CHAPTER I
INTRODUCTION

1.1 Introduction

The electricity supply industry is generally classified into three main functions, i.e. generation, transmission, and distribution. For several decades, the electricity industry word-wide has been dominated by vertically integrated utilities, which means that all components of power industry is owned and regulated by a monopoly electricity company. During the decade of 1990s, many electric utilities both in developed and developing countries have been forced to change their way of business from vertically integrated mechanism to a deregulated market system. The new deregulated business model as well as the reasons have differed over regions and countries [1, 2]. Among the developing countries, a main issue concerns highly demand growth coupled with insufficient financial resources to support huge investment in the electric sector. The problems about electricity reform in developing country and its comparison with electricity deregulation in developed countries will be elaborated in this chapter.

1.2 Deregulation in Electricity Supply Industry

1.2.1 Background

Prior to 1980s, electricity sectors almost everywhere on the globe were based on vertically integrated structure, either state-owned or privately owned. Primary components of the electricity supply, i.e. generation, transmission, distribution, and retail supply, were normally integrated within each electric utility. The performance of these regulated monopolies varied widely across the countries. These firms in turn had de facto exclusive franchises to supply electricity to residential, commercial and industrial retail consumers within a defined geographic area.

During the 1990s, a deep transformation in the electricity supply industry took place in many countries, which moved from a monopoly based structure to a more competitive one through restructuring and deregulation processes. Under restructuring and deregulation, vertically integrated utilities have been legally or functionally unbundled. Competition has been introduced in the wholesale generation and retailing of electricity. The trend of deregulation around the word is shown in Figure 1.1 [1, 3-5].

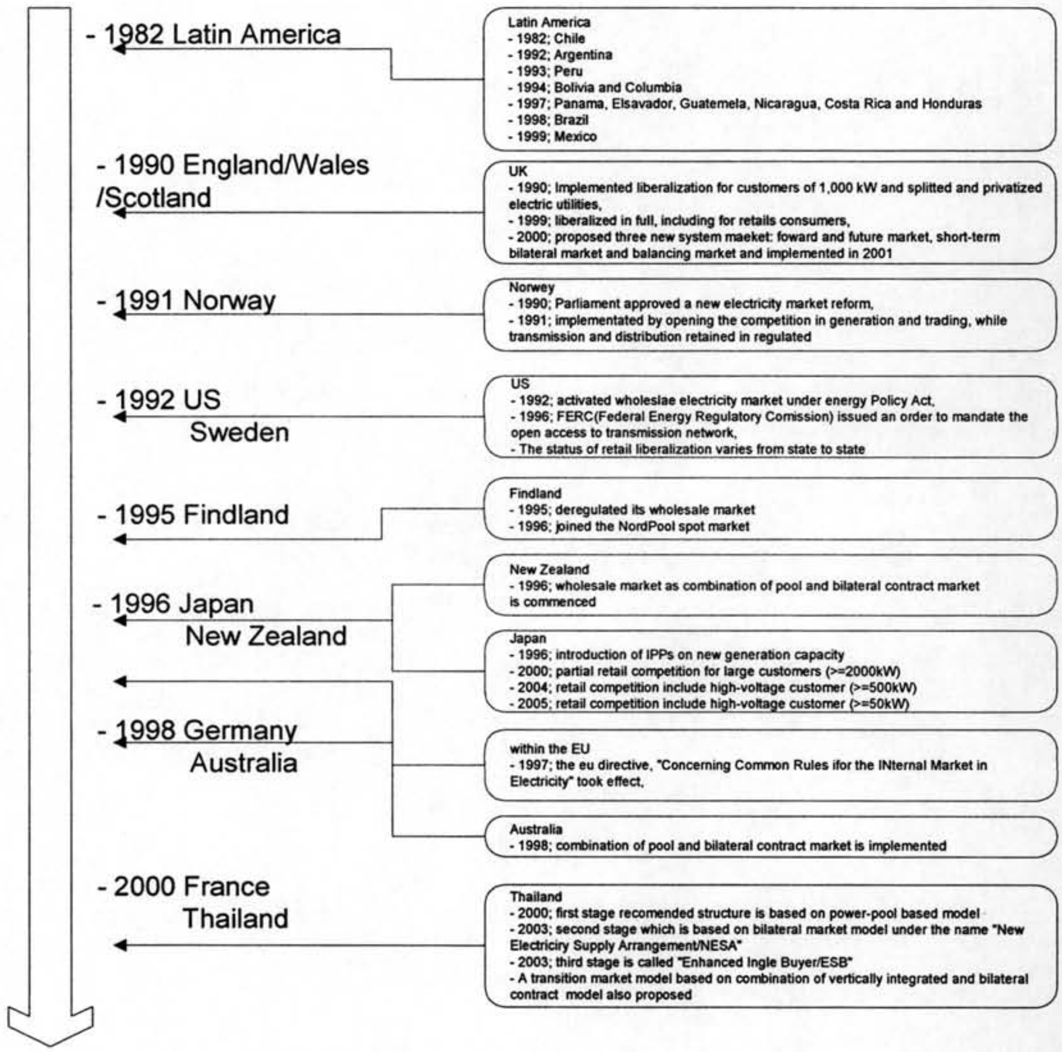

Figure 1.1 Deregulation trends of the world's electricity market

1.2.2 Hierarchical Level of Deregulation

The variety of market structures can be categorized according to increasing degree of competition, as follows [6].

- Model 1 (monopoly model) has no competition at all, only monopoly at all levels of the supply chain. A single monopolist produces and delivers electricity to the users.

- Model 2 (purchasing agency or single buyer model) allows a single buyer or purchasing agency to encourage competition between generators by choosing its sources of electricity from a number of different electricity producers. The agency then sells electricity to distribution companies and large power users without competition from other suppliers.
- Model 3 (wholesale competition model) allows distribution companies to purchase electricity directly from generators they choose, transmit this electricity under open access arrangements over the transmission system to their service area, and deliver it over their local grids to their customers, which brings competition into the wholesale supply market but not the retail power market.
- Model 4 (retail competition model) allows all customers to choose their electricity supplier, which implies full retail competition, under open access for suppliers to the transmission and distribution systems.

The pioneering reforms to power sectors in Chile, England and Wales, and Norway during the 1980s (which fall under model 3) have motivated numerous industrialized and developing countries to follow them during the 1990s. A mixture of these two variants of model 3 (the power pool design of the Chilean model, the independent transmission and system operator of the England and Wales model) has been widely adopted in South America (Argentina, Brazil, Bolivia, Colombia, and Peru). Other countries have implemented variations on this model, particularly for the use of bilateral contracts between producers and suppliers (Georgia, Hungary, and Moldova). Several countries are in the process of reforming their power sectors based on similar approaches, some of whom (Ecuador, Armenia, Bulgaria, and Romania) have completed the initial restructuring and regulatory steps but have yet to privatize most of their generation and distribution entities.

Also in the 1990s, the model of IPPs (Independent Power Producer), selling to a state-owned power utility (model 2) spreads across Asia (China, India, Indonesia, Malaysia, Nepal, Pakistan, Philippines, Thailand, Vietnam, and Jordan) and Central America and the Caribbean (Guatemala, Honduras, Belize, Jamaica, Panama, and the Dominican Republic). Model 4 has been adopted in England and Wales (where model 3 was transitional) and in Norway, but not yet in any developing countries. Hence, models 2 and 3 have emerged as the main options for the developing countries that have yet to select one.

Beside the above model, Japan has been deregulated its electricity industry sector by implementing a combination of vertically integrated structure and bilateral contract mechanism, i.e. a combination of model 2 and model 3. The first step in Japan deregulation process was the introduction of IPPs which were allowed to sign long term contract with vertically integrated utilities in wholesale level. IPPs submitted many long-term based bids to the utility companies since 1995 through 2000. After the introduction of IPPs, since March 2000, electricity customer, with a contracted supply of 2,000kW or higher and a voltage connection from 20kV and above, have been allowed to choose freely their electricity supplier. These eligible customers can search in the market for the solution that better fit with their needs. There are 10 vertically integrated, investor-owned utilities (IOUs) in Japan, each with an exclusive service area, which are: Hokkaido Electric Power, Tohuku Electric Power, Tokyo Electric Power, Chubu Electric Power, Hokuriku Electric Power, Kansai Electric Power, Chugoku Electric Power, Sikoku Electric Power, Kyushu Electric Power, and Okinawa Electric Power. The deregulation in Japan is partially in which the current structure can be seen in Figure 1.2 [7].

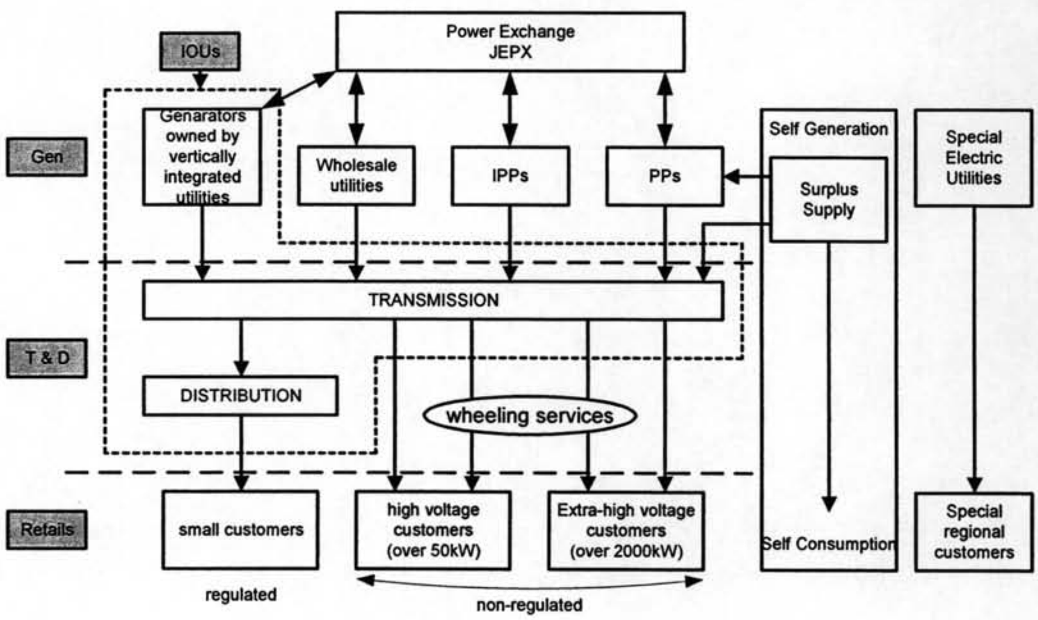

Figure 1.2 Structure of Japanese electric power industry as of 2005

In principle, free entry into the retail market and the rates new entrants charge are free from regulation, and they are under no legal supply obligation. The integrated utilities, on the other hand, are still required to fulfill the role of public utilities and, as the owners of the transmission system, to maintain stable operation and power quality. The integrated utilities have ultimate responsibility, moreover, for serving as the provider of last resort in their service area when no contract has been signed between a customer and a supplier.

In FY 2001, ended March 2002, the integrated utilities generated 72.3% of all the electric power production, 1,076 TWh. The power source mix in FY 2001 was 52.9% of thermal power, 8.3% hydroelectric power, and 38.7% of nuclear power. The ten integrated utilities sold a total of 824TWh of electricity in FY 2001. Annual consumption of the eligible customers, who can choose among various suppliers, represents about 30% of the total consumption in Japan. Two large wholesale electric utilities generated 6.9% of the total, while wholesale suppliers generated 6.5%. Self-generators, mostly owned by large industrial customers, accounted for 14.3%. Special electric utilities and suppliers of specified scale currently provide only a small fraction of total retail supply (1.4% in April 2003) [8].

1.2.3 Drivers of Deregulation in Developing Countries

In many developing countries, and in particular those in Asia, the Middle East, and Africa, deregulation of the power sector starts from a market structure that is dominated by a state-owned national power utility with a legally endowed monopoly and a vertically integrated supply chain encompassing power generation, transmission, distribution, and customer services. The rationale for this structure is minimization of the costs of coordination between these functions and of financing the development of power systems. The pre-deregulation structure in other countries, notably in South America, places distribution and customer services with local companies, separate from national companies that provide power generation and transmission.

In developing countries, the electricity sectors were characterized by low labor productivity, poor service quality, high system losses, inadequate investment in power supply facilities, unavailability of service to large portions of the population and price were too low to cover cost and support new investment [9, 10]. In these countries, deregulation has been driven by a variety of factors whose level of importance differs across countries. In the East Asian cases, as well as in a few Latin American countries such as Guatemala and Colombia, initial reforms were largely a response to the government inability to meet a high electricity demand, prompting them to allow independent power producers (IPPs) to operate. Huge financial deficits in the power sector emanating from defaults on international loans were also important drivers of reform in Latin American [11]. Lack of capital to boost domestic power supply was a key reason for China and Asia Pacific countries embarking on reform[12].

The principal driving forces behind this deregulation in developing countries can be summarized as [13]: *(a)* the poor performance of the state-run electricity sector in terms of high costs, inadequate expansion of access to electricity service for the population, and/or unreliable supply; *(b)* the inability of the state sector to finance needed expenditures on new investment and/or maintenance; *(c)* the need to remove subsidies to the sector in order to release resources for other pressing public expenditure needs; and *(d)* the desire to raise immediate revenue for the government through the sale of assets from the sector.

1.2.4 The Extent of Deregulation in Developing Countries

Even though the deregulation in electricity supply industry in developing countries have been started many years ago, but the progress was very slow. This can be seen from the results of a survey as reported in [13]. About 70 of the 150 developing countries have embarked on deregulating their power markets since the early 1990s in response to poor technical and financial performance and lack of public financing needed to expand power supply. Deregulations of these markets, however, are generally tentative and incomplete, and are still works in progress [9]. The remaining countries have retained the traditional structure of a vertically integrated monopoly, in some cases because they felt it impossible or undesirable to embark on any reform strategy that entails opening electricity production or sales to private participants.

The countries that have embarked on deregulation have progressed to date to various stages, which can be categorized in ascending extent of reform as follows:

- A vertically integrated monopolist with independent power producers (IPPs) that sell power to it.
- A national generation, transmission or distribution entity, a combined national generation and transmission entity or a combined transmission and distribution

entity acting as the only wholesale power trader (single buyer) with IPPs that sell power to it and regional distribution entities unbundled from the monopolist that buy power from it.

- Many distribution entities and generation entities and a transmission entity formed from unbundling the monopolist, in which the transmission entity acts as a single buyer of power from the generators and IPPs and sells power to the distribution entities and large users of power.
- An organized market of generation entities, distribution entities and large users in which power is traded competitively, supported by a transmission entity, a power system operator and a power market administrator.

Power market reform programs in developing countries currently exhibit this variety of progress, particularly in market structure, degree of private participation, and development of the regulatory framework. This variety is shown by the lists of countries in Table 1.1 that have reached each reform stage [13].

Table 1.1 Distribution of power structure in developing countries by region[13]

Region and total number of countries in the region		Vertically integrated monopolist	Vertically integrated monopolist + IPPs	Regional DISCOs,IPPs, a GENCO-TRANSCO as single buyer	Many DISCOs, GENCOs,TRANSCO as single buyer	Power market GENCOs,DISCOs and larger users,TRANSCO &ISO
Africa	49	39	8	2	0	0
EAP	17	10	6	1	0	0
ECA	28	7	2	10	5	4
LAC	32	14	8	0	1	9
MENA	13	6	5	2	0	0
SAR	11	3	7	1	0	0
Total	150	79	36	16	6	13

Note: EAP-East Asia and the Pacific; ECA-Europe and Central Asia; LAC-Latin America and the Caribbean; MENA-Middle East and North Africa; SAR-South Asia.

1.2.5 Case study of ESI reform in Thailand

Thailand's electricity sector currently consists of three state-owned utilities. The Electricity Generating Authority of Thailand (EGAT) owns most of grid-connected generation and transmission. It supplies power to end customers through the

Metropolitan Electricity Authority (MEA) and the Provincial Electricity Authority (PEA), the two distribution utilities serving the greater Bangkok area and the rest of the country, respectively. In general the system has been providing satisfactory services with relatively low T&D losses, and more than 95% of all villages electrified by 2000. The utilities are in good financial condition with the implementation of the cost-plus tariff structure [14]. The system has been expanded rapidly, keeping roughly in step with the Thai economy during a period in which it was one of the world's fastest-growing, i.e. mid 1980s–mid 1990s [15].

The first recommended structure of Thai ESI, a power-pool based model, started in March of 2000, and was expected to be implemented with a full competition by the year 2003. According to the proposed model [16], generation companies, PowerGens, and IPPs have to bid the electric energy price and its quantity to a power pool. Additionally, the model allows PowerGens/IPPs for trading outside the pool through bilateral contracts. The distribution companies, DisCo, and supply company, SupplyCo, are regulated as electricity delivery company, REDCo, have responsible to provide the electricity to all consumers. The retail company, RetailCos, is allowed to compete in providing electricity to non-captive consumers through the transmission company, GridCo, and DisCo. Characteristic of the proposed power pool model can be described in Figure 1.3.

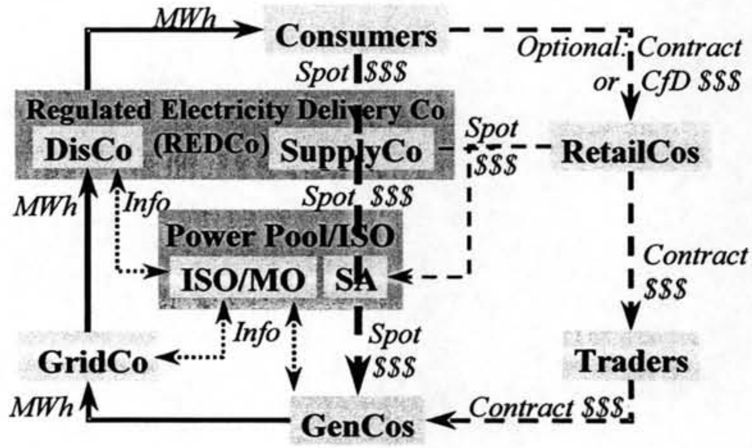

Figure 1.3 The proposed power pool model of Thailand ESI

According to some weak points in a power pool model e.g. may result in highly volatile pool price, it was abandoned and finally revised to be another structure under the name of "the New Electricity Supply Arrangement (NESA)", which is a bilateral based market. Under NESA, most of transactions are bilateral contracts with a system balancing mechanism. The imbalances between contractual and physical electricity consumption in real time are handled by a balancing mechanism in balance market (BM). This model is based on the NETA of England and Wales. The structure of Thai ESI under NESA is shown in Figure 1.4.

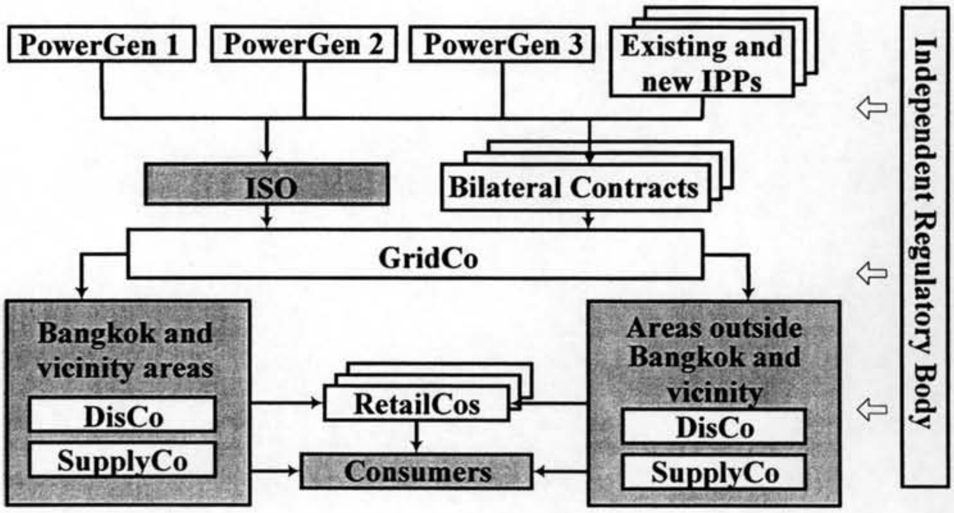

Figure 1.4 The proposed NESA for ESI of Thailand

In September 2003, the Cabinet withdrew its resolution of NESA. Subsequently, in December 2003, the Cabinet approved the new ESI structure, called the Enhanced Single Buyer (ESB) model. The ESB Model still maintains the Electricity Generating Authority of Thailand (EGAT) as the only power buyer authorized to sell power to the Metropolitan Electricity Authority (MEA) and the Provincial Electricity Authority (PEA). Some EGAT regulatory works will be transferred to a newly-established Regulatory Body that will oversee the power industry.

In November 2007, an Energy Supply Industry (ESI) Act has been approved and expected to be enacted in 2008. Under the Act, the ESB like model still remains. However, the policy and regulatory function, which is presently under the responsibility of the Energy Policy and Planning Office (EPPO) of the Energy Ministry, will be separated from each other. The ministry of energy will be responsible for energy policy and direct the development of Thailand Electric Supply Industry whereas the new regulating body will be established to officially regulate the electric supply industry, including natural gas transmission pipelines.

1.3 ESI Model used in the Dissertation

In this dissertation, the work firstly focuses on the generation scheduling problem in a vertically integrated system, which is usually state-owned in most of developing countries. Generally there are several types of generating units in the system, however only thermal units are considered in this dissertation. Under this old structure, it is assumed that all the units in the system are available to be scheduled to supply the forecasted demand. To ensure the reliability of the power supply to consumers, spinning reserve is scheduled by system operator which is set based on deterministic criteria, i.e. as a certain percentage of the demand. The model of vertically integrated system can be seen in the left side of Figure 1.5 (a).

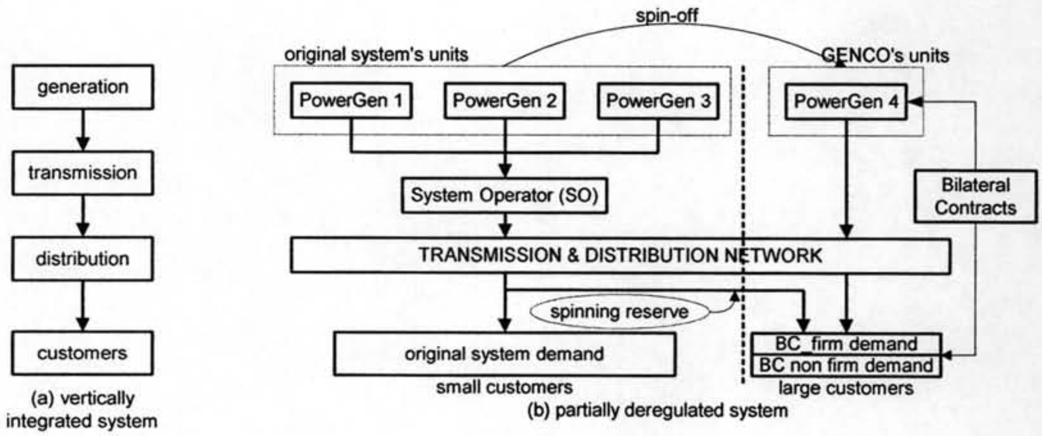

Figure 1.5 ESI Model used in the Dissertation

Based on the model of electric supply deregulation as presented in section 1.2, it shows that privatization of some of the state-owned generating units is one of the common ways to reform the utility structure which has been adopted in many developing countries. By privatizing the generating units which is then operated by private generation companies (GENCOs), customers, especially large customers, have choices to buy electric power directly from these GENCOs. Meanwhile, all the rest of the units in the system are still owned and operated by vertically regulated utility, which is called in this dissertation as "the original system."

Among the established GENCOs, they have to compete with each other for contracting with large customers. It is also assumed that some part of GENCO customers is a firm demand (non-interruptible demand). Consequently, if GENCO faces shortage of generation capacity for supplying their firm demand due to unexpected outage of generators, the GENCOs have to provide a back-up power. The need of back-up power might be provided by the utility, i.e. the original system, in the form of spinning reserve power. Accordingly, during scheduling period, the original system may have to schedule additional spinning reserve capacity for maintaining the reliability of its own demand and selling its reserve capacity to GENCOs. The combination of vertically integrated utility and bilateral contract transaction in this dissertation is called as partially deregulated utility. The model of partially deregulated is shown on the right side of Figure 1.5 (b).

1.4 Aspects in Short-term Operation of Power Systems

1.4.1 Uncertainties Consideration

Short-term operational planning refers to the preparation of future generation for supplying short-term demand, generally covering period less than one week. Information from the past survey [17] shows that the most significant factors of uncertainty in the short-term operation is load uncertainty. Based on that survey, the second rank of uncertainty source is the availability of generating unit.

It is found that the load uncertainty is mainly due to lack of the accurate weather forecast. Other factors which usually contribute to the load forecast error are time and customer behavior. The load uncertainty imposes additional risk in short term generation scheduling covering unit commitment and spinning reserve scheduling. For example, if the load forecast for the next day is rather high, the utility will face the risk of committing either too much or too little capacity. In either case, the electric utility may incur additional cost. The necessity of incorporating the load uncertainty in determination of short-term operating strategy can be seen from the results of the previous study [18], which shows that one percent increase in load forecast error for the British system resulted in losses of 10 millions pounds per year. Another study [19] also shows the economic impact of inaccurate load forecast. The determination of the cost of high varying load, which is evaluated by calculating the difference cost of generation caused by unit commitment with and without the high load variation, have been reported in [20]. Load uncertainty, modeled as normal distribution function [19, 21-24], will be utilized in this research work. Meanwhile, generating unit availability is normally predicted from the historical operating data, e.g. failure and repair rates, and varies by types and sizes of units. The availability of generating units can be calculated based on the application of a Markov model [21-25].

1.4.2 Economic Consideration

Electric power utilities always pay a great deal of attention in the determination of optimal operating strategy of thermal generation system since it has highly impact to the operating cost of the companies. This can be obviously seen from the fact that the demand of most utilities is principally met by thermal power generation [26]. The cost of production from thermal units, consisting of fuel cost, operation and maintenance cost, contributes significantly to the annual total cost at 40-60% [27]. Since the fuel cost is a major component, reducing it by just a little as 0.5% can result in saving millions of dollar per year [28, 29]. Therefore the optimal scheduling strategy of this type of unit will give significant impact in reducing the annual operating cost. Due to these facts, a production cost simulation method in association with appropriate operating strategy by considering various features and constraints have been received a great deal of attention over several decades [30-38].

The simulation of short-term operation to evaluate its economic impact can be done by assuming that there are a set of available units to be scheduled and certain forecasted demand for the specified considered lead time, which usually in the range from one day up to one week. The estimation of operation cost in this deterministic model is obtained by evaluating the power generation level of each scheduled units, including start-up and shut-down costs over the whole considering intervals [39].

In the case the future demand is not accurately known, the production cost evaluation cannot be appropriately done by a deterministic model as previously described. Therefore a probabilistic based method should be incorporated in the evaluation process. A number of researchers [40-42] have already applied the probabilistic or stochastic technique in solving the generation scheduling in this regard.

1.4.3 Reliability Consideration

Reliability of the power supply is one of the most important considerations in determining operating strategy. This consideration becomes much more crucial especially in industrial and commercial areas due to its high damage cost from electricity interruption. Accordingly appropriate operating strategy will provide suitable generation capacity to ensure that the expected demand can be supplied with a certain reliability level.

For compensating insufficient committed capacity caused by unexpected events, e.g. failure of the units and unanticipated load variation, the spinning reserve should be appropriately scheduled for each time interval. In practice, most utilities define an amount of spinning reserve using deterministic criterion which is generally set based on experience [43]. By adopting this criteria, the spinning reserve may be scheduled in relation with the largest committed generator or a fraction of the forecasted demand [39].

While the deterministic criterion is convenient to implement, it does not match the stochastic nature of the problem and does not take into account the intrinsic reliability of each scheduled generator. Accordingly, the probabilistic based method for computing spinning reserve requirement has been proposed by incorporating risk indices in the short-term operation problem [25, 44, 45].

The effects of applying both deterministic and probabilistic criteria to the obtained short-term operating strategy will be investigated in this research.

1.4.4 Operating Constraint Consideration

Even though the objective of short-term operating strategy is to generate power at minimum total cost and at a reasonable reliability level, the operation of generating units have to consider some aspects which related to physical capability of the unit in generating power.

Minimum and maximum power: these particular time constraints are intended to provide time for temperature equalization in generating unit, thereby controlling material stress arising from thermal gradients within turbine. The minimum up-time constraint permits a generating unit to be started only if it will run for a minimum number of continuous hours whereas the minimum down-time permits a generating unit to be shut-down only if it will remain shut-down for a minimum number of consecutive hours.

Minimum up and down times: there are maximum and minimum power output levels which can be delivered by each thermal generating units. The maximum power is influenced by the turbine limitations such as shell and rotor metal differential temperature, and their expansions [39]. The minimum power is more influenced by the boiler than the turbine where a flame cannot be continuously controlled down to zero – beyond a certain point it extinguishes. Typical minimum power are in the range of 20-40% for oil and gas-fired and 40-50% for coal fired units [46].

1.5 Objectives of the Research

The objective of this research can be summarized below:

1. To develop a method for determining suitable operating strategy in both vertically integrated utility and combination of vertically integrated and bilateral contract scheme by considering both generation and demand uncertainty based on decision analysis method.
2. To investigate and conduct sensitivity analysis with respect to some considered parameters, e.g. system size, level of forecast error, and value of loss load, to evaluate the impacts of these parameters to the obtained strategy and associated cost.
3. To investigate the impact of bilateral transaction to the obtained strategy and associated cost. The sensitivity analysis is conducted with respect to both number of involved bilateral contract participants and the amount of bilateral contract demand.
4. To determine the acceptable reserve price for the utilized reserve power by GENCO taking into account both generation and demand uncertainties.

1.6 Scope and Limitations

Several limitations on the considered problem are summarized below.

a. The application of the proposed method in order to obtain the best short-term operating strategy is employed both in vertically integrated utility and the combination of vertically integrated with some private generation companies are allowed to directly supply their customers through bilateral contract scheme. According to that case, the objective function of the problem is minimization of total cost.

b. Only thermal generating units are considered in this research. The quadratic cost function of each unit is approximated by using two piece-wise segments.

c. Both deterministic and probabilistic criteria are employed in this research.

d. The proposed method will be implemented to solve the short-term operating strategy in a modified IEEE-24 bus test system and its replication, and a modified EGAT system.

1.7 Dissertation Arrangement

Chapter 2 presents the literature review on generation scheduling including formulation of unit commitment problems, demand uncertainty consideration, economic dispatch, and reliability consideration. The solving techniques for unit commitment problem based on mixed-integer linear programming, and application of decision analysis in generation scheduling are also presented.

Chapter 3 proposes a decision analysis based method for determining the best strategy by considering demand and generating unit uncertainty. Meanwhile, unit uncertainty is considered by incorporating risk cost to the total cost. Several scenarios are created by considering the number of load level and spinning reserve strategy. In this chapter, deterministic criterion which is based on percentage of forecasted demand is utilized in determining the spinning reserve strategy. The best strategy is selected among the developed scenarios which give minimum expected total cost. It is then tested by IEEE-24 bus test system and its replication. The replication is intended to investigate the impact of system size to the obtained strategy and associated costs. Sensitivity analysis is carried out with respect to system size, value of loss load (VOLL), probability of load level, and standard deviation of forecast error.

Chapter 4 presents the application of decision analysis in solving short-term generation scheduling problem with consideration of system uncertainty. Three scenarios are created based on the number of the considered load level. In each scenario, the spinning reserve requirement is evaluated using probabilistic criterion. The best strategy is selected among the created scenarios. Then sensitivity analysis is presented with respect to reliability level, demand uncertainty, VOLL.

Chapter 5 presents the proposed method for solving short-term operating strategy by considering system uncertainty and bilateral transactions. The basic approach for solving system uncertainty in this chapter is similar with the proposed method in Chapter 3, comprising nine scenarios representing the combination of three spinning reserve strategies with three load levels. A partially deregulated is considered in the structure of the system. Sensitivity analysis with respect to the amount of bilateral contracted demand and the number of GENCOs is presented.

Finally, Chapter 6 concludes of the chapter presented earlier. This chapter also presents the concept for the future research based on this dissertation.