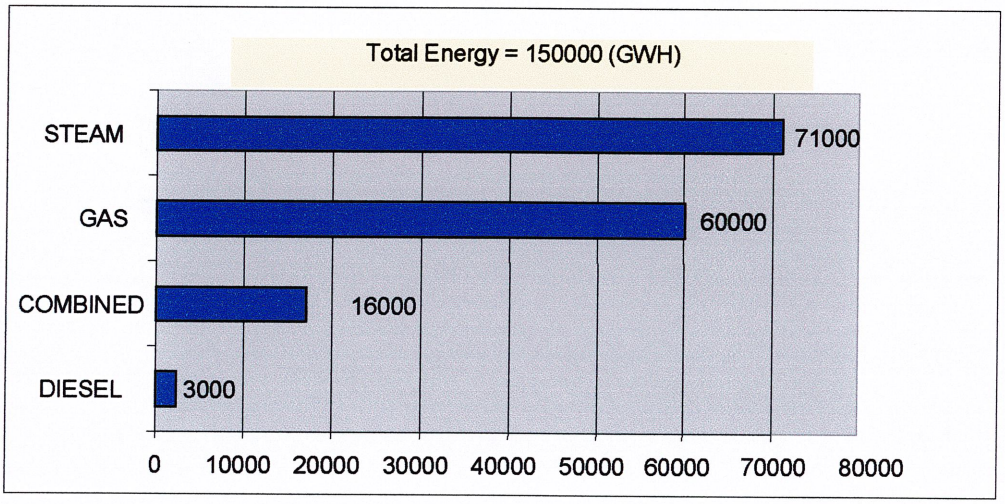


Figure 2.5
SEC Energy Generation as per Unit Type (GWH) in 2005

SEC is generating more than 84% of the energy needed as shown in Figure 2.6 and import the remaining from other plants from the oil company Saudi ARAMCO and from desalination plants with contracted prices for each KWH.

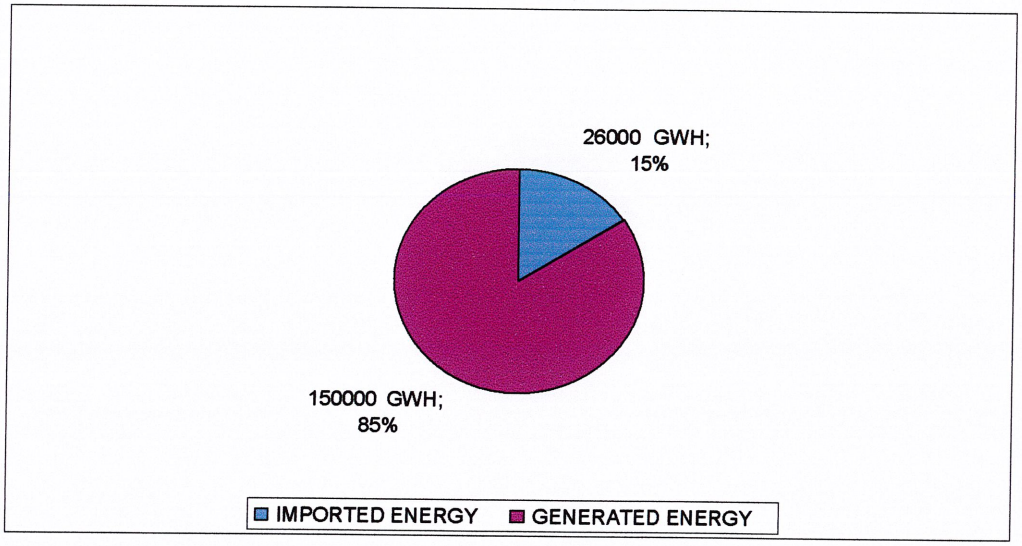


Figure 2.6
Generated / Imported Energy During 2005

2.1.2 Corporate and General Services

General services namely: facilities, industrial security, transportation, finance, IT, materials, and human resources have been developing and implementing Service Level Agreements (SLA). All corporate and general services are charged to each business unit as a customer or user.

Finance B.L. is providing all financial support to all business lines including capital allocation and budgeting.

Human resources departments are providing training support and manpower planning beside the regular activities related to employees governed by employee relation manual.

Industrial security departments are providing all business lines with security and training according to SEC safety policy in addition to hosting guidelines outlining policies and procedures.

Facilities B.L. is providing full service related to buildings, offices and all facilities requirements to all business lines including guidelines outlining policies and procedures.

Transportation departments are supporting all business lines with all transport requirements such as new vehicle requests, vehicle maintenance including related policies.

Materials departments are providing all material requirements like policies, contracting services, and inventory management.

IT departments are supporting all business lines with all services related to computers and telecommunication requirements including policies, troubleshooting, providing equipments, upgrading, operation and maintenance.

2.1.3 SEC general strategies and features

Some of SEC general strategies and features are listed below:-

1. Strategic planning for long-term planning.
2. Annual operating and capital budget planning.
3. Quality of supply to customers has been measured by the following means:-
    - System average interruption duration index (SAIDI).
    - System average interruption frequency index (SAIFI).
    - Restoration in one hour.
4. Experience indicates that customers prefer not to be interrupted, but in the event of an interruption; speed of restoration and accurate information on outage duration become very important. The provision of such information is possible both through call center technology and via internet services.

5. The significant areas of investment have been in insulated conductors, auto re-closers on overhead lines, and network remote control using SCADA system.
6. The planning skills of the more experienced staff are gradually being transferred to the less experienced team members and the less competencies being replaced.

The data mentioned in this section is to be kept in mind while going through the rest of the study.

2.2 Ongoing Deregulation Process [39]

Forming SEC by joining all existing electrical companies in year 2000 was the first step toward deregulating the electricity industry in Saudi Arabia. The second step was shifting from isolated four operating areas doing individually all activities to new organization operating as separated business lines according to activities of generation, transmission, and distribution as the main core functions in addition to other corporate affairs and general services as illustrated in Figure 2.7.

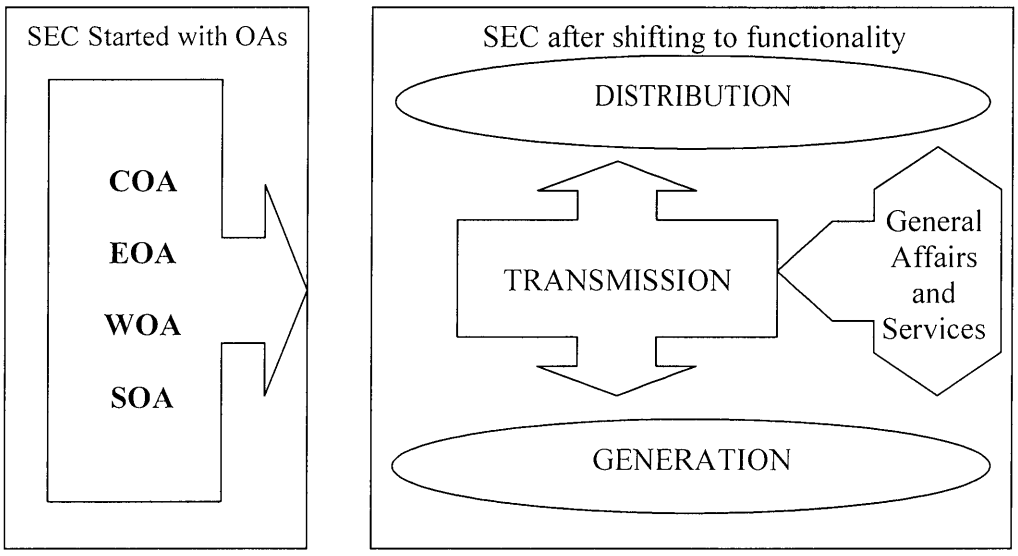


Figure 2.7
SEC Shifting Stage from OA's to Functional Organization

As the first stage in deregulating process; SEC is functioning in years 2003 and 2004 with the new organization shown in Figure 2.8.

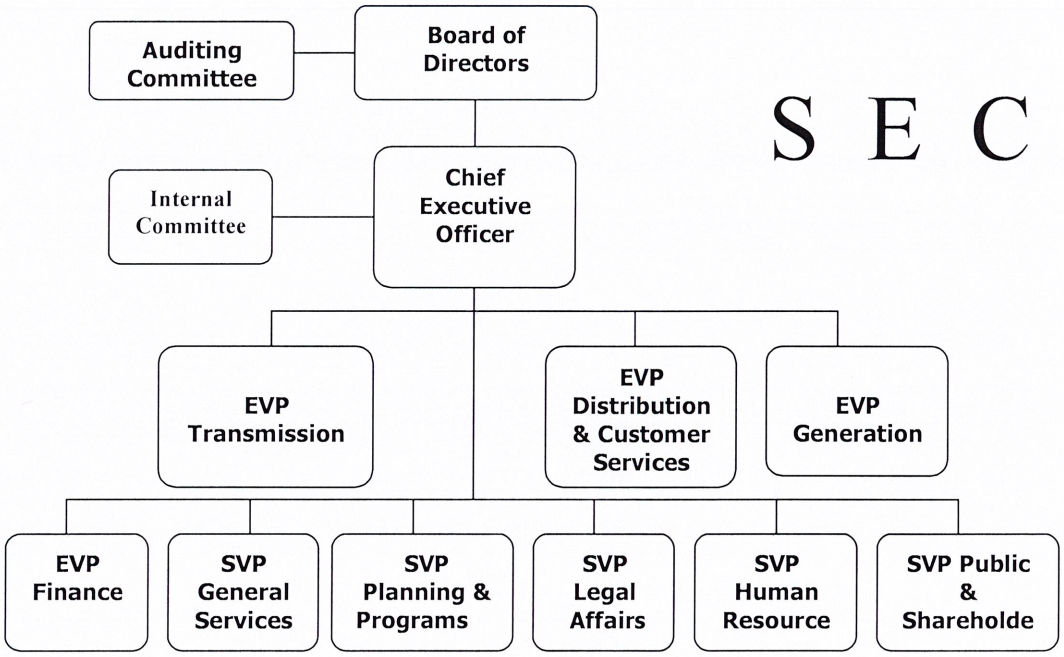


Figure 2.8
SEC Ongoing Organization Chart

During this stage; the following activities are carried out:-

- Each of the three main business lines (generation, transmission, and distribution) has interface and a planning role with other BL's, as well as the general service's organization and corporate services.
- Setting procedures to support the main BL's to act independently.
- Distributing the fixed assets among BL's.
- Fixing the interface points between BL's.
- Studying the sell and buy energy prices at the interface points.
- The three main BL's practicing as separated companies owned by SEC to be ready for the actual unbundling in the future.

- Allowing outsiders to participate in generation capacity and putting for sale with encouraging prices some of the generation units if any investor interested to enter to the market.
- SLA is already approved; agreeing on different cost for different quality level of service for all kind of services between BL's.
- Introducing Enterprise Resource Planning (ERP) to have the most updated comprehensive program to join all the needs of the existing programs. The main purpose is to have an automated business with one database to support the existing procedures and produce all required reports.
- All procedures, polices, and practices in distribution B.L. are unified among the four rejoins in Saudi Arabia keeping in mind the investment sense.
- Customer service culture is emphasized.
- Starting the Customer Call Centre (CCC).
- New co-generation company was established which is Water & Electricity Co. (WEC) where the ownership is shared between SEC and Saline Water Conversion Corporation (SWCC). WEC relations with SEC and others are shown in Figure 2.9.

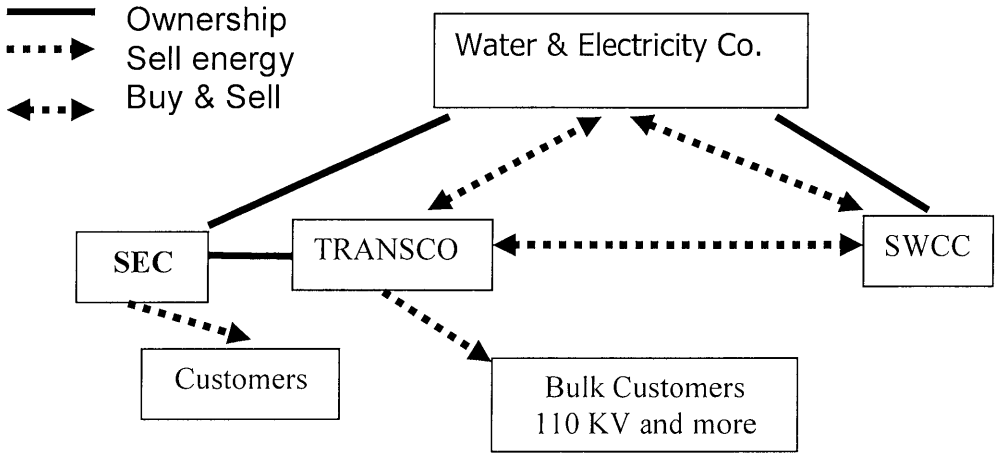


Figure 2.9
SEC Relationship with SWCC

As a second stage toward deregulation; legal separation for TRANSCO was done in the first quarter of 2005 to encourage outside investors in the generation. TRANSCO ia required to give equal opportunities and information to inside and outside competitors. During the second stage; the following activities are carried out:-

- TRANSCO is officially a separate company owned by SEC as per Figure 2.10.
- SLA is practiced as a trial and the actual implementation will be at the start of year 2007.
- To implement ERP; the program selected is SAP and expected to start in end of 2008.
- Starting new contracts between TRANSCO and bulk customers outside the government KWH price.

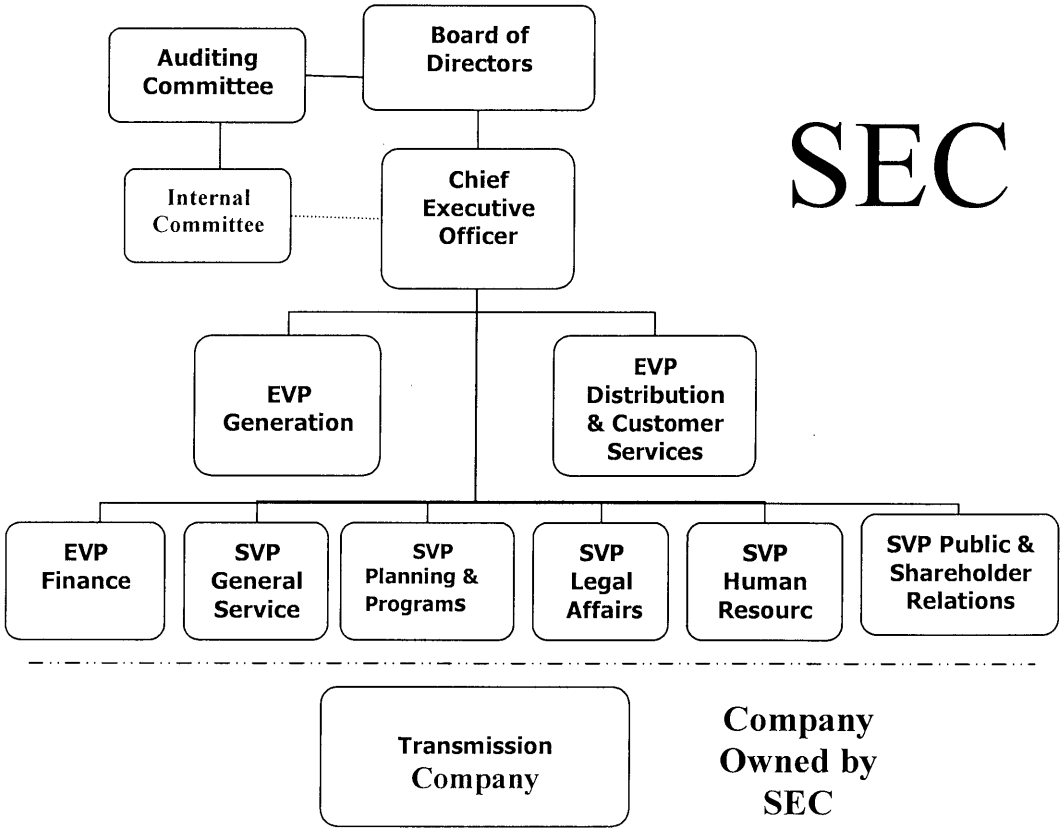


Figure 2.10
Transmission Separated from SEC

The above two stages are the ongoing stages and the remaining will be in the SEC plans including the following main highlights:-

- Actual separation of TRANSCO to be carried out.
- All financial matters to be finalized among BL's by January 2007.
- IPP's to enter to the market and contracts to be signed and implemented.
- Generation to be divided into sub generation companies.
- Insure availability of enough spinning reserve.
- Insure competitive market through large number of competitors.
- The last stage will be to divide the distribution B.L. to sub distribution companies.

The future plan as seen by SEC planners is illustrated in Figure 2.11.

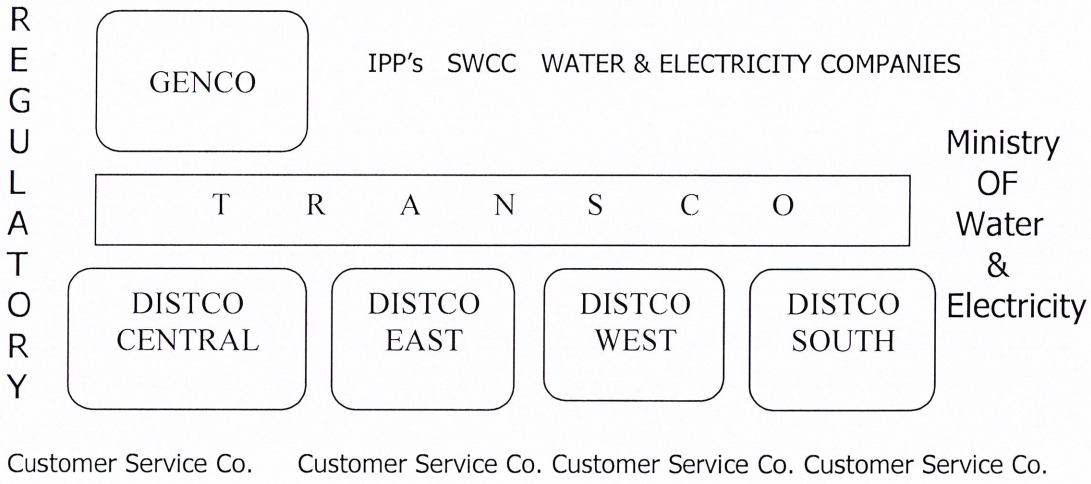


Figure 2.11
Future SEC Vision

To conclude this chapter, it can be pointed out that the present regulatory process in Saudi Arabia which involves yearly reviews along with fix income for a specific coming year's period creates a risk. Increased reinforcement expenditure could affect other capital programs which could end for the time being with customer dissatisfaction.

Customer dissatisfaction is the expected short term outcome even with the additional efforts and emphasis on customer services as mentioned earlier.

Next chapter summarizes and analyzes some of the market models with special emphasis on the system operator.

3 DEREGULATED MARKET STRUCTURE

3.1 Market Structure

Before deregulating the electric industry, typically, vertically integrated utilities as the most popular practice all over the world have the right of a monopoly in its area. This monopoly includes producing, transmitting, distributing, and selling energy to customers. However, deregulation is a non-monopolist system with a competitive market atmosphere by giving customers the right to choose their suppliers. The question of how to design the market structure to hit the deregulation objectives is to be analyzed in this section. Unlike conventional power system; a separation of main entities from each other is required to avoid unjust use of the network by any of them.

Due to the complexity and uniqueness of the electric industry market, it is impractical to design an ideal market model. However, the aim should be to design a near ideal model to fit all needs with the existing limitations. So, the participants will not be the same in all electric industries but could be sharing mostly similar activities with different arrangements. Depending on the nature of the market; deregulated electric system could be composed of some of the following participants [5]:-

- Generation Company (GENCO) and Independent Power Plant (IPP) which generates power.
- Transmission Company (TRANSCO) which owns the transmission network.
- Distribution Company (DISTCO) which distributes or delivers electricity.
- System Operator (SO) which operates the system in a secured and reliable manner.
- Market Operator (MO), Power Exchange (PX), or Power Pool (PP) which operates the market trading in a fair and reliable manner.
- Retailer which provides energy services.
- Customer who consumes electricity.
- Scheduling Coordinator (SC) which prepares balanced schedules.

- Regional Transmission Organization (RTO) which operates all transmission facilities within its region.
- Regulatory Institute (RI) producing electrical industry rules and polices.

3.1.1 GENCO's and IPP's

GENCO's are responsible for operating and maintaining generators or plants. In some of the industries GENCO's take the shape of big companies which own different plants in different areas and some are only a plant by itself which is called in this case IPP's. The size of each plant is depending on the fuel used, location, investors, market needs, and the visibility study. A large number of GENCO's or IPP's in the market will increase the competition level which leads to the following advantages [38]:-

- Innovation
- Cost savings
- Reliability
- Flexibility in scheduling production due to selling electricity on the spot market.
- Reduce the risk of staying idle using long-term contracts in selling the power.
- Reduce the need for transmission networks over long distances.
- Renewable energy

GENCO's could be encouraged to build new plants or extend existing plants to take advantage of the fact that electric power consumption in the world is growing at annual rate of 03% . [18]

3.1.2 TRANSCO

TRANSCO's are responsible for transporting electricity from GENCO's to other participants (DISTCO's, Bulk Customers, or Retailers). In some industries TRANSCO

owns and operates the whole network like in UK. In other industries it owns the network only and leaves operation to other entity like the situation in California. In some other industries it is preferred to have a TRANSCO in each region owning and operating the network. For any of the previous forms of the transmission entity, the following requirements to be met [6]:-

- Open access to all participants.
- Maintaining high quality of transmission services to be acceptable by market participants.
- Planning network expansion.
- Enhance the total capacity according to transmission constraints of thermal limits, voltage limits, stability limits, uncertainties in load forecasts and distribution, balancing load and generation, allowances for parallel path, and variations in generation dispatch.

The competitive nature is expected to drive TRANSCO to the following advantages:-

- Reliability is expected to improve in order to attract more customers.
- Innovation
- Cost savings
- Enhance the information system

To give a meaning to a competitive market and encourage more participants to enter the market, a strong system is required to facilitate transmission open access. OASIS is playing this rule by giving equal right of access to the transmission network to all participants without any kind of discriminations. [3]

In some industries like most of USA models it was hardly recommended to separate ownership of transmission network from operation to guarantee fair usage and a correct application of OASIS. In those industries ISO is the solution and National Electricity Market Management Company (NEMMCO) is the established entity in Australia. [25]

3.1.3 DISTCO's

DISTCO's could be responsible for two major activities namely:-

1. Constructing (owning), operating, and maintaining the distribution network in its designated area.
2. Providing electric energy sales to retailers and end users.

In some industries, the second activity is provided by suppliers which are separated from DISTCO's.

Shifting to deregulated industry force DISTCO's to work hard in analyzing the ongoing cost from investment point of view keeping in mind to improve the customer service. This difficult equation of reducing cost and improving services cannot be accomplished unless management and staff of DISTCO's realize the following:-

- Be or not to be due to the competitive market as incentive to achieve the minimum requirements at the least cost.
- Reducing the cost on the customer will grab more customers.
- All valid management tools (TQM, PPI as examples) to be adapted to enhance the process, productivity, and quality of service.
- Training is second if safety is first and customer is first plus.
- Marketing is the report of what you have done which means that if you have failed in marketing you have done nothing.
- Performance management is a must to encourage pioneers to keep going and others to follow them.

Beside the two main activities mentioned above, DISTCO's services include adding distribution network, energy metering, and billing. Level of investment will be affected by internal influences like budget availability and profitability as well as external influences like business growth and regulatory changes. [5]

Different industries have different names of DISTCO's but with almost same activities and different practices. Utility Distribution Companies (UDC) is used in the California market; Regional Electricity Companies (REC) is the term used in England and Wales. [25]

3.1.4 System Operators

SO is responsible to operate the system in a secured and reliable manner with the following main activities [38]:-

- Controlling and directing the dispatch of generators.
- Responding to system contingencies.
- Controlling and directing the loads and load shedding.
- Balancing operationally loads and generation capacities.
- Ensure fair access to the transmission system for all participants.
- Participating in load forecasting.
- Participating in ancillary services and congestion management that have not been resolved by other participant.
- Participating in transmission system enhancements.
- Administer OASIS.
- Participating in developing operation and maintenance guidelines.

Electric industry is complex in nature, so, System Operator could practice some of the following difficulties:-

- Unpredictable discrepancy of the forecasted demand with the actual.
- Lack of coordination between the markets could lead to discrepancy of supply availability and transmission congestion. [34]
- Unclear cut in responsibilities between market participants.
- Unfair practices by some of the participants.
- Market power by any of the GENCO's. [33]

- Fast load growth with slow generation addition to the system. [23]
- Lack of experience.
- Inaccurate price calculation.

In England and Wales, the system operator activities are carried out by the power pool represented by NGC along with other activities. Actually NGC in its market playing the role of three major players namely: TRANSCO's, SO, and MO. While most of USA industries are adopting the ISO entity which is a non profit entity which operates the transmission facilities to provide non-discriminatory open access to the transmission grid to all participants and leaves the market trading to PX and or SC's and leaves the ownership of the transmission network to Investor Owner Utilities (IOUs).
The ancillary services such as system control (reactive power supply) operation reserve services, and voltage control, losses, regulation and frequency support, and black start capability service are anticipated by ISO in USA, NGC in UK, NEMMCO in Australia, and Nordic Pool in Nordic area. However, the reactive power supply is not compensated by Nordic markets as per reference. [6]

A reliable system can be rewarded by the SO or the PP by paying to the GENCO's or IPP's additional money to encourage them to maintain their equipments.

3.1.5 Market Operators / Power Exchange / Power Pools

MO roles are carried out by PX in USA industries and by NGC in England and Wales. In Australia NEMMCO is the market operator and the system operator in the same time but not owning the network like NGC in UK. In Alberta of Canada the power pool is the market operator and also the Nordic pool is the market operator in Nordic area.

Some of activities of the market operator are listed below [38]:-

- Operates the market trading in a fair manner.

- Matching supply with demand based on the bid prices by choosing the lowest bidders from GENCO's or IPP's until hitting the supply satisfying the demanded power.
- Calculate the spot market and make it available to all users.
- Implement pricing policies.
- Ensuring the settlement of payments between sellers and purchasers.
- Tracks bilateral contracts between participants.
- Strong coordination with SO to act properly.
- Submit ancillary services bids to SO to maintain system reliability.
- Apply price management tools like hedging and price capping to control and protect the market from corruptions.

Any transaction in the market has to go through MO to analyze it and permit it. In some industries, it is allowed to make transactions outside the PP or the PX but at least MO is to be informed if any.

3.1.6 Scheduling Coordinators

SC's are responsible for preparing balanced schedules to SO between GENCO's and customers or retailers. It is rarely separated as stand alone entity as in California model. However most of other industries are not allowing SC's to act independently like in UK. [5]

SC has broader limits than PX since it can act according to rules differed from the power poles rules. This advantage for SC's could add to industry and increase the flexibility in condition that the market power is avoided.

SC's could participate in solving transmission congestion by direct contracts with generators and retailers utilizing computer programs to point out the congestion area after getting approval from SO. [38]

3.1.7 Retailers

Retailers are the service providers in term of energy sales mostly to end users and rarely to other retailers. They are buying electric energy from DISTCO's or some times directly from PP if they satisfy the requirement of direct access. All transactions between retailers and other entities should be informed to market operator. Such retailers can play an important role in the electric industry process by competing to perform an excellent service to customers with automated systems and servicing the customer at his place. [4]

Retailers are expected to be more customer oriented than any other entity in the industry.

3.1.8 Customers

Customers are the electricity consumers who are expected to benefit from deregulating the industry. Since the financing of whole electric industry should be initiated from customers including profit as well as non-profit entities, all other participants are working hard to satisfy the customers' needs.

Customers could be residential, commercial, agricultural, or industrial. They could also be small or bulk customers in terms of amount of energy they consume. Some bulk customers can participate effectively in load management by good coordination with MO and benefiting from lower Tariff.

Unlike conventional method, the complete competitive market will give to customers the right to choose their suppliers.

3.1.9 Regional Transmission Organizations

RTO operates all transmission facilities within its proposed region. It is established in USA due to unsatisfactory results from the ongoing deregulating process. The shortcoming was due to inefficiencies in handling transmission network along with market power enforcement in the industry. [1]
Other world pioneers in the deregulated industries are not suffering much. In UK, transmission is believed to be nature monopoly and it is more advantageous not to separate it. This is why NGC owns mostly all the national transmission network.

Flexible structure is allowed in USA in introducing RTO. "RTO could act as an ISO (non-profit institution), stand-alone transmission companies (for-profit TRANSCO's), hybrids or any other form that could accomplish the aims of Order No. 2000." [38] Chapter 8 of the same reference illustrates nicely all details about RTO including minimum characteristics, minimum functions, and benefits.

3.1.10 Regulatory Council

Even in the deregulated industry, regulators are hardly needed but with light hand from governments. Because of the complexity of the electric industry and its nature as an essential need in our life, crises could happen if the door is opened 100% for free market and the system could collapse.

The Regulatory council could play very important roles in the industry and driving it toward a competitive market instead of being a burden in the industry. Some of the roles are listed as follows [6]:-

- Producing electrical industry's main rules and polices.
- Ensure reasonability of prices.

- Ensure fair and indiscriminate acts in the electrical industry.
- Ensure sufficient supply to all customers throughout the country.
- The legal reference in case of disagreements.

Next chapter is proposing a model for Saudi electricity supply industry along with the proposed trading and pricing methods.

4 SEC PROPOSED FRAMEWORK

4.1 Introduction

Electricity is coming in the second level of needs after air, water, & food to support us doing other life activities. It is guaranteed to the degree of being forgotten unless it is disconnected or a high consumption bill is found to be paid at the end of the month. In Saudi Arabia, outages are rare events due to the highly existing reliable system. So, high bill is the part that worries customers in Saudi Arabia. Even though, the Saudi Riyal per KWH (SR*/ KWH) is relatively low compared to others world prices, the bill becomes relatively high due to the fact that Saudis are high consumers and also due to the current Tariff structure.

For the above and for the fact that demand of electricity in Saudi Arabia is rapidly expanded, Saudi Electricity Supply Industry (SESI) is to be restructured in a way to meet the future demand without burdening the government budget, along with reducing electricity bill and at the same time maintaining a safe and reliable system.

4.2 Historical Background

SESI was explained in Chapter 2 of this study along with the ongoing deregulation activities by SEC. However, it needs to be emphasized in this section that what has been approved or written about the future vision of SESI structure inside and outside SEC. The aim of that is to start from where others end and recognize others' effort.

* 1 US $ = 3.761 SR

The three stage plan in SESI restructuring process was presented in Bahrain in 2005 by the executive vice president of transmission B.L. in SEC, at that time, Eng. Tariq Al-Betairi. He presented the plan as follows:-

"Stage 1 By 2002-2006

- Single Buyer Model
- SEC functions more as a holding company
- System of transfer payments creates a 'virtual' industry

Stage 2 By 2006-2010

- Transition to (Wholesale Competition) Market Model
- Market function is separated from technical function in Transmission (TSM); OR
- Either Generation or TSM is divested from SEC

Stage 3 By 2010-2014

- Transition to Full Competition Model
- Private sector participation increases and competition intensifies."[40]

The above vision as per reference [41] is also adopted by SEC management as presented by Dr. Amer Al-Swaha, senior vice president of HR in SEC at that time, to top SEC management where the long term vision was illustrated in the reference as per Figure 4.1.

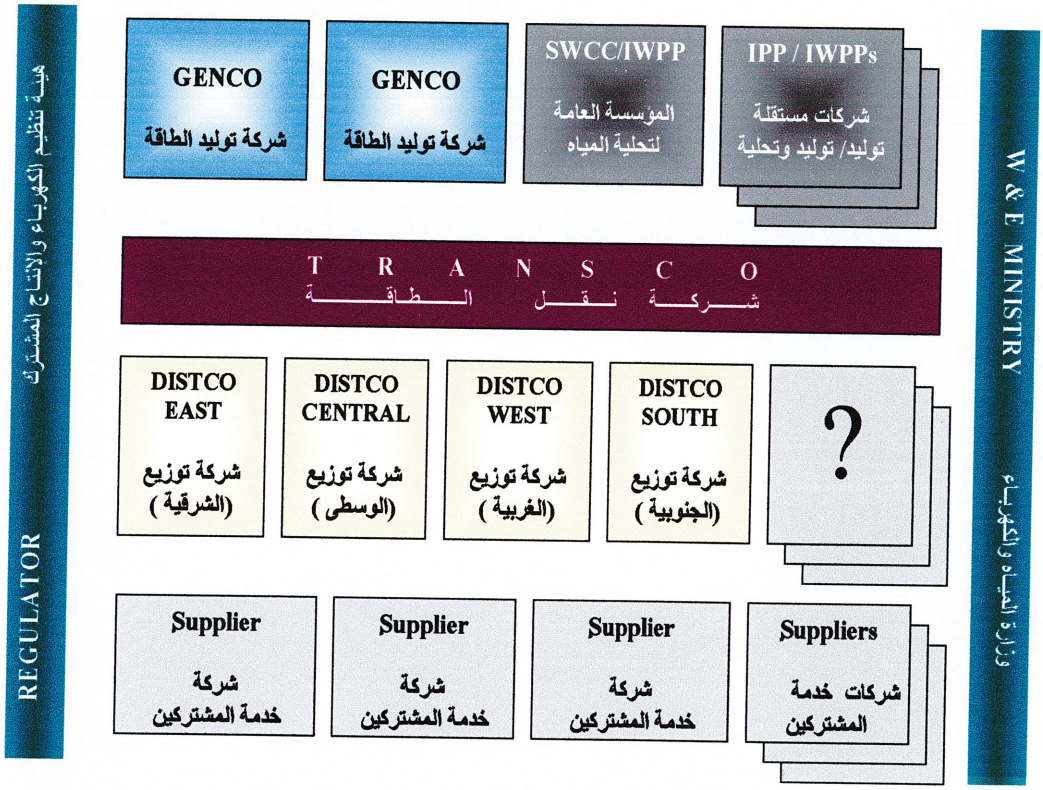


Figure 4.1 [41]

Ultimate Vision of SEC Management for SESI Structure

It is worth to report here that the official reports by SEC Management are always considering TRANSCO as a network owner and operator as shown in Figure 4.1. Furthermore, the official report never went through any detailed proposal for separating customer services from distribution companies.

Professor Ibrahim Al-Amin (expert in the subject from King Fahad University of Petroleum and Minerals) has set a criterion for grouping power plants of SEC as follows:-

" • SEC generating plants to be divided into 3-5 companies irrespective of geographical location.

- MW capacity of each company should be approximately the same.
- Production cost of each company should be as close to the weighted full system average cost.
- East based plants to be fairly divided among the companies.
- Each company should have a fair mix of generating unit type (ST, CC, GT, & DE).
- Generating plants sharing common facilities will belong to the same company (e.g. PP4 & PP4X)."[42]

4.3 Proposal's Principals

- It is not recommended to deregulate the whole industry aiming for full competition without analyzing the nature of each participant in the industry. Wires including transmission and distribution lines and equipments are natural monopoly businesses due to the tendency of duplicating the existing lines by new investment of constructing new lines [3]. However, generation and retail businesses are not a natural monopoly and the doors are open for the competition to encourage new technologies and innovations in generation part. This competitive atmosphere is also needed to provide better services in the retail part; including value – added services like price hedging to reduce risk and automating remote services.

- The proposal is expected to support a competitive environment wherever possible and not to be guided by the existing positions. Despite that, after finalizing a suitable structure a well established implementation plan is required to consider the existing resources and apply the most economical possible way of exchanging the duties and responsibilities.

- The ownership of any participant is to be set by the structure in a way to avoid any market power or conflict of interest and to provide OASIS and provide same rights to connect to the grid. So, private participation should be in a competitive manner and transparent with no privileges given to any party among others. [38]

  For the above, transmission business is to be independent from generation business to allow direct purchases between customers and producers. Also, all functions of system operator, market operator and schedule coordinator are to be carried out by an independent non-profit entity from the whole industry. To support this principle, private sector is to be encouraged to participate in generation and retail sales, but transmission and distribution (wires) are to be non-profit governmental entities.

- The last principle is that Saudi Arabia like others has a unique situation and restrictions to be taking care of like :-
  - The type of fuel used in generation and the fact that ARAMCO is the single source of gas and its availability in Eastern and Central regions only.

  - Gulf interconnection project carried by the Gulf Cooperation Council Interconnection Authority. The first stage will connect Saudi Arabia, Qatar, Bahrain, and Kuwait by 2006/2007. Then UAE and Oman to be connected as the second stage by 2011.

  - The council of Ministers Resolution # 169 which represents the direction of Saudi government to have similar deals among household customers all over the country regardless of the region.

  - High annual percentage growth in power consumption in Saudi Arabia.

4.4 The Proposed SESI Structure

Power Supply Providers (PSP's) in generation business are represented by GENCO's, IPP's & IWPP's which are to compete to sell in the wholesale market controlled by Saudi Electricity System Operation & Marketing entity (SESOM). This entity is to be responsible for the duties of system operator, market operator and schedule coordinator. There will be other competition among Customer Service Providers (CSP's) represented by retailers as new entries or the once to be separated from DISTCO's which are called Customer Services Companies (CSC's) to leave DISTCO's with wires only as owners and operators. This will enhance retail services in terms of prices and quality. While PSP's are encouraged to be private generation entities, Saudi Electricity National Grid (SENG) is to be a non-profit government entity owning but not operating the high voltage transmission grid system with open access to all participants in a fair manner. Also, DISTCO's are to be regulated as Saudi Electricity Distribution entity (SED) which is to be a non-profit entity owned by the government. CSC's and other retailers are to be unregulated private entities competing to provide electrical supply and other related services. The already established Saudi Electricity and Co-generation Regulatory Authority (ECRA) is to have an important role in promoting real market competition among generation and retail businesses and make sure to regulate wire businesses (transmission & distribution).

Figures from 4.2 to 4.5 show the SESI proposed structure with respect to ownership, physical electricity flow, financial flow, and the full proposed framework.

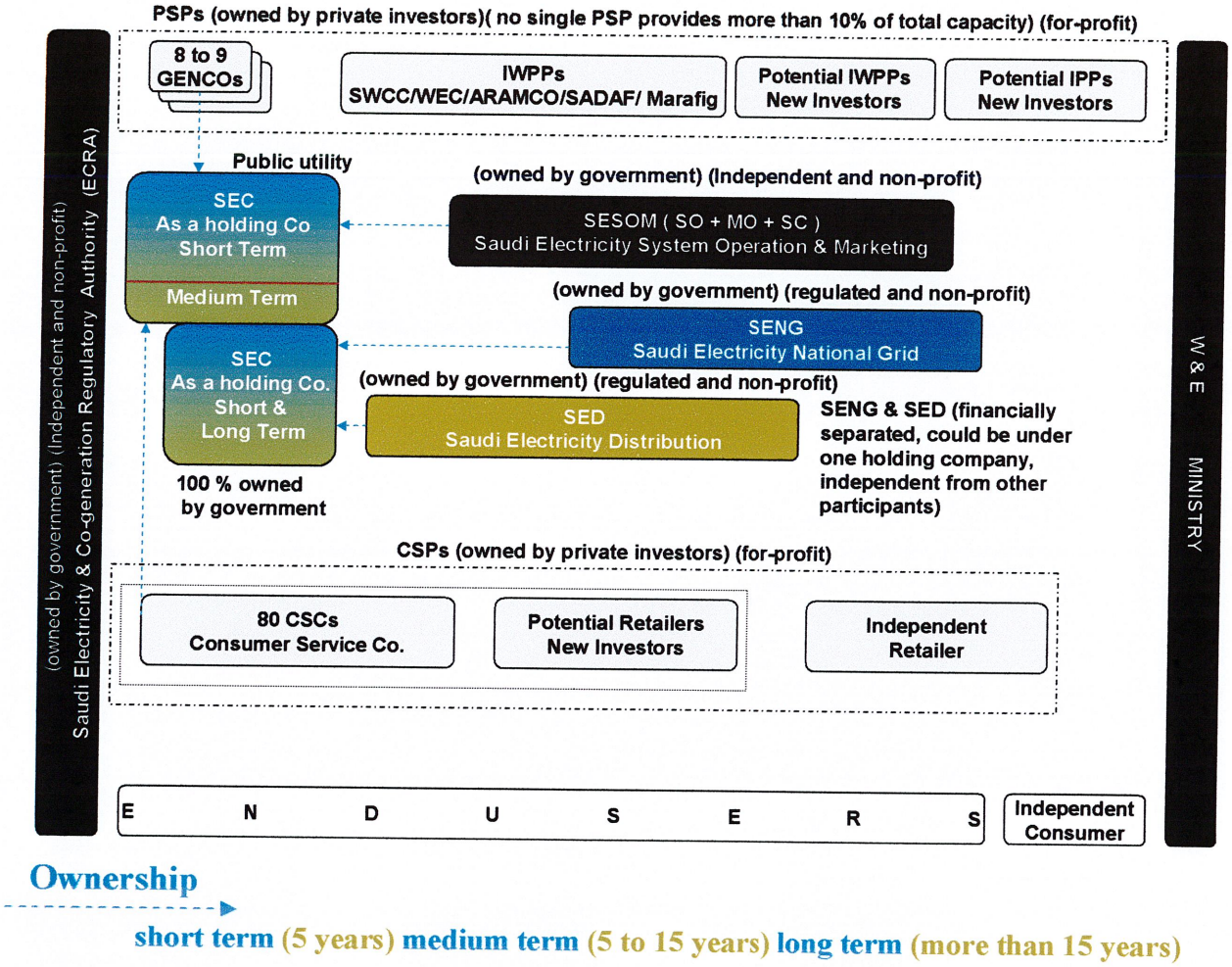


Figure 4.2

The proposed SESI Framework (Ownership)

From Figure 4.2, it can be seen that SEC in its current status can be the holding company for SESOM and GENCO's in the short term only. And CSC's to be financially separated from SED to be ready for complete separation from SEC in the medium term. Furthermore, SEC at its long term form to be the holding company for SENG and SED only. By that time, SEC expected to be 100 % governmental and non-profit utility.

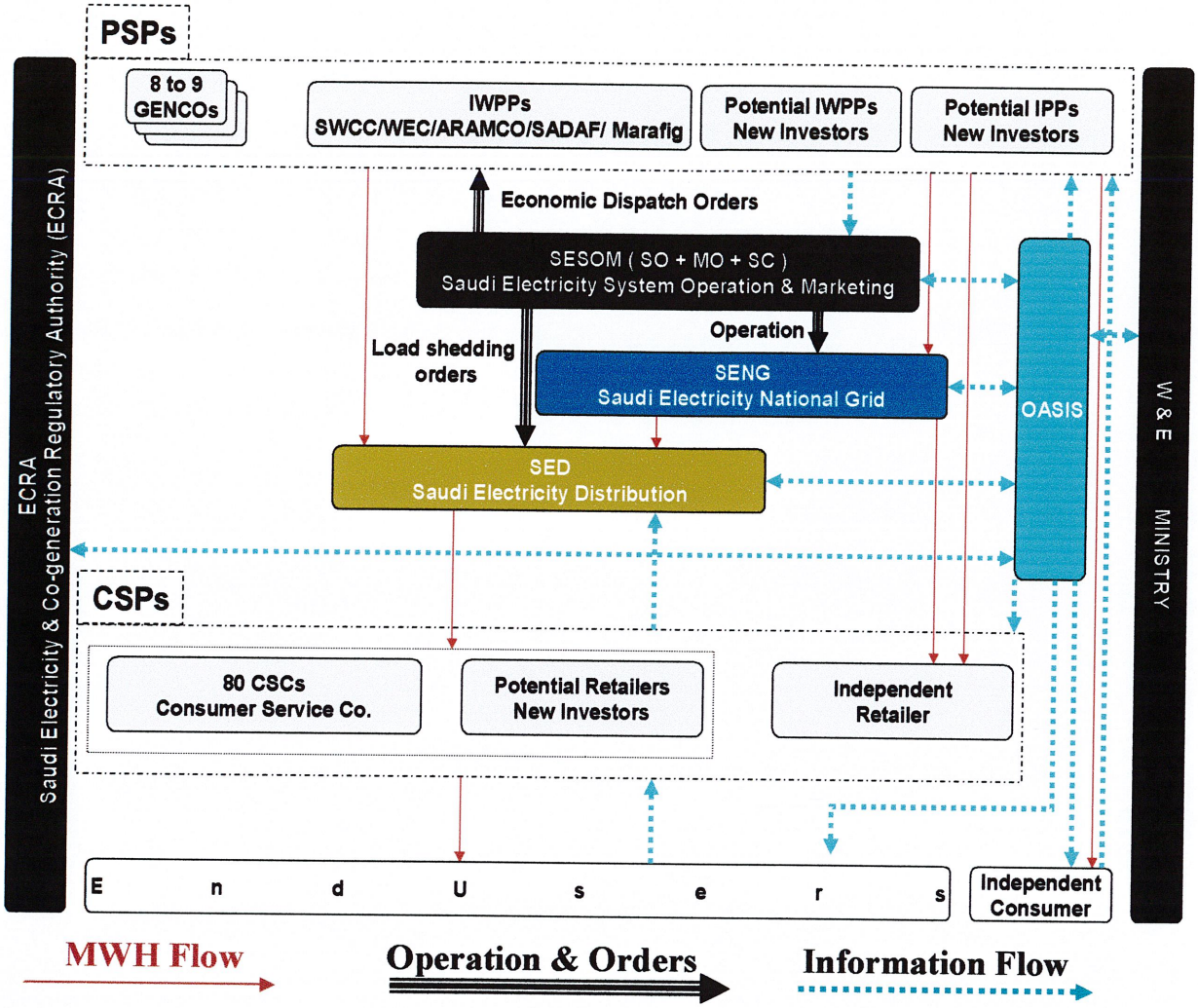


Figure 4.3

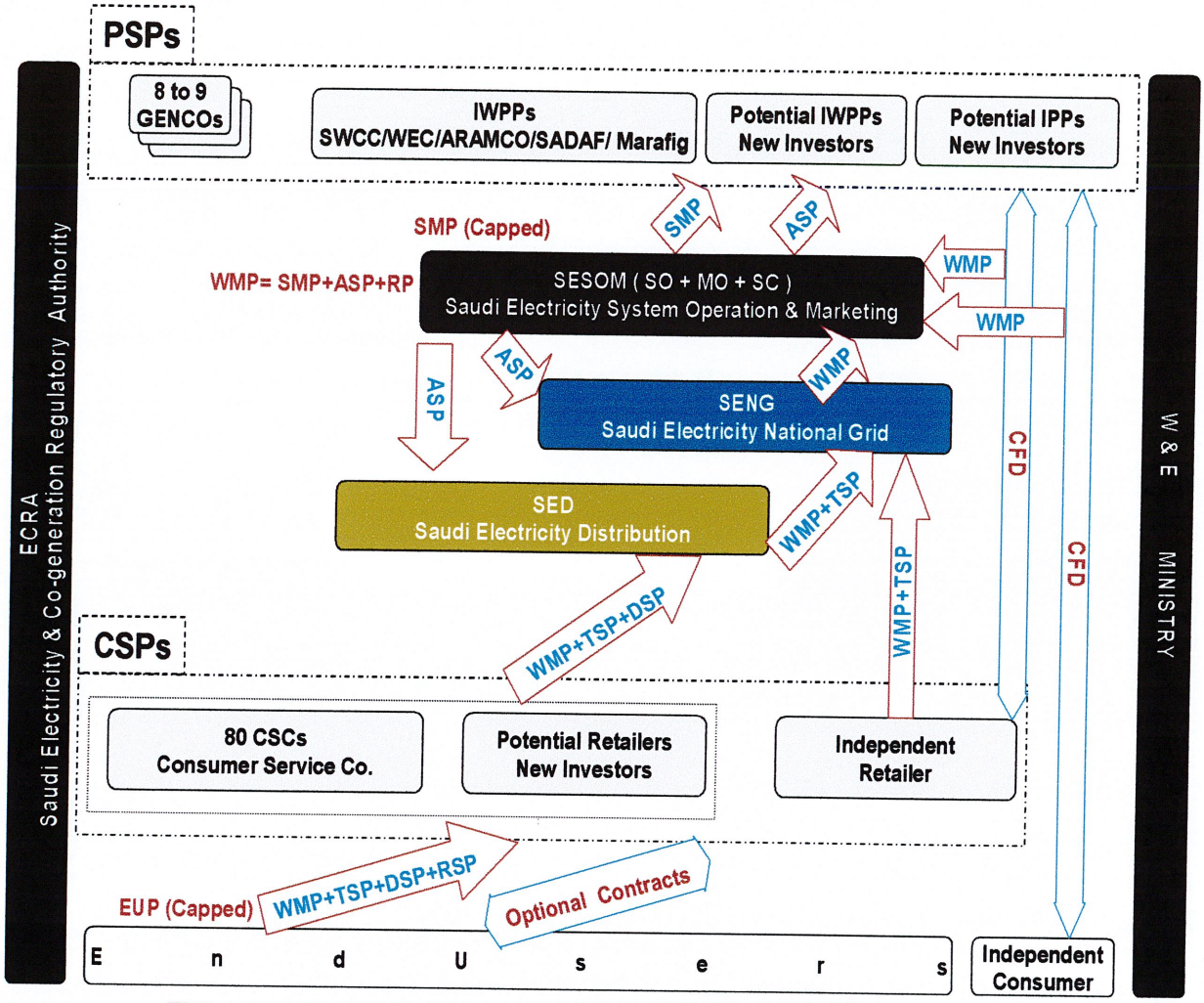
The proposed SESI Framework (MWH, Operation, and Info. Flow)

Even though, the customer and the retailer can get power directly from PSP's with and without the usage of the regulated wires, the actual operation is under full control by SESOM. As shown in Figure 4.3, SESOM is to be responsible for releasing dispatch orders to PSP's and conducting the actual operation of SENG network. Beside that, SEASOM gives load shedding orders to SED if needed according to contingency plans.

OASIS is to be a very sophisticated information system to provide all the information required by market participants in the same time [38]. Figure 4.3 shows all the possible flow of information with directions. Any specific category of participants has a specific authority to access OASIS.

Figure 4.4 illustrates the financial flow among participants which will be elaborated in the trading and pricing sections. However, it is worth to report here that all money movement is to be controlled and managed by the schedule coordinator under SESOM.

Figure 4.5 gives the complete proposal outlining the main interactions among participants which will be elaborated in the next sections.



Payments Contracts

Figure 4.4

The proposed SESI Framework (Financial Flow)

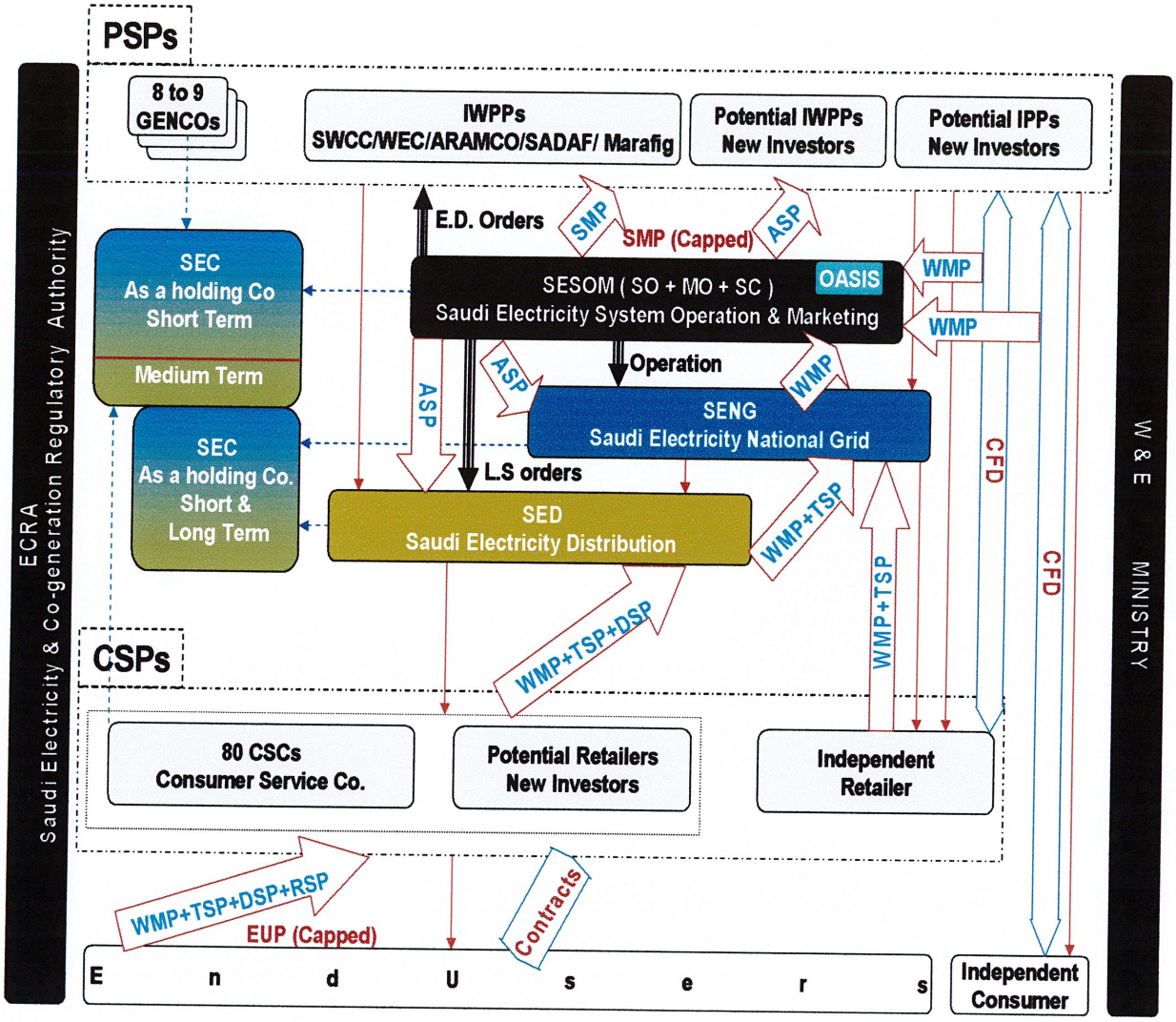


Figure 4.5

The proposed SESI Framework (Complete Picture)

4.4.1 Power Service Providers [GENCO's, IPP's, and IWPP's]

In designing the generation sector in Saudi Arabia, the existing situation should be kept in mind and how it should be converted.

As illustrated in Chapter 2, SEC is generating almost 85% of the energy needed and imports the remaining from other plants belonging to ARAMCO, SWCC, or SADAF (Petrochemical Company in Saudi Arabia) in addition to the already established company WEC which is owned by SEC and SWCC.

In the ongoing deregulation process by SEC, the first step has been done by separating generation B.L. financially from other BL's and even the general services are performed through SLA to keep independency.

Next step is the challenge of letting the power plants owned by SEC (73 power plants by end of 2005) compete to sell to the wholesale market. It should be kept in mind that some of the existing power plants are with low efficiency which cause increase in the overall costs of generating each KW. So, new IPP's or IWPP's will be able to generate power at a lower generation cost compared to SEC.

The key solution is to encourage private sectors to participate in the market to bring down the overall generation cost of Saudi Arabia. The new participants are expected to enhance the capacity availability to meet the rapid expansions and the related demands without calling for government subsidies or increasing the end user prices.

The possibility of having small power plants to be owned by private sector is relatively good in Saudi Arabia due to the thermal power generation nature from oil, diesel and/or natural gas. But the question is how to induce investors to provide the required capacity to insure a reliable system with adequate reserve capacity? The direct answer is to let

SEC to divest ownership of GENCO's to IPP's or IWPP's and some of them are to be retained, at a short & medium term, by the holding company (SEC) to reduce risk.

It is also recommended to learn from Argentina practice of avoiding any single generator with ability to serve more than 10% of the market to avoid any market power in the industry [25]. In addition, GENCO's, IPP's and IWPP's should have no affiliation with SESOM or SENG as shown in Figure 4.2.

The above recommendation could be implemented by means of a well established rules and regulations by ECRA along with government and SEC management's support. Such rules and support from management is hardly recommended to encourage all qualified generators to enter to the market with equal access to the transmission grid and a non-discriminated rate.

To expedite the wholesale market, it is recommended to group all power plants owned by SEC (85% of the total capacity of the country) into 8 to 9 GENCO's, then support and encourage those GENCO's to be sold or shared with other private sectors. The grouping criterion was quoted in Section 4.2. However, it is recommended here to have 8 to 9 GENCO's to reduce market power chances and enhance the process of new owners or partnerships entry. Also, it should not be mandatory to have the same capacity for each GENCO, since the important factor is to have the same production cost.

4.4.2 Saudi Electricity System Operation and Marketing (SESOM)

It is hardly recommended by this study that ECRA to move forward in issuing a regulatory order for immediate establishment of SESOM as an independent and a non-profit entity. It is to be separated from SEC and covers the activities of SO, MO and SC. It is accepted at initial stage to let SEC be the holding company; but the sooner the better to separate it fully from all other entities in the industry.

The independency is needed for SESOM to act freely in operating, monitoring, and controlling the power system according to specified standards without any outside influences.

As mentioned earlier, SESOM responsibility is a combination of the SO, MO and SC responsibilities. Where SO is mainly responsible for the security of the power system along with issuing economic merit order dispatch and participating in the national power system plans. MO is to administer the wholesale market which includes determining the market clearing prices and measuring the trade transactions in the industry. And, SC is to be responsible for the billing (flow of money) and the final settlement among participants.

In addition to the main activities of SESOM which are listed in Chapter 3 (Section 3.1.4, 3.1.5 and 3.1.6), the following two activities are to be performed by SESOM:-

- Search and develop new opportunities to enhance the competitive atmosphere.
- Improve its own performance as a new entity which requires a lot of efforts to meet challenges.

Beside that, it is worthwhile to emphasize and elaborate in some of the most critical activities with respect to SESI.

Security and reliability of electrical supply is to be maintained by SESOM to ensure a reliable supply satisfying demand at all times. This can be measured by having a capacity to continue operating within specific limits despite losing any of the power providers. Spinning reserve is the tool to be used where the system is required to run at all times with a minimum level of reserve to meet the required standard of system security and reliability.

SESOM is to be operated with well established regulated rules which are to be mandatory for all participants. Such rules have to be with some freedom allowing participants to plan their own generation actions within system constraints.

It is advisable to have supervision over SESOM functions by a board (SESOM board) which is to be staffed by well selected experience independent members. The main responsibility of SESOM board beside the supervision and controlling of SESOM operations are [5]:-

- To participate in issuing market rules and get it approved by ECRA.
- To recommend transmission expansions plans and submit it to ECRA for approval.
- To recommend SESOM charges and submit it to ECRA for approval.
- To review requirements of new entries and forward it to ECRA.
- To recommend any action to be approved by ECRA to enhance SESI.

Market operation as a part of SESOM is also responsible to provide SO with prices, balance schedules, and ancillary services schedules. In order to improve the wholesale market; MO has to analyze the market design, monitor performance and implement system charges. The basic activity of MO, but critical, is to provide participants with general information along with supports.

Among the activities of SC with SESOM are [38]:-

- To determine debits and credits among participants.
- Acquisition of metering data & billing.
- To facilitate cash transaction.

The immediate step recommended in this area is to financially and functionally separate the operation activities from transmission B.L.

The next step is to establish SESOM as a non-profit independent entity to cover the activities of SO, MO and SC. The main outlines of SESOM chart is proposed to be as per Figure 4.6

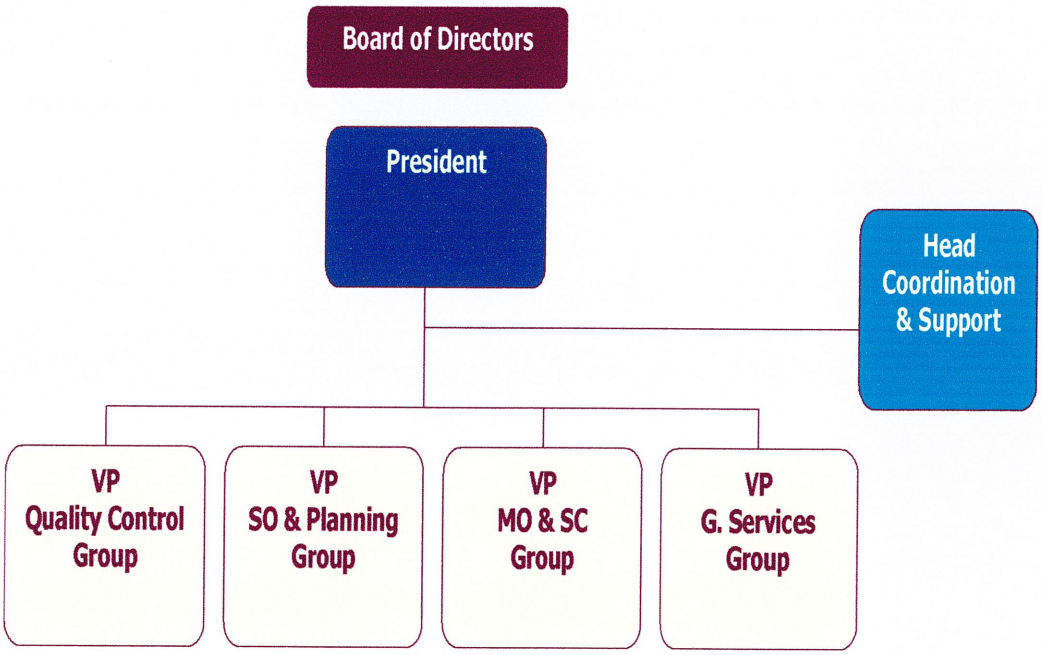


Figure 4.6

SESOM Proposed Organization Chart Outline

Most of the activities in the above chart are to be conducted by units, departments and groups which already exist in SEC chart.

From transmission B.L.

- Most of commercial business group → MO & SC Group.
- Most of system operation & control departments → SO & planning group.
- Some of the services coordination & regulation units → QC group.

From generation B.L.

- Most of the area operation planning departments → SO & planning group
- Most of quality & control divisions → Q&C group.

From distribution B.L.

- Most of customer services group → Q&C group.
- Some of business development & QC divisions → Q&C group.

The general services group is proposed to be fully abstracted from the existing finance B.L., general services group, and HR group.

Before ending this section, it is to be emphasized that SESOM is a non-profit entity to be owned by government but it should operate on a break-even basis. Participants are to pay levieted fees to SESOM to recover its fixed and variable costs. The participants' shares on those fees should be according to benefits of SESOM services.

4.4.3 Saudi Electricity National Grid (SENG)

SENG is to be a non-profit government regulated entity. This entity should owns, carries out maintenance work of the grid, provides open access to all participants, maintains high quality of transmission services, participates in network expansion plans, and enhances the total capacity within the available constraints.

The above recommendation of regulating SENG was according to the first proposal principle of Section 4.3. Transmission is a natural monopoly business due to the tendency of duplication and due to the loop-flows characteristics which allow power to flow in both directions making it hard to share power selling with other carrier. Beside that transmission expansion requires large costs and land right of way (ROW) which is impossible to be duplicated for another investor in the same location.

SENG is to be responsible for transporting electricity from GENCO's, IPP's or IWPP's to other participants like: SED, legible customers and retailers.

Beside the mandatory open access to all participants, SENG has to support and encourage competition among unregulated participants by having an effective transmission pricing to be just adequate for maintenance costs, capacity expansion and other running costs.

Rarely activities are interlinked in a way between SENG and SESOM. Power system security is known to be a major activity of SESOM and part of that is the integrity of SENG equipments and wires. In addition, SENG is required to provide information and some other services to SESOM to be able to secure the system.

Why to separate SESOM from transmission wires owner? Even though, England/Wales of UK, Norway and New Zealand are favoring that transmission owning and system operations to be under one entity, others are not like: Australia, California and New York of USA, Alberta and Ontario of Canada, and Spain. [25]

It is recommended in this study to separate the two entities due to the following reasons:-

- **Different Functions**

  In the existing structure of SEC, even though, the transmission owning and operation are under transmission B.L., it is handled separately by different divisions with totally separated responsibility and different management structure operated by deferent professionals. In addition, they have nothing common in terms of procedures or technical standards.

- **Strong links between SESOM and all participants**

SESOM activities are strongly linked with all participants especially with generation section in a degree not less that transmission wires.

- **Avoid discrepancies**

  Combining the two entities could give a chance for SESOM to favor its own transmission company at expense of other participants in any possible decision. Those decisions including accepting maintenance schedules, distribution of ancillary services, fees recommendation, job priorities, size of investment in the grid expansions , allocation of funds... etc.

- **Ensure fair information and services**

  In order to have accurate information to be released freely without any hesitation to all participants in the same time, it is recommended to have integrated market operator which must be separated from the sources of information like generation sector, transmission and distribution wires and retailers.

- **Increase trust on SESOM plans**

  Planning for both activities of transmission expansions requirements and in the other side planning for any development by SESOM in the industry structure are to be set free from any influences. In case of separation of the two entities, the plans are to be set freely and it will be trusted and easier to be approved by ECRA.

- **Volume of work**

  The two entities if combined will represent almost half of the industry in size of work, especially after giving SESOM the new rules and activities. So, it will make it difficult to manage all these huge activities covering the entire country of Saudi Arabia which is the world's 15th largest country in terms of geographical area.

4.4.4 Saudi Electricity Distribution (SED)

SED is to be a non-profit government regulated entity. This entity should own, operates and maintains the distribution network in the whole country.

The distribution wires are to be regulated for the same reasons mentioned for regulating the transmission wires in the previous section.

The existing DISTCO's are to be de-integrated into SED owning and operating the physical distribution system as a non-profit entity and into retail suppliers represented by CSC's which will be discussed in detail in the next section.

SED is to be independent from other unregulated participants, however, it can be along with SENG under the same holding company of SEC with separate financial accounts to facilitate correct pricing and consequently enhance the competitive atmosphere for other unregulated participants. Furthermore, SED has to encourage competition among unregulated participants by having efficient regulated distribution service charges.

Due to economics of sale in the metering services, it is not recommended to shift these services from SED to retailers. Otherwise, increase in costs could result from having more than one provider for metering services.

Shifting to deregulated industry will endorse a challenge to SED; even if it is regulated, due to dealing with and serving outside private companies. CSC's and other retailers are expected to push SED for time constraint to serve their customer better and increase profitability.

SED has limited interactions with SESOM. Load shedding order from SESOM to SED to maintain the power system requirements is one of the few interactions between the two entities.

4.4.5 Customer Service Providers [Customer Service Co's. and other Retailers]

Retailing businesses are to be carried out in Saudi Arabia by CSC's. Those companies are to be private for-profit competitive entities. Having more CSC's in the industry is a desirable target to maintain a real competitive market.

CSC's are to be allowed to sell energy to their customers with regulated capped prices along with other services like energy conservation, supplying saline water, cable TV services and internet services or any other related value-added services. In addition, Customers are to be allowed to choose their own CSP from any of the approved CSC's or future retailers.

CSC's are normally getting power from SED; however, they could act as independent retailers and purchase power directly from PSP's or from the wholesale market in SESOM.

CSC's have to be paid for the energy by their customers according to a well established price formula including the wholesale price, the separated and regulated transmission services cost, distribution services cost, and SESOM costs. All transactions between CSP's and other entities should be informed to the market operator of SESOM. Furthermore, CSC's are to be allowed for optional price hedging contracts with customers along with time of use deals to share price benefits with their customers.

Reading of meters, billing, and collecting of payments from customers are part of the activities of CSP's.

At the time that the sale of electricity in a specific town or village is conducted by deferent CSP's, this will indicate a real full-competition in retailing market. But, this is to be done in systematic steps as follows:-

- Financial separation for each division in all OA's which has capability to act as customer service provider (15 in EOA, 28 in COA, 19 in WOA and 18 in SOA) which represent customer relation divisions in the existing SEC chart.
- Financial separation of the four customer affairs departments in the four OAs.
- Financial separation of the customer services group in the Headquarter.
- Wait for SESOM to be established.
- Wait for the pricing system to be approved by ECRA.
- Wait for the market rules to be issued by ECRA.
- Complete separation of 80 CSC's under the holding company SEC in the medium term plan.
- Ensure a correct metering system at interface points.
- On the first day of wholesale market operation by SESOM, CSC's are expected to start actual trading with SED and customers.
- SEC to sell all CSC's to outside private sector in the long term proposal.

4.4.6 Saudi Electricity & Co-generation Regulatory Authority (ECRA)

Saudi Electricity Regulatory was established on 2001 by a council of ministry resolution # 236 to support the restructuring process decided at that time. After three years another responsibility was added to their functions. This responsibility is the co- generation of water and electricity by the council of ministry resolution # 163 in 2004 with the new name of ECRA. [39]

Giving the full authority to ECRA as the independent regulatory entity to be able to regulate the SESI operation, is the most effective factor in creating an efficient system

and in the same time providing fairness among participants and satisfying government vision and requirements.

Protection of customers against monopoly is the main and first objective of ECRA. The second important objective is regulating natural monopoly businesses (SENG and SED) and promoting real competition in competitive businesses (PSP's and CSP's).

Another four main objectives which need to be emphasized here are:-

- To promote an efficient use of energy and natural resources.
- To ensure a reasonable rate of return for PSP's and CSP's and at the same time to be fair for end-users.
- To ensure reasonable charges to SENG and SED services to be adequate for them to run the organization in break-even manner and to maintain the system security and reliability.
- To improve retail market activities including innovations and new technologies.

Some of the roles of ECRA are listed in Section 3.1.10 in Chapter 3. Two additional roles can be emphasized here:-

- To approve national network expansion plans.
- To determine which activity need to be licensed or not and approve licenses.

ECRA should be self financed in a break-even manner to cover its expenses from license fees and adequate portion of energy costs. In case shortage in its budget occurs, ECRA can request for government subsidy to cover its operation. Such subsidies are recommended to be avoided if possible.

4.5 Trading

Market operators and schedule coordinators inside SESOM must have full responsibility of trading activities in SESI among all participants.

4.5.1 Wholesale Market

In the wholesale market, bulk electricity is to be traded between PSP's and CSP's in all over the interconnected areas in Saudi Arabia at the first day of operating SESOM. Some areas are expected to be delayed in the ongoing efforts of establishing the complete interconnected national network like North East Area of the country which is to be out of the wholesale marketing until being interconnected with CTA and DTA.

It is recommended to implement a forward market and real time operation strategies, which allow PSP's to offer competitive bids to SESOM one day ahead to sell energy. SENG is required to report the conditions of the grid system one day ahead also. Then, supply and demand are to be matched through a central-coordinated dispatch process by SESOM. Since, the condition of the supply and demand are expected to change before the real dispatch hour, both PSP & SENG should update inputs every one hour. The latest information is to be the basis for SESOM automated systems to dispatch the generators required to produce electricity meeting the demands in the most cost-efficient way.

It is also recommended by this study to apply the uniform-price technique where a System Marginal Price (SMP) is to be established from the price of the most expensive competitive bid required to meet demand. Then all PSP's whose bids are below SMP earn the same marginal price.

The dispatch instructions could be with smaller intervals than the trading intervals. In this case the average of the dispatch prices during the preceding one-hour will be the trading price.

More restrictions in the wholesale market price are recommended in pricing section to avoid market power.

SESOM finally has to calculate the financial liability of all participants on daily basis and settle transactions for all trades in monthly basis.

4.5.2 Billing

All market participants are required to ensure that metering equipments are available in the right location to measure consumptions. SED is responsible for ensuring that all consumptions passes through its wires and equipment are metered. SENG also is responsible for ensuring metering all delivered consumptions passes through its network. Any other direct connected retailer or end-customer is also responsible for his consumption metering.

SENG and SED are responsible for measuring the value of energy delivered, validating and testing the meters, applying wire loss functions, providing the information to SESOM to be validated with PSP's information. Such information is needed by SESOM to be able to calculate and perform financial settlement.

4.5.3 Bilateral Contracts

In addition to wholesale market, bilateral contracts are recommended to be allowed by any of the buyers and sellers outside SESOM. Both parties of the bilateral contract are expected to agree on a certain amount of energy subject to the system constraint at a

particular date in the future and at a fixed price. SESOM should be informed by the two parties of the bilateral contract about contracted amounts to secure the system.

In some cases, the PSP's could not be able to hit the contracted amount due to constraints or lower prices in the wholesale market compared to his generation cost. So, PSP is to be allowed to purchase the required energy from SESOM and provide it to his contract partner. In all cases, settlements must be made through SESOM.

Contract for Differences (CFD) is a purely financial contract with no associated physical delivery, whereby for a contracted quantity of electricity, the buyer pays the seller the difference between the reference price (usually the spot price) and the contract price whenever the reference price is below the contract price. Moreover, the seller pays the buyer the difference between the reference price and the contract price whenever the reference price is above the contract price.

4.5.4 Ancillary Services

Ancillary Services including reserve capacity, generation capacity, transmission loss compensation, black-start capacity charges, and system characteristics control (voltage & frequency) are to be paid and covered partly as a regulated amount in the customer bill. The other part is to be paid by the participant responsible for a situation that requires ancillary services.

SESOM uses ancillary service charges to manage the system security and reliability, maintain technical characteristic, and cover costs for system re-start process. [38]

4.6 Pricing

Correct pricing is the key to drive the reform in Saudi Arabia, as well as other countries at the same stage of restructuring process, to great success. On the other hand, if wrong pricing is implied, it would unbalance participants' capabilities to form an inefficient industry and it could lead to system collapse or other kinds of shortcomings.

This section will go over the advised pricing techniques applicable to Saudi Arabia. However, SEC and ECRA are recommended to exert great effort to support the existing pricing group with expertise and tools. Also, the pricing group is to be allowed to gather the required information with full authority to be a good basis for correct and comprehensive costs data for all intended participants. And then correct decisions are to be made for the profit margin percentage and other pricing formula parameters.

4.6.1 Pricing Objectives

An effective pricing mechanism should meet the following objectives:-

- Recovery of investment costs for all participants.
- Sending price signals to end users to give them the right to react according to wholesale market prices to be a default participant in securing the power system and load management.
- Providing incentives to private investors to enter the market which could enhance competition and eliminate market power.
- Providing incentives to help in congestion management of transmission grid.
- Providing incentives to PSP's to reduce their production cost and consequently reducing end users bills.
- Promoting simplicity and transparency to avoid discrimination of any of the participants.

- Convergence of ancillary costs to ensure capability of maintaining a reliable and a secured system.
- Supporting contracts and long term sustained success and contingencies coverage.
- Promoting new technologies and innovations for all regulated and unregulated entities.
- Favoring PSP's with reformed technologies.
- Satisfying the uniqueness requirements and situations of Saudi Arabia in terms of political government vision to have equal bill value all over the country for each customer category, in addition to the fuel type, source, and availability constraints. Other effective factors like: high consumption growth, religious directions, and culture background.

4.6.2 Pricing Method

System Marginal Price Cap

The uniform-price technique recommended in the previous section needs efficient PSP's competing in a correct atmosphere to maintain reasonable SMP values. But, at this stage in Saudi Arabia, still the existing PSP's even after the proposed grouping have some inefficient power plants which are still needed to be operated to satisfy the supply and demand schedules. Operating such power plants will drive SMP to high values. And more worse in the uniform-price technique, the price is to be paid to all purchased energy leading to unaccepted and unreal high wholesale SMP.

For the above, it is recommended by this study to set a well determined system marginal price cap to allow PSP's to compete under its value. But, PSP's will be paid the price cap value as a maximum system marginal price in case the market drives the SMP over the price cap.

The determination of SMP cap is to meet the following objectives:-

- Give enough room for competition.
- Maintain the incentive for new investment.
- System marginal price at low peak season should not hit the price cap value.
- Allow all participants to survive with the regulated end user KWH price, since the price cap will be the worst scenario as part of the end user price formula.
- Drive PSP's to get red of inefficient generating units and replacing them with new ones.

It is recommended to review the price cap value after one year of operating the wholesale market and then to be reviewed every 5 years.

Even though, price caps are not supporting a full competition, they could allow for required competition and have the following advantages:-

- Prevent crises from happening and limit the worst case scenario.
- To be a base for all other prices determination.
- In a way it will encourage entry to the market due to the investors' culture of not taking high or open risks.
- To be a good reference for ECRA to review the regulated end user KWH pricing technique.
- It will encourage bilateral contracts; since PSP's will know the range of benefits or losses on behalf of stable prices they are getting from the contracts.

PSP Price

The capped SMP generated by the wholesale market which is determined according to the last bid value at the real dispatching time is to be the price paid to PSP's for each KWH delivered.

Additional prices should be paid to some of PSP's to be compensated for the spinning and spared reserves. Generation capacity availability is also to be paid to PSP's. Moreover, incentives are to be paid for efficient PSP's to encourage them continue and encourage others to increase their efficiency and replace the inefficient units.

Wholesale Market Price (WMP)

This price should include the SMP and all ancillary services mentioned in Section 4.5.4 in addition to Regulation Prices (RP).

This RP's are proposed to be with two components, one is to be a regulated price to cover portion of expenses encountered by SESOM operating costs. The other component is also to be regulated and approved by the ministry to recover a portion of ECRA operating costs. Equation 4.1 shows all WMP components:-

$$WMP = SMP + ASP + RP \quad (4.1)$$

Transmission Service Price (TSP)

TSP is to be regulated by ECRA and paid by all wholesale buyers who are to be served through transmission network. It is advised that two prices are regulated for TSP, one without congestion and the other with congestion to help in avoiding adding loads though congested lines.

Apart from TSP, SENG is to charge another regulated connection charges according to the voltage of the connection point as the existing practice in Saudi Arabia.

Distribution Service Price (DSP)

DSP is to be regulated by ECRA and paid by any customer or retailer connected to the distribution wires. SED as per existing practice is collecting another regulated connection charges at the first time the customer connected.

Both TSP and DSP are to be specifically determined only to allow both SENG and SED to break-even financially. But, projects for future expansions are to be considered in the price determination. Due to the high budget needed for transmission interconnection projects, it is recommended to finance such projects by SEC at ongoing stages to avoid disturbing future reforming process.

Retailing Service Price (RSP)

Customer service companies and other retailers are to compete in the market to get RSP which is to be enough for their survival to recover their operation cost, management cost, capital investment cost, and profit margin. However, they are bonded by a regulated end user price as a maximum price.

End User Prices (EUP)

EUP is recommended to be regulated to satisfy government directions to have the same charges all over the country and to satisfy Saudi culture to reduce uncertainty in the electricity bill.

Equation 4.2 shows all EUP components:-

$$EUP = WMP + TSP + DSP + RSP \quad (4.2)$$

Where:-

WMP is the wholesale market price as per equation 4.1 which is to be capped but unfixed.

And,

TSP and DSP are to be regulated.

And,

RSP is to be unfixed but determined by other regulated prices and WMP.

CSC's and other retailers can play a great role in the success of SESI, since they can sense the price signals and translate it in different ways to end users.

Traditional components of the monthly bill are will illustrated in reference [19] including how to relate power quality with its costs.

4.6.3 Comments on SEC Existing Tariff and fees

It is recommended by this study that ECRA is to review carefully the current regulated end-user tariff and connection fees.

Consumption Tariff

The current tariff design is set that high consumption customers in one month are to be penalized regardless of their participation on the peak loads or not. This design is not supportive for a competitive market and the customer will not participate or react with the pricing signals from wholesale market.

The design of the Tariff is to be sensitive to the following:-

- Capacity availability
- Peak and off-peak use

So, the design recommended is to be composed of:-

1. Demand charge which is to be fixed (SR/KW) monthly charge per each circuit breaker size. This charge will cover part of the SED, and SENG service charges in a related manner.

2. A consumption charge which is to be a fixed amount of Halals for each KWH consumed. This is proposed because until now, the energy meter which can provide the Time of Use (TOU) measurement is expensive to be installed for

household customers. However, CSC's and retailers can sense the peak and off-peak prices from the wholesale market price component in equation 4.2. Then, they can play a good role to pass the price signals to end customer by contracting with some of customers for lesser that the regulated tariff with conditions like: conservation, TOU and load management.

The benefits of the above proposals are:-

- The tariff will be more related to service costs.
- The tariff could react according to price signal.
- The aim of avoiding burden on small customers is still valid due to positive relation between demand charge and circuit breaker size.
- This design will reduce the headache of SED management regarding the number of energy meters deserved for each customer since there are no more benefits from more meters.

Connection fees

Connection fee design is also to be reviewed and to be logically set to avoid abusage and cheating practices.

In the existing practice a customer with 200 A meter will pay around 2 times the price to be paid by the customer with two meters each of 100 A. This will lead to customer un-satisfaction, in addition to abusage and cheating practices. So, it is recommended that up to a certain limit, the fee to be a constant multiplied by AMPS. This limit is to be specified according to actual costs differences and customer categories.

The end user is to be given the chance to choose his supplier in addition to choosing between the regulated price and any bilateral contract with CSC or other retailer.

4.7 Comments & Recommendations on SEC Action Plan

4.7.1 Comments on SEC implemented actions

Action Taken

SEC was formed in year 2000 as the first step in deregulating SESI. The second step, in year 2003, was shifting from vertically integrated utilities to functionally separated BL's as shown in Figure 2.7 in Chapter 2. SEC is still functioning with the same organization chart of Figure 2.8 up to the time of writing this revision.

Comments

These two steps were very important move to introduce competition in the generation and retail businesses which is recommended by this study. Also, the action taken was mandatory to facilitate a complete reform in the future.

Action Taken

Allowing outsiders to participate in generation capacity and putting for sale some of the power plants with encouraging prices, and establishing a new co-generation company (WEC) owned by both SEC and SWCC as shown in Figure 2.9 of Chapter 2.

Comments

Those actions are good ignition tools to start competition in the generation part. Nevertheless, generation units which are to be released with encouraging prices to investors are to be relatively efficient units and SEC is advised to avoid selling old low efficient units. This last condition is required at this stage to ensure financial security of the intended investors which could lead to a healthy competitive atmosphere.

For WEC, it is recommended that SEC reduce its share gradually and sell it to SWCC or outsiders. The reason behind that is to go on-line with the final proposed SESI structure

especially with the recommendation of avoiding any single market participant to own more than 10% of the overall generation capacity as learned from Argentina practice.

Action Taken

Start adapting the idea of Customer Call Center (CCC).

Comments

Since the proposed structure is recommending a retail business competition, the design of CCC should be based on service charges to be imposed on CSC's or other retailers if they like to provide this service to their customers. So, it is recommended to be an optional priced service to allow for a real competitive market which links quality of service with its price and cost.

Action Taken

Start of new contracts between transmission B.L. and bulk customers.

Comments

The action is supportive to the bilateral contracts recommended in this study in a way that it orients bulk customers for such contracts. Also, it helps in establishing the service cost and pricing technique to be a base for SESOM and ECRA to decide the regulated transmission service. However, in this study, transmission is to be represented by SENG which is a non-profit entity; getting a regulated transmission fees. So, such practice of bilateral contract is to be shifted from transmission to SESOM to be a base for future Contract for Differences between PSP's, CSP's and customers. SENG and SED are recommended not to sign bilateral contracts.

4.7.2 Comments & Recommendations for SEC Approved Future Action

Approved Plan

All financial mater to be finalized among BL's by start of 2007 to have five financially separated companies (Generation, Transmission, Distribution, Corporate Affairs, and General Services) under SEC as a holding company. [39]

Comments & Recommendations

It is recommended to implement this approved plan since it is essential for all future action plans in restructuring process. Even though the approved separation is not 100% on-line with the proposed structure in this study, it will facilitate the proposal in its preliminary stage.

Approved Plan

SLA is practiced on trial basis and the actual implementation will be at the start of year 2007. [39]

Comments & Recommendations

It is a basic requirement in any separation plan, but it should have been started long time ago to avoid any disturbance in the actual separation process of the companies which is planned to be at the same time of applying SLA.

Approved Plan

Actual separation of TRANSCO is to be carried out. [39]

Comments & Recommendations

It is recommended to hold this action in order to maintain SEC authority and capability to carry on other recommended actions in SESI restructuring process. However, the immediate step recommended at this stage is financially and functionally to separate the

operation activities from transmission B.L. Then, SESOM is to be established as a non-profit independent entity to cover the activities of system operation, system marketing and schedule coordination as illustrated in Section 4.4.2.

Approved Plan

Generation B.L. is to be divided into sub-generation companies (GENCO's). [39]

Comments & Recommendations

This plan is recommended to be the igniting mechanism for future generation competition market. Moreover, it is recommended to group SEC power plants (73 PP's as per 2005 actual) into 8 to 9 groups with the proposed criteria mentioned in Section 4.4.1.

Approved Plan

As the last stage, it is planned to divide the distribution B.L. to sub distribution companies. [39]

Comments & Recommendations

This action is not recommended to be carried out. However, the immediate step recommended at this stage is to financially separate customer services related functions from all other wiring related functions. The next step is to de-integrate the existing DISTCO into SED owning & operating the physical distribution system as a non-profit entity as mentioned in Section 4.4.4. And the customer service part is to be divided into CSC's to act as competitive CSP's along with future intended new privately owned retailers. More details about CSP's are to be found in Section 4.4.5.

4.8 Conclusion

Saudi Arabia Electricity Supply Industry as well as any other industry has its own characteristics, limitations and advantages. Such uniqueness would drive the researcher to specific selections of the world wide experiences on each component of the whole framework. So, the proposed framework in this chapter as a whole design is becoming a unique design which is not identical to any of the world electrical industries.

In summary, the key elements of the proposal are:-

1. Transmission wires and distribution wires are naturally monopoly businesses. So, it is proposed to be represented by SENG & SED respectively which are governmental owned non-profit utilities which can be under SEC as a holding company even as a long term structure.

2. Generation and retail businesses are to be opened for competition. So, grouping technique for existing power plants and separation of CSC's from distribution wires are proposed as a tool to start and encourage private investors to enter the market. GENCO's along with other IPP's and IWPP's are the proposed private for-profit entities to act as PSP's. Moreover, CSC's and other retailers are the proposed private-for-profit entities to act as CSP's. Both GENCO's and CSC's could be under SEC as a holding company in the short and medium terms. But SEC should release them all in the long term proposal.

3. SO, MO, & SC are to be under one entity separated from all other participants including transmission wires. This entity is to be presented by SESOM as a governmental owned non-profit independent entity which can be under SEC as a holding company in the short term. But, it should be the first entity separated from SEC after ability to be self-financed.

4. ECRA as the only regulatory power with proper authority is to be a 100% self-financed independent entity. It could be financed by government in the short term plan but not in the long term plan.

5. Capped system marginal pricing technique is proposed to wholesale marketing, and capped end user tariff is considered in the pricing formula. Such caps are important to secure the market from abuses and satisfying the customer with bill amount stability. Bilateral contracts along with contracts for differences are also proposed to help in providing more stable prices for critical nature customers.

6. System security, reliability and related requirement are to be ensured by SESOM using ancillary services charges to be paid by participants in a fairly manner.

To conclude this chapter, it is to be emphasized that the guidelines proposed by this study are the general framework to determine the outlines for plans' scope of work. In actual practice, ECRA and SESOM are to form new groups to work along with the existing groups to finalize a detailed design with great emphasis in the pricing technique since it is the key for the proposed structure success.

5 THE MODIFIED OPTIMIZATION MODEL

5.1 Introduction

Prior to deregulation, generation sector or business line in a vertically integrated utility is concerned mainly about system stability and reliability giving the cost a very low priority. Even in the advanced industries the cost which is encountered in their automatic control systems is limited to the production cost neglecting the transmission cost since it is small compared to other costs and transmission network had been built and owned by the same utility.

In a deregulated industry GENCO's or IPP's compete to satisfy the market demand before others do. In addition to willingness to sell more they are aiming to reduce cost to minimum in order to increase profit. Apart from the cost of production; other costs are to be paid by GENCO's to work on optimal majors.

GENCO's could be encouraged to build new plants or extend existing plant to take advantage of the fact that electric power consumption in the world is growing fast (world annual rate is more than 03% as mentioned in Section 1.4). So, GENCO's, investors, and system planners are willing to use the most suitable optimization tool to know the future generation potential areas in the industry starting from economic load dispatch tool to the most advanced optimal power flow and unit commitment tools if needed.

By the end of this chapter, a MW L P- Based Optimal Power Flow is proposed to be used to match supply with demand limiting the data required to run the program to minimum.

Going briefly across the available tools will help understanding the proposed tool advantages and limitations.

5.2 Power System Nature

Power generated from power plants is delivered to customers by a transmission network, which must be operated according to limits. Limits are on the amount of electric power that can be transmitted from location A to location B like line capacity, transmission equipments limits, voltage and stability limits which could cause either or both of transmission losses and congestion. [4]

Power system constraints are:-

- Power flow laws.
- Generator capacity.
- Transmission lines thermal capacity and other limits.
- Minimum & maximum voltage of energy bus.
- Transformer tap limits.

Congestion occurs when one or more of those network limits is reached. Congestion implies that some expensive generation is used in stead of the cheaper one due to its location.

The effects of losses and transmission system constraints are handled by Congestion Management System (CMS) which assigns costs of supplying energy across those limited or congested lines.

CMS provides a price incentive to [34]:-

- New GENCO's for proper location.
- TRANSCO for extending transmission lines that are needed to be installed.
- DISTCO's / Retailers for the locations where demand elasticity is most beneficial.

It is important to note that the transmission charges are dependent on the flow in each transmission line as well as each generator's contribution to that flow and therefore cannot be computed before practicing the power flow analysis.

5.3 Economic Load Dispatch [38]

ELD is considered the basic optimization tool to dispatch the power system. Its objective is to keep the total operation cost to minimum while allocating the total load to the available generation units without breaking operation constraints and neglecting transmission constraints.

The unit production cost can be given by the system operator or calculated as the product of the fuel cost function by the input-output function. So by knowing the heat rate characteristic to each generator, the unit cost can be calculated. Model parameters are classified as follows:-

- Decision variables are P_{gi} in MW where the values are the model output.
- Data to be given or calculated before running the model are:-

P_{li}, C_{gi}, n, P_{gi}^{min}, P_{gi}^{max}, and, P_{loss}. (List of symbols is given on page 15).

ELD can be formulated in a simple general form with the following objective function and constraints:-
The objective function is to minimize the cost:-

$$\text{Minimize} \sum_{i=1}^{n} C_{gi}(P_{gi}) \qquad \textbf{(5.1)}$$

Subject to the operating constraints which are:-

1. *System real power balance*

   As the total generated power is equal the total load added to the lost power which is represented by the following formula:-

$$\sum_{i=1}^{n} P_{gi} = \sum_{i=1}^{n} P_{li} + P_{loss} \qquad \textbf{(5.2)}$$

2. *Generation unit limits*

   As the generation output level to be within the max and min of the capacity of the generation unit which can be represented as:-

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \qquad \text{for } i = 1,2,..n \qquad \textbf{(5.3)}$$

   The above model can be solved by any of the advanced mathematical methods like Lagrange Relaxation or using linear programming tool either manual or by suitable software depending on the problem size. The shortcoming of this method is ignoring the transmission constraints. But still ELD can be valid for some applications like power dispatching in non-congested networks.

5.4 Unit Commitment

Units are to be set on or off to satisfy the variable demand in the least expensive manner for a period of time while satisfying the operational constraints of generators and the transmission system. This is done by solving a UC problem which is actually the same as ELD problem with more complications [6]:-

- It forecasts for a time range of a day or a week, so time element is to be inserted in the formulation.
- Binary element is to be added to count for the commitment state.

UC problem can be formulated in its basic general form in the same way ELD is formulated with the following differences:-

The objective function is to minimize system cost with some enhancements:-

- The cost function to be multiplied by a commitment state function.
- The start-up and shutdown costs to be added.
- Time index to be inserted.

Subject to operating constraints which are:-

- *System real power balance* as in ELD with insertion of:-
    a. Commitment state function
    b. Time index

- *Generation unit limits* as in ELD with time index insertion.

Other constrains to be added for the UC model are [24]:-

- *Minimum "on" or "off" limits* to ensure the minimum time where the unit is "on" before shutdown and the minimum time where the unit is "off" before getting it back to service.
- Other constraint could be added according to the nature of the problem like ramp rate, fuel, multi area, must run unit, and crew constraints.

Also, if required advance model of UC could account for transmission constraints which are must in some applications.

The UC model can be solved by any of the advanced mathematical methods like Lagrange Relaxation or Priority List or using Binary Linear Programming tools.

5.5 Optimal Power Flow

The power system is non-linear by nature which could be operated using an optimum power flow (OPF) procedure to meet all demands at minimum total cost, subject to operation and transmission line capacity constraints, meeting minimum voltage constraints. OPF is not only solving the nonlinear power balance equations, but it often determines the correct values for large number of automatic controls like capacitors and transformer tap settings, generator AVR status, phase shifting transformer, reactive compensator, and the values of FACTS. [6]

The output of OPF model is more accurate estimate than ELD outputs due to the nature of the electric system which requires the non-linearity. This output contains voltage magnitudes and phase angles at each bus in addition to the real and reactive power flow.

OPF model can be formulated in its basic general form in the same way ELD is formulated with the following differences [38]:-

Objective function is to minimize system cost with enhancement:-

- Reactive power cost is to be added to the cost function.

Subject to operating constraints which are:-

- *System power balance* as in ELD with insertion of:-
    a. Reactive power
    b. Bus voltages and angle
    c. Bus admittance and angle

- *Generation unit limits* as in ELD with real and reactive power limitations

Other constrains to be added for the OPF model are:-

- *Bus voltage limits*
- *Power flow limits in transmission network*
- Other constraint could be added according to the nature of the problem.

OPF model can be solved by any of the advanced mathematical methods which are very complicated processes. However computer software handling non-linear programming method will be the most suitable approach to solve OPF in addition to a linear programming approach after linearizing the non linear coefficients in the formulation process.

5.6 DC Optimal Power Flow

DC-OPF is a simplified OPF with some assumptions not affecting the requirement of specific problems. Such assumptions are [1]:-

- Real power only to be considered in the model.
- Setting voltage magnitudes to one per unit.
- The system is lossless.
- Consider the transmission network as a line.

DC-OPF model can be solved by any of the same tools used to solve ELD models.

5.7 MW LP- Based OPF (Proposed Model)

This proposed model is a Linear Program-Based OPF established to help in deciding the future generation potential areas in a deregulated industry. Its objective is to keep the total operation cost, generation and transmission, to minimum while allocating the total

load to the available generation units without breaking operation constraints and transmission constraints.

Since the objective of the electrical system is to deliver real power to satisfy the loads; the model is set in a way to be extremely simplified without affecting the main limitations in the power flow. The model is limited to the following characteristics and constraints:-

- MW-only formulation (Real power only to be considered in the model).
- Generator capacity (Power plant min and max).
- Transmission lines MW limits.
- Transformers MW limits.
- The cost of generating one MWH is constant for a specific bus.
- The cost of wheeling one MWH is per KM per Circuit.
- Power reserves in the system are not considered.
- Losses are considered to be fixed.

Even though, the power system is non-linear by nature, this modified model uses a linear-programming method which will do the purpose of the optimization.

5.7.1 Model Formulation

Model parameters are classified as follows:-

- Decision variables are Pgi, Pdij in MW where the values are the model output.
- Data to be given or calculated before running the model are:-

P_{li}, C_{gi}, C_{ij}, n, N_{ij}, P_{gi}^{min}, P_{gi}^{max}, and C_{lij} (list of symbols are given on page 15).

The general formulation of the optimization model is as follows:-

A) Objetive Function

To minimize the generation cost and the wheeling cost without priority, so, the accuracy of the cost given for the generated unit of MWH and the transferred unit of MWH will affect the model output. So, It is not recommended to use normal costs used in other models (the operation cost based in the fuel cost & heat exchange) but the actual cost is to be used involving all parameters where GENCO's are willing to sell to outsiders and TRANSCO's are willing to be paid for utilizing their networks. The calculation of the cost will be explained in next chapter while applying the model to actual network as a case study.

$$\text{Minimize} \sum_{i=1}^{n} C_{gi}(P_{gi}) + \sum_{i=1}^{n}\sum_{j=1}^{n} N_{ij} C_{ij} P_{dij} \qquad \text{for } i \neq j \qquad \textbf{(5.4)}$$

This general form covers all busses in the system and all connections between them allowing reveres flow. So, it should be tailored well when applying it to a real system to avoid maximizing the size of the problem. *For any bus without a power plant, the cost should be set high to avoid the system to propose locations without control.*

B) Constraints

1. *Real power balance at each bus*

   At each bus the power flow-in from generators and from other transmission lines should be equal to power-out to load and to transmission lines at any point of time,

   Subject to:-

$$P_{gi} - \sum_{j=1}^{n} N_{ij} P_{dij} + \sum_{j=1}^{n} N_{ij} P_{dji} = P_{li} \qquad \text{where } i = 1, 2 \ldots n \quad \& \text{ for } i \neq j \qquad \textbf{(5.5)}$$

   Only real power is considered.

2. *System real power balance*

As the total generated power equal to the total load added assuming fixed losses in the system.

Subject to:-

$$\sum_{i=1}^{n} P_{gi} = \sum_{i=1}^{n} P_{li.} + \text{Losses} \qquad \textbf{(5.6)}$$

Only real power is considered.

3. *Generation unit limits*

As the generation output level is to be within the max. and min. of the capacity of the generation at each bus,

Subject to:-

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \qquad \text{for } i = 1,2,\ldots n \qquad \textbf{(5.7)}$$

Only real power is considered.

4. *Limits on power flow*

As the transmission lines are limited by its capacity which should be determined by the thermal capacity; however, it could be approximated and determined by MW capacity,

Subject to:-

$P_{dij} \leq C_{lij}$ for all i -j pairs & $i \neq j$ **(5.8)**

5. *Non negativity*

To satisfy the linear programming restrictions and the direction of the flow, non negativity is a must,

Subject to:-

$P_{dij} \geq 0$ for all i -j pairs. **(5.9)**

Testing the model by applying it to a real system and comparing the outputs is covered in the next chapter.

5.7.2 Solution method

The model developed in the previous section is proposed by this study to be solved using LINDO optimizer software as a powerful tool for solving linear programming problems.

Figure 5.1 is a flow chart listing steps to be followed to make use of the model.

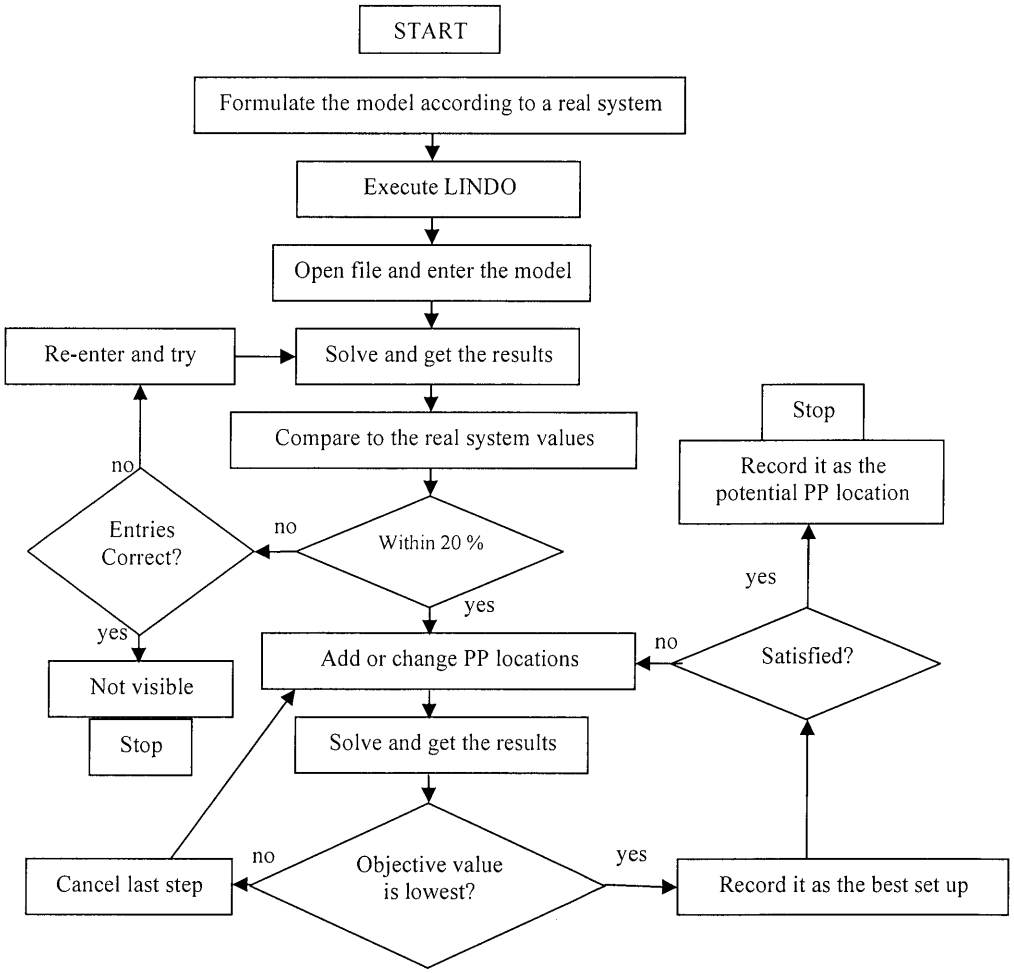


Figure 5.1
MW LP- Based OPF Flow Chart

6 APPLICATION OF THE MODIFIED MODEL

6.1 Application to Practical System

As per the flow chart in Figure 5.1; the established MW LP-Based OPF model will be applied to the real power 56-bus system in eastern province of Saudi Arabia, which is presented in Figure 6.1.

The model is to be formulated as follows:-

A) Objective function:-

Equation 5.4 in Section 5.7.1 is the general model where values can be substituted as follows:-

- In Figure 6.1 the busses are numbered from 1 to 56 and each bus represents either a power plant or a grid station or a pure load and it could represent a combination of some or all of them. So, i = 1, 2, 3, up to 56 and j = 1, 2, 3, up to 56.
- Cgi is the generation cost per MWH in Saudi Riyals (SR)* for each power plant as listed in Table 6.1. The cost calculation is one of the products of this study illustrated in the next section.
- Cgi is set high (1000) for all busses without generation to avoid the system to propose a power plant in every bus.
- C'ij is the wheeling cost per MWH per circuit in Saudi Riyals as listed in Table 6.2. The cost calculation is also a product of this study illustrated in Section 6.3.
- Nij is the number of circuits between bus i and bus j from Table 6.2 and Figure 6.1.
- Pgi, Pdij are the decision variables in MW where the values are the model output.

* 1 $ = 3.761 SR.

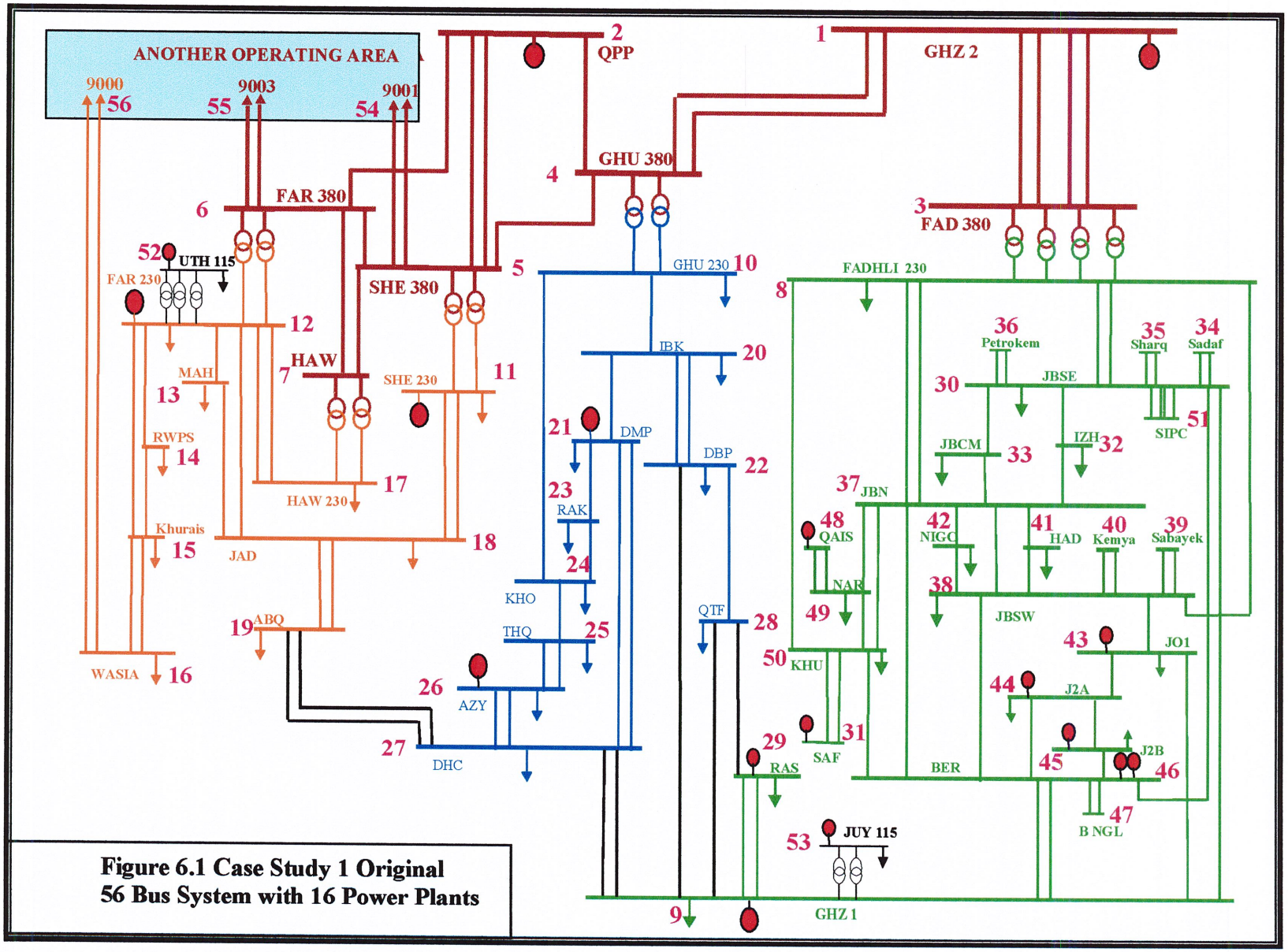


Figure 6.1 Case Study 1 Original 56 Bus System with 16 Power Plants

B) Constraints

Subject to:-

I. *real power balance at each bus*

Equation # 5.5 in Section 5.7.1 is the general model where it can be substituted for P_{li} from Table 6.1 and the other variables as illustrated in (A) above.

II. System real power balance

Equation # 5.6 in Section 5.7.1 is the general model where Figure 6.1 and Table 6.1 are used for substitutions.

III. Generation unit limits

Equation # 5.7 in Section 5.7.1 is the general model where the data of maximum and minimum output of each power plant are listed in Figure 6.1 and Table 6.1.

IV. *Limits on power flow*

Equation # 5.8 in Section 5.7.1 is the general model where Figure 6.1 and Table 6.2 are used for substitutions.

V. Non negativity

Equation # 5.9 in Section 5.7.1 is the general model where Lindo software is handling non negativity as a built-in feature.

Table 6.1 56 Bus Information for Bus System with 16 Power Plants

Bus No. I	PP OR SS NAME	BUS VOLTAGE (Kv)	Min MW P_{gi}^{min} (MW)	Max MW P_{gi}^{max} (MW)	LOAD P_{li} (MW)	Unit Generation Cost C_{gi} (SR/MWH)	Type of Fuel Used
1	GHZ380 PP	380	100	2528	120	64	Steam-Gas Crude
2	Q PP	380	200	2500	102	51	Steam-Gas Crude
3	FAD380 SS	380			--	1000*	
4	GHU380 SS	380			--	1000*	
5	SHE380 SS	380			--	1000*	
6	FAR380 SS	380			--	1000*	
7	HAW380 SS	380			--	1000*	
8	FADHLI230 SS	230			33	1000*	
9	GHZ230 PP	230	220	1600	273	63	Steam-Gas Crude
10	GHU230 SS	230			6	1000*	
11	SHE230 PP	230	100	1219	690	72	Gas
12	FAR230 PP	230	100	910	578	74	Gas
13	MAH SS	230			341	1000*	
14	RWPS SS	230			27	1000*	
15	KHURAIS SS	230			7	1000*	
16	WASIA SS	230			50	1000*	
17	HAW230 SS	230			191	1000*	
18	JAD	230			--	1000*	
19	ABQ	230			172	1000*	
20	IBK	230			490	1000*	
21	DMP PP	230	100	400	468	108	Gas-Diesel
22	DBP	230			369	1000*	
23	RAK	230			120	1000*	
24	KHO	230			380	1000*	
25	THQ	230			377	1000*	
26	AZY PP	230	100	850	--	132	Steam
27	DHC	230			139	1000*	
28	QTF	230			389	1000*	
29	RAS PP	230	20	120	148	101	Gas
30	JBSE	23			1	1000*	
31	SAF PP	230	20	75	223	100	Gas
32	IZH	230			62	1000*	
33	JBCM	230			189	1000*	
34	SADAF	230			273	1000*	
35	SHARQ	230			127	1000*	
36	PETROKEM	230			143	1000*	
37	JBN	230			9	1000*	
38	JBSW	230			153	1000*	
39	SABAYEK	230			2	1000*	
40	KEMYA	230			43	1000*	

Table 6.1 (Continue) 56 Bus Information for Bus System with 16 Power Plants

Bus No. I	PP OR SS NAME	BUS VOLTAGE (Kv)	Min MW P_{gi}^{min} (MW)	Max MW P_{gi}^{max} (MW)	LOAD P_{li} (MW)	Unit Generation Cost C_{gi} (SR/MWH)	Type of Fuel Used
41	HAD	230			461	1000*	
42	NIGC	230			141	1000*	
43	JO1 PP	230	80	300	--	132	Steam
44	J2A PP	230	80	300	--	132	Steam
45	J2B PP	230	80	300	--	132	Steam
46	BER PP	230	80	215	500	75	Gas
47	BNGL	230			68	1000*	
48	QAIS PP	230	20	108	210	148	Diesel
49	NAR	230			103	1000*	
50	KHURAIS	230			55	1000*	
51	SIPC	230			1	1000*	
52	UTH PP	115	80	272	--	70	Gas
53	JUY PP	115	40	118	--	85	Gas
54	R9001	380			925	1000*	
55	KH9003	380			814	1000*	
56	R9000	380			158	1000*	
Total System Loads					**10131**	**Loads + 4% (System Losses) = 10553 MW**	

* (1000) is set high for all busses without generation to avoid the system to propose a power plant in any bus.

The bus information for the whole Saudi eastern province electrical network (Figure 6.1) is summarized in Table 6.1. This table is to be used as the input data for the formed model which is to be solved by LINDO software. Table 6.1 contains the unit generation cost (C_{gi}) which is the product of Table 6.3. Also, other data related to busses from generation limitations including maximum and minimum power plants capacities and load information, are listed in Table 6.1. This data is actual as per reference [39] except for the SR 1000 value which is set for all busses (without generation) to avoid proposing a power plant in any bus without control.

Table 6.2 Line Information for 56-Bus System with 16 Power Plants

Line No. ij	Line Name	Line Voltage (kV)	Normal Capacity CL_{ij} (MW)	Circuit Length (KM)	No. of Circuits N_{ij} (No.)	Wheeling Cost Per Km Per circuit (SR/MWH)	Wheeling Cost Per Circuit C_{ij} (SR/MWH)	$N_{ij} * C_{ij}$ (SR/MWH)
0103	GHZ2 – FAD	380	2659	89	4	0.1473	13.1057	52.42
0104	GHZ2 – GHU	380	2659	112	2	0.1473	16.4925	32.99
0204	QPP – GHU	380	2659	44	1	0.2356	10.3667	10.37
0205	QPP – SHE	380	2659	85	2	0.1473	12.5166	25.03
0206	QPP – FAR	380	2659	136	1	0.2356	32.0426	32.04
0308	FAD T/F	380 – 230	3*T750	--	4	14.0885	14.0885	56.35
0405	GHU – SHE	380	2659	74	1	0.2356	17.4349	17.43
0410	GHU T/F	380 – 230	T750	--	2	28.1771	28.1771	56.35
0506	SHE – FAR	380	2659	54	1	0.2356	12.7228	12.72
0507	SHE – HAW	380	2659	110	1	0.2356	25.9168	25.92
0511	SHE T/F	380 - 230	T750	--	2	28.1771	28.1771	56.35
0554	SHE – R9001	380	2659	313	2	0.1473	46.0907	92.18
0607	FAR – HAW	380	2659	47	1	0.2356	11.0735	11.07
0612	FAR T/F	380 - 230	T750	--	2	28.1771	28.1771	56.35
0655	FAR – KH9003	380	2659	266	2	0.1473	39.1697	78.34
0717	HAW T/	380 - 230	T750	--	2	28.1771	28.1771	56.35
0830	FAD – JBSE	230	741	38.2	2	0.1080	4.1251	8.25
0837	FAD – JBN	230	741	48	2	0.1080	5.1834	10.37
0838	FAD – JBSW	230	741	41	1	0.1669	6.8424	6.84
0850	FAD – KHU	230	741	42	1	0.1669	7.0093	7.01
0922	GHZI – DBP	230	741	49.4	1	0.1669	8.2443	8.24
0927	GHZI – DHC	230	741	69.2	2	0.1080	7.4727	14.95
0928	GHZI – QTF	230	741	31.8	1	0.1669	5.3071	5.31
0929	GHZI – RAS	230	741	33.3	2	0.1080	3.5960	7.19
0930	GHZI – JBSE	230	741	52.2	1	0.1669	8.7116	8.71
0943	GHZI - J01	230	741	23.9	1	0.1669	3.9886	3.99
0946	GHZI – BER	230	741	38.6	2	0.1080	4.1683	8.34
0953	GHZI- JUY+T/F	115	185/T400	7.4	2	13.7993	14.8046	29.61
1020	GHU – IBK	230	741	23	1	0.1669	3.8384	3.84
1024	GHU – KHO	230	741	25	1	0.1669	4.1722	4.17
1118	SHE – JAD	230	741	19	2	0.1080	2.0517	4.10
1213	FAR – MAH	230	741	32.5	1	0.1669	5.4239	5.42
1214	FAR – RWPS	230	741	102	1	0.1669	17.0226	17.02
1215	FAR – KHR	230	741	131	1	0.1669	21.8624	21.86
1217	FAR – HAW	230	741	52	2	0.1080	5.6153	11.23
1218	FAR – JAD	230	741	73	1	0.1669	12.1829	12.18
1252	FAR - UTH+T/F	115	370/T400	2.4	2	13.7993	14.0192	28.04
1318	MAH – JAD	230	741	40.5	1	0.1669	6.7590	6.76
1415	RWPS – KHR	230	741	30.6	1	0.1669	5.1068	5.11
1516	KHR – WASIA	230	741	52.2	2	0.1080	5.6369	11.27
1656	WASIA - R9000	380	2659	77	2	0.1473	11.3386	22.68
1819	JAD – ABQ	230	741	26	2	0.1080	2.8077	5.62
1927	ABQ – DHC	230	741	52	2	0.1080	5.6153	11.23
2021	IBK – DMP	230	741	7.8	1	0.1669	1.3017	1.30
2022	IBK – DBP	230	741	2.1	2	0.1080	0.2268	0.45
2123	DMP – RAK	230	297	9	1	0.1669	1.5020	1.50
2127	DMP – DHC	230	741	18	2	0.1080	1.9438	3.89

Table 6.2 (continue) : Line Information for 56-Bus System with 16 Power Plants

Line No. ij	Line Name	Line Voltage (kV)	Normal Capacity CL_{ij} (MW)	Circuit Length (KM)	No. of Circuits N_{ij} (No.)	Wheeling Cost Per Km Per circuit (SR/MWH)	Wheeling Cost Per Circuit C_{ij} (SR/MWH)	$N_{ij} * C_{ij}$ (SR/MWH)
2228	DBP – QTF	230	741	17.6	1	0.1669	2.9372	2.94
2324	RAK – KHO	230	297	2	1	0.1669	0.3338	0.33
2425	KHO – THQ	230	297	2.9	1	0.1669	0.4840	0.48
2526	THQ – AZY	230	741	7.6	2	0.1080	0.8207	1.64
2627	AZY – DHC	230	741	15.6	2	0.1080	1.6846	3.37
2829	QTF – RAS	230	741	43.6	1	0.1669	7.2763	7.28
3032	JBSE – IZH	230	741	2	1	0.1669	0.3338	0.33
3033	JBSE – JBCM	230	741	9.3	1	0.1669	1.5521	1.55
3034	JBSE – SADAF	230	741	2	2	0.1080	0.2160	0.43
3035	JBSE – SHARQ	230	741	2	2	0.1080	0.2160	0.43
3036	JBSE – PETRO	230	370	2	2	0.1080	0.2160	0.43
3046	JBSE – BER	230	741	2	1	0.1669	0.3338	0.33
3051	JBSE – SIPC	230	741	2	2	0.1080	0.2160	0.43
3150	SAF – KHU	230	741	107.9	2	0.1080	11.6518	23.30
3237	IZH – JBN	230	741	2	1	0.1669	0.3338	0.33
3337	JBCM – JBN	230	741	7.1	1	0.1669	1.1849	1.18
3738	JBN – JBSW	230	741	6.4	1	0.1669	1.0681	1.07
3741	JBN – HAD	230	741	2	1	0.1669	0.3338	0.33
3742	JBN – NIGC	230	741	2	1	0.1669	0.3338	0.33
3746	JBN – BER	230	741	12	1	0.1669	2.0027	2.00
3749	JBN – NAR	230	741	129.5	1	0.1669	21.6121	21.61
3750	JBN – KHU	230	741	43.5	1	0.1669	7.2597	7.26
3839	JBSW-SABAYEK	230	741	2	2	0.1080	0.2160	0.43
3840	JBSW– KEMYA	230	741	2	2	0.1080	0.2160	0.43
3841	JBSW – HAD	230	741	2	1	0.1669	0.3338	0.33
3842	JBSW – NIGC	230	741	2	1	0.1669	0.3338	0.33
3843	JBSW - J01	230	741	29.5	1	0.1669	4.9232	4.92
3846	JBSW – BER	230	741	9.4	1	0.1669	1.5688	1.57
4344	J01 – J2A	230	741	2	1	0.1669	0.3338	0.33
4445	J2A – J2B	230	741	2	1	0.1669	0.3338	0.33
4446	J2A – BER	230	741	21.5	1	0.1669	3.5881	3.59
4546	J2B – BER	230	741	21.5	1	0.1669	3.5881	3.59
4647	BER – BNG	230	741	2	2	0.1080	0.2160	0.43
4650	BER – KHU	230	741	48.5	1	0.1669	8.0941	8.09
4849	QAIS – NAR	230	741	282	2	0.1080	30.4523	60.90
4950	NAR – KHU	230	741	86	1	0.1669	14.3524	14.35

The line information for the whole Saudi eastern province electrical network (Figure 6.1) is summarized in Table 6.2. This table is to be used as the input data for the formed

model which is to be solved by LINDO software. Table 6.2 contains the wheeling cost (C_{ij}) which is the product of Section 6.3.

6.2 Unit Generation Cost Calculation

The cost calculation is differs from one way to another depending on two main factors; namely the information availability and other is the aim of calculating a specific cost.

Since the unit generation cost will be used in the model as explained in the previous chapter to decide potential areas for future generation expansions, it should not be limited to operation costs. But it should cover total generation costs including revenue requirements to help the investor to decide whether to build a proposed P.P. in a selected location.

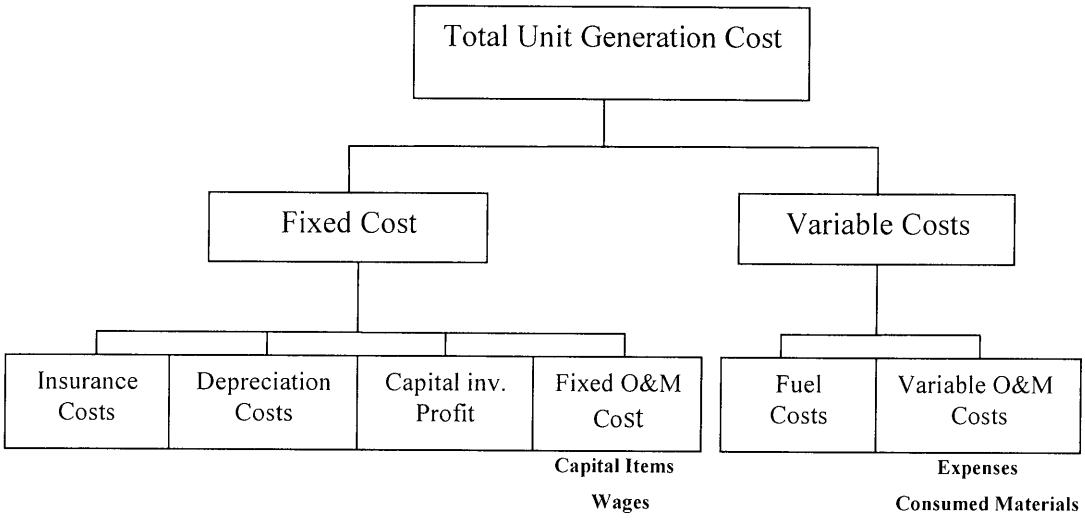


Figure 6.2
Unit Generation Cost Components

Figure 6.2 illustrates all unit generation cost components, from which the following equation has been derived:-

Unit Generation Cost = [Fixed Costs + Variable Costs] X [1+Risk Factor] **(6.1)**

Where:-

Fixed Costs =

Insurance Costs + Depreciation Costs + Capital Inv. Profit. + Fixed O&M Costs.

And;

Variable Costs = Fuel Costs + Variable O&M Costs.

Table 6.3 presents all required data to calculate the total unit generation cost in SR per MVA. This table is organized to facilitate any future updates to be a useful tool. Table 6.4 illustrates Table 6.3 fields with more details.

Table 6.3 Unit Generation Cost SEC-EOA

PP Name	Life Cycle Year	Usage Factor	Asset Value (SR*1000)	Generated [1];Energy (GWH)	Fixed Costs (SR/MWH)					Variable Cost (SR/MWH)			Risk Error	Total Unit Generation Costs (SR/MWH)
					Insurance [2];Costs	Depreciation Costs	Capital Inv. Error!	O&M Fixed Costs	Total Fixed Costs	Fuel Costs	O&M Variable Costs	Total Var. Costs		
QPP	30	20 %	2,710,000	17,100	0.1	5.3	12.6	2.5	20.5	26	1.8	27.8	5%	51
GHZ230	30	25 %	2,357,800	9,600	0.2	8.2	18.4	4.7	31.5	27.4	1.4	28.8	5%	63
GHQ380	30	20 %	4,902,390	17,100	0.2	9.5	22.8	2.5	35	24.7	1.4	26.1	5%	64
UTH	25	80 %	160,500	600	0.1	10,7	5.4	7.8	24	40	3	43	5%	70
SHE230	25	60 %	1,112,500	3,600	0.1	12.4	12.4	6.7	31.6	34.5	2.1	36.6	5%	72
FAR230	25	60 %	801,500	2,600	0.1	12.3	12.3	7.1	31.8	36.6	2.4	38.4	5%	74
BER	25	75 %	139,600	500	0.1	11.2	9.8	7.9	29	38.6	3.6	42.2	5%	75
JUY	25	80 %	77,100	200	0.1	15.4	7.7	8.7	32	45.7	3.3	49	5%	85
SAF	25	85 %	44,100	100	0.1	17.6	6.6	11.3	35.6	56.3	3.5	59.8	5%	100
RAS	25	60 %	80,000	200	0.2	16	16	10	42.2	50	4	54	5%	101
DMP	25	80 %	361,800	600	0.1	24.1	12.1	15.4	51.7	46.4	4.4	50.8	5%	108
AZY	25	60 %	1,200,000	1,200	0.4	40	40	7	87.4	36	2.5	38.5	5%	132
J01	25	60 %	400,000	400	0.4	40	40	7	87.4	36	2.5	38.5	5%	132
J2A	25	60 %	400,000	400	0.4	40	40	7	87.4	36	2.5	38.5	5%	132
J2B	25	60 %	400,000	400	0.4	40	40	7	87.4	36	2.5	38.5	5%	132
QAIS	25	90 %	279,400	200	0.1	55.9	14	14.5	84.5	49	51.3	56.2	5%	148

1- Generated Energy is based on annual average energy for the last 5 years. 2- Insurance factor is assumed to be (1/1000) of the depreciated book values.

3- The cap. Inv. profit margin is assumed to be 10% of the depreciated book values. 4- The risk factor is assumed to be 5% of the total unit generation cost.

Table 6.4 Unit Generation Cost Fields Descriptions

Field name	Give / cal.	Field Description	Assumption
Life Cycle	Given	30 years for Qur. / Gazl. PP's and the rest are 25 years. [39]	_
Usage Factor	Given	As the average ages of P.P equipments. [39]	_
Asset Value	Given	The original asset values without depreciation. [39]	_
Generated Energy	Calculated	Calculated as the annual average generated energy for the last 5 years (2001-2005). [39]	_
Insurance	Calculated	As a percentage of the net book value after depreciation is deducted over annual generated energy = $\frac{\text{Asset Value}}{\text{Annual Generated Energy}}$ *[1-Usage F.]*[Insurance F.]	Insurance Factor = 0.1 %
Depreciation	Calculated	$\frac{\text{Asset Value}}{\text{Annual Generated Energy}} * \frac{1}{\text{Life Cycle}}$	_
Capital Inv. Profit	Calculated	As a percentage of the net book value after depreciation is deducted over annual generated energy = $\frac{\text{Asset Value}}{\text{Annual Generated Energy}}$ *[1-Usage F.]*[Profit M.]	Profit Margin = 10 %
Fixed O&M Costs	Given	Capital Items & Wages which is independent of generated energy on actual sense. [39]	_
Fuel Costs	Given	Actual costs data for the last 5 years (2001-2005). [39]	_
Variable O&M Costs	Given	Non-fuel consumable expenditures including materials, invoices, and other indirect expenditures. [39]	_
Risk Factor	Calculated	Assumed by this work	5%
Total Gen. Unit Cost	Calculated	[Total Fixed cost s + Total Variable Costs] X 1.05 in SR/MWH	_

The basis for calculating the unit generation cost is mainly related to a given data from the utility. However, three factors are made by this study as illustrated by Table 6.4. These factors, which are debatable, namely: Insurance Factor, Profit Margin, and Risk Factor. So, it is needed to study and analyze the effect of changing their values on the unit generation cost for each power plant. This practice is done under a separate excel

worksheet in Appendix 1 by fixing two variables and changing the third. The results are illustrated in Figure 6.3.

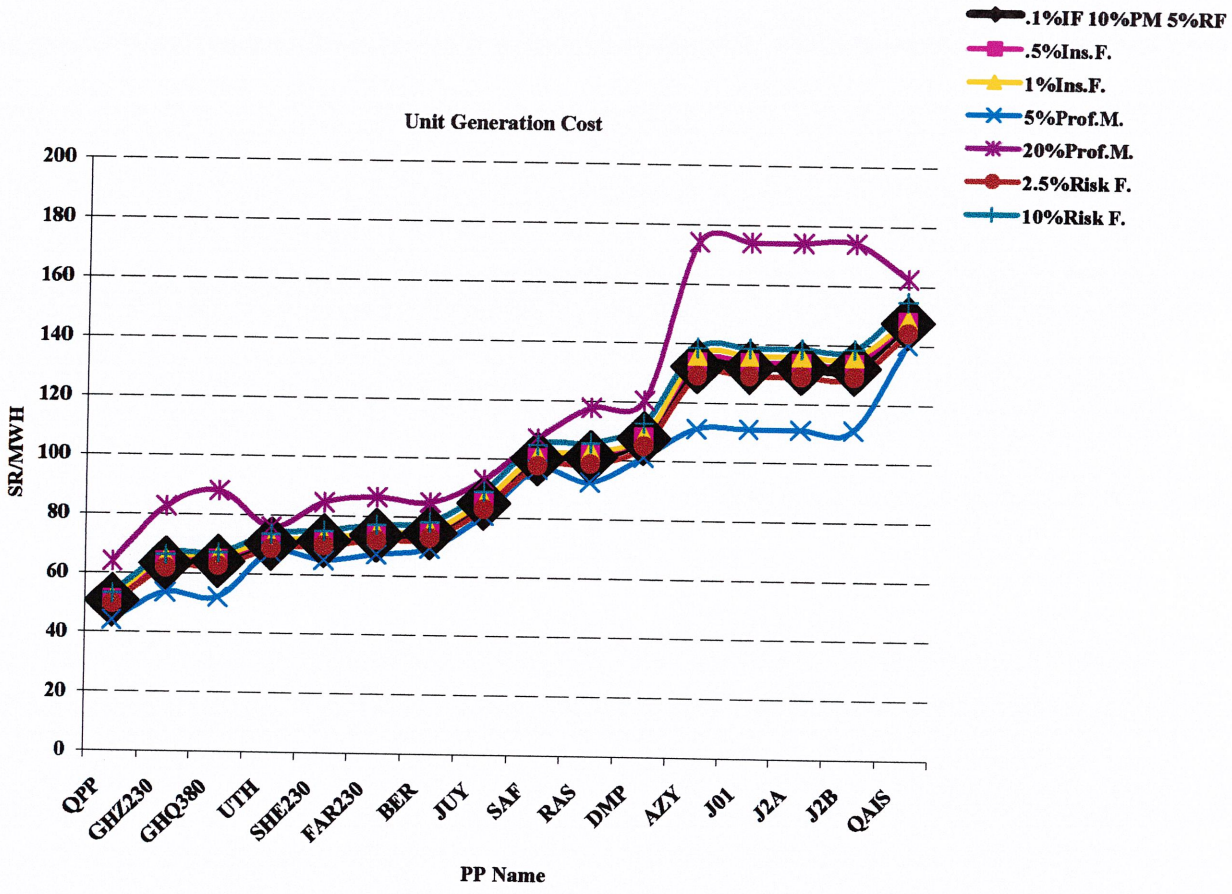


Figure 6.3
Unit Generation Cost Chart (Varying Ins. Factor, Risk Factor, and Profit Margin)

From the figure above, it can be noticed that even though the insurance factor value changed from 0.1% to 1.0% (10 times); it has a negligible effect on the unit generation cost. In the same way, the risk factor has a minor effect on the cost even if it changed from 2.5 % to 10 %. However, the profit margin is the two lines in Figure 6.3 which represent the upper and the lower generation cost values while changing from 5% to

20%. So, it is worth considering this new generation costs and analyze how it could affect the model output. This activity is to be covered by Case Study 1-2 in Section 6.4.

6.3 Unit Wheeling Cost Calculation

In order to get the wheeling cost in each line of any network per km per circuit, it is needed first to calculate the total unit wheeling cost for the whole network and then proportionate each specific branch cost to the total cost. The total network unit wheeling cost could be calculated according to the following equation:-

Total unit wheeling cost for the whole network in SR/MWH = [Cap. Inv. Profit + Depreciation Cost + Insurance Cost + O&M Cost] X [1+ Risk Factor] **(6.2)**

Where:

Capital Inv. Profit (SR/MWH) = (Transmission Depreciated Book Value ÷ Average Energy Consumption) X Profit Margin.

And:

Depreciation Cost (SR/MWH) = (Transmission Asset Value ÷ Average Energy Consumption) X (1÷ Life C.).

And:

Insurance Cost (SR/MWH) = (Transmission depreciated book value ÷ Average Energy Consumption) X Insurance Factor.

And:

O&M Cost (SR/MWH) = Average annual variable & fixed O&M cost per unit of energy.

The capital investment profit for transmission is needed to be considered despite the fact that transmission is needed to be a non-profit entity. This price will be used to finance new expansions.

The transmission data related to the model of Figure 6.1 are summarized in Table 6.5.

Table 6.5 Unit Wheeling Cost Fields Descriptions

Field name	Source of information	Value
Transmission Network Book Value	Given in reference 39	16,000 million
Transmission Depreciated Book Value	Given in reference 39	7,000 million
Annual Energy Consumption	Average value of last five years actual energy generation	55,000,000 MWH
Profit Margin	Assumed by this work as per actual experiences in eastern province.	10%
Life Cycle	Given in reference 39	25 years
Insurance Factor	Assumed by this work as an approximation to actual	0.1%
Annual Transmission O&M Cost	Average value of last five years actual O&M costs.	2.3 SR/MWH
Risk Factor	Assumed by this work	5%

Substituting the data of Table 6.5 to equation 6.2:-

Capital Inv. Profit = 7000.000.000X0.10 ÷ 55.000.000 = 12.73 SR/MWH

Depreciation Cost = 16.000.000.000X0.04 ÷ 55.000.000 = 11.64 SR/MWH

Insurance Cost = 7.000.000.000X0.001 ÷ 55.000.000 = 0.13 SR/MWH

Average Annual O&M cost from the last 5 Years = 2.3 SR/MWH

The Risk Factor = 5%

Unit Wheeling Cost as per eq. 6.2 = [12.73+11.64+0.13+2.3] X 1.05 = 28.14 SR/MWH

The basis for calculating the unit wheeling cost is mainly related to a given data from the utility. However, three factors are made in this study as illustrated in Table 6.5. These factors, which are debatable, namely: Insurance Factor, Profit Margin, and Risk Factor. So, it is needed to study and analyze the effect of changing their values on the unit wheeling cost. This practice is done under a separate excel worksheet in Appendix 2 by fixing two variables and changing the third. The results are illustrated by Figure 6.4.

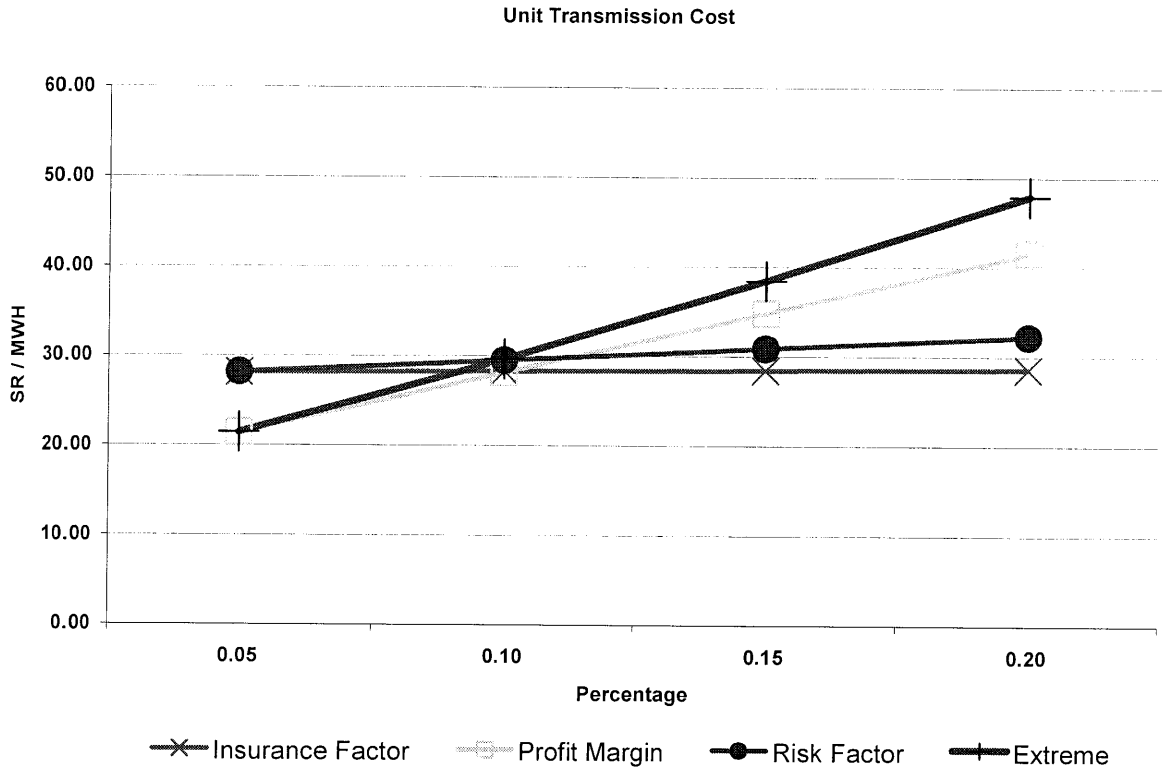


Figure 6.4
Unit Wheeling Cost Chart (Varying Ins. F., Risk Factor, and Profit Margin)

From the figure above, it can be noticed that insurance factor line is almost a flat line which indicates that it has a negligible effect on the unit wheeling cost. Also, the chart indicates that the risk factor has a minor effect on the cost. However, the profit margin is the most related to the wheeling cost. The fourth line in Figure 6.4 represents the extreme case with the maximum values of all factors. It is worth to analyze how the extreme case values could affect the wheeling costs and the model output. This activity is to be covered by Case Study 1-3 in Section 6.4.

The wheeling cost for each type of OHL or substation could be calculated according to the following equation:-

Wheeling Cost for Z type of OHL or Substation per MWH =
(Z type of OHL or Substation Cost per KM or T/F ÷ Z type Transmission Cost)
X Unit Transmission Cost per MWH X Weighing Factor. **(6.3)**

Where:

The weighing factor for OHL's = Unit Transmission Cost per MWH ÷ Cluster average wheeling cost per main links = 28.14 ÷ 1.0082* = 27.91 (Unit less)

And to avoid over weighing the substation locations, since, it will be required in future expansions which is not considered in this work formulation, the weighing factor for substations = the weighing factor ÷ No. of circuits = 27.91÷ No. of circuits.

The network of Figure 6.1 model mainly consists of Overhead Lines & Substations with different parameters listed in Table 6.6.

Table 6.6 Cost Data for Transmission Network

Voltage & Size	Length (Km)	No. of Circuits	Cost (SR/Km)	Total Line Cost (SR)
380S	465	1	1,200,000	558,000,000
380D	954	2	750000	1,431,000,000
230S	1,223	1	850000	1,039,550,000
230D	876	2	550000	963,600,000
110D	10	1	800000	8,000,000
Total OHD Lines. Cost				**4,000,150,000**

Item	No. of T/F	Cost of one T/F & its breakers (SR)	Total Cost of T/F's & its breakers (SR)
750 MVA	12	52,875,000	634,500,000
400 MVA	4	25,600,000	102,400,000
Total Substation Cost			**736,900,000**

*Cluster average wheeling cost per main links is calculated in Appendix 2

Substituting Table 6.6 data into equation (6.3); the wheeling cost for Z type of OHL per circuit per MWH will be equal:-

Wheeling cost for 380 D (single and double) =

(750 ÷ 4,000,150) X 28.14 X 27.91 = 0.1473 SR/MWH/KM/Circuit

Wheeling cost for 380 S (single) =

(1200 ÷ 4,000,150) X 28.14 X 27.91 = 0.2356 SR/MWH/KM/Circuit

Wheeling cost for 230 D (single and double) =

(550 ÷ 4,000,150) X 28.14 X 27.91 = 0.1080 SR/MWH/KM/Circuit

Wheeling cost for 230 S (single) =

(850 ÷ 4,000,150) X 28.14 X 27.91 = 0.1669 SR/MWH/KM/Circuit

Wheeling cost for 110 D (single and double) =

(800 ÷ 4,000,150) X 28.14 X 27.91 = 0.1571 SR/MWH/KM/Circuit

And the wheeling cost for Z type of substation per T/F per MWH:-

Wheeling cost for 750 T/F as part of two circuits =

(52,875 ÷ 736,900) X 28.14 X 27.91 ÷ 2 = 28.1771 SR/MWH/Circuit

Wheeling cost for 750 T/F as part of four circuit =

(52,875 ÷ 736,900) X 28.14 X 27.91 ÷ 4 = 14.0885 SR/MWH/Circuit

Wheeling cost for 400 T/F as part of two circuit =

(25,600 ÷ 736,900) X 28.14 X 27.91 ÷ 2 = 13.6422 SR/KWH/Circuit

All the above wheeling costs are listed in Table 6.2 to be used as a direct reference by next section of case studies.

6.4 Case Studies

The flow chart in Figure 5.1 in Chapter 5 listed the steps to be followed to utilize the model in the actual business. As per the flow chart, the process is divided mainly into two parts. The first part is to check validity of the proposed model by comparing it to a real system. This part is to be covered in this section as the first case study which compares the actual system output with three of the model outputs. These three models cover the original model data calculated in the previous sections of this chapter along with changing the data according to the sensitivity analysis for both unit generation cost and unit wheeling cost calculation as recommended in Sections 6.2 and 6.3.

The second part of Figure 5.1 is to search for the potential power plant locations. This part is to be covered in this section as the second and third case studies. The second case study covers the interface locations between eastern province and central province of Saudi Arabia while the third case study is to be carried out by adding one power plant at a time in each bus location of the existing network analyzing the results.

6.4.1 Case Study 1

As reported earlier this case study is meant to check the validity of the proposed model by three sub-case studies.

6.4.1.1 Case Study 1-1

In this first case study; the model is applied to the actual eastern province power system in Saudi Arabia as it is without any changes as formulated in Appendix 4 by LINDO software using Tables 6.1 and 6.2 as the data source. It is solved by the software where the output and the sensitivity ranges are listed in Appendix 4. The optimum solution is

found at objective function value of 1001137 SR with unit generation cost of 71 SR/MWH as an average cost.

6.4.1.2 Case Study 1-2

In this case study; the model is applied to the actual eastern province power system in Saudi Arabia but with changes in the values of unit generation cost as recommended at the end of Section 6.2 after analyzing Figure 6.3. The unit generation values are the ones corresponding to a profit margin of 20 % in the table of Appendix 1 as the upper limit. Case Study 1-2 is formulated in Appendix 5 by LINDO software using Tables 6.1 and 6.2 and Appendix 1 as the data source. The formulation is a copy of Case1-1 with only change in the coefficients of P_{gi} in the first part of the objective function. It is solved by running the software where the output and the sensitivity ranges are listed in Appendix 5. The optimum solution is found at objective function value of 1190010 SR with unit generation cost of 73 SR/MWH as an average cost.

6.4.1.3 Case Study 1-3

In this case study; the model is applied to the actual eastern province power system in Saudi Arabia but with changes in the values of unit wheeling cost as recommended in Section 6.3 after analyzing Figure 6.4. The unit wheeling values in Appendix 2 are the ones corresponding to the extreme case with 20% profit margin, 20% risk factor, and 0.4% insurance factor. Case Study 1-3 is formulated in Appendix 6 by LINDO software using Tables 6.1, 6.2, and Appendix 2 as the data source. The formulation is a copy of Case1-1 with only change in the coefficients of P_{dij} in the second part of the objective function. It is solved by running the software where the output and the sensitivity ranges are listed in Appendix 6. The optimum solution is found at an objective function value of 1181413 SR with unit generation cost of 71 SR/MWH as an average cost.

Table 6.7 summarizes all case studies' dispatched MW's along with the optimal values. This table is used as a worksheet to calculate the unit generation average cost and distribute the optimal values among generation costs and wheeling costs.

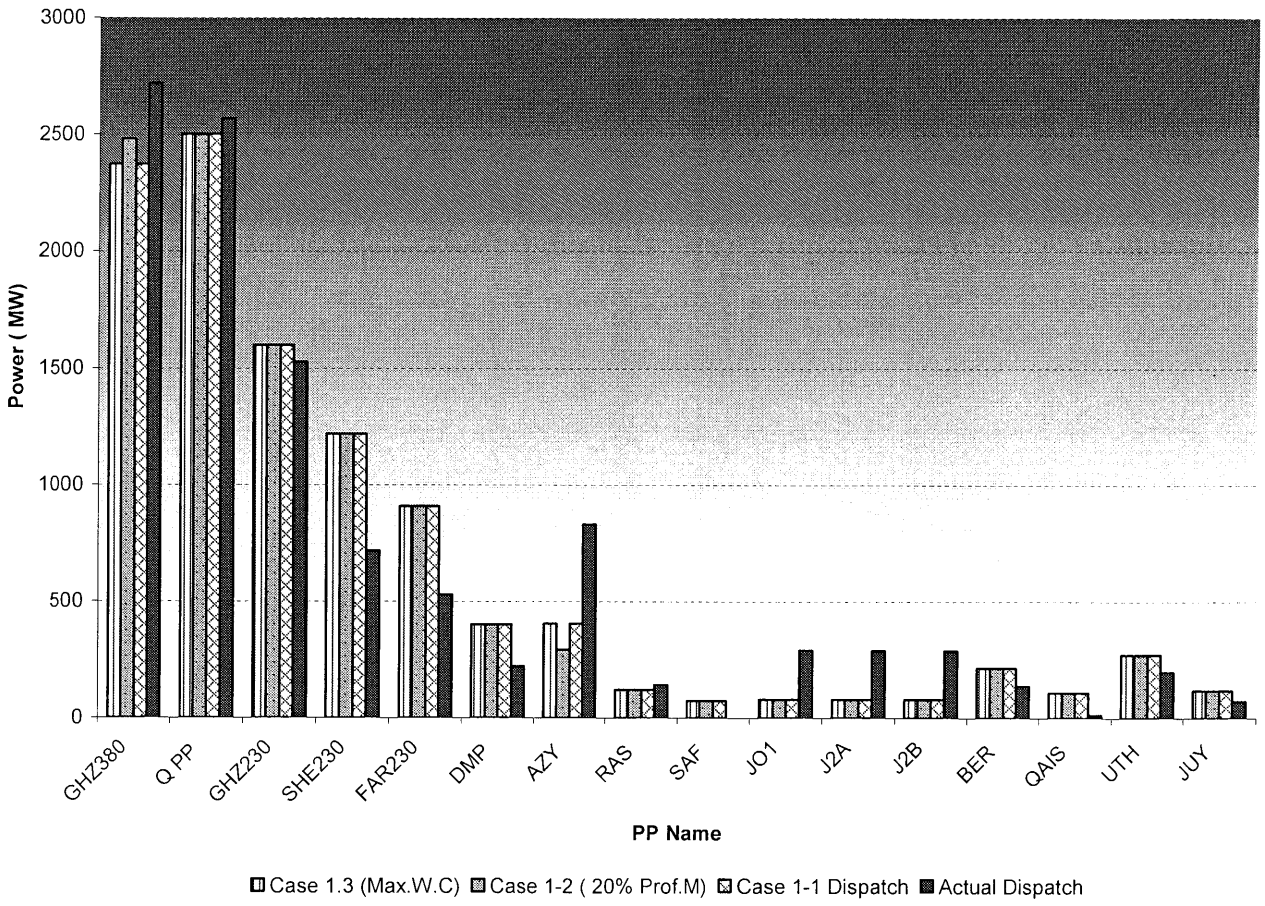
Table 6.7 All Case Studies' Dispatched Power

Bus No. i	PP NAME	Act. Disp. MW	Case 1-1 Disp. MW	Case 1-2 Disp. MW	Case 1-3 Disp. MW	Case 2-1 Disp. MW	Case 2-2 Disp. MW	Case 2-3 Disp. MW	Case 2-4 Disp. MW	Case3 Bus#/ PP NAME	Optimal Value	Case3 Bus No. / PP NAME	Optimal Value	U.G. Cost C_{gi}	U.G. Cost case 1-2 C_{gi}
1	GHZ380	2718	2372	2482	2372	2195	2195	2280	2280	3/FAD	987389	27/DHC	945055	64	67
2	Q PP	2569	2500	2500	2500	1466	852	1317	1317	4/GHU	994427	28QTF	937395	51	53
9	GHZ230	1527	1600	1600	1600	1600	1600	1600	1600	5/SHE	993774	30/JBSE	917958	63	66
11	SHE230	720	1219	1219	1219	1219	1219	1219	1219	6/FAR	985006	32/IZH	948194	72	75
12	FAR230	529	910	910	910	910	910	910	910	7/HAW	990796	33/JBCM	945892	74	77
21	DMP	223	400	400	400	100	100	100	100	8/FAD	928440	34/SADAF	942684	108	113
26	AZY	832	404	294	404	100	100	100	100	10/GHU	953905	35/SHARQ	946667	132	138
29	RAS	142	120	120	120	120	120	120	120	13/MAH	969683	36/PET	966702	101	106
31	SAF	0	75	75	75	75	75	75	75	14/RWPS	980126	37/JBN	913049	100	105
43	JO1	291	80	80	80	80	80	80	80	15/KHU	979822	38/JBSW	913097	132	138
44	J2A	290	80	80	80	80	80	80	80	16/WAS	979202	39/SAB	950737	132	138
45	J2B	290	80	80	80	80	80	80	80	17/HAW	976950	40/KEMIA	949605	132	138
46	BER	138	215	215	215	215	215	215	215	18/JAD	947102	41/HAD	938310	75	78
48	QAIS	14	108	108	108	20	20	20	20	19/ABQ	947111	42/NIGC	946239	148	155
52	UTH	197	272	272	272	272	272	272	272	20IBK	912238	47/BNGL	915022	70	74
53	JUY	73	118	118	118	40	40	40	40	22DMP	916516	49/NAR	961718	85	89
54	R9001	Prop.	0	0	0	925	1539	925	925	23/RAK	967808	50/KHU	927491		
55	KH9003	Prop.	0	0	0	814	814	875	814	24/KHO	946666	51/SIPC	950198		
56	R9000	Prop.	0	0	0	242	242	242	306	25/THQ	946104				
			CASE 1			**CASE 2**				**CASE 3**					
Average Cost SR/MWH		75	**71**	73	71	69	62	66	69						
Optimal Value			1001137	1190010	1181413	903766	853555	871170	901100						
Gen. Cost SR/H			744223	769516	744223	726818	657300	695442	726818						
Wheel. Cost SR/H			256914	420494	437190	176948	196255	175728	174282						

6.4.1.4 Case Study 1 Observations

The values of the decision variables for the three sub-cases are compared with actual system dispatching values as illustrated in Figure 6.5.

Figure 6.5 Actual vs. Model Dispach Results (case 1)



The general shape of Figure 6.5 validates that the model is working in the same direction of the actual dispatch process. However, the actual dispatch is affected by other aspects like maintenance schedules and existing contracts.

The clear differences from the graph is in Aziziyah (AZY) power plant and the three Jubail power plants (JO1, J2A, and J2B) which are actually separate entities owned by SWCC where the energy is contracted with SEC in fair prices. This explains why the actual is much more than the model. The model selected the more economical power plants based on the unit generation cost calculation (not as per contract) which explains the increase in dispatched power from Shadgam, Faras, Dammam, Barri, and Uthmaniyah power plants. Qaisomah (QAIS) & Safaniyah (SAF) power plants were under maintenance which explains why the actual is much less than the model.

Other observations are listed as follows:-

- From Table 6.7 the percentage of the wheeling cost in Case 1-1 to the generation cost is almost 35%. This percentage is not far from 38% representing the percentage of the unit wheeling cost calculated in Section 6.3 (28.14 SR/MWH) over the average unit generation cost (75 SR/MWH). This indicates that the model is supporting the calculation accuracy and keeping the correct weighing between the generation and the transmission costs.
- The optimal value of Case 1-1 is lesser than each of cas1-2 and Case1-3 which is expected due to the selection of higher values of unit generation cost in Case 1-2 and higher unit wheeling cost in Case 1-3.
- The higher average cost of 73 SR/MWH in Case 1-2 indicates the effect of raising the profit margin from 10% to 20% in the generation industry.

The above observations in Case Study 1 prove the validity of the model.

6.4.2 Case Study 2

This case study is conducted to help in taking a decision whether to continue sending power from EOA to COA or to build one or more power plants in the interface locations and, if so at what cost. The costs are to be encouraging for investors to build a new plant in COA, otherwise, increasing the capacity of EOA and transmit to COA would be the option to choose.

Busses 54, 55, and 56 are the existing loads in COA and fed from EOA as per Figure 6.1. So, to conduct this study, four sub-case studies were carried out.

6.4.2.1 Case Study 2-1

In this case study, three power plants are proposed at R9001, KH9003, and R9000 corresponding to busses 54, 55, and 56 respectively. The power plants are to be proposed at the same time with unit generation costs equal to the average cost on original model (71 SR/MWH of Case Study 1-1) keeping other power plants without changes.

To consider busses 54, 55, and 56 as generating units in our original model; the objective function is modified by assigning a cost of 71 SR/MWH instead of the high cost of 1000 SR/MWH that was assigned to these busses earlier. Also it is required to add the MW generated by the selected busses "P_{g54}, P_{g55}, and P_{g56}" to the real power balancing constraint.

The maximum and minimum of generator limits were not imposed to have more flexibility.

Case Study 2-1 is formulated in Appendix 7 by LINDO software using Tables 6.1 and 6.2 and Appendix 1 as the data source. The formulation is a copy of Case1-1 with only

changes mentioned in the last two paragraphs. It is solved by running the software where the output and the sensitivity ranges are listed in Appendix 7. The optimum solution is found at objective function value of 903766 SR with unit generation cost of 69 SR/MWH as an average cost. This information and the dispatched power values are listed in Table 6.7. It can be noticed that, the proposed power plants are dispatched only to cover their own loads except for R9000 (bus 56) which feeds 84 MW more than its loads.

6.4.2.2 Case Study 2-2

The aim of this case study is to report at which unit generation cost the proposed power plant at R9001 bus 54 is going to be dispatched for loads from other busses.

Running a sensitive analysis by LINDO software for Case Study 2-1 can help to specify the required value reducing the trial and error iterations. From Appendix 7, the allowable decrease value corresponding to the variable Pg54 is 54. Then the recommended cost will be (71 -54 = 17 SR/MWH).

In Case Study 2-2, three power plants are proposed at bus 54, 55, and 56 at the same time with unit generation cost equal to the average cost of 71 SR/MWH for busses 55 and 56 while bus 54 with cost of 17 SR/MWH keeping other power plants without changes.

Case Study 2-2 is formulated in Appendix 8 using LINDO software. The formulation is a copy of Case 2-1 with only one change, replacing $71P_{g54}$ by $17P_{g54}$ in the first part of the objective function. It is solved by running the software where the output and the sensitivity ranges are listed in Appendix 8. The optimum solution is found at objective function value of 853555 SR with unit generation cost of 62 SR/MWH as an average cost. This information and the dispatched power values are listed in Table 6.7. It can be noticed that, the proposed power plant at bus 54 is dispatched to cover 1539 MW of loads while the bus loads are 925. The selection of 17 SR/MWH as the border value for R9001

(bus 54) can be tested by running the software with $18P_{g54}$ instead of $17P_{g54}$, then the dispatched power should go back to 925 MW.

6.4.2.3 Case Study 2-3

The aim of this case study is to report at which unit generation cost the proposed power plant at KH9003 bus 55 is going to be dispatched for loads from other busses.

Running a sensitivity analysis by LINDO software for Case Study 2-1 more than one time to reach to the border value of 31 SR/MWH.

In Case Study 2-3, three power plants are proposed at bus 54, 55, and 56 at the same time with unit generation cost equal to the average cost of 71 SR/MWH for busses 54 and 56 while bus 55 with cost of 31 SR/MWH keeping other power plants without changes.

Case Study 2-3 is formulated in Appendix 9 using LINDO software. The formulation is a copy of Case 2-1 with only one change of replacing $71P_{g55}$ by $31P_{g55}$ in the first part of the objective function. It is solved by running the software where the output and the sensitivity ranges are listed in Appendix 9. The optimum solution found at objective function value of 871170 SR with unit generation cost of 66 SR/MWH as an average cost. This information and the dispatched power values are listed in Table 6.7. It can be noticed that, the proposed power plant at bus 55 is dispatched to cover 875 MW of loads while the bus loads are 814. The selection of 31 SR/MWH as the border value for KH9003 (bus 55) can be tested by running the software with $32P_{g55}$ instead of $31P_{g55}$, then the dispatched power should go back to 814 MW.

6.4.2.4 Case Study 2-4

The aim of this case study is to report at which unit generation cost the proposed power plant at R9000 bus 56 is going to be dispatched for loads from other busses.

Running a sensitive analysis by LINDO software for Case Study 2-1 more than one time to reach to the border value of 60 SR/MWH.

In Case Study 2-4, three power plants are proposed at bus 54, 55, and 56 at the same time with unit generation cost equal to the average cost of 71 SR/MWH for busses 54 and 55 while bus 56 with cost of 60 SR/MWH keeping other power plants without changes.

Case Study 2-4 is formulated in Appendix 10 using LINDO software. The formulation is a copy of Case 2-1 with only one change of replacing $71P_{g56}$ by $60P_{g56}$ in the first part of the objective function. It is solved by running the software where the output and the sensitivity ranges are listed in Appendix 10. The optimum solution found at objective function value of 901100 SR with unit generation cost of 69 SR/MWH as an average cost. This information and the dispatched power values are listed in Table 6.7. It can be noticed that, the proposed power plant at bus 56 is dispatched to cover 306 MW of loads while the bus loads are 158.

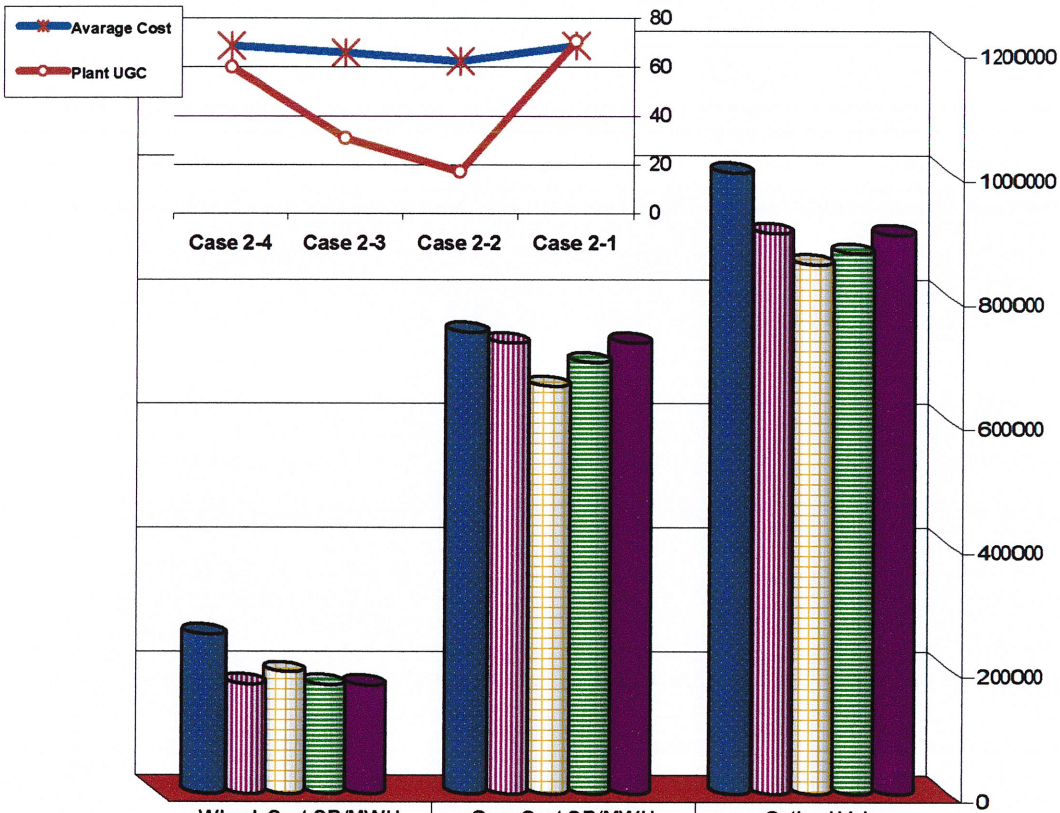
6.4.2.5 Case Study 2 Observations

Figure 6.6 compares the four sub-cases with each other and with the original model in terms of optimal value, system generation cost, and system wheeling cost. The figure also illustrates which sub-case is with low system average unit generation cost and at which cost the investor is forced not to exceed.

Reading Figure 6.6, reveals that the optimal values for any of the sub-cases is less than the optimal value for the original model. This means that the system could run with less

cost. However, the challenge is at what price will the system allow each power plant to dispatch the stated amount of power?

Figure 6.6 Case 2 Analysis



	Wheel. Cost SR/MWH	Gen. Cost SR/MWH	Optimal Value
Original	256914	744223	1001137
Case2-1	176947.5278	726818.4722	903766
Case2-2	196255.3343	657299.6657	853555
Case2-3	175727.6468	695442.3532	871170
Case2-4	174282	726818	901100

Other observations could be summarized from Figure 6.6 and Table 6.7 as follows:-

- In Case Study 2-1 (71 SR/MWH for the three locations) the system runs with less cost than the original. However, the proposed power plants are dispatching only to cover their bus loads. This is true even for bus 56 where the difference between

the dispatched power (242 MW) and the bus loads (158 MW) is only to feed (as can be seen from Figure 6.1 and Table 6.1) Wasia , Khurais, and RWPS which are still in the borders of COA.

- In Case Study 2-2 (17 SR/MWH for R90001 bus 54) the system runs with less cost than all other cases, however, the mandatory cost of 17 SR/MWH is a very low cost and it is not encouraging to any investor to built a power plant with low purchasing prices.

- In Case Study 2-3 (31 SR/MWH for KH90003 bus 55) the system runs with less cost than other cases except for Case 2-2. However, the mandatory cost of 31 SR/MWH is still very low cost compared to the lowest existing Qurayah power plant with unit generation cost of 51 SR/MWH. So, it is not visible to investors to build with these limitations.

- In Case Study 2-4 (60 SR/MWH for R9000 bus 56) the system runs with less cost than the original and the allowable unit generation cost is good enough to grab investors. However, the loads on the bus are quite low, so, investors should check first the feasibility study with the existing limitations of load quantity and related prices if a load increases.

6.4.3 Case Study 3

This case study is conducted to help in taking a decision whether to build a power plant on the existing busses' locations and in which priority?

This third case study is to be carried out by adding one power plant with the original model average cost of 71 SR/MWH at a time in each bus location of the existing network and analyze the results.

To consider bus i as a generating unit in our original model; the objective function is modified by assigning a cost of 71 SR/MWH instead of the high cost of 1000 SR/MWH that was assigned to the selected bus earlier. Also it is needed to add the MW generated by the selected bus "P_{gi}" to the real power balancing constraint. This step is repeated for each bus in Figure 6.1 without power plant where i = 3, 4, 5, 6, 7, 8, 10, 13, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 27, 28, 30, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 47, 49, 50, and 51.

The maximum and minimum of generator limits were not imposed to have more flexibility.

Case Study 3 is formulated in Appendix 11 by LINDO software for bus 3 as a sample for all busses. The formulation is a copy of Case1-1 with only changes mentioned in the above two paragraphs. It is solved by running the software where the optimum solution found at objective function value listed in Table 6.7.

6.4.3.1 Case Study 3 Observations

Table 6.8 lists all selected busses in a priority order starting with the least optimal value. The table also reports the power dispatched by each proposed power plant to be a supportive information in making a decision to build a new power plant in the selected location or not.

Table 6.8 Proposed Power Plants Priority

Priority	Bus No. i	PP NAME According to Priority	Case 3 Dispatched MW	Optimal Value
1	20	IBK	3454	912238
2	37	JBN	3449	913049
3	38	JBSW	3602	913097
4	47	BNGL	3449	915022
5	22	DMP	3333	916516
6	30	JBSE	3122	917958
7	50	KHU	3177	927491
8	8	FAD	3314	928440
9	28	QTF	2612	937395
10	41	HAD	1943	938310
11	34	SADAF	1755	942684
12	27	DHC	1632	945055
13	33	JBCM	1671	945892
14	25	THQ	1632	946104
15	42	NIGC	1623	946239
16	24	KHO	1715	946666
17	35	SHARQ	1609	946667
18	18	JAD	2961	947102
19	19	ABQ	2961	947111
20	32	IZH	1544	948194
21	40	KEMYA	1525	949605
22	51	SIPC	1483	950198
23	39	SABAYEK	1484	950737
24	10	GHU	1488	953905
25	49	NAR	2533	961718
26	36	PETROKEMIA	883	966702
27	23	RAK	714	967808
28	13	MAH	1557	969683
29	17	HAW	1543	976950
30	16	WASIA	306	979202
31	15	KHURAIS	306	979822
32	14	RWPS	340	980126
33	6	FAR	1120	985006
34	3	FAD	2252	987389
35	7	HAW	304	990796
36	5	SHE	304	993774
37	4	GHU	304	994427

It could be noticed from Table 6.8 that all optimal values are less than the original model. This is expected , since, each proposed power plant has average cost of the model and will take its adjacent loads with less wheeling cost.

The first five priorities selected by the model are IBK (bus20), JBN (bus37), JBSW (bus38), BNGL (bus47), and DMP (bus22). These selected locations are actually the center of loads in eastern province of Saudi Arabia. The outcome of Case 3 approves two main points:-

- Validity of the model
- No congestion on the exiting transmission network which allows the model to select the center locations.

6.5 Conclusions

Proper location selection for a new power plant to be built is a complete process with many factors like: land ownership, type of fuel, load distribution, environment limitations, water and other resources accessibility. The proposed model in this chapter is handling the major factor affecting the decision which is the cost related part along with load distribution.

OPF model is a very sophisticated method in the optimization problems but most of the times we need to do approximations and reach to our objectives from the short paths since there are always better ways to hit different targets.

Beside the main usage of the modified model which is to dispatch the power system for the purpose of localizing the potential power plant; the model could be used for other purposes with some modifications like:-

- Addition of power loss and power reserve parameters.
- Addition of a binary equation to the model to facilitate the possibility of the units to be "on" or "of", where it is needed in this case to count for the start-up cost and the minimum time before in or out the unit. And LINDO has this tool in a very simple form.

However, the model cannot be used to optimize the power flow for operation purposes due to the lack of the following parameters:-

- The impedance
- The reactive power
- The time index
- The bus represents a power plant (not each unit).
- The model uses a constant cost for any bus (Power plant).

Despite the shortcomings of the model, it is simple, fast, efficient, and effective. The model can be considered as a unique model in solving both operation and power flow equations by the flow of active power only. The model is more effective by putting more emphasis to the costs which effect the decision.

Accuracy is expensive in terms of both money and time; however, in the competitive market a balance between accuracy and cost is needed.

7 CONCLUSIONS

This study was started in year 2003, which is the same year SEC had started functioning. This was considered the first practical stage in Saudi Electricity Supply Industry deregulating process. In the middle of this study, the second stage of deregulating SESI was carried out by SEC as illustrated in Chapter 2. The third stage is already planned by SEC but not yet implemented up to the time of writing this conclusion.

This timing coincidence had formed the thesis objectives mentioned in Chapter 1. However, SEC has its own timetable in going through some or all of the restructuring stages. So, it is hoped that the timing of this Study is supportive to add additional analysis learning from the worldwide experiences. The aim is to find out the best way to provide reliable and low-cost electricity suiting the uniqueness of SESI.

7.1 Summary of Findings

From Chapter 1, it can be concluded that each country has its own ESI characteristics which may call for deregulating the industry or not. And each ESI, if to be deregulated, needs to have its own framework suitable for its needs but not necessary for others.

Restructuring is recommended in Saudi Arabia due to its geographical large area, the availability of investment power, high demand growth rate, political stability, and for the fact that power generation is thermal (no nuclear power plants).

SEC efforts in the ongoing deregulating process explained in Chapter 2 indicates that the direction toward deregulating the industry is handled seriously by SEC and pushed by the ministry of W&E. Despite that, the data are not showing any financial support from outside SEC to recover the restructuring costs. This could affect other programs which

could lead, in the short run, to customer dissatisfaction even if the intention is toward enhancing the quality of customer service.

By reviewing the most popular market models in Chapter 3, it can be concluded that it is not practical to design an ideal market model. This is due to the complexity and uniqueness of any ESI. However, the aim should be to have near ideal model to fit most needs with the existing limitations.

Chapter 4 proposes SESI framework including the structure, trading and pricing methods.

SESOM is to be established to act as SO, MO, and SC. It would administer and operate the wholesale market where supply and demand are to be balanced at the real time through a centralized mechanism to be efficient and secured. SESOM is required to dispatch generators according to economic merits order. The last generator being dispatched to meet the required demands will be considered the price leader. This uniform price is the SMP which is proposed to be capped.

The end user price will be a combination of wholesale price (includes the ancillary prices and the regulatory prices) and wires services prices for both transmission and distribution in addition to the retailer price. The end user price is also to be capped by the regulator.

In the recommended structures, customers can choose their supplier who can provide additional value-added services.

This chapter also comments on the ongoing SEC restructuring process as follows:-

- Inefficient generation units are not to be released by SEC to private investors.
- To reduce the share of WEC by SEC.
- CCC is to be a priced optional service.

- Existing bilateral contracts by transmission BL's are to be converted to CFD by SESOM.
- SLA actual implementation is to be expedited.
- To put hold on the action of actual separation of TRANSCO and instead financial separation of operation activities from transmission wires.
- To group SEC GENCO's into 8 to 9 groups.
- To put hold on the idea of dividing DISTCO's and instead pursue financial separation of customer services from distribution wires.

Although the market rules (to be issued by ECRA) are mandatory to all market participants, competitive participants (PSP's & CSP's) will have some room of freedom to set their own plans. This freedom could be in terms of operation schedules by PSP's or additional services by CSP's. Moreover, it could be in terms of contracts agreements and profit margins for both PSP & CSP.

PSP's system planners are willing to use the most suitable optimization tool to know the future generation potential areas. Those tools including economic load dispatch, unit commitment, optimal power flow, & DC optimal power flow are briefed in Chapter 5. This brief links the available tools together and compares them in terms of complexity, advantages, limitations and the proper usages.

The above learning process enables researcher to set the characteristics of the required model. The modified model is a linear program MW-based OPF established by this study to help in deciding the future generation potential areas in a deregulated industry. The same model with slight modifications can be used for additional purposes.

The proposed model is a unique model in solving all operations and power flow equations by the flow of active power only for simplicity and to give more emphasis to the costs which effect the decision.

LINDO is the optimization software used as a tool to solve the MW LP-Based OPF model. The flow chart in Figure 5.1 illustrates all steps to be followed to make use of the model.

The proposed model is tested in Chapter 6 by applying it to the real power 56-bus system in the eastern province of Saudi Arabia.

All input data required to run the program are mainly direct data except two costs are to be calculated namely: Unit generation cost and unit wheeling cost.

Unit generation costs calculation proposed scheme is one of the products of this Study. Since this cost is to be used in the model to decide potential areas for future generation, it should not be limited to operation costs. So, it is proposed to cover total generation costs including revenue requirements.

Unit wheeling cost calculation scheme is also proposed in the same chapter. The technique used to calculate the unit wheeling cost in SR/MWH/KM is based on the unit transmission cost for the whole network. Then, this cost is to be proportionate to each specific branch cost to the total cost.

The validity of the two costs calculation scheme depends on two factors. The first factor is the availability and accuracy of the data used in the calculation process. The second factor is the correctness and the acceptance of the assumptions made for the profit margin, the insurance factor, and the risk factor. The profit margin in transmission is only to finance new expansions. Moreover, sensitivity analysis is carried out for all assumptions to answer (what if?) question for each case.

Case studies are carried out on the modified optimization model and the first case study approves the validity of the model. The second case study covers the interface locations between eastern province and central province of Saudi Arabia while the third case study is carried out by adding one power plant at a time in each bus location of the existing network and recommended all possible locations according to priority.

7.2 Challenges

In the short and medium terms, ECRA, SESOM and other market participants are expected to face a lot of challenges, some of which are summarized in the next paragraphs.

- Reverse flow characteristics of electricity limit the pricing choices and complicate the methodology. Moreover, up to nowadays technology, energy can not be stored which requires real time balancing of supply and demand which is critical and no shortcomings are allowed to occur.

- Major investment requirements by SEC, in the short term, to establish SESOM as well as funding transmission expansion for the intended interconnected network. More investment is needed for funding generation expansion to maintain enough medium term capacity and to deplete the old units. Finally, some funds are required for distribution infrastructure.

- Even if the wholesale prices went down, in the start of real competition stage, retail prices and end user prices may not be decreased to the desired level. Such expectation is due to the need of recovering capital investment costs especially for the interconnection projects.

- Market power is difficult to be avoided in the short and medium terms of moving toward competitive market. The expected market power is due to the fact that SEC is providing almost 85% of the whole energy consumptions.

- Unavailability of reasonable priced smart energy meters. Such meters are to be used for households as well as for other customers. This is needed to let the end users sense the price signals of wholesale market.

7.3 Expected Benefits

The proposed framework satisfies most of the criteria needed to have a stable competitive market. This could drive the industry to have more security, more reliability, less fuel consumption, less pollution emissions, more innovations, new renewable energy technologies, and more value-added services to end users. Such improvements will lead to customer satisfaction and government satisfaction for hitting the targets without subsidies.

Another expected benefit is having more reliability and at the same time lesser reserve capacity which is an incentive to reduce generation cost. When SESOM start operating the system, reserve capacity is expected to be lower than when the industry is under regulation. However, the competition is expected to improve the operating efficiency which will lead to more reliability.

At retailing level and after promoting real competition among various CSP's, the customer has the right to choose his CSP. Therefore, CSP would compete to grab more customers by avoiding disconnections for non-payment bill, cost hedging, lowering contracted prices under the regulated price, and providing other value-added services. Value-added services could include one or a combination of related services such as:

desalinated water, cable TV services, internet services, and energy conservation consultations.

In the long term, end users are expected to participate in the demand side management. This is to be accomplished if the price signals passes to them. So, they could reduce their loads in the peak time. In the medium term, this participation could also be accomplished with smart retailing business moves.

7.4 Recommendations

The following summary of main recommendations covers all the Study key actions advised to be implemented by SESI participants or any other outside interested readers. Some of these recommendations are general which is applicable to most of ESI's and some of them are specifically related to SESI structure and uniqueness.

The recommendations are:-

1. ECRA is advised to form various function groups to be membered by a well selected expertise from ECRA, W&E ministry, SEC expertise, and legal consultant companies. The groups are required to develop all rules and regulations. This includes codes, contracts, efficient pricing criteria, and all other issues needed to drive the industry to the right direction.

2. At this ongoing reform stage in SESI, all participants are advised to shorten the period of any new contract to be signed. The reason behind that is to give a chance to different kinds of contracts to be carried out like CFD when SESOM is established and the wholesale market started.

3. It is recommended to transfer to ECRA all required regulatory authority from existing concerned agencies namely: Deputy Ministry of Electricity, S.A. General Investment Authority, Ministry of Oil and Natural resources, Ministry of Finance, and Supreme Economic Council. In addition to that, a clear determination of duties and responsibilities of each concerned agency is required. The aim of this recommendation is to avoid overlapping of authority which could discourage new investors or induce high regulatory in the intended competitive market.

4. ECRA and SEC are advised to seek one time subsidy from government to cover infrastructure costs in deregulation process to enhance the industry and drive the process to success.

5. ECRA is advised to review the existing connection fees and consumption tariff. Chapter 4 proposes brief ideas for more suitable prices.

6. It is recommended to ensure 100% independency of SESOM and ECRA. Ensuring fairness among all market participants is behind this recommendation.

7. Transmission wires and distribution wires are to be regulated due to their nature of monopoly. While generation and retail businesses are to be competitive with no particular large scale power plant or retailer. Also, distinct separation between the regulated entities and the competitive entities is a mandatory action in the long term structure.

8. OASIS is to be sophisticated enough to meet the complexity of the industry and the intended increase of participants.

9. SESOM is advised to learn from other industries incidences. High protection for the system is required to avoid any chance of cascaded blackouts that have happened in other countries like: California, France, Canada, and New Zealand.

10. New investors are to be supported in the beginning by SEC allowing SESOM to give them priority to run their capacity. Later, when a competitive market is well established, SESOM should dispatch with priority to the power plants of lower prices regardless of being SEC property or other's property.

11. SEC has to encourage investors by all means to invest in the generation as well as retailing businesses to have large number of competitors in the industry. Otherwise, market power could be induced affecting the market and the industry in a negative way.

12. No particular PSP or CSP is to be allowed for supply monopoly over any specific area, city, town, village, or any government or non government authority. But rural areas could be allowed for supply monopoly under specific conditions, since it is mostly not economical to compete unless the network is available.

13. The proposed MW LP-based OPF tool can be used by new investors to decide the correct location of their generators. This would be beneficial in case of SESOM support of giving detailed and accurate data.

7.5 Possible Future Researches

Problems have been reported during deregulating electrical industries and after the deregulation had taken place along with problems raised by researchers in the field, make this area a good land for economist and electrical engineer researchers.

Due to complexity of electricity commodity, economists could seek a help from electrical engineers even if the problem is related to pricing or trading. The opposite is true also, due to the need of cost calculation criteria in most of the newly raised problems. So, the output of a researcher with electrical engineering background and master in economics is expected to be more comprehensive output. This could be accomplished by joint work also.

One of the Study products is the calculation criteria for the wheeling cost per energy per KM of electrical lines. However, the criterion used has shortcoming of requiring a lot of data in order to establish the cost. So, economists are called to develop a formula to calculate cost per MWH per KM without long calculation.

There is a need for future research in co-generation of water and electricity process, its viability and how far it should go.*

Enhancement of the proposed MW LP-based OPE, is another subject for future research. The key issue here is to select a wide range of usage in addition to the localization of potential power plants. Then modify the model without losing the advantage of the approximation by using active power only in the formula (No reactive power and no line characteristics). This is meant to let the cost drive the decision.

Still more problems are expected to be raised when SESI is completing the final stage of reform process and SESOM starts to run the competitive market. At that time, immediate researches would be called for and they will be based on realism.

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* This point is verbally advised by Prof. Abdullah Al-Shehri (Faculty of King Fahad University of Petroleum & Minerals and V.P. of Saudi Electricity & Co-generation Regulatory Authority)

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APPENDIX 1 (Sensitivity Analysis for Unit Generation Cost)

	Insurance Costs Changing I%				Capital Inv. Profit Changing P%				Total Fixed Costs Changing I & P					
PP name	Insurance Costs .10%	Insurance Costs .50%	Insurance Costs 1.0%	Depreciation Costs	Capital Inv. Profits 10%	Capital Inv. Profits 5%	Capital Inv. Profits 20%	O&M Fixed Costs	Total Fixed Costs I=.1 P=10	Total Fixed Costs I=.5	Total Fixed Costs I=1	Total Fixed Costs P=5	Total Fixed Costs P=20	Total Variable Costs
QPP	0.10	0.50	1.00	5.30	12.60	6.30	25.20	2.50	20.50	20.90	21.40	14.20	33.10	27.80
GHZ230	0.20	1.00	2.00	8.20	18.40	9.20	36.80	4.70	31.50	32.30	33.30	22.30	49.90	28.80
GHQ380	0.20	1.00	2.00	9.50	22.80	11.40	45.60	2.50	35.00	35.80	36.80	23.60	57.80	26.10
UTH	0.10	0.50	1.00	10.70	5.40	2.70	10.80	7.80	24.00	24.40	24.90	21.30	29.40	43.00
SHE230	0.10	0.50	1.00	12.40	12.40	6.20	24.80	6.70	31.60	32.00	32.50	25.40	44.00	36.60
FAR230	0.10	0.50	1.00	12.30	12.30	6.15	24.60	7.10	31.80	32.20	32.70	25.65	44.10	38.40
BER	0.10	0.50	1.00	11.20	9.80	4.90	19.60	7.90	29.00	29.40	29.90	24.10	38.80	42.20
JUY	0.10	0.50	1.00	15.40	7.70	3.85	15.40	8.70	31.90	32.30	32.80	28.05	39.60	49.00
SAF	0.10	0.50	1.00	17.60	6.60	3.30	13.20	11.30	35.60	36.00	36.50	32.30	42.20	59.80
RAS	0.20	1.00	2.00	16.00	16.00	8.00	32.00	10.00	42.20	43.00	44.00	34.20	58.20	54.00
DMP	0.10	0.50	1.00	24.10	12.10	6.05	24.20	15.40	51.70	52.10	52.60	45.65	63.80	50.80
AZY	0.40	2.00	4.00	40.00	40.00	20.00	80.00	7.00	87.40	89.00	91.00	67.40	127.4	38.50
J01	0.40	2.00	4.00	40.00	40.00	20.00	80.00	7.00	87.40	89.00	91.00	67.40	127.4	38.50
J2A	0.40	2.00	4.00	40.00	40.00	20.00	80.00	7.00	87.40	89.00	91.00	67.40	127.4	38.50
J2B	0.40	2.00	4.00	40.00	40.00	20.00	80.00	7.00	87.40	89.00	91.00	67.40	127.4	38.50
QAIS	0.10	0.50	1.00	55.90	14.00	7.00	28.00	14.50	84.50	84.90	85.40	77.50	98.50	56.20

APPENDIX 1 (Continue)
(Sensitivity Analysis for Unit Generation Cost)

Total Unit Generation Costs Changing IF , PM, & RF

PP name	Total Unit Generation Costs (SR/MWH) I=.1% P=10% RF=5%	Total Unit Generation Costs (SR/MWH) I=.5% P=10%	Total Unit Generation Costs (SR/MWH) I=1% P=10%	Total Unit Generation Costs (SR/MWH) I=.1% P=5%	Total Unit Generation Costs (SR/MWH) I=.1% P=20%	Total Unit Generation Costs (SR/MWH) RF=2.5	Total Unit Generation Costs (SR/MWH) RF=10
QPP	51	51	52	44	64	50	53
GHZ230	63	64	65	54	83	62	66
GHQ380	64	65	66	52	88	63	67
UTH	70	71	71	68	76	69	74
SHE230	72	72	73	65	85	70	75
FAR230	74	74	75	67	87	72	77
BER	75	75	76	70	85	73	78
JUY	85	85	86	81	93	83	89
SAF	100	101	101	97	107	98	105
RAS	101	102	103	93	118	99	106
DMP	108	108	109	101	120	105	113
AZY	132	134	136	111	174	129	138
J01	132	134	136	111	174	129	138
J2A	132	134	136	111	174	129	138
J2B	132	134	136	111	174	129	138
QAIS	148	148	149	140	162	144	155

APPENDIX 2
(Sensitivity Analysis for Unit Wheeling Cost)

Unit Wheeling Cost (Changing Ins.F., Profit M., Risk F.)

Insurance Factor Original	Insurance Cost	Capital Inv. Profit	Insurance Factor	UTC SR/MWH	Profit Margin	UTC SR/MWH	Risk Factor	UTC SR/MWH
0.001	0.1273	6.3636	0.05	28.14	0.05	21.46	0.05	28.14
0.002	0.2545	12.7273	0.10	28.27	0.10	28.14	0.10	29.48
0.003	0.3818	19.0909	0.15	28.40	0.15	34.82	0.15	30.82
0.004	0.5091	25.4545	0.20	28.54	0.20	41.50	0.20	32.16

Extreme	*UTC SR/MWH*
0.05	21.45
0.10	29.61
0.15	38.42
0.20	47.88

APPENDIX 2 (Continue)

Table 6.2 but with changing the unit wheeling cost from 28.14 to 47.88 as the extreme case in the above table

Line No. ij	Line Name	Line Voltage (kV)	Normal MW Capacity CL_{ij}	Circuit KM	No. of Circuit N_{ij}	Wheeling Cost SR/MWH/ Km / circuit	Wheeling C_{ij} SR/MWH /circuit	$N_{ij} * C_{ij}$ (SR/MWH)
0103	GHZ2 – FAD	380	2659	89	4	0.2506	22.2992	89.20
0104	GHZ2 – GHU	380	2659	112	2	0.2506	28.0619	56.12
0204	QPP - GHU	380	2659	44	1	0.4009	17.6389	17.64
0205	QPP - SHE	380	2659	85	2	0.2506	21.2970	42.59
0206	QPP - FAR	380	2659	136	1	0.4009	54.5203	54.52
0308	FAD T/F	380 - 230	3*T750	0	4	23.9715	23.9715	95.89
0405	GHU - SHE	380	2659	74	1	0.4009	29.6654	29.67
0410	GHU T/F	380 - 230	T750	0	2	47.9431	47.9431	95.89
0506	SHE - FAR	380	2659	54	1	0.4009	21.6477	21.65
0507	SHE - HAW	380	2659	110	1	0.4009	44.0973	44.10
0511	SHE T/F	380 - 230	T750	0	2	47.9431	47.9431	95.89
0554	SHE - R9001	380	2659	313	2	0.2506	78.4230	156.85
0607	FAR - HAW	380	2659	47	1	0.4009	18.8416	18.84
0612	FAR T/F	380 - 230	T750	0	2	47.9431	47.9431	95.89
0655	FAR - KH9003	380	2659	266	2	0.2506	66.6470	133.29
0717	HAW T/F	380 - 230	T750	0	2	47.9431	47.9431	95.89
0830	FAD - JBSE	230	741	38.2	2	0.1837	7.0188	14.04
0837	FAD - JBN	230	741	48	2	0.1837	8.8195	17.64
0838	FAD - JBSW	230	741	41	1	0.2840	11.6423	11.64
0850	FAD - KHU	230	741	42	1	0.2840	11.9263	11.93
0922	GHZI - DBP	230	741	49.4	1	0.2840	14.0276	14.03
0927	GHZI – DHC	230	741	69.2	2	0.1837	12.7147	25.43
0928	GHZI - QTF	230	741	31.8	1	0.2840	9.0299	9.03
0929	GHZI - RAS	230	741	33.3	2	0.1837	6.1185	12.24
0930	GHZI - JBSE	230	741	52.2	1	0.2840	14.8227	14.82
0943	GHZI - J01	230	741	23.9	1	0.2840	6.7866	6.79
0946	GHZI - BER	230	741	38.6	2	0.1837	7.0923	14.18
0953	GHZI-JUY+T/F	115	185/T400	7.4	2	23.4794	25.1898	50.38
1020	GHU - IBK	230	741	23	1	0.2840	6.5311	6.53
1024	GHU - KHO	230	741	25	1	0.2840	7.0990	7.10
1118	SHE - JAD	230	741	19	2	0.1837	3.4910	6.98
1213	FAR - MAH	230	741	32.5	1	0.2840	9.2287	9.23
1214	FAR - RWPS	230	741	102	1	0.2840	28.9639	28.96
1215	FAR - KHR	230	741	131	1	0.2840	37.1987	37.20
1217	FAR - HAW	230	741	52	2	0.1837	9.5544	19.11
1218	FAR - JAD	230	741	73	1	0.2840	20.7291	20.73
1252	FAR - UTH+T/F	115	370/T400	2.4	2	23.4794	23.8536	47.71
1318	MAH - JAD	230	741	40.5	1	0.2840	11.5004	11.50
1415	RWPS – KHR	230	741	30.6	1	0.2840	8.6892	8.69
1516	KHR - WASIA	230	741	52.2	2	0.1837	9.5912	19.18
1656	WASIA - R9000	380	2659	77	2	0.2506	19.2926	38.59
1819	JAD - ABQ	230	741	26	2	0.1837	4.7772	9.55
1927	ABQ - DHC	230	741	52	2	0.1837	9.5544	19.11
2021	IBK - DMP	230	741	7.8	1	0.2840	2.2149	2.21
2022	IBK - DBP	230	741	2.1	2	0.1837	0.3859	0.77

APPENDIX 2 (Continue)

Line No. ij	Line Name	Line Voltage (kV)	Normal MW Capacity CL_{ij}	Circuit KM	No. of Circuit N_{ij}	Wheeling Cost SR/MWH/ Km / circuit	Wheeling C_{ij} SR/MWH /circuit	$N_{ij} * C_{ij}$ (SR/MWH)
2123	DMP - RAK	230	297	9	1	0.2840	2.5556	2.56
2127	DMP - DHC	230	741	18	2	0.1837	3.3073	6.61
2228	DBP - QTF	230	741	17.6	1	0.2840	4.9977	5.00
2324	RAK - KHO	230	297	2	1	0.2840	0.5679	0.57
2425	KHO - THQ	230	297	2.9	1	0.2840	0.8235	0.82
2526	THQ - AZY	230	741	7.6	2	0.1837	1.3964	2.79
2627	AZY - DHC	230	741	15.6	2	0.1837	2.8663	5.73
2829	QTF - RAS	230	741	43.6	1	0.2840	12.3806	12.38
3032	JBSE - IZH	230	741	2	1	0.2840	0.5679	0.57
3033	JBSE - JBCM	230	741	9.3	1	0.2840	2.6408	2.64
3034	JBSE - SADAF	230	741	2	2	0.1837	0.3675	0.73
3035	JBSE - SHARQ	230	741	2	2	0.1837	0.3675	0.73
3036	JBSE - PETRO	230	370	2	2	0.1837	0.3675	0.73
3046	JBSE - BER	230	741	2	1	0.2840	0.5679	0.57
3051	JBSE - SIPC	230	741	2	2	0.1837	0.3675	0.73
3150	SAF - KHU	230	741	107.9	2	0.1837	19.8254	39.65
3237	IZH - JBN	230	741	2	1	0.2840	0.5679	0.57
3337	JBCM - JBN	230	741	7.1	1	0.2840	2.0161	2.02
3738	JBN - JBSW	230	741	6.4	1	0.2840	1.8173	1.82
3741	JBN - HAD	230	741	2	1	0.2840	0.5679	0.57
3742	JBN - NIGC	230	741	2	1	0.2840	0.5679	0.57
3746	JBN - BER	230	741	12	1	0.2840	3.4075	3.41
3749	JBN - NAR	230	741	129.5	1	0.2840	36.7728	36.77
3750	JBN - KHU	230	741	43.5	1	0.2840	12.3522	12.35
3839	JBSW - SB'YEK	230	741	2	2	0.1837	0.3675	0.73
3840	JBSW - KEMYA	230	741	2	2	0.1837	0.3675	0.73
3841	JBSW – HAD	230	741	2	1	0.2840	0.5679	0.57
3842	JBSW - NIGC	230	741	2	1	0.2840	0.5679	0.57
3843	JBSW - J01	230	741	29.5	1	0.2840	8.3768	8.38
3846	JBSW – BER	230	741	9.4	1	0.2840	2.6692	2.67
4344	J01 – J2A	230	741	2	1	0.2840	0.5679	0.57
4445	J2A – J2B	230	741	2	1	0.2840	0.5679	0.57
4446	J2A - BER	230	741	21.5	1	0.2840	6.1051	6.11
4546	J2B - BER	230	741	21.5	1	0.2840	6.1051	6.11
4647	BER - BNG	230	741	2	2	0.1837	0.3675	0.73
4650	BER - KHU	230	741	48.5	1	0.2840	13.7720	13.77
4849	QAIS - NAR	230	741	282	2	0.1837	51.8143	103.63
4950	NAR - KHU	230	741	86	1	0.2840	24.4205	24.42

APPENDIX 2 (Continue)

6.2 but without weighing factor to calculate the Cluster average wheeling cost per main links

Line No. ij	Line Name	Line Voltage (kV)	Normal MW Capacity CL_{ij}	Circuit KM	No. of Circuit N_{ij}	Wheeling Cost SR/MWH/ Km / circuit	Wheeling C_{ij} SR/MWH /circuit	$N_{ij} * C_{ij}$ (SR/MWH)
0103	GHZ2 - FAD	380	2659	89	4	0.01	0.47	1.88
0104	GHZ2 - GHU	380	2659	112	2	0.01	0.59	1.18
0204	QPP - GHU	380	2659	44	1	0.01	0.37	0.37
0205	QPP - SHE	380	2659	85	2	0.01	0.45	0.90
0206	QPP - FAR	380	2659	136	1	0.01	1.15	1.15
0308	FAD T/F	380 - 230	T750	0	4	2.02	2.02	8.08
0405	GHU - SHE	380	2659	74	1	0.01	0.62	0.62
0410	GHU T/F	380 - 230	T750	0	2	2.02	2.02	4.04
0506	SHE - FAR	380	2659	54	1	0.01	0.46	0.46
0507	SHE - HAW	380	2659	110	1	0.01	0.93	0.93
0511	SHE T/F	380 - 230	T750	0	2	2.02	2.02	4.04
0554	SHE - R9001	380	2659	313	2	0.01	1.65	3.30
0607	FAR - HAW	380	2659	47	1	0.01	0.40	0.40
0612	FAR T/F	380 - 230	T750	0	2	2.02	2.02	4.04
0655	FAR - KH9003	380	2659	266	2	0.01	1.40	2.81
0717	HAW T/F	380 - 230	T750	0	2	2.02	2.02	4.04
0830	FAD - JBSE	230	741	38.2	2	0.00	0.15	0.30
0837	FAD - JBN	230	741	48	2	0.00	0.19	0.37
0838	FAD - JBSW	230	741	41	1	0.01	0.25	0.25
0850	FAD - KHU	230	741	42	1	0.01	0.25	0.25
0922	GHZI - DBP	230	741	49.4	1	0.01	0.30	0.30
0927	GHZI - DHC	230	741	69.2	2	0.00	0.27	0.54
0928	GHZI - QTF	230	741	31.8	1	0.01	0.19	0.19
0929	GHZI - RAS	230	741	33.3	2	0.00	0.13	0.26
0930	GHZI - JBSE	230	741	52.2	1	0.01	0.31	0.31
0943	GHZI - J01	230	741	23.9	1	0.01	0.14	0.14
0946	GHZI - BER	230	741	38.6	2	0.00	0.15	0.30
0953	GHZI - JUY+T/F	115	185/T400	7.4	2	0.98	1.02	2.04
1020	GHU - IBK	230	741	23	1	0.01	0.14	0.14
1024	GHU - KHO	230	741	25	1	0.01	0.15	0.15
1118	SHE - JAD	230	741	19	2	0.00	0.07	0.15
1213	FAR - MAH	230	741	32.5	1	0.01	0.19	0.19
1214	FAR - RWPS	230	741	102	1	0.01	0.61	0.61
1215	FAR - KHR	230	741	131	1	0.01	0.78	0.78
1217	FAR - HAW	230	741	52	2	0.00	0.20	0.40
1218	FAR - JAD	230	741	73	1	0.01	0.44	0.44
1252	FAR - UTH+T/F	115	370/T400	2.4	2	0.98	0.99	1.98
1318	MAH - JAD	230	741	40.5	1	0.01	0.24	0.24
1415	RWPS - KHR	230	741	30.6	1	0.01	0.18	0.18
1516	KHR - WASIA	230	741	52.2	2	0.00	0.20	0.40
1656	WASIA - R9000	380	2659	77	2	0.01	0.41	0.81

APPENDIX 2 (Continue)

6.2 but without weighing factor to calculate the Cluster average wheeling cost per main links

Line No. ij	Line Name	Line Voltage (kV)	Normal MW Capacity CL_{ij}	Circuit KM	No. of Circuit N_{ij}	Wheeling Cost SR/MWH/ Km / circuit	Wheeling C_{ij} SR/MWH /circuit	$N_{ij} * C_{ij}$ (SR/MWH)
1819	JAD - ABQ	230	741	26	2	0.00	0.10	0.20
1927	ABQ - DHC	230	741	52	2	0.00	0.20	0.40
2127	DMP - DHC	230	741	18	2	0.00	0.07	0.14
2228	DBP - QTF	230	741	17.6	1	0.01	0.11	0.11
2627	AZY - DHC	230	741	15.6	2	0.00	0.06	0.12
2829	QTF - RAS	230	741	43.6	1	0.01	0.26	0.26
3150	SAF - KHU	230	741	107.9	2	0.00	0.42	0.83
3749	JBN - NAR	230	741	129.5	1	0.01	0.77	0.77
3750	JBN - KHU	230	741	43.5	1	0.01	0.26	0.26
3843	JBSW - J01	230	741	29.5	1	0.01	0.18	0.18
4446	J2A - BER	230	741	21.5	1	0.01	0.13	0.13
4546	J2B - BER	230	741	21.5	1	0.01	0.13	0.13
4650	BER - KHU	230	741	48.5	1	0.01	0.29	0.29
4849	QAIS - NAR	230	741	282	2	0.00	1.09	2.18
4950	NAR - KHU	230	741	86	1	0.01	0.51	0.51
Cluster average wheeling cost per main links								**1.0082**

APPENDIX 3
(LINDO BREAF DISCRIBTION)
"Quoted from the software HELP"

LINDO (Linear, Interactive, and Discrete Optimizer) is a convenient, but powerful tool for solving linear, integer, and quadratic programming problems. These problems occur in areas of business, industry, research and government. Specific applications areas where LINDO has proven to be of great use would include product distribution, ingredient blending, production and personnel scheduling, inventory management.

The guiding design philosophy for LINDO has been that, if a user wants to do something simple, then there should not be a large setup cost to learn the necessary features of LINDO. If, for example, a user wishes to:

Maximize 2X + 3Y
Subject to

4X + 3Y < 10

3X + 5Y < 12

Then that is exactly what the user types into LINDO immediately after starting the program.
At the other extreme, LINDO has been used to solve real industrial linear, quadratic, and integer programs of respectable size. For commercial applications, LINDO is frequently used to solve problems with tens of thousands of constraints and hundreds of thousands of variables.
There are three basic styles of using the LINDO software. For small to medium sized problems, LINDO is simple to use interactively from the keyboard. Entering a model is quite easy to do. It's also possible to use LINDO with files created elsewhere, containing scripts of commands and input data, and producing files for reporting purposes. Finally, custom-created subroutines may be linked directly with LINDO to form an integrated program containing both your code and the LINDO optimization libraries.

SENSITIVITY RANGES:-

The RANGE command displays the sensitivity analysis of the currently installed solution of the model in memory. This includes:

- a warning if the current solution is not guaranteed to be optimal or feasible,
- variable names with their current objective function coefficients and allowable increases and decreases, and:
- row numbers (or names) with their current right-hand side values and allowable increases and decreases

Interpretation of the range report is as follows: the OBJ COEFFICIENT RANGES for each variable are the amount by which the objective coefficient can be increased or decreased without causing a change in the basis (the set of nonzero variables).

In the following small model, we've made changes after solving to demonstrate.

```
MAX    20 COMP1 + 30 COMP2
SUBJECT TO
     2)  COMP1 <=  60
     3)  COMP2 <=  70
     4)  COMP1 + 2 COMP2 <=  120

END

LP OPTIMUM FOUND AT STEP     2
     OBJECTIVE FUNCTION VALUE
     1)     2100.000

 VARIABLE        VALUE          REDUCED COST
   COMP1       60.000000          .000000
   COMP2       30.000000          .000000

DO RANGE (SENSITIVITY) ANALYSIS?  Y

RANGES IN WHICH THE BASIS IS UNCHANGED:

                    OBJ COEFFICIENT RANGES
VARIABLE        CURRENT       ALLOWABLE       ALLOWABLE
                  COEF         INCREASE        DECREASE
   COMP1       20.000000      INFINITY         5.000000
   COMP2       30.000000      10.000000        30.000000
```

Now, we will change the objective coefficient of COMP1 to 14 (decreasing it by 1 more than the allowable decrease) and re-solve.

```
     OBJECTIVE FUNCTION VALUE
     1)     1800.000

 VARIABLE        VALUE          REDUCED COST
   COMP1          .000000        1.000000
   COMP2       60.000000          .000000
```

The value of COMP1 becomes 000 instead of 60; however, if we change the objective coefficient of COMP1 to 15 (decreasing it by the allowable decrease) and re-solve, the COMP1 value will be 60 (without any change in the original value)

APPENDIX 4
(Case Study 1-1 Program Run Out, Results, and Sensitivity Ranges)

```
! CASE STUDY 1-1 TO APPROVE VALIDITY OF THE MODEL AND THE PROGRAM BY
! APPLIENG IT TO THE ACTUAL EASTERN PROVINCE SYSTEM IN SAUDI ARABIA
! WITHOUT ANY CHANGES TO THE MODEL.

! Objective function:
! Minimize C =sum Cgi (Pgi) + sum   sum Nij Cij Pdij
!              i=1,n            i=1,n  j=1,n          (As per equation 5.4 section 5.7.1)

! THE FIRST PART OF THE OBJECTIVE FUNCTION
! C = sum Cgi Pgi   (Substitute for values of Cgi from table 6.1 for each i= Bus number in Power
! Plants)

min   64Pg01+51Pg02+63Pg09+72Pg11+74Pg12+108Pg21+132Pg26+101Pg29+100Pg31+132Pg43
    +132Pg44+132Pg45+75Pg46+148Pg48+70Pg52+85Pg53

! FOR BUSSES WITHOUT POWER PLANTS
! C = sum 1000 Pgi   (Substitute for values of Cgi from table 6.1 for each i = Bus number for all
!                     busses without Power Plants)

+1000Pg03+1000Pg04+1000Pg05+1000Pg06+1000Pg07+1000Pg08+1000Pg10+1000Pg13
+1000Pg14+1000Pg15+1000Pg16+1000Pg17+1000Pg18+1000Pg19+1000Pg20+1000Pg22
+1000Pg23+1000Pg24+1000Pg25+1000Pg27+1000Pg28+1000Pg30+1000Pg32+1000Pg33
+1000Pg34+1000Pg35+1000Pg36+1000Pg37+1000Pg38+1000Pg39+1000Pg40+1000Pg41
+1000Pg42+1000Pg47+1000Pg49+1000Pg50+1000Pg51+1000Pg54+1000Pg55+1000Pg56

! FOR THE SECOND PART OF THE OBJECTIVE FUNCTION
! sum sum Nij Cij  Pdij  (Substitute for values of Nij and Cij from table 6.2)

+       52.42   Pd0103 +       52.42   Pd0301
+       32.99   Pd0104 +       32.99   Pd0401
+       10.37   Pd0204 +       10.37   Pd0402
+       25.03   Pd0205 +       25.03   Pd0502
+       32.04   Pd0206 +       32.04   Pd0602
+       56.35   Pd0308 +       56.35   Pd0803
+       17.43   Pd0405 +       17.43   Pd0504
+       56.35   Pd0410 +       56.35   Pd0104
+       12.72   Pd0506 +       12.72   Pd0605
+       25.92   Pd0507 +       25.92   Pd0705
+       56.35   Pd0511 +       56.35   Pd1105
+       92.18   Pd0554 +       92.18   Pd5405
+       11.07   Pd0607 +       11.07   Pd0706
+       56.35   Pd0612 +       56.35   Pd1206
+       78.34   Pd0655 +       78.34   Pd5506
+       56.35   Pd0717 +       56.35   Pd1707
+       8.25    Pd0830 +       8.25    Pd3008
+       10.37   Pd0837 +       10.37   Pd3708
+       6.84    Pd0838 +       6.84    Pd3808
+       7.01    Pd0850 +       7.01    Pd5008
+       8.24    Pd0922 +       8.24    Pd2209
+       14.95   Pd0927 +       14.95   Pd2709
+       5.31    Pd0928 +       5.31    Pd2809
+       7.19    Pd0929 +       7.19    Pd2909
```

+	8.71	Pd0930	+	8.71	Pd3009
+	3.99	Pd0943	+	3.99	Pd4309
+	8.34	Pd0946	+	8.34	Pd4609
+	29.61	Pd0953	+	29.61	Pd5309
+	3.84	Pd1020	+	3.84	Pd2010
+	4.17	Pd1024	+	4.17	Pd2410
+	4.10	Pd1118	+	4.10	Pd1811
+	5.42	Pd1213	+	5.42	Pd1312
+	17.02	Pd1214	+	17.02	Pd1412
+	21.86	Pd1215	+	21.86	Pd1512
+	11.23	Pd1217	+	11.23	Pd1712
+	12.18	Pd1218	+	12.18	Pd1812
+	28.04	Pd1252	+	28.04	Pd5212
+	6.76	Pd1318	+	6.76	Pd1813
+	5.11	Pd1415	+	5.11	Pd1514
+	11.27	Pd1516	+	11.27	Pd1615
+	22.68	Pd1656	+	22.68	Pd5616
+	5.62	Pd1819	+	5.62	Pd1918
+	11.23	Pd1927	+	11.23	Pd2719
+	1.30	Pd2021	+	1.30	Pd2120
+	0.45	Pd2022	+	0.45	Pd2220
+	1.50	Pd2123	+	1.50	Pd2321
+	3.89	Pd2127	+	3.89	Pd2721
+	2.94	Pd2228	+	2.94	Pd2822
+	0.33	Pd2324	+	0.33	Pd2423
+	0.48	Pd2425	+	0.48	Pd2524
+	1.64	Pd2526	+	1.64	Pd2625
+	3.37	Pd2627	+	3.37	Pd2726
+	7.28	Pd2829	+	7.28	Pd2928
+	0.33	Pd3032	+	0.33	Pd3230
+	1.55	Pd3033	+	1.55	Pd3330
+	0.43	Pd3034	+	0.43	Pd3430
+	0.43	Pd3035	+	0.43	Pd3530
+	0.43	Pd3036	+	0.43	Pd3630
+	0.33	Pd3046	+	0.33	Pd4630
+	0.43	Pd3051	+	0.43	Pd5130
+	23.30	Pd3150	+	23.30	Pd5031
+	0.33	Pd3237	+	0.33	Pd3732
+	1.18	Pd3337	+	1.18	Pd3733
+	1.07	Pd3738	+	1.07	Pd3837
+	0.33	Pd3741	+	0.33	Pd4137
+	0.33	Pd3742	+	0.33	Pd4237
+	2.00	Pd3746	+	2.00	Pd4637
+	21.61	Pd3749	+	21.61	Pd4937
+	7.26	Pd3750	+	7.26	Pd5037
+	0.43	Pd3839	+	0.43	Pd3938
+	0.43	Pd3840	+	0.43	Pd4038
+	0.33	Pd3841	+	0.33	Pd4138
+	0.33	Pd3842	+	0.33	Pd4238
+	4.92	Pd3843	+	4.92	Pd4338
+	1.57	Pd3846	+	1.57	Pd4638
+	0.33	Pd4344	+	0.33	Pd4443
+	0.33	Pd4445	+	0.33	Pd4544
+	3.59	Pd4446	+	3.59	Pd4644
+	3.59	Pd4546	+	3.59	Pd4645
+	0.43	Pd4647	+	0.43	Pd4746

```
+       8.09    Pd4650 +        8.09    Pd5046
+       60.90   Pd4849 +        60.90   Pd4948
+       14.35   Pd4950 +        14.35   Pd5049

! THE FIRST CONSTRAINT
! Real power balance at each bus
! Subject to:
! Pgi - sum Nij Pdij + sum Nij Pdji = Pli      where i =1,2...n
!       j=1             j=1,n
! (Substitute for values of Pli from table 6.1 and Nij from table 6.2)

st
Pg01-4Pd0103-2Pd0104+4Pd0301+2Pd0401=120
Pg02-Pd0204-2Pd0205-Pd0206+Pd0402+2Pd0502+Pd0602=102
Pg03-4Pd0308+4Pd0803-4Pd0301+4Pd0103=0
Pg04-2Pd0401-Pd0402-Pd0405-2Pd0410+2Pd0104+Pd0204+Pd0504+2Pd1004=0
Pg05-2Pd0502-Pd0504-Pd0506-Pd0507-2Pd0511-
2Pd0554+2Pd0205+Pd0405+Pd0605+Pd0705+2Pd1105+2Pd5405=0
Pg06-Pd0602-Pd0605-Pd0607-2Pd0612-2Pd0655+Pd0206+Pd0506+Pd0706+2Pd1206+2Pd5506=0
Pg07-Pd0705-Pd0706-2Pd0717+Pd0507+Pd0607+2Pd1707=0
Pg08-4Pd0803-2Pd0830-2Pd0837-Pd0838-Pd0850+Pd0308+2Pd3008+2Pd3708+Pd3808+Pd5008=33
Pg09-Pd0922-2Pd0927-Pd0928-2Pd0929-Pd0930-Pd0943-2Pd0946-
2Pd0953+Pd2209+2Pd2709+Pd2809+2Pd2909+Pd3009+Pd4309+2Pd4609+2Pd5309=273
Pg10-2Pd1004-Pd1020-Pd1024+2Pd0410+Pd2010+Pd2410=6
Pg11-2Pd1105-2Pd1118+2Pd0511+2Pd1811=690
Pg12-2Pd1206-Pd1213-Pd1214-Pd1215-2Pd1217-Pd1218-
Pd1252+2Pd0612+Pd1312+Pd1412+Pd1512+2Pd1712+Pd1812+Pd5212=578
Pg13-Pd1312-Pd1318+Pd1213+Pd1813=341
Pg14-Pd1412-Pd1415+Pd1214+Pd1514=27
Pg15-Pd1512-Pd1514-2Pd1516+Pd1215+Pd1415+2Pd1615=7
Pg16-2Pd1615-2Pd1656+2Pd1516+2Pd5616=50
Pg17-2Pd1707-2Pd1712+2Pd0717+2Pd1217=191
Pg18-2Pd1811-2Pd1813-2Pd1819+2Pd1118+2Pd1318+2Pd1918=0
Pg19-2Pd1918-2Pd1927+2Pd1819+2Pd2719=172
Pg20-Pd2010-Pd2021-2Pd2022+Pd1020+Pd2120+2Pd2220=490
Pg21-Pd2120-Pd2123-2Pd2127+Pd2021+Pd2321+2Pd2721=468
Pg22-Pd2209-2Pd2220-Pd2228+Pd0922+2Pd2022+Pd2822=369
Pg23-Pd2321-Pd2324+Pd2123+Pd2423=120
Pg24-Pd2410-Pd2423-Pd2425+Pd1024+Pd2324+Pd2524=380
Pg25-Pd2524-2Pd2526+Pd2425+2Pd2625=377
Pg26-2Pd2625-2Pd2627+2Pd2526+2Pd2726=0
Pg27-2Pd2719-2Pd2721-2Pd2726+2Pd1927+2Pd2127+2Pd2627=139
Pg28-Pd2809-Pd2822-Pd2829+Pd0928+Pd2228+Pd2928=389
Pg29-2Pd2909-Pd2928+Pd0929+Pd2829=148
Pg30-Pd3009-Pd3032-Pd3033-2Pd3034-2Pd3035-2Pd3036-Pd3046-
2Pd3051+Pd0930+Pd3230+Pd3330+2Pd3430+2Pd3530+2Pd3630+Pd4630+2Pd5130=1
Pg31-2Pd3150+Pd5031=223
Pg32-Pd3230-Pd3237+Pd3032+Pd3732=62
Pg33-Pd3330-Pd3337+Pd3033+Pd3733=189
Pg34-2Pd3430+2Pd3034=273
Pg35-2Pd3530+2Pd3035=127
Pg36-2Pd3630+2Pd3036=143
Pg37-2Pd3708-Pd3732-Pd3733-Pd3738-Pd3741-Pd3742-Pd3746-Pd3749-
Pd3750+2Pd0837+Pd3237+Pd3337+Pd3837+Pd4137+Pd4237+Pd4637+Pd4937+Pd5037=9
Pg38-Pd3837-2Pd3839-2Pd3840-Pd3841-2Pd3842-Pd3843-
Pd3846+Pd3738+2Pd3938+2Pd4038+Pd4138+Pd4238+Pd4338+Pd4638=153
```

```
Pg39-2Pd3938+2Pd3839=2
Pg40-2Pd4038+2Pd3840=43
Pg41-Pd4137-Pd4138+Pd3741+Pd3841=461
Pg42-Pd4237-Pd4238+Pd3742+Pd3842=141
Pg43-Pd4309-Pd4338-Pd4344+Pd0943+Pd3843+Pd4443=0
Pg44-Pd4443-Pd4445-Pd4446+Pd4344+Pd4544+Pd4644=0
Pg45-Pd4544-Pd4546+Pd4445+Pd4645=0
Pg46-2Pd4609-Pd4630-Pd4637-Pd4638-Pd4644-Pd4645-2Pd4647-
Pd4650+2Pd0946+Pd3046+Pd3746+Pd3846+Pd4446+Pd4546+2Pd4746+Pd5046=500
Pg47-2Pd4746+2Pd4647=68
Pg48-2Pd4849+2Pd4948=210
Pg49-Pd4937-2Pd4948-Pd4950+Pd3749+2Pd4849+Pd5049=103
Pg50-Pd5008-2Pd5031-Pd5037-Pd5046-Pd5049+Pd0850+2Pd3150+Pd3750+Pd4650+Pd4950=55
Pg51-2Pd5130+2Pd3051=1
Pg52-2Pd5212+2Pd1252=0
Pg53-2Pd5309+2Pd0953=0
Pg54-2Pd5405+2Pd0554=925
Pg55-2Pd5506+2Pd0655=814
Pg56-2Pd5616+2Pd1656=158

! THE SECOND CONSTRAINT
! System real power balance
! sum Pgi  =  sum Pli
! i=1,n      i=1,n
! (Substitute for sum of Pli from table 6.1)

Pg01+Pg02+Pg09+Pg11+Pg12+Pg21+Pg26+Pg29+Pg31+Pg43+Pg44+Pg45+Pg46+Pg48+Pg52
+Pg53=10553

! THE THIRD CONSTRAINT
! Generation unit limits
! Pgi (min) <= Pgi <= Pgi (max)     for i = 1, 2, ...n
! (Substitute for the values of Pgi(min & max) from table 6.1)

Pg01 >= 100  Pg01 <= 2528  Pg02>= 200  Pg02 <= 2500  Pg09>= 220  Pg09<= 1600
Pg11 >= 100  Pg11 <= 1219  Pg12>= 100  Pg12 <= 910   Pg21>=100   Pg21<= 400
Pg26 >= 100  Pg26 <= 850   Pg29>= 20   Pg29 <= 120   Pg31>=20    Pg31<= 75
Pg43 >= 80   Pg43 <= 300   Pg44>= 80   Pg44 <= 300   Pg45>=80    Pg45<= 300
Pg46 >= 80   Pg46 <= 215   Pg48>= 20   Pg48 <= 108   Pg52>=80    Pg52<= 272
Pg53 >= 40   Pg53 <= 118

! THE FOURTH CONSTRAINT
! Limits on power flow
! Pdij <= Clij   for all i-j pairs (Substitute for the values of Clij from table 6.2)

Pd0103 <= 2659 Pd0104  <= 2659 Pd0301 <=2659 Pd0401 <= 2659
Pd0204 <= 2659 Pd0205  <= 2659 Pd0206 <=2659 Pd0402 <=2659 Pd0502 <=2659
Pd0602 <= 2659
Pd0308 <= 563   Pd0803  <= 563
Pd0405 <= 2659 Pd0504  <= 2659
Pd0410 <= 375   Pd1004  <= 375
Pd0506 <= 2659 Pd0507  <= 2659 Pd0554 <= 2659 Pd0605 <= 2659 Pd0705<= 2659
Pd5405 <= 2659
Pd0511 <= 375   Pd1105  <= 375
Pd0607 <= 2659 Pd0655  <= 2659 Pd0706 <= 2659 Pd5506 <= 2659
Pd0612 <= 375   Pd1206  <= 375
```

```
Pd0717 <= 375  Pd1707  <= 375
Pd0830 <= 741  Pd0837  <= 741  Pd0838 <=741 Pd0850  <= 741 Pd3008  <=741 Pd3708  <=741
Pd3808 <=741
Pd5008 <= 741
Pd0922 <= 741 Pd0927  <= 741  Pd0928 <=741 Pd0929  <= 741 Pd0930  <=741 Pd0943  <=741
Pd0946 <= 741 Pd2209  <= 741  Pd2709 <=741 Pd2809  <= 741 Pd2909  <=741 Pd3009  <=741
Pd4309 <= 741
Pd4609 <= 741
Pd0953 <= 185 Pd5309  <= 185
Pd1020 <= 741 Pd1024  <= 741  Pd2010 <= 741 Pd2410 <= 741
Pd1118 <= 741 Pd1811  <= 741
Pd1213 <= 741 Pd1214  <= 741  Pd1215 <= 741 Pd1217 <= 741 Pd1218 <=741 Pd1312  <=741
Pd1412 <= 741
Pd1512 <= 741 Pd1712  <= 741  Pd1812 <= 741
Pd1252 <= 370 Pd5212  <= 370
Pd1318 <= 741 Pd1813  <= 741
Pd1415 <= 741 Pd1514  <= 741
Pd1516 <= 741 Pd1615  <= 741
Pd1656 <= 2659Pd5616 <= 2659
Pd1819 <= 741 Pd1918  <= 741
Pd1927 <= 741 Pd2719  <= 741
Pd2021 <= 741 Pd2022  <= 741 Pd2120 <= 741 Pd2220 <= 741
Pd2123 <= 297 Pd2127  <= 297 Pd2321 <= 297 Pd2721 <= 297
Pd2228 <= 741 Pd2822  <= 741
Pd2324 <= 297 Pd2423  <= 297
Pd2425 <= 297 Pd2524  <= 297
Pd2526 <= 741 Pd2625  <= 741
Pd2627 <= 741 Pd2726  <= 741
Pd2829 <= 741 Pd2928  <= 741
Pd3032 <= 741 Pd3033  <= 741 Pd3034 <= 741 Pd3035 <= 741 Pd3046 <= 741 Pd3051 <= 741
Pd3230 <= 741
Pd3330 <= 741 Pd3430  <= 741 Pd3530 <= 741 Pd4630 <= 741 Pd5130 <= 741
Pd3036 <= 370 Pd3630  <= 370
Pd3150 <= 741 Pd5031  <= 741
Pd3237 <= 741 Pd3732  <= 741
Pd3337 <= 741 Pd3733  <= 741
Pd3738 <= 741 Pd3741  <= 741 Pd3742 <= 741 Pd3746 <= 741 Pd3749 <= 741 Pd3750 <= 741
Pd3837 <= 741
Pd4137 <= 741 Pd4237  <= 741 Pd4637 <= 741 Pd4937 <= 741 Pd5037 <= 741
Pd3839 <= 741 Pd3840  <= 741 Pd3841 <= 741 Pd3842 <= 741 Pd3843 <= 741 Pd3846 <= 741
Pd3938 <= 741
Pd4038 <= 741 Pd4138  <= 741 Pd4238 <= 741 Pd4338 <= 741 Pd4638 <= 741
Pd4344 <= 741 Pd4443  <= 741
Pd4445 <= 741 Pd4446  <= 741 Pd4544 <= 741 Pd4644 <= 741
Pd4546 <= 741 Pd4645  <= 741

! THE LAST CONSTRAINT
! NON NEGATIVITY
! Pgi >= 0 ,  Pdij >= 0  for all i-j pairs   (It is a built in feature by LINDO SOFTWARE)
end
```

APPENDIX 4 *(Continue)*
(Case Study 1-1 Results and Sensitivity Ranges)

LP OPTIMUM FOUND AT STEP 108

OBJECTIVE FUNCTION VALUE

1) 1001137

VARIABLE	VALUE	REDUCED COST
PG01	2372.000000	0.000000
PG02	2500.000000	0.000000
PG09	1600.000000	0.000000
PG11	1219.000000	0.000000
PG12	910.000000	0.000000
PG21	400.000000	0.000000
PG26	404.000000	0.000000
PG29	120.000000	0.000000
PG31	75.000000	0.000000
PG43	80.000000	0.000000
PG44	80.000000	0.000000
PG45	80.000000	0.000000
PG46	215.000000	0.000000
PG48	108.000000	0.000000
PG52	272.000000	0.000000
PG53	118.000000	0.000000

RANGES IN WHICH THE BASIS IS UNCHANGED:

	OBJ COEFFICIENT RANGES		
VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
PG01	64.000000	28.863750	7.714996
PG02	51.000000	39.584999	INFINITY
PG09	63.000000	61.494999	INFINITY
PG11	72.000000	50.395000	INFINITY
PG12	74.000000	57.205002	INFINITY
PG21	108.000000	26.270000	INFINITY
PG26	132.000000	6.925000	24.690001
PG29	101.000000	36.084999	INFINITY
PG31	100.000000	64.595001	INFINITY
PG43	132.000000	INFINITY	7.255000
PG44	132.000000	INFINITY	6.925000
PG45	132.000000	INFINITY	6.925000
PG46	75.000000	53.665001	INFINITY
PG48	148.000000	26.959999	INFINITY
PG52	70.000000	41.095001	INFINITY
PG53	85.000000	24.690001	INFINITY

APPENDIX 5
(Case Study 1-2 Program Run Out, Results, and Sensitivity Ranges)

```
! CASE STUDY 1-2 TO APPROVE VALIDITY OF THE MODEL.BY CHANGING THE
! UNIT GENERATION COST OF ALLPOWER PLANTS TO NEW EXTREEM VALUES
! AFTER CHANGING THE PROFIT MARGIN FROM 10% TO 20%. THE CHANGE IS
! ONLY IN THE OBJECTIVE FUNCTION (REPLACING VALUSE OF Pgi).

! Objective function:
! Minimize C =sum Cgi (Pgi) + sum   sum Nij Cij Pdij
!             i=1,n           i=1,n j=1,n
!(As per equation 5.4 section 5.7.1)

! THE FIRST PART OF THE OBJECTIVE FUNCTION
! C = sum Cgi Pgi    (Substitute for values of Cgi from Appendix
! 1 for each i= Bus number in Power Plants)

min
88Pg01+64Pg02+83Pg09+85Pg11+87Pg12+120Pg21+174Pg26+118Pg29+107Pg3
1+174Pg43+174Pg44+174Pg45+85Pg46+162Pg48+76Pg52+93Pg53
```

Results

```
LP OPTIMUM FOUND AT STEP    109

OBJECTIVE FUNCTION VALUE

1)      1190010

VARIABLE        VALUE          REDUCED COST
PG01       2482.000000          0.000000
PG02       2500.000000          0.000000
PG09       1600.000000          0.000000
PG11       1219.000000          0.000000
PG12        910.000000          0.000000
PG21        400.000000          0.000000
PG26        294.000000          0.000000
PG29        120.000000          0.000000
PG31         75.000000          0.000000
PG43         80.000000          0.000000
PG44         80.000000          0.000000
PG45         80.000000          0.000000
PG46        215.000000          0.000000
PG48        108.000000          0.000000
PG52        272.000000          0.000000
PG53        118.000000          0.000000
```

Case 1-2 Sensitivity Ranges

RANGES IN WHICH THE BASIS IS UNCHANGED:

		OBJ COEFFICIENT RANGES	
VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
PG01	88.000000	0.445000	0.100001
PG02	64.000000	58.299999	INFINITY
PG09	83.000000	82.535004	INFINITY
PG11	85.000000	77.989998	INFINITY
PG12	87.000000	84.800003	INFINITY
PG21	120.000000	55.310001	INFINITY
PG26	174.000000	0.100001	0.445000
PG29	118.000000	60.125000	INFINITY
PG31	107.000000	99.080002	INFINITY
PG43	174.000000	INFINITY	8.215000
PG44	174.000000	INFINITY	7.885000
PG45	174.000000	INFINITY	7.885000
PG46	85.000000	84.705002	INFINITY
PG48	162.000000	54.000000	INFINITY
PG52	76.000000	75.690002	INFINITY
PG53	93.000000	57.730000	INFINITY

APPENDIX 6
(Case Study 1-3 Program Run Out, Results, and Sensitivity Ranges)

```
! CASE STUDY 1-3 TO APPROVE VALIDITY OF THE MODEL.BY CHANGING THE
! UNIT WHEELING COST TO NEW EXTREEM VALUES AFTER CHANGING THE ALL
! ASSUMPTIONS TO MAX.(Insurance f.=0.04%, Profit M.=20%
! Risk F. = 20%. THE CHANGE IS ONLY IN THE OBJECTIVE FUNCTION
!(REPLACING VALUSE OF Pdij).


! FOR THE SECOND PART OF THE OBJECTIVE FUNCTION
! sum sum Nij Cij  Pdij  (Substitute for values of Nij and Cij
! from Appendix 2)

+     89.20 Pd0103      +     89.20 Pd0301
+     56.12 Pd0104      +     56.12 Pd0401
+     17.64 Pd0204      +     17.64 Pd0402
+     42.59 Pd0205      +     42.59 Pd0502
+     54.52 Pd0206      +     54.52 Pd0602
+     95.89 Pd0308      +     95.89 Pd0803
+     29.67 Pd0405      +     29.67 Pd0504
+     95.89 Pd0410      +     95.89 Pd0104
+     21.65 Pd0506      +     21.65 Pd0605
+     44.10 Pd0507      +     44.10 Pd0705
+     95.89 Pd0511      +     95.89 Pd1105
+     156.8 Pd0554      +     156.8 Pd5405
+     18.84 Pd0607      +     18.84 Pd0706
+     95.89 Pd0612      +     95.89 Pd1206
+     133.3 Pd0655      +     133.3 Pd5506
+     95.89 Pd0717      +     95.89 Pd1707
+     14.04 Pd0830      +     14.04 Pd3008
+     17.64 Pd0837      +     17.64 Pd3708
+     11.64 Pd0838      +     11.64 Pd3808
+     11.93 Pd0850      +     11.93 Pd5008
+     14.03 Pd0922      +     14.03 Pd2209
+     25.43 Pd0927      +     25.43 Pd2709
+     9.03  Pd0928      +     9.03  Pd2809
+     12.24 Pd0929      +     12.24 Pd2909
+     14.82 Pd0930      +     14.82 Pd3009
+     6.79  Pd0943      +     6.79  Pd4309
+     14.18 Pd0946      +     14.18 Pd4609
+     50.38 Pd0953      +     50.38 Pd5309
+     6.53  Pd1020      +     6.53  Pd2010
+     7.10  Pd1024      +     7.10  Pd2410
+     6.98  Pd1118      +     6.98  Pd1811
+     9.23  Pd1213      +     9.23  Pd1312
+     28.96 Pd1214      +     28.96 Pd1412
+     37.20 Pd1215      +     37.20 Pd1512
+     19.11 Pd1217      +     19.11 Pd1712
+     20.73 Pd1218      +     20.73 Pd1812
+     47.71 Pd1252      +     47.71 Pd5212
+     11.50 Pd1318      +     11.50 Pd1813
+     8.69  Pd1415      +     8.69  Pd1514
+     19.18 Pd1516      +     19.18 Pd1615
+     38.59 Pd1656      +     38.59 Pd5616
+     9.55  Pd1819      +     9.55  Pd1918
```

+	19.11	Pd1927	+	19.11	Pd2719
+	2.21	Pd2021	+	2.21	Pd2120
+	0.77	Pd2022	+	0.77	Pd2220
+	2.56	Pd2123	+	2.56	Pd2321
+	6.61	Pd2127	+	6.61	Pd2721
+	5.00	Pd2228	+	5.00	Pd2822
+	0.57	Pd2324	+	0.57	Pd2423
+	0.82	Pd2425	+	0.82	Pd2524
+	2.79	Pd2526	+	2.79	Pd2625
+	5.73	Pd2627	+	5.73	Pd2726
+	12.38	Pd2829	+	12.38	Pd2928
+	0.57	Pd3032	+	0.57	Pd3230
+	2.64	Pd3033	+	2.64	Pd3330
+	0.73	Pd3034	+	0.73	Pd3430
+	0.73	Pd3035	+	0.73	Pd3530
+	0.73	Pd3036	+	0.73	Pd3630
+	0.57	Pd3046	+	0.57	Pd4630
+	0.73	Pd3051	+	0.73	Pd5130
+	39.65	Pd3150	+	39.65	Pd5031
+	0.57	Pd3237	+	0.57	Pd3732
+	2.02	Pd3337	+	2.02	Pd3733
+	1.82	Pd3738	+	1.82	Pd3837
+	0.57	Pd3741	+	0.57	Pd4137
+	0.57	Pd3742	+	0.57	Pd4237
+	3.41	Pd3746	+	3.41	Pd4637
+	36.77	Pd3749	+	36.77	Pd4937
+	12.35	Pd3750	+	12.35	Pd5037
+	0.73	Pd3839	+	0.73	Pd3938
+	0.73	Pd3840	+	0.73	Pd4038
+	0.57	Pd3841	+	0.57	Pd4138
+	0.57	Pd3842	+	0.57	Pd4238
+	8.38	Pd3843	+	8.38	Pd4338
+	2.67	Pd3846	+	2.67	Pd4638
+	0.57	Pd4344	+	0.57	Pd4443
+	0.57	Pd4445	+	0.57	Pd4544
+	6.11	Pd4446	+	6.11	Pd4644
+	6.11	Pd4546	+	6.11	Pd4645
+	0.73	Pd4647	+	0.73	Pd4746
+	13.77	Pd4650	+	13.77	Pd5046
+	103.6	Pd4849	+	103.6	Pd4948
+	24.42	Pd4950	+	24.42	Pd5049

Case 1-3 Results, and Sensitivity Ranges

LP OPTIMUM FOUND AT STEP 126

OBJECTIVE FUNCTION VALUE

1) 1181413

VARIABLE	VALUE	REDUCED COST
PG01	2372.000000	0.000000
PG02	2500.000000	0.000000
PG09	1600.000000	0.000000
PG11	1219.000000	0.000000
PG12	910.000000	0.000000
PG21	400.000000	0.000000
PG26	404.000000	0.000000
PG29	120.000000	0.000000
PG31	75.000000	0.000000
PG43	80.000000	0.000000
PG44	80.000000	0.000000
PG45	80.000000	0.000000
PG46	215.000000	0.000000
PG48	108.000000	0.000000
PG52	272.000000	0.000000
PG53	118.000000	0.000000

RANGES IN WHICH THE BASIS IS UNCHANGED:

	OBJ COEFFICIENT RANGES		
VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
PG01	64.000000	1.392500	60.834999
PG02	51.000000	10.530000	INFINITY
PG09	63.000000	56.230000	INFINITY
PG11	72.000000	43.650002	INFINITY
PG12	74.000000	56.639999	INFINITY
PG21	108.000000	27.855000	INFINITY
PG26	132.000000	11.790000	1.392500
PG29	101.000000	39.639999	INFINITY
PG31	100.000000	87.459999	INFINITY
PG43	132.000000	INFINITY	12.360000
PG44	132.000000	INFINITY	11.790000
PG45	132.000000	INFINITY	11.790000
PG46	75.000000	51.320000	INFINITY
PG48	148.000000	57.095001	INFINITY
PG52	70.000000	26.420000	INFINITY
PG53	85.000000	9.040000	INFINITY

APPENDIX 7
(Case Study 2-1 Program Run Out, Results, and Sensitivity Ranges)

```
! CASE STUDY 2-1  PROPOSE NEW PP ON BUSSES 54,55,56 WITH SYSTEM
! AVERAGE COST (71 SR / MWH) CHANGES DONE IN THE OBJECTIVE
! FUNCTION AND IN THE SYSTEM REAL POWER BALANCE

! Objective function:
! Minimize C =sum Cgi (Pgi) + sum   sum  Nij Cij Pdij
!             i=1,n          i=1,n  j=1,n
!(As per equation 5.4 section 5.7.1)


! CASE STUDY 2-1 PROPOSE NEW PP ON BUSSES 54, 55, 56 WITH
! COST 71 SR / MWH
! THE FIRST PART OF THE OBJECTIVE FUNCTION
! C = sum Cgi Pgi    (Substitute for values of Cgi from table 6.1
! for each i= Bus number in Power Plants)

min    64Pg01+51Pg02+63Pg09+72Pg11+74Pg12+108Pg21+132Pg26+101Pg29
+100Pg31+132Pg43+132Pg44+132Pg45+75Pg46+148Pg48+70Pg52+85Pg53
+71Pg54+71Pg55+71Pg56

! CASE STUDY 2-1 PROPOSE NEW PP ON BUSSES 54, 55, 56
! FOR BUSSES WITHOUT POWER PLANTS
! C = sum 1000 Pgi   (Substitute for values of Cgi from table 6.1
! for each i = Bus number for all busses without Power  Plants)

+1000Pg03+1000Pg04+1000Pg05+1000Pg06+1000Pg07+1000Pg08+1000Pg10
+1000Pg13+1000Pg14+1000Pg15+1000Pg16+1000Pg17+1000Pg18+1000Pg19
+1000Pg20+1000Pg22+1000Pg23+1000Pg24+1000Pg25+1000Pg27+1000Pg28
+1000Pg30+1000Pg32+1000Pg33+1000Pg34+1000Pg35+1000Pg36+1000Pg37
+1000Pg38+1000Pg39+1000Pg40+1000Pg41+1000Pg42+1000Pg47+1000Pg49
+1000Pg50+1000Pg51

! FOR THE SECOND PART OF THE OBJECTIVE FUNCTION
! sum sum Nij Cij  Pdij  (Substitute for values of Nij and Cij from
table 6.2)

+     52.42 Pd0103      +     52.42 Pd0301
+     32.99 Pd0104      +     32.99 Pd0401
+     10.37 Pd0204      +     10.37 Pd0402
+     25.03 Pd0205      +     25.03 Pd0502
+     32.04 Pd0206      +     32.04 Pd0602
+     56.35 Pd0308      +     56.35 Pd0803
+     17.43 Pd0405      +     17.43 Pd0504
+     56.35 Pd0410      +     56.35 Pd0104
+     12.72 Pd0506      +     12.72 Pd0605
+     25.92 Pd0507      +     25.92 Pd0705
+     56.35 Pd0511      +     56.35 Pd1105
+     92.18 Pd0554      +     92.18 Pd5405
+     11.07 Pd0607      +     11.07 Pd0706
+     56.35 Pd0612      +     56.35 Pd1206
+     78.34 Pd0655      +     78.34 Pd5506
+     56.35 Pd0717      +     56.35 Pd1707
+     8.25  Pd0830      +     8.25  Pd3008
```

+	10.37	Pd0837	+	10.37	Pd3708
+	6.84	Pd0838	+	6.84	Pd3808
+	7.01	Pd0850	+	7.01	Pd5008
+	8.24	Pd0922	+	8.24	Pd2209
+	14.95	Pd0927	+	14.95	Pd2709
+	5.31	Pd0928	+	5.31	Pd2809
+	7.19	Pd0929	+	7.19	Pd2909
+	8.71	Pd0930	+	8.71	Pd3009
+	3.99	Pd0943	+	3.99	Pd4309
+	8.34	Pd0946	+	8.34	Pd4609
+	29.61	Pd0953	+	29.61	Pd5309
+	3.84	Pd1020	+	3.84	Pd2010
+	4.17	Pd1024	+	4.17	Pd2410
+	4.10	Pd1118	+	4.10	Pd1811
+	5.42	Pd1213	+	5.42	Pd1312
+	17.02	Pd1214	+	17.02	Pd1412
+	21.86	Pd1215	+	21.86	Pd1512
+	11.23	Pd1217	+	11.23	Pd1712
+	12.18	Pd1218	+	12.18	Pd1812
+	28.04	Pd1252	+	28.04	Pd5212
+	6.76	Pd1318	+	6.76	Pd1813
+	5.11	Pd1415	+	5.11	Pd1514
+	11.27	Pd1516	+	11.27	Pd1615
+	22.68	Pd1656	+	22.68	Pd5616
+	5.62	Pd1819	+	5.62	Pd1918
+	11.23	Pd1927	+	11.23	Pd2719
+	1.30	Pd2021	+	1.30	Pd2120
+	0.45	Pd2022	+	0.45	Pd2220
+	1.50	Pd2123	+	1.50	Pd2321
+	3.89	Pd2127	+	3.89	Pd2721
+	2.94	Pd2228	+	2.94	Pd2822
+	0.33	Pd2324	+	0.33	Pd2423
+	0.48	Pd2425	+	0.48	Pd2524
+	1.64	Pd2526	+	1.64	Pd2625
+	3.37	Pd2627	+	3.37	Pd2726
+	7.28	Pd2829	+	7.28	Pd2928
+	0.33	Pd3032	+	0.33	Pd3230
+	1.55	Pd3033	+	1.55	Pd3330
+	0.43	Pd3034	+	0.43	Pd3430
+	0.43	Pd3035	+	0.43	Pd3530
+	0.43	Pd3036	+	0.43	Pd3630
+	0.33	Pd3046	+	0.33	Pd4630
+	0.43	Pd3051	+	0.43	Pd5130
+	23.30	Pd3150	+	23.30	Pd5031
+	0.33	Pd3237	+	0.33	Pd3732
+	1.18	Pd3337	+	1.18	Pd3733
+	1.07	Pd3738	+	1.07	Pd3837
+	0.33	Pd3741	+	0.33	Pd4137
+	0.33	Pd3742	+	0.33	Pd4237
+	2.00	Pd3746	+	2.00	Pd4637
+	21.61	Pd3749	+	21.61	Pd4937
+	7.26	Pd3750	+	7.26	Pd5037
+	0.43	Pd3839	+	0.43	Pd3938
+	0.43	Pd3840	+	0.43	Pd4038
+	0.33	Pd3841	+	0.33	Pd4138
+	0.33	Pd3842	+	0.33	Pd4238
+	4.92	Pd3843	+	4.92	Pd4338

```
+      1.57  Pd3846      +      1.57  Pd4638
+      0.33  Pd4344      +      0.33  Pd4443
+      0.33  Pd4445      +      0.33  Pd4544
+      3.59  Pd4446      +      3.59  Pd4644
+      3.59  Pd4546      +      3.59  Pd4645
+      0.43  Pd4647      +      0.43  Pd4746
+      8.09  Pd4650      +      8.09  Pd5046
+      60.90 Pd4849      +      60.90 Pd4948
+      14.35 Pd4950      +      14.35 Pd5049


! THE FIRST CONSTRAINT
! Real power balance at each bus
! Subject to:
! Pgi - sum Nij Pdij + sum Nij Pdji = Pli where i =1, 2...n
!       j=1            j=1, n
! (Substitute for values of Pli from table 6.1 and Nij from table
! 6.6)

st
Pg01-4Pd0103-2Pd0104+4Pd0301+2Pd0401=120
Pg02-Pd0204-2Pd0205-Pd0206+Pd0402+2Pd0502+Pd0602=102
Pg03-4Pd0308+4Pd0803-4Pd0301+4Pd0103=0
Pg04-2Pd0401-Pd0402-Pd0405-Pd0410+2Pd0104+Pd0204+Pd0504+2Pd1004=0
Pg05-2Pd0502-Pd0504-Pd0506-Pd0507-2Pd0511-
2Pd0554+2Pd0205+Pd0405+Pd0605+Pd0705+2Pd1105+2Pd5405=0
Pg06-Pd0602-Pd0605-Pd0607-2Pd0612-
2Pd0655+Pd0206+Pd0506+Pd0706+2Pd1206+2Pd5506=0
Pg07-Pd0705-Pd0706-2Pd0717+Pd0507+Pd0607+2Pd1707=0
Pg08-4Pd0803-2Pd0830-2Pd0837-Pd0838-
Pd0850+Pd0308+2Pd3008+2Pd3708+Pd3808+Pd5008=33
Pg09-Pd0922-2Pd0927-Pd0928-2Pd0929-Pd0930-Pd0943-2Pd0946-
2Pd0953+Pd2209+2Pd2709+Pd2809+2Pd2909
+Pd3009+Pd4309+2Pd4609+2Pd5309=273
Pg10-2Pd1004-Pd1020-Pd1024+2Pd0410+Pd2010+Pd2410=6
Pg11-2Pd1105-2Pd1118+2Pd0511+2Pd1811=690
Pg12-2Pd1206-Pd1213-Pd1214-Pd1215-2Pd1217-Pd1218-
Pd1252+2Pd0612+Pd1312+Pd1412+Pd1512+2Pd1712+Pd1812+Pd5212=578
Pg13-Pd1312-Pd1318+Pd1213+Pd1813=341
Pg14-Pd1412-Pd1415+Pd1214+Pd1514=27
Pg15-Pd1512-Pd1514-2Pd1516+Pd1215+Pd1415+2Pd1615=7
Pg16-2Pd1615-2Pd1656+2Pd1516+2Pd5616=50
Pg17-2Pd1707-2Pd1712+2Pd0717+2Pd1217=191
Pg18-2Pd1811-2Pd1813-2Pd1819+2Pd1118+2Pd1318+2Pd1918=0
Pg19-2Pd1918-2Pd1927+2Pd1819+2Pd2719=172
Pg20-Pd2010-Pd2021-2Pd2022+Pd1020+Pd2120+2Pd2220=490
Pg21-Pd2120-Pd2123-2Pd2127+Pd2021+Pd2321+2Pd2721=468
Pg22-Pd2209-2Pd2220-Pd2228+Pd0922+2Pd2022+Pd2822=369
Pg23-Pd2321-Pd2324+Pd2123+Pd2423=120
Pg24-Pd2410-Pd2423-Pd2425+Pd1024+Pd2324+Pd2524=380
Pg25-Pd2524-2Pd2526+Pd2425+2Pd2625=377
Pg26-2Pd2625-2Pd2627+2Pd2526+2Pd2726=0
Pg27-2Pd2719-2Pd2721-2Pd2726+2Pd1927+2Pd2127+2Pd2627=139
Pg28-Pd2809-Pd2822-Pd2829+Pd0928+Pd2228+Pd2928=389
Pg29-2Pd2909-Pd2928+Pd0929+Pd2829=148
Pg30-Pd3009-Pd3032-Pd3033-2Pd3034-2Pd3035-2Pd3036-Pd3046-2Pd3051
+Pd0930+Pd3230+Pd3330+2Pd3430+2Pd3530+2Pd3630+Pd4630+2Pd5130=1
```

```
Pg31-2Pd3150+Pd5031=223
Pg32-Pd3230-Pd3237+Pd3032+Pd3732=62
Pg33-Pd3330-Pd3337+Pd3033+Pd3733=189
Pg34-2Pd3430+2Pd3034=273
Pg35-2Pd3530+2Pd3035=127
Pg36-2Pd3630+2Pd3036=143
Pg37-2Pd3708-Pd3732-Pd3733-Pd3738-Pd3741-Pd3742-Pd3746-Pd3749-
Pd3750+2Pd0837+Pd3237+Pd3337+Pd3837+Pd4137+Pd4237+Pd4637+Pd4937
+Pd5037=9
Pg38-Pd3837-2Pd3839-2Pd3840-Pd3841-2Pd3842-Pd3843-
Pd3846+Pd3738+2Pd3938+2Pd4038+Pd4138+Pd4238+Pd4338+Pd4638=153
Pg39-2Pd3938+2Pd3839=2
Pg40-2Pd4038+2Pd3840=43
Pg41-Pd4137-Pd4138+Pd3741+Pd3841=461
Pg42-Pd4237-Pd4238+Pd3742+Pd3842=141
Pg43-Pd4309-Pd4338-Pd4344+Pd0943+Pd3843+Pd4443=0
Pg44-Pd4443-Pd4445-Pd4446+Pd4344+Pd4544+Pd4644=0
Pg45-Pd4544-Pd4546+Pd4445+Pd4645=0
Pg46-2Pd4609-Pd4630-Pd4637-Pd4638-Pd4644-Pd4645-2Pd4647-
Pd4650+2Pd0946+Pd3046+Pd3746+Pd3846+Pd4446+Pd4546+2Pd4746
+Pd5046=500
Pg47-2Pd4746+2Pd4647=68
Pg48-2Pd4849+2Pd4948=210
Pg49-Pd4937-2Pd4948-Pd4950+Pd3749+2Pd4849+Pd5049=103
Pg50-Pd5008-2Pd5031-Pd5037-Pd5046-
Pd5049+Pd0850+2Pd3150+Pd3750+Pd4650+Pd4950=55
Pg51-2Pd5130+2Pd3051=1
Pg52-2Pd5212+2Pd1252=0
Pg53-2Pd5309+2Pd0953=0
Pg54-2Pd5405+2Pd0554=925
Pg55-2Pd5506+2Pd0655=814
Pg56-2Pd5616+2Pd1656=158


! CASE STUDY 2-1 PROPOSE NEW PP ON BUS 54, 55, 56
! THE SECOND CONSTRAINT
! System real power balance
! sum Pgi   =   sum Pli
! i=1,n         i=1,n
! (Substitute for sum of Pli from table 6.1)

Pg01+Pg02+Pg09+Pg11+Pg12+Pg21+Pg26+Pg29+Pg31+Pg43+Pg44+Pg45+Pg46+Pg48+P
g52+Pg53+Pg54+Pg55+Pg56=10553


! THE THIRD CONSTRAINT
! Generation unit limits
! Pgi (min) <= Pgi <= Pgi (max)      for i = 1, 2,…n
! (Substitute for the values of Pgi(min & max) from table 6.1)

Pg01 >= 100  Pg01 <= 2528  Pg02 >= 200  Pg02 <= 2500 Pg09 >= 220  Pg09
<= 1600 Pg11 >= 100   Pg11 <= 1219 Pg12 >= 100  Pg12 <= 910   Pg21
>=100   Pg21 <= 400   Pg26 >= 100  Pg26 <= 850  Pg29>= 20   Pg29 <= 120
Pg31>=20      Pg31<= 75
Pg43 >= 80   Pg43 <= 300   Pg44 >= 80   Pg44 <= 300   Pg45 >=80    Pg45
<= 300  Pg46 >= 80    Pg46 <= 215  Pg48 >= 20    Pg48 <= 108   Pg52 >=
80   Pg52 <= 272   Pg53 >= 40   Pg53 <= 118
```

```
! THE FOURTH CONSTRAINT
! Limits on power flow
! Pdij <= Clij   for all i-j pairs (Substitute for the values of
! Clij from table 6.2)

Pd0103 <= 2659 Pd0104  <= 2659 Pd0301 <=2659 Pd0401 <= 2659
Pd0204 <= 2659 Pd0205  <= 2659 Pd0206 <=2659 Pd0402 <=2659
Pd0502 <= 2659 Pd0602  <= 2659
Pd0308 <= 563  Pd0803  <= 563
Pd0405 <= 2659 Pd0504  <= 2659
Pd0410 <= 375  Pd1004  <= 375
Pd0506 <= 2659 Pd0507  <= 2659 Pd0554 <= 2659 Pd0605 <= 2659 Pd0705 <=
2659 Pd5405  <= 2659
Pd0511 <= 375  Pd1105  <= 375
Pd0607 <= 2659 Pd0655  <= 2659 Pd0706 <= 2659 Pd5506 <= 2659
Pd0612 <= 375  Pd1206  <= 375
Pd0717 <= 375  Pd1707  <= 375
Pd0830 <= 741  Pd0837  <= 741  Pd0838 <=741 Pd0850  <= 741  Pd3008 <=
741  Pd3708  <= 741  Pd3808 <=741
Pd5008 <= 741
Pd0922 <= 741  Pd0927  <= 741  Pd0928 <=741 Pd0929  <= 741
Pd0930 <= 741  Pd0943  <= 741
Pd0946 <= 741  Pd2209  <= 741  Pd2709 <=741 Pd2809  <= 741
Pd2909 <= 741 Pd3009   <= 741  Pd4309 <=741
Pd4609 <= 741
Pd0953 <= 185 Pd5309  <= 185
Pd1020 <= 741 Pd1024  <= 741  Pd2010 <= 741 Pd2410 <= 741
Pd1118 <= 741 Pd1811  <= 741
Pd1213 <= 741 Pd1214  <= 741  Pd1215 <= 741 Pd1217 <= 741
Pd1218 <= 741 Pd1312  <= 741  Pd1412  <=741
Pd1512 <= 741 Pd1712  <= 741  Pd1812 <= 741
Pd1252 <= 370 Pd5212  <= 370
Pd1318 <= 741 Pd1813  <= 741
Pd1415 <= 741 Pd1514  <= 741
Pd1516 <= 741 Pd1615  <= 741
Pd1656 <= 2659Pd5616  <= 2659
Pd1819 <= 741 Pd1918  <= 741
Pd1927 <= 741 Pd2719  <= 741
Pd2021 <= 741 Pd2022  <= 741 Pd2120 <= 741 Pd2220 <= 741
Pd2123 <= 297 Pd2127  <= 297 Pd2321 <= 297 Pd2721 <= 297
Pd2228 <= 741 Pd2822  <= 741
Pd2324 <= 297 Pd2423  <= 297
Pd2425 <= 297 Pd2524  <= 297
Pd2526 <= 741 Pd2625  <= 741
Pd2627 <= 741 Pd2726  <= 741
Pd2829 <= 741 Pd2928  <= 741
Pd3032 <= 741 Pd3033  <= 741 Pd3034 <= 741 Pd3035 <= 741
Pd3046 <= 741 Pd3051 <= 741 Pd3230 <= 741
Pd3330 <= 741 Pd3430  <= 741 Pd3530 <= 741 Pd4630 <= 741
Pd5130 <= 741
Pd3036 <= 370 Pd3630  <= 370
Pd3150 <= 741 Pd5031  <= 741
Pd3237 <= 741 Pd3732  <= 741
Pd3337 <= 741 Pd3733  <= 741
Pd3738 <= 741 Pd3741  <= 741 Pd3742 <= 741 Pd3746 <= 741
Pd3749 <= 741 Pd3750  <= 741 Pd3837 <= 741
```

```
Pd4137 <= 741 Pd4237  <= 741 Pd4637 <= 741 Pd4937 <= 741
Pd5037 <= 741
Pd3839 <= 741 Pd3840  <= 741 Pd3841 <= 741 Pd3842 <= 741
Pd3843 <= 741 Pd3846  <= 741 Pd3938 <= 741
Pd4038 <= 741 Pd4138  <= 741 Pd4238 <= 741 Pd4338 <= 741
Pd4638 <= 741
Pd4344 <= 741 Pd4443  <= 741
Pd4445 <= 741 Pd4446  <= 741 Pd4544 <= 741 Pd4644 <= 741
Pd4546 <= 741 Pd4645  <= 741

! THE LAST CONSTRAINT
! NON NEGATIVITY
! Pgi >= 0 ,  Pdij >= 0  for all i-j pairs
! (It is a built in feature by LINDO SOFTWARE)

end
```

Case 2-1 Results and Sensitivity Ranges

```
LP OPTIMUM FOUND AT STEP    129

        OBJECTIVE FUNCTION VALUE

        1)      903766

  VARIABLE        VALUE          REDUCED COST
      PG01      2195                0.000000
      PG02      1466                0.000000
      PG09      1600.000000         0.000000
      PG11      1219.000000         0.000000
      PG12       910.000000         0.000000
      PG21       100.000000         0.000000
      PG26       100.000000         0.000000
      PG29       120.000000         0.000000
      PG31        75.000000         0.000000
      PG43        80.000000         0.000000
      PG44        80.000000         0.000000
      PG45        80.000000         0.000000
      PG46       215.000000         0.000000
      PG48        20.000000         0.000000
      PG52       272.000000         0.000000
      PG53        40.000000         0.000000
      PG54       925.000000         0.000000
      PG55       814.000000         0.000000
      PG56       242.000000         0.000000
```

RANGES IN WHICH THE BASIS IS UNCHANGED:

		OBJ COEFFICIENT RANGES	
VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
PG01	64.000000	0.723750	0.780000
PG02	51.000000	0.780000	0.723750
PG09	63.000000	33.355000	INFINITY
PG11	72.000000	19.690001	INFINITY
PG12	74.000000	24.900000	INFINITY
PG21	108.000000	INFINITY	3.890000
PG26	132.000000	INFINITY	28.150000
PG29	101.000000	7.945000	INFINITY
PG31	100.000000	37.419998	INFINITY
PG43	132.000000	INFINITY	35.395000
PG44	132.000000	INFINITY	35.064999
PG45	132.000000	INFINITY	35.064999
PG46	75.000000	25.525000	INFINITY
PG48	148.000000	INFINITY	1.180000
PG52	70.000000	10.390000	INFINITY
PG53	85.000000	INFINITY	3.450000
PG54	71.000000	38.605000	53.575001
PG55	71.000000	38.894997	39.445000
PG56	71.000000	22.834999	10.935001

APPENDIX 8
(Case Study 2-2 Program Run Out, Results, and Sensitivity Ranges)

```
! CASE STUDY 2-2 CHANGE THE UNIT GENERATION COST OF THE PROPOSED
! PP AT R9001 BUS 54 TO BE 17 SR / MWH BY CHANGING THE OBJECTIVE
! FUNCTION OF CASE 2-1.

! Objective function:
! Minimize  C =sum Cgi (Pgi) + sum   sum  Nij Cij Pdij
!              i=1,n          i=1,n  j=1,n
! (As per equation 5.4 section 5.7.1)

! CASE STUDY 2-2 PROPOSE NEW PP ON BUSSES 54, 55, 56 WITH
! COST 71 SR / MWH FOR BUSSES 55 AND 56
! WHILE BUS 54 WITH THE COST 17 SR / MWH
! THE FIRST PART OF THE OBJECTIVE FUNCTION

! C = sum Cgi Pgi    (Substitute for values of Cgi from table 6.1
! for each i= Bus number in Power Plants)

min    64Pg01+51Pg02+63Pg09+72Pg11+74Pg12+108Pg21+132Pg26+101Pg29
+100Pg31+132Pg43+132Pg44+132Pg45+75Pg46+148Pg48+70Pg52+85Pg53
+17Pg54+71Pg55+71Pg56
```

Case 2-2 Results, and Sensitivity Ranges

```
LP OPTIMUM FOUND AT STEP    135

        OBJECTIVE FUNCTION VALUE

        1)      853555

  VARIABLE        VALUE          REDUCED COST
      PG01      2195               0.000000
      PG02       852.000000        0.000000
      PG09      1600.000000        0.000000
      PG11      1219.000000        0.000000
      PG12       910.000000        0.000000
      PG21       100.000000        0.000000
      PG26       100.000000        0.000000
      PG29       120.000000        0.000000
      PG31        75.000000        0.000000
      PG43        80.000000        0.000000
      PG44        80.000000        0.000000
      PG45        80.000000        0.000000
      PG46       215.000000        0.000000
      PG48        20.000000        0.000000
      PG52       272.000000        0.000000
      PG53        40.000000        0.000000
      PG54      1539               0.000000
      PG55       814.000000        0.000000
      PG56       242.000000        0.000000
```

RANGES IN WHICH THE BASIS IS UNCHANGED:

		OBJ COEFFICIENT RANGES	
VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
PG01	64.000000	0.298750	1.205000
PG02	51.000000	11.010000	0.424998
PG09	63.000000	32.930000	INFINITY
PG11	72.000000	19.264999	INFINITY
PG12	74.000000	23.908333	INFINITY
PG21	108.000000	INFINITY	4.315000
PG26	132.000000	INFINITY	28.575001
PG29	101.000000	7.520000	INFINITY
PG31	100.000000	36.428333	INFINITY
PG43	132.000000	INFINITY	35.820000
PG44	132.000000	INFINITY	35.490002
PG45	132.000000	INFINITY	35.490002
PG46	75.000000	25.100000	INFINITY
PG48	148.000000	INFINITY	1.605000
PG52	70.000000	9.965000	INFINITY
PG53	85.000000	INFINITY	3.875000
PG54	17.000000	0.424998	0.298750
PG55	71.000000	37.903332	40.436665
PG56	71.000000	21.843334	11.926667

APPENDIX 9
(Case Study 2-3 Program Run Out, Results, and Sensitivity Ranges)

```
! CASE STUDY 2-3 CHANGE THE UNIT GENERATION COST OF THE PROPOSED
! PP AT KH9003 BUS 55 TO BE 31 SR / MWH BY CHANGING THE OBJECTIVE
! FUNCTION OF CASE 2-1.

! Objective function:
! Minimize C =sum Cgi (Pgi) + sum   sum Nij Cij Pdij
!             i=1,n          i=1,n  j=1,n
!(As per equation 5.4 section 5.7.1)

! CASE STUDY 2-3 PROPOSE NEW PP ON BUSSES 54, 55, 56 WITH
! COST 71 SR / MWH FOR BUSSES 54 AND 56
! WHILE BUS 55 WITH THE COST 31 SR /MWH
! THE FIRST PART OF THE OBJECTIVE FUNCTION
! C = sum Cgi Pgi    (Substitute for values of Cgi from table 6.1
! for each i= Bus number in Power Plants)

min    64Pg01+51Pg02+63Pg09+72Pg11+74Pg12+108Pg21+132Pg26+101Pg29
+100Pg31+132Pg43+132Pg44+132Pg45+75Pg46+148Pg48+70Pg52+85Pg53
+71Pg54+31Pg55+71Pg56
```

Case 2-3 Results and Sensitivity Ranges

```
      LP OPTIMUM FOUND AT STEP    134

            OBJECTIVE FUNCTION VALUE

            1)      871170

     VARIABLE        VALUE          REDUCED COST
         PG01      2280.000000          0.000000
         PG02      1317.000000          0.000000
         PG09      1600.000000          0.000000
         PG11      1219.000000          0.000000
         PG12       910.000000          0.000000
         PG21       100.000000          0.000000
         PG26       100.000000          0.000000
         PG29       120.000000          0.000000
         PG31        75.000000          0.000000
         PG43        80.000000          0.000000
         PG44        80.000000          0.000000
         PG45        80.000000          0.000000
         PG46       215.000000          0.000000
         PG48        20.000000          0.000000
         PG52       272.000000          0.000000
         PG53        40.000000          0.000000
         PG54       925.000000          0.000000
         PG55       875.000000          0.000000
         PG56       242.000000          0.000000
```

RANGES IN WHICH THE BASIS IS UNCHANGED:

		OBJ COEFFICIENT RANGES	
VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
PG01	64.000000	0.416250	0.780000
PG02	51.000000	0.780000	0.237857
PG09	63.000000	33.355000	INFINITY
PG11	72.000000	19.690001	INFINITY
PG12	74.000000	24.344999	INFINITY
PG21	108.000000	INFINITY	3.890000
PG26	132.000000	INFINITY	28.150000
PG29	101.000000	7.945000	INFINITY
PG31	100.000000	37.419998	INFINITY
PG43	132.000000	INFINITY	35.395000
PG44	132.000000	INFINITY	35.064999
PG45	132.000000	INFINITY	35.064999
PG46	75.000000	25.525000	INFINITY
PG48	148.000000	INFINITY	1.180000
PG52	70.000000	10.112500	INFINITY
PG53	85.000000	INFINITY	3.450000
PG54	71.000000	38.605000	53.575001
PG55	31.000000	0.555000	12.965000
PG56	71.000000	22.280001	11.490001

APPENDIX 10
(Case Study 2-4 Program Run Out, Results, and Sensitivity Ranges)

```
! CASE STUDY 2-4 CHANGE THE UNIT GENERATION COST OF THE PROPOSED
! PP AT KH9003 BUS 56 TO BE 60 SR / MWH BY CHANGING THE
! OBJECTIVE FUNCTION OF CASE 2-1.

! Objective function:
! Minimize  C =sum Cgi (Pgi) + sum   sum  Nij Cij Pdij
!              i=1,n           i=1,n j=1,n
! (As per equation 5.4 section 5.7.1)


! CASE STUDY 2-4 PROPOSE NEW PP ON BUSSES 54, 55, 56 WITH
! COST 71 SR / MWH FOR BUSSES 54 AND 55
! WHILE BUS 56 WITH THE COST 60 SR /MWH
! THE FIRST PART OF THE OBJECTIVE FUNCTION
! C = sum Cgi Pgi     (Substitute for values of Cgi from table 6.1
! for each i= Bus number in Power Plants)

min    64Pg01+51Pg02+63Pg09+72Pg11+74Pg12+108Pg21+132Pg26+101Pg29
+100Pg31+132Pg43+132Pg44+132Pg45+75Pg46+148Pg48+70Pg52+85Pg53
+71Pg54+71Pg55+60Pg56
```

Case 2-4 Results and Sensitivity Ranges

```
      LP OPTIMUM FOUND AT STEP      1

            OBJECTIVE FUNCTION VALUE

            1)      901100

     VARIABLE        VALUE          REDUCED COST
         PG01       2280              0.000000
         PG02       1317.000000       0.000000
         PG09       1600.000000       0.000000
         PG11       1219.000000       0.000000
         PG12        910.000000       0.000000
         PG21        100.000000       0.000000
         PG26        100.000000       0.000000
         PG29        120.000000       0.000000
         PG31         75.000000       0.000000
         PG43         80.000000       0.000000
         PG44         80.000000       0.000000
         PG45         80.000000       0.000000
         PG46        215.000000       0.000000
         PG48         20.000000       0.000000
         PG52        272.000000       0.000000
         PG53         40.000000       0.000000
         PG54        925.000000       0.000000
         PG55        814.000000       0.000000
         PG56        306              0.000000
```

RANGES IN WHICH THE BASIS IS UNCHANGED:

		OBJ COEFFICIENT RANGES	
VARIABLE	CURRENT COEF	ALLOWABLE INCREASE	ALLOWABLE DECREASE
PG01	64.000000	0.048750	0.780000
PG02	51.000000	0.780000	0.027857
PG09	63.000000	33.355000	INFINITY
PG11	72.000000	19.690001	INFINITY
PG12	74.000000	24.834999	INFINITY
PG21	108.000000	INFINITY	3.890000
PG26	132.000000	INFINITY	28.150000
PG29	101.000000	7.945000	INFINITY
PG31	100.000000	37.419998	INFINITY
PG43	132.000000	INFINITY	35.395000
PG44	132.000000	INFINITY	35.064999
PG45	132.000000	INFINITY	35.064999
PG46	75.000000	25.525000	INFINITY
PG48	148.000000	INFINITY	1.180000
PG52	70.000000	10.357500	INFINITY
PG53	85.000000	INFINITY	3.450000
PG54	71.000000	38.605000	53.575001
PG55	71.000000	38.829998	39.509998
PG56	60.000000	0.065000	13.455000

APPENDIX 11
(Case Study 3 Program Run Out and Results)
(Pg3)

```
! CASE STUDY 3 PROPOSES NEW PP AT EACH BUS WITH SYSTEM AVERAGE
! COST (71 SR / MWH) (Pg3)
! CHANGES DONE IN THE OBJECTIVE FUNCTION AND IN THE SYSTEM REAL
! POWER BALANCE

! Objective function:
! Minimize C =sum Cgi (Pgi) + sum   sum Nij Cij Pdij
!             i=1,n           i=1,n  j=1,n
!(As per equation 5.4 section 5.7.1)


! CASE STUDY 3 PROPOSE NEW PP AT BUS of (Pg3) WITH AVERAGE
! COST (71 SR / MWH)
! THE FIRST PART OF THE OBJECTIVE FUNCTION
! C = sum Cgi Pgi    (Substitute for values of Cgi from table
! 6.3 for each i= Bus number in Power Plants)

min    64Pg01+51Pg02+63Pg09+72Pg11+74Pg12+108Pg21+132Pg26+101Pg29
+100Pg31+132Pg43+132Pg44+132Pg45+75Pg46+148Pg48+70Pg52+85Pg53
+71Pg03


! CASE STUDY 3 PROPOSE NEW PP AT Bus of (Pg3), SO, 1000 Pg3 to be
! removed
! C = sum 1000 Pgi
+1000Pg04+1000Pg05+1000Pg06+1000Pg07+1000Pg08+1000Pg10+1000Pg13
+1000Pg14+1000Pg15+1000Pg16+1000Pg17+1000Pg18+1000Pg19+1000Pg20
+1000Pg22+1000Pg23+1000Pg24+1000Pg25+1000Pg27+1000Pg28+1000Pg30
+1000Pg32+1000Pg33+1000Pg34+1000Pg35+1000Pg36+1000Pg37+1000Pg38
+1000Pg39+1000Pg40+1000Pg41+1000Pg42+1000Pg47+1000Pg49+1000Pg50
+1000Pg51+1000Pg54+1000Pg55+1000Pg56

! FOR THE SECOND PART OF THE OBJECTIVE FUNCTION
! sum sum Nij Cij  Pdij  (Substitute for values of Nij and
! Cij from table 6.2)

+     52.42 Pd0103      +     52.42 Pd0301
+     32.99 Pd0104      +     32.99 Pd0401
+     10.37 Pd0204      +     10.37 Pd0402
+     25.03 Pd0205      +     25.03 Pd0502
+     32.04 Pd0206      +     32.04 Pd0602
+     56.35 Pd0308      +     56.35 Pd0803
+     17.43 Pd0405      +     17.43 Pd0504
+     56.35 Pd0410      +     56.35 Pd0104
+     12.72 Pd0506      +     12.72 Pd0605
+     25.92 Pd0507      +     25.92 Pd0705
+     56.35 Pd0511      +     56.35 Pd1105
+     92.18 Pd0554      +     92.18 Pd5405
+     11.07 Pd0607      +     11.07 Pd0706
+     56.35 Pd0612      +     56.35 Pd1206
+     78.34 Pd0655      +     78.34 Pd5506
```

+	56.35	Pd0717	+	56.35	Pd1707
+	8.25	Pd0830	+	8.25	Pd3008
+	10.37	Pd0837	+	10.37	Pd3708
+	6.84	Pd0838	+	6.84	Pd3808
+	7.01	Pd0850	+	7.01	Pd5008
+	8.24	Pd0922	+	8.24	Pd2209
+	14.95	Pd0927	+	14.95	Pd2709
+	5.31	Pd0928	+	5.31	Pd2809
+	7.19	Pd0929	+	7.19	Pd2909
+	8.71	Pd0930	+	8.71	Pd3009
+	3.99	Pd0943	+	3.99	Pd4309
+	8.34	Pd0946	+	8.34	Pd4609
+	29.61	Pd0953	+	29.61	Pd5309
+	3.84	Pd1020	+	3.84	Pd2010
+	4.17	Pd1024	+	4.17	Pd2410
+	4.10	Pd1118	+	4.10	Pd1811
+	5.42	Pd1213	+	5.42	Pd1312
+	17.02	Pd1214	+	17.02	Pd1412
+	21.86	Pd1215	+	21.86	Pd1512
+	11.23	Pd1217	+	11.23	Pd1712
+	12.18	Pd1218	+	12.18	Pd1812
+	28.04	Pd1252	+	28.04	Pd5212
+	6.76	Pd1318	+	6.76	Pd1813
+	5.11	Pd1415	+	5.11	Pd1514
+	11.27	Pd1516	+	11.27	Pd1615
+	22.68	Pd1656	+	22.68	Pd5616
+	5.62	Pd1819	+	5.62	Pd1918
+	11.23	Pd1927	+	11.23	Pd2719
+	1.30	Pd2021	+	1.30	Pd2120
+	0.45	Pd2022	+	0.45	Pd2220
+	1.50	Pd2123	+	1.50	Pd2321
+	3.89	Pd2127	+	3.89	Pd2721
+	2.94	Pd2228	+	2.94	Pd2822
+	0.33	Pd2324	+	0.33	Pd2423
+	0.48	Pd2425	+	0.48	Pd2524
+	1.64	Pd2526	+	1.64	Pd2625
+	3.37	Pd2627	+	3.37	Pd2726
+	7.28	Pd2829	+	7.28	Pd2928
+	0.33	Pd3032	+	0.33	Pd3230
+	1.55	Pd3033	+	1.55	Pd3330
+	0.43	Pd3034	+	0.43	Pd3430
+	0.43	Pd3035	+	0.43	Pd3530
+	0.43	Pd3036	+	0.43	Pd3630
+	0.33	Pd3046	+	0.33	Pd4630
+	0.43	Pd3051	+	0.43	Pd5130
+	23.30	Pd3150	+	23.30	Pd5031
+	0.33	Pd3237	+	0.33	Pd3732
+	1.18	Pd3337	+	1.18	Pd3733
+	1.07	Pd3738	+	1.07	Pd3837
+	0.33	Pd3741	+	0.33	Pd4137
+	0.33	Pd3742	+	0.33	Pd4237
+	2.00	Pd3746	+	2.00	Pd4637
+	21.61	Pd3749	+	21.61	Pd4937
+	7.26	Pd3750	+	7.26	Pd5037
+	0.43	Pd3839	+	0.43	Pd3938
+	0.43	Pd3840	+	0.43	Pd4038
+	0.33	Pd3841	+	0.33	Pd4138

```
+      0.33  Pd3842      +      0.33  Pd4238
+      4.92  Pd3843      +      4.92  Pd4338
+      1.57  Pd3846      +      1.57  Pd4638
+      0.33  Pd4344      +      0.33  Pd4443
+      0.33  Pd4445      +      0.33  Pd4544
+      3.59  Pd4446      +      3.59  Pd4644
+      3.59  Pd4546      +      3.59  Pd4645
+      0.43  Pd4647      +      0.43  Pd4746
+      8.09  Pd4650      +      8.09  Pd5046
+      60.90 Pd4849      +      60.90 Pd4948
+      14.35 Pd4950      +      14.35 Pd5049

! THE FIRST CONSTRAINT
! Real power balance at each bus
! Subject to:
! Pgi - sum Nij Pdij + sum Nij Pdji = Pli where i =1,2…n
!       j=1            j=1,n
! (Substitute for values of Pli from table 6.1 and Nij from table
! 6.6)

st
Pg01-4Pd0103-2Pd0104+4Pd0301+2Pd0401=120
Pg02-Pd0204-2Pd0205-Pd0206+Pd0402+2Pd0502+Pd0602=102
Pg03-4Pd0308+4Pd0803-4Pd0301+4Pd0103=0
Pg04-2Pd0401-Pd0402-Pd0405-2Pd0410+2Pd0104+Pd0204+Pd0504
+2Pd1004=0
Pg05-2Pd0502-Pd0504-Pd0506-Pd0507-2Pd0511-
2Pd0554+2Pd0205+Pd0405+Pd0605+Pd0705+2Pd1105+2Pd5405=0
Pg06-Pd0602-Pd0605-Pd0607-2Pd0612-
2Pd0655+Pd0206+Pd0506+Pd0706+2Pd1206+2Pd5506=0
Pg07-Pd0705-Pd0706-2Pd0717+Pd0507+Pd0607+2Pd1707=0
Pg08-4Pd0803-2Pd0830-2Pd0837-Pd0838-
Pd0850+Pd0308+2Pd3008+2Pd3708+Pd3808+Pd5008=33
Pg09-Pd0922-2Pd0927-Pd0928-2Pd0929-Pd0930-Pd0943-2Pd0946-
2Pd0953+Pd2209+2Pd2709+Pd2809+2Pd2909
+Pd3009+Pd4309+2Pd4609+2Pd5309=273
Pg10-2Pd1004-Pd1020-Pd1024+2Pd0410+Pd2010+Pd2410=6
Pg11-2Pd1105-2Pd1118+2Pd0511+2Pd1811=690
Pg12-2Pd1206-Pd1213-Pd1214-Pd1215-2Pd1217-Pd1218-
Pd1252+2Pd0612+Pd1312+Pd1412+Pd1512+2Pd1712+Pd1812+Pd5212=578
Pg13-Pd1312-Pd1318+Pd1213+Pd1813=341
Pg14-Pd1412-Pd1415+Pd1214+Pd1514=27
Pg15-Pd1512-Pd1514-2Pd1516+Pd1215+Pd1415+2Pd1615=7
Pg16-2Pd1615-2Pd1656+2Pd1516+2Pd5616=50
Pg17-2Pd1707-2Pd1712+2Pd0717+2Pd1217=191
Pg18-2Pd1811-2Pd1813-2Pd1819+2Pd1118+2Pd1318+2Pd1918=0
Pg19-2Pd1918-2Pd1927+2Pd1819+2Pd2719=172
Pg20-Pd2010-Pd2021-2Pd2022+Pd1020+Pd2120+2Pd2220=490
Pg21-Pd2120-Pd2123-2Pd2127+Pd2021+Pd2321+2Pd2721=468
Pg22-Pd2209-2Pd2220-Pd2228+Pd0922+2Pd2022+Pd2822=369
Pg23-Pd2321-Pd2324+Pd2123+Pd2423=120
Pg24-Pd2410-Pd2423-Pd2425+Pd1024+Pd2324+Pd2524=380
Pg25-Pd2524-2Pd2526+Pd2425+2Pd2625=377
Pg26-2Pd2625-2Pd2627+2Pd2526+2Pd2726=0
Pg27-2Pd2719-2Pd2721-2Pd2726+2Pd1927+2Pd2127+2Pd2627=139
Pg28-Pd2809-Pd2822-Pd2829+Pd0928+Pd2228+Pd2928=389
Pg29-2Pd2909-Pd2928+Pd0929+Pd2829=148
```

```
Pg30-Pd3009-Pd3032-Pd3033-2Pd3034-2Pd3035-2Pd3036-Pd3046-2Pd3051
+Pd0930+Pd3230+Pd3330+2Pd3430+2Pd3530+2Pd3630+Pd4630+2Pd5130=1
Pg31-2Pd3150+Pd5031=223
Pg32-Pd3230-Pd3237+Pd3032+Pd3732=62
Pg33-Pd3330-Pd3337+Pd3033+Pd3733=189
Pg34-2Pd3430+2Pd3034=273
Pg35-2Pd3530+2Pd3035=127
Pg36-2Pd3630+2Pd3036=143
Pg37-2Pd3708-Pd3732-Pd3733-Pd3738-Pd3741-Pd3742-Pd3746-Pd3749-
Pd3750+2Pd0837+Pd3237+Pd3337+Pd3837+Pd4137+Pd4237+Pd4637+Pd4937
+Pd5037=9
Pg38-Pd3837-2Pd3839-2Pd3840-Pd3841-2Pd3842-Pd3843-
Pd3846+Pd3738+2Pd3938+2Pd4038+Pd4138+Pd4238+Pd4338+Pd4638=153
Pg39-2Pd3938+2Pd3839=2
Pg40-2Pd4038+2Pd3840=43
Pg41-Pd4137-Pd4138+Pd3741+Pd3841=461
Pg42-Pd4237-Pd4238+Pd3742+Pd3842=141
Pg43-Pd4309-Pd4338-Pd4344+Pd0943+Pd3843+Pd4443=0
Pg44-Pd4443-Pd4445-Pd4446+Pd4344+Pd4544+Pd4644=0
Pg45-Pd4544-Pd4546+Pd4445+Pd4645=0
Pg46-2Pd4609-Pd4630-Pd4637-Pd4638-Pd4644-Pd4645-2Pd4647-
Pd4650+2Pd0946+Pd3046+Pd3746+Pd3846+Pd4446+Pd4546+2Pd4746
+Pd5046=500
Pg47-2Pd4746+2Pd4647=68
Pg48-2Pd4849+2Pd4948=210
Pg49-Pd4937-2Pd4948-Pd4950+Pd3749+2Pd4849+Pd5049=103
Pg50-Pd5008-2Pd5031-Pd5037-Pd5046-
Pd5049+Pd0850+2Pd3150+Pd3750+Pd4650+Pd4950=55
Pg51-2Pd5130+2Pd3051=1
Pg52-2Pd5212+2Pd1252=0
Pg53-2Pd5309+2Pd0953=0
Pg54-2Pd5405+2Pd0554=925
Pg55-2Pd5506+2Pd0655=814
Pg56-2Pd5616+2Pd1656=158


! CASE STUDY 3 PROPOSE NEW PP AT Bus of (Pg3)
! THE SECOND CONSTRAINT
! System real power balance
! sum Pgi   =   sum Pli
! i=1,n         i=1,n
! (Substitute for sum of Pli from table 6.1)

Pg01+Pg02+Pg09+Pg11+Pg12+Pg21+Pg26+Pg29+Pg31+Pg43+Pg44+Pg45+Pg46+Pg48+P
g52+Pg53+Pg03=10553


! THE THIRD CONSTRAINT
! Generation unit limits
! Pgi (min) <= Pgi <= Pgi (max)      for i = 1, 2, ...n
! (Substitute for the values of Pgi(min & max) from table 6.1)

Pg01 >= 100   Pg01 <= 2528   Pg02>= 200   Pg02 <= 2500   Pg09>= 220   Pg09
<= 1600
Pg11 >= 100   Pg11 <= 1219   Pg12>= 100   Pg12 <= 910    Pg21>=100    Pg21
<= 400
```

```
Pg26 >= 100  Pg26 <= 850   Pg29>= 20   Pg29 <= 120   Pg31>=20    Pg31
<= 75
Pg43 >= 80   Pg43 <= 300   Pg44>= 80   Pg44 <= 300   Pg45>=80    Pg45
<= 300
Pg46 >= 80   Pg46 <= 215   Pg48>= 20   Pg48 <= 108   Pg52>=80    Pg52
<= 272
Pg53 >= 40   Pg53 <= 118


! THE FOURTH CONSTRAINT
! Limits on power flow
! Pdij <= Clij   for all i-j pairs (Substitute for the values of
! Clij from table 6.2)

Pd0103 <= 2659Pd0104  <= 2659 Pd0301 <=2659 Pd0401 <= 2659
Pd0204 <= 2659Pd0205  <= 2659 Pd0206 <=2659 Pd0402 <=2659
Pd0502 <= 2659Pd0602  <= 2659
Pd0308 <= 563 Pd0803  <= 563
Pd0405 <= 2659Pd0504  <= 2659
Pd0410 <= 375 Pd1004  <= 375
Pd0506 <= 2659Pd0507  <= 2659 Pd0554 <= 2659 Pd0605 <= 2659 Pd0705 <=
2659 Pd5405 <= 2659
Pd0511 <= 375 Pd1105  <= 375
Pd0607 <= 2659Pd0655  <= 2659 Pd0706 <= 2659 Pd5506 <= 2659
Pd0612 <= 375 Pd1206  <= 375
Pd0717 <= 375 Pd1707  <= 375
Pd0830 <= 741 Pd0837  <= 741  Pd0838 <=741 Pd0850  <= 741
Pd3008 <= 741 Pd3708  <= 741 Pd3808  <=741
Pd5008 <= 741
Pd0922 <= 741 Pd0927  <= 741  Pd0928 <=741 Pd0929  <= 741
Pd0930 <= 741 Pd0943  <= 741
Pd0946 <= 741 Pd2209  <= 741  Pd2709 <=741 Pd2809  <= 741
Pd2909 <= 741 Pd3009  <= 741  Pd4309 <=741
Pd4609 <= 741
Pd0953 <= 185 Pd5309  <= 185
Pd1020 <= 741 Pd1024  <= 741  Pd2010 <= 741 Pd2410 <= 741
Pd1118 <= 741 Pd1811  <= 741
Pd1213 <= 741 Pd1214  <= 741  Pd1215 <= 741 Pd1217 <= 741
Pd1218 <= 741 Pd1312  <= 741  Pd1412  <=741
Pd1512 <= 741 Pd1712  <= 741  Pd1812 <= 741
Pd1252 <= 370 Pd5212  <= 370
Pd1318 <= 741 Pd1813  <= 741
Pd1415 <= 741 Pd1514  <= 741
Pd1516 <= 741 Pd1615  <= 741
Pd1656 <= 2659Pd5616  <= 2659
Pd1819 <= 741 Pd1918  <= 741
Pd1927 <= 741 Pd2719  <= 741
Pd2021 <= 741 Pd2022  <= 741 Pd2120 <= 741 Pd2220 <= 741
Pd2123 <= 297 Pd2127  <= 297 Pd2321 <= 297 Pd2721 <= 297
Pd2228 <= 741 Pd2822  <= 741
Pd2324 <= 297 Pd2423  <= 297
Pd2425 <= 297 Pd2524  <= 297
Pd2526 <= 741 Pd2625  <= 741
Pd2627 <= 741 Pd2726  <= 741
Pd2829 <= 741 Pd2928  <= 741
Pd3032 <= 741 Pd3033  <= 741 Pd3034 <= 741 Pd3035 <= 741
Pd3046 <= 741 Pd3051  <= 741 Pd3230 <= 741
```

```
Pd3330 <= 741 Pd3430  <= 741 Pd3530 <= 741 Pd4630 <= 741
Pd5130 <= 741
Pd3036 <= 370 Pd3630  <= 370
Pd3150 <= 741 Pd5031  <= 741
Pd3237 <= 741 Pd3732  <= 741
Pd3337 <= 741 Pd3733  <= 741
Pd3738 <= 741 Pd3741  <= 741 Pd3742 <= 741 Pd3746 <= 741
Pd3749 <= 741 Pd3750  <= 741 Pd3837 <= 741
Pd4137 <= 741 Pd4237  <= 741 Pd4637 <= 741 Pd4937 <= 741
Pd5037 <= 741
Pd3839 <= 741 Pd3840  <= 741 Pd3841 <= 741 Pd3842 <= 741
Pd3843 <= 741 Pd3846  <= 741 Pd3938 <= 741
Pd4038 <= 741 Pd4138  <= 741 Pd4238 <= 741 Pd4338 <= 741
Pd4638 <= 741
Pd4344 <= 741 Pd4443  <= 741
Pd4445 <= 741 Pd4446  <= 741 Pd4544 <= 741 Pd4644 <= 741
Pd4546 <= 741 Pd4645  <= 741


! THE LAST CONSTRAINT
! NON NEGATIVITY
! Pgi >= 0 ,  Pdij >= 0  for all i-j pairs
!(It is a built in feature by LINDO SOFTWARE)

end
```

Case 3(Pg3) Results and Sensitivity Ranges

LP OPTIMUM FOUND AT STEP 1

OBJECTIVE FUNCTION VALUE

1) 987389

VARIABLE	VALUE	REDUCED COST
PG01	120.000000	0.000000
PG02	2500.000000	0.000000
PG09	1600.000000	0.000000
PG11	1219.000000	0.000000
PG12	910.000000	0.000000
PG21	400.000000	0.000000
PG26	404.000000	0.000000
PG29	120.000000	0.000000
PG31	75.000000	0.000000
PG43	80.000000	0.000000
PG44	80.000000	0.000000
PG45	80.000000	0.000000
PG46	215.000000	0.000000
PG48	108.000000	0.000000
PG52	272.000000	0.000000
PG53	118.000000	0.000000
PG03	2252.000000	0.000000
PG04	0.000000	1018.219971

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SAUDI ELECTRICITY COMPANY
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الشركة السعودية للكهرباء

بسم الله الرحمن الرحيم

رسالة الدكتوراه في الهندسة الكهربائية

طارق عبدالله المهاوش

3 يونيو 2007 م

الإطار العام لصناعة الكهرباء بالسعودية خلال الفترة الانتقالية لعملية إعادة التنظيم

خلاصة البحث

معظم دول العالم في السنوات الأخيرة تتبنى وبجدية إعادة هيكلة قطاع الكهرباء ليُدار على نمط تجاري عن طريق خصخصة بعض مرافقه. وذلك لما يواجه القطاع من تحديات أهمها يتمحور حول احتمالية تدهور الخدمات وفقد السيطرة وارتفاع التكاليف. هذه المخاوف بناءً على الطلب المتنامي على الطاقة الكهربائية بسبب زيادة السكان بالإضافة إلى مشاريع استثمارية تعكس حقيقة تطور الاقتصاد الوطني ، احتمالية نضوب موارد الطاقة الأساسية اللازمة لإنتاج الكهرباء، هذا بالإضافة إلى التأثيرات السلبية على البيئة. وقد يكون إعادة التنظيم لأسباب أخرى كالبحث عن التنافسية لعدم جدارة المؤسسات والمرافق القائمة على قطاع الكهرباء حاليا و لتلافي تقديم دعم مادي من قبل الدولة.

حيث أن إعادة التنظيم قد بدأت فعليا بالمملكة العربية السعودية فعلى المسئولين والعاملين بكامل قطاع الكهرباء المبادرة بالمشاركة في تأسيس إطار وشكل تنظيمي فعال لهذه الصناعة. يجب أن يُبْنى هذا الإطار على أسس صحيحة ليحقق خفض في الأسعار وتوفير الطاقة المستقبلية اللازمة لمواجهة الطلب المتزايد على الكهرباء بدون الاعتماد على دعم مادي خارجي. مع الأخذ في الاعتبار الحفاظ على سلامة البيئة وتزويد المشتركين (العملاء) بطاقة آمنة وبموثوقية عالية.

هذا البحث يقترح إطاراً عاماً لصناعة الكهرباء بالسعودية لمواجهة نمو الأحمال بالمملكة. تم الاطلاع على معظم التجارب العالمية الرائدة في هذا المجال ونتيجة لذلك تم اقتراح الإطار العام ليحقق التنافسية ويُمكّن القطاع الخاص من الاستثمار في تطوير صناعة الكهرباء . أحتوى البحث أيضا على مقترحات لكيفية تصميم وتحديد التعرفة الكهربائية وتكاليف التوصيل والأسعار التي يجب تداولها وكيفية تداولها بين العملاء ومختلف القطاعات المشاركة في تكوين هذه الصناعة.

يقدّم هذا البحث أيضا مقترح لنموذج تخطيطي لحساب تدفُّق الطاقة يعتمد على الميجا وات. يستطيع هذا النموذج أن يحدد أماكن التوليد المطلوبة مستقبلا في أي قطاع لصناعة الكهرباء في أي بلد. تم تطبيق النموذج المقترح على شبكة الكهرباء بالمنطقة الشرقية بالسعودية كحالة دراسية وتم استخراج النتائج وتحليلها.

في النهاية قدَّم البحث استنتاجات ونصائح و قدَّم أيضا مقترحات لدراسات مستقبلية محتملة ومطلوبة.