Chapter-1
INTRODUCTION

Earlier, almost all electric power utilities throughout the world were operated with an organizational model in which one controlling authority the-utility-operated the generation, transmission, and distribution systems located in a fixed geographic area and it referred as vertically integrated electric utilities (VIEU). There was an iota of doubt whether the monopoly organization was efficient. There is rapid change in philosophies in respect of Telecom, Air Lines, and IT Sectors, which brought a revolution in power sector. The present day power systems operation has assumed commercial significance and technical considerations like availability, demand and transmission adequacy, which weigh against the economic background of countries. The electric utility introduced new concept of deregulation in this sector in order to improve availability, efficiency and derive the economic benefits. Many electrical utilities and power network companies worldwide have been forced to change their ways of doing business from vertically integrated mechanism to open market system. This kind of process is termed as deregulation or restructuring or unbundling. At present, the power utility has been restructured as separate entities of generation (GENCO), transmission (TRANSCO) and distribution (DISCO).
These changes in the structure of electric utilities and the creation of free markets for energy trading are bringing about a redefinition of power system operation and control and forcing a re-examination of the design concepts for power system control centers. Many utilities throughout the world are on the threshold of a new beginning in system operation and control as they enter into the arena of a free electricity market. In recent decades, several improvements have been achieved in power system operation and control. The evolution was mainly in the development of computational and communication systems. Both areas allowed the analysis of complex models of power system operation and control that resulted in a more flexible system, that is controlled in almost real-time mode. All these improvements favoured the change of power system operation to a new environment, in which VIEU became deregulated with operations based on energy market regulations. In this environment, not only security, but also the monitoring of power flow direction and the control, represent critical issues.

The operation and control of the generation-transmission-distribution grid is quite complex because this large system has to operate in synchronism and because many different organizations are responsible for different portions of the grid in this new scenario. Many public and private electric power companies are interconnected. Thus, many organizations have to coordinate to operate the grid, and this coordination can take many forms, from a loose agreement of operational
principles to a strong pooling arrangement of operating together. Constant review and monitoring of all the different markets is done to track the advancement of the power market.

The other structure is open access; in which one dominated by bilateral contracts and bulk of energy transactions are directly organized between generator and consumer.

1.1. **Power System Operation and Control**

Power-system operations can be divided into three stages: operations planning, real-time control, and after-the-fact accounting. The main goal is to minimize operations cost while maintaining the reliability (security) of power delivery to customers. Operations’ planning is the optimal scheduling of generation resources to meet anticipated demand in the next few hours, weeks, or months. This includes the scheduling of water, fossil fuels, and equipment maintenance over many weeks, and the commitment (start-up and shutdown) of generating units over many hours. Real-time control of the system is required to respond to the actual demand of electricity and any unforeseen contingencies (equipment outages). Maintaining security of the system so that a possible contingency cannot disrupt power supply, is an integral part of real-time control. After-the-fact accounting is the tracking of purchases and sales of energy between organizations so that billing can be generated.
1.2. Real Time Power System Operation in VIEU

The monitoring and control of a power system from a centralized control center became desirable quite early in Vertically Integrated Electrical Utility when generating stations were connected together to supply the loads. As electrical utilities interconnected and evolved into complex networks of generators, transmission lines, distribution feeders, and loads, the control center became the operations headquarters for each utility. Since the generation and delivery of electrical energy are controlled from this center, it is referred as the energy control center or energy management system. In this monopolistic framework, a regulated VIEU makes planning and operational decisions based on least cost objective, subject to constraints (Generator and System) and reliability criterion. This planning and operational process typically necessitates a deployment of a suite of scheduling procedures, each utility specializing in solving a particular optimization problem over a distinct time frame.

In real time Operation this involves economic dispatch procedures which achieve a real time balance between supply and demand in a least cost manner. Generation scheduling and dispatch are modeled by a merit order of generators. Generators are stacked up, according to the merit order, to meet the load demand at every point in time. The simulation is typically done on a weekly or monthly basis. More advanced economic dispatch algorithms such as optimal power flow (OPF) type considered optimal dispatch subject to security constraints including transmission
line limits, voltage levels, reserve and regulation. In longer frames unit commitment (UC) is used to obtain an optimal schedule i.e. the on/Off and dispatch decisions for generators, for periods of time of up to one week. These UC procedures account for inter temporal constraints such as ramping rates, minimum up and down times that are particularly important for systems with large thermal plants which are limited by these types of constraints. System security issues such as the provision of reserve and transmission constraints can also be included in these UC procedures. As the time horizon increases from the operational time frame (seconds to hours) into the planning time frame (weeks to years) the deterministic power system models are replaced by probabilistic models. In this planning phase capital investment decisions are made. This planning and operational process is a continuous process. As the time for delivery approaches, the schedules and dispatch are continually refined to adapt to current circumstances.

1.3. Real Time Power System Operation in Deregulated Environment
A deregulated electricity market comprises of many players such as generator owners, load supply entities (or load aggregators), and transmission owners. Each market has an independent grid operator, known as the ISO (independent system operator), responsible for the day-to-day and, some times, long-term operation of the power system. The discussion will evolve around power system issues for these players.
There are a number of factors present in the power system operation within the restructured industry. They are

- Growing uncertainties in planning and operation of power systems.
- Growing pressures in market-oriented industries to be accountable for decisions.
- Increased need for the exchange of data among market players.
- Growing concerns to understand the impact of renewable energy.
- Sources and environmental economics.
- Requirement to quantify the value of different energy sources among the market players.
- Software technologies and numerical methods for the power industry.

Although electric energy can be stored in batteries it would be uneconomical to store it in large quantities and hence electricity is a real time commodity being produced and consumed instantly. The electricity demand has significant daily, weekly and seasonal variations and also has a significant random component. The main commodity being bought and sold in an electricity market is energy. There are, however, other services such as reserves, reactive power and automatic generator control (ACG), which must be provided in order that the electricity system can function reliably. These ancillary services need to be provided and an electricity market needs to be structured to facilitate trading of these services. The generators and their customers are typically well distributed geographically and Kirchhoff’s laws determine the routes
taken by the power on the transmission system. The consequence of this is that congestion can occur on this transport system and altering the supply (generator outputs) and demand (customers’ consumption) alleviates this congestion. These adjustments are a constraint to competition. Energy, ancillary services and transmission are interdependent and this coupled with the real time stochastic nature of the electricity demand makes designing of an efficient electricity market a great challenge.

1.3.1. Role of ISO in Power System Operation and Control

The ISO may be authorized to set rules for transactions between suppliers and consumers, scheduling and dispatch of generators, loads and network services, maintenance of system security and reliability, congestion management, service quality assurance and promotion of economic efficiency. To this end, the ISO procures various ancillary services from ancillary providers.

The ISO collects information of all the hour-by-hour transactions that are to take place the next day. These transactions can either be decided by an independent market operator based on bidding mechanism, as in the hourly spot market, or through bilateral contract between the genco and customer, based on independent negotiations. The ISO does not involve in any of these processes. Once the transactions are available to the ISO, ISO carries out power flow studies and other simulations such as alleviation of transmission congestion etc.
based on its load forecast for the next day, availability of transmission capacity and other factors to determine the level of system security. If required, it makes provision for additional transmission capacity, ancillary services, or orders curtailment of certain transactions. After finding the feasible trades, ISO monitors the system for power flows, frequency and voltage conditions and trades in real time. It interacts with the regional networks and control rooms of utilities for providing adequate frequency regulation services, reactive support and voltage control service. Power imbalances are corrected by making provision for parties, which shall be responsible for this and charge the same to the defaulting parties. After real-time, It calculates allocation of total transmission loss among the generators and consumers. ISO has to compensate the allocated losses from other service supplies. ISO coordinates the settlement of the accounts and payments for the ancillary service providers.

1.3.2. Types of ISOs

There are two distinct models for ISOs. They are pool model and bilateral / multilateral Model.

i) Pool Model (centralized)

For pool-type operations, ISO is set up where the operational decisions may be made centrally and then implemented by each utility. As a result all electricity output from generators is pooled and then scheduled to meet electricity market. In this structure, there is a need for supply to be
constantly responsive to variations in demand and the power consumed by a particular consumer can never be determined. For a large utility, there may be another level in the hierarchy where the decisions are further distributed to different geographical areas of the same utility. All of this requires significant data communication as well as engineering computation within a utility as well as between utilities. The use of modern computers and communications makes this possible, and the heart of system operations in a utility is the energy control center.

**ii) Bilateral (Decentralized)**

In decentralized systems, the ISO does not control energy markets. Free market activity allows each generator and customer to negotiate with each other to determine their preferred schedules (bilateral contracts) outside of the ISOs control. The ISO tries to accommodate these preferred schedules, and only manages the transmission market. The ISO alleviates congestion by intervening in the energy market only when congestion occurs. However, unlike the comprehensive optimization by ISO in the pool market, ISO in the bilateral markets does not coordinate markets for energy and transmission explicitly. To alleviate congestion, this ISO uses adjustment bids given by market participants. The bids express the amounts participants are willing to increase or decrease above or below the preferred schedules, and specify their costs or savings according to supply or demand.
iii) Multilateral Markets (Power Exchange)

The deregulated power industry shifted the electrical systems to new paradigms of system operation. The reforms have brought sea changes in electrical market through increased number of private players, creating very dynamic marketplaces and changed the pricing pattern. The main objective of application of economics in relation to pricing in power sector is optimization and equilibrium for trading of energy. The application of microeconomics in electricity market addresses the optimizing behavior of buyers (load) and sellers (Generators). The equilibrium prices through energy market help bidding of electrical energy economically and efficiently. Market forces are generally illustrated in supply and demand curves. The balancing of the short-term supply and demand for electricity occurs through a centrally coordinated dispatch process i.e. power exchanges.

Power exchange is a place where power is bought and sold. The operations of Power Exchange are akin to a stock exchange. Power Exchange is an organization that facilitates wholesale power buyers / sellers to participate in the process of auction.

If market activity is separated from the control of the power system, a power exchange market (PX) can be formulated in addition to bilateral contracts. Clearing the energy market may result in a flow exceeding the transmission capacity. The preferred schedules from the PX are quite similar to the Centralized-ISO schedules, except for
consideration of network constraints. At the same time, free market activity allows each generator and customer to negotiate directly to determine its preferred schedules (bilateral contracts) outside the PX. Consequently, the PX receives requests to use the transmission lines from several ISOs and bilateral contracts. The PX uses adjustment bids given by market participants to alleviate congestion, as in the bilateral model. Therefore, if congestion occurs, the PX intervenes in the energy market, but does not force any participants to trade power between different markets.

1.4. Importance of Ancillary Services in Power System Operation

The services of scheduling and dispatch, frequency regulation, voltage control, generation reserves, etc. which are now commonly referred to as ancillary services, are required by the power system apart from the basic energy and power delivery services. Ancillary services are mainly defined by the basic contributions they make to fulfill the system functions. They generally supply or absorb reactive power and control the voltage as well as contribute to the maintenance of the system frequency. They are essential for ensuring reliable operation of interconnected power system. In a vertically integrated system, the ancillary services are an integral part of responsibility of electrical utility where as a separate market mechanism exists for ancillary services in deregulated electricity market. The reliable operation of power system requires availability of reserved generation so as to meet any generation and transmission contingencies.
The ancillary services are necessary to support the transmission of power from sellers to buyers according to the obligation of control areas. The ancillary services in deregulated market environment are categorized into six groups. They are

i) **Energy imbalances**

Frequency control is an important aspect of power system operation. Frequency is an indication of power balance between total generation and total load in the system. Frequency deviation from normal (whether it is 50Hz or 50Hz) requires immediate actions to balance supply and demand of electricity. The control area operator controls generation in real-time to maintain generation/load balance.

ii) **Scheduling and Dispatching**

Scheduling and Dispatching in which transmitting utilities would schedule and coordinate transactions with other entities and confirm the power exchange in and out of their control areas.

iii) **Compensation of real Power Loss**

Every trading arrangement is required to take care of its own losses or services that compensate the losses.

iv) **Voltage control**

This service keeps maintaining system voltages within required ranges by the injection or absorption of reactive power from generators or capacitors.
v) **Spinning Reserve (reliability)**

The provision of unloaded generating capacity that is synchronized to the grid and can immediately respond to correct for generation/load imbalances, caused by generation and/or transmission outages, and that is fully available within several minutes.

vi) **Load following**

The use of generation to meet the hour-to-hour and daily variations in load.

These are basic ancillary services needed in deregulated markets for smooth power system operation.

1.5. **Main Objectives of Thesis**

The introduction of deregulation involves many technically complicated issues ranging from system planning, operation to commercial and market areas. The introduction of deregulation and subsequent open access policy in electricity sector has brought competition in energy market. But, it also caused certain difficulties in some areas especially the transmission network loss sharing and the responsibility of Automatic Control of generation. These issues were identified and motivated to develop certain models for allocations of transmission loss and frequency regulation services.
The main objectives of the work reported in the thesis are:

- To Investigate Current Trends in the Deregulated Electricity Market in developing countries with particular reference to Indian power sector under inadequate generation resources and transmission capabilities commensurate with load growth.

- To develop new methodologies for:
  
  o Loss allocation Problem by Cooperative game theory for Multi transactions.
  o Loss allocation by utilization of generation under open access.
  o Loss compensation Scheme.

- To develop an approach for frequency regulation problem.

1.6. Organization of Thesis

This thesis is organized in seven chapters. First chapter introduces the area of Real Time Power System Operation under deregulated environment. Since the topic taken up for study is in evolving stage, a detailed literature survey is presented in second chapter. The third chapter enlightens the real time power system operation prevailing in developing countries with particular reference to Indian power sector scenario. Fourth chapter proposes Proportional Nucleolus of CGT as a model for the allocation of the transactional transmission losses in Multiple-Transaction Electricity Markets. In the fifth chapter, a detailed algorithm for Transmission loss allocation in
usage-based methodology and development, application of the equivalent loss compensation concept procedure for open access environment are presented. The sixth chapter proposes a methodology for evaluating frequency linked price and loss scheduling under deregulation market environment. Seventh chapter concludes with the summary of contributions of thesis with scope for further work in this new area of specialization. A comprehensive bibliography of documented literature on this topic of research is given in references.