CHAPTER 4

DEREGULATED POWER SYSTEM

4.1 INTRODUCTION

Electric utilities have been vertically integrated monopolies that have built generation, transmission, and distribution facilities to serve the needs of the customers in their service territories. Significant capital commitments were required to construct large power stations and to coordinate generation, transmission and distribution. The price of electricity was traditionally set by a regulatory process, rather than by market forces, which were designed to recover the cost of producing and delivering electricity to customers, as well as the capital costs. Under this monopolistic service regime, customers had no choice of supplier; and suppliers were not free to pursue customers outside their designated service territories. Since the nineties, most of the electric power industry has been going through a process of transition and restructuring by moving away from vertically integrated monopolies and towards more competitive market models. This has been achieved through a clear separation between transmission and generation activities, as well as creating competition in the generation activities. Competition breeds innovation, efficiency and lowers costs. The goal of deregulation is to enable competition based upon regional efficiencies, and to disable the monopoly control and market imperfections that existed/exist under the vertically integrated utility structure.
In this chapter the structural components representing various segments of the deregulated electricity market and the new trading structures are presented. Technical issues like congestion management and reactive power management are presented. Generalized framework for pool and bilateral transactions are also presented. A simple model for reactive power cost derived from the loading capability diagram is also explained.

4.2 ADVANTAGES OF DEREGULATION

Advantages of deregulation are:

(i) Electricity price may drop due to innovation and competition.

(ii) Expected to result in wider customer choice and more attention to improve service.

(iii) In countries where Government wishes to sell state owned utilities, deregulation may provide potential buyers and new producers.

(iv) A competitive power industry will provide rewards to risk takers and encourage the use of new technologies and business approaches.

4.3 UNBUNDLING GENERATION, TRANSMISSION AND DISTRIBUTION

- The generation sub system has a high degree of freedom in the selection of energy sources, ranging from capital-intensive low-operation cost resources to others with low capital and high operation costs. Hence, significant
economics of scale or natural monopoly features, except in the case of large-scale-hydro-electric potential, are not an impediment to competition in generation.

- There are no clear economics of scale, but there is a geographic monopoly, in the distribution subsystem and therefore some form of regulation is needed. The distribution business is, however, further unbundled into (a) a wires business, which maintains the distribution network and provides facilities for electricity delivery, and (b) a retail or supply business, which provides electric energy to end consumers.

- The transmission subsystem is a natural monopoly in the economic, the geographic and the technical sense, and therefore must continue to function as an integrated and regulated entity.

However, to implement competition in the generation and retail sides, it is necessary to unbundle these two from the transmission system and ensure that the latter offers open access on an equitable basis to all power suppliers and consumers. The transmission system thus becomes the focus of attention in organizing competition and must act as a level playing field and the rules for managing access by all participants must be transparent and non-discriminatory.

4.4 STRUCTURAL COMPONENTS OF A RESTRUCTURED SYSTEM

The structural components (Loi Lei Lai 2001) representing various segments of the electricity market as Generation Companies (GENCOS),
Power Marketers (PM), Power Exchange (PX), Scheduling Coordinators (SC), Transmission Owners (TO), Independent System Operator (ISO), Ancillary Services (AS), Retail Service Providers (R), and Distribution Companies (DISCOS) are shown in Figure 4.1. Depending on the structure and the regulatory framework some of these components may be consolidated together or may be further unbundled.

![Diagram of structural components]


**Figure 4.1 Structural components of restructured system**

### 4.4.1 Gencos and Power Marketers

Gencos and Power Marketers are the primary and secondary generation sectors respectively. Gencos are responsible for operating and maintaining generating plant in the generation sector and in most of the cases are the owners of the plant. Open transmission access allows Gencos to access the transmission network without distinction and competition.
4.4.2 Discos and Retailers

Discos assume the same responsibility on the distribution side as in a traditional supply utility. However, a trend in deregulation is that Discos may now be restricted in maintaining the distribution network and providing facilities for electricity delivery while retailers are separated from Discos and provide electric energy sales to end consumers. Another trend in developing countries is to sell to an investor, or to corporatise, portions of the distribution system so that investment for reinforcement can be raised and better operating practices implemented.

4.4.3 Transmission Owners

The basic premise of transmission open access is that the transmission owners/providers treat all transmission users on a nondiscriminatory and comparable basis regarding access to and use of the transmission system and services. This requirement could be difficult to ensure if the transmission owners have any financial interests in energy generation or supply. A general trend is, therefore to designate an ISO to operate the transmission system and facilitate provision of transmission services. Maintenance of the transmission system remains the responsibility of the transmission owners.

4.4.4 Power Exchange

The power exchange handles the power pool, which provides a forum to match electric energy supply and demand based on bid prices. The time horizon of the pool market may range from half an hour to a week or longer. The most usual is the day-ahead market to facilitate energy trading one day before each operating day. An hour-ahead market is also useful since
it provides additional opportunities for energy trading to redress short-term imbalance. The working process of the power exchange is (1) receive bids from power producers and customers. (2) match the bids, decide the market clearing price prepare scheduling plan (3) provide schedules to the ISO or transmission system operators (4) adjust the scheduling plan when the transmission system is congested.

4.4.5 Scheduling Coordinators

Scheduling Coordinators (SC) aggregate participants in the energy trade and are free to use protocols that may differ from pool rules. In other words, market participants may enter an SC’s market under the SC’s rules and this could give rise to different market strategies. Scheduling Coordinators are entities that put together supply and demand energy schedules without necessarily abiding by the rules of a power exchange. The power exchange may thus be viewed as a regulated SC’s. Scheduling coordinators generally need a combination of classical energy scheduling computer applications such as unit commitment, as well as a mix of new tools for market analysis, strategic bidding and contract optimization. They would generally also do metering, accounting, settlement and billing systems to settle to their clients and with the ISO.

4.4.6 Ancillary Services

Ancillary service providers supply the transmission network support services that are needed for reliable operation of the power system. The majority of ancillary services are in fact real or reactive power/energy resources needed to operate the transmission system in a secure and reliable manner.
Depending on the organizational structure adopted, ancillary services may be traded in the power exchange, the ISO market, or both. In either case, the ancillary services may be provided in a bundled manner or as an unbundled menu. Ancillary services such as operating spinning reserve, regulating reserve, supplemental operating reserve (non spinning reserve), energy imbalance, frequency regulation, load following may be self provided by the user of the transmission system. In case transmission user does not provide them directly or through third party arrangements, the user must purchase them from the ISO. The ISO must offer these services, and will usually procure them through a competitive auction in the forward market and charge the users according to their ancillary service responsibility not self provided. Two other ancillary services such as reactive power/voltage support and system control/re-dispatch are procured and provided by the ISO, and the users must purchase them from the ISO. Some other transmission support services such as loss compensation or backup support, may or may not be offered by the ISO.

4.4.7 Independent System Operator

The ISO is the supreme entity in the control of the transmission system. The basic requirement of an ISO is disassociation from all market participants and absence from any financial interest in the generation and the distribution business. The ISO operates the transmission grid and provides transmission services to all transmission customers.

**ISO functions and responsibilities:** The system operator plays a critical role in both the traditional utility environment and the emerging unbundled systems, although some activities and responsibilities have changed considerably. In the traditional utility environment the system is vertically integrated and the operator, as the top manager, takes over the entire
business so far as operating the physical system is concerned. In these utilities the range of operator responsibilities which encompasses operational aspects of corporate economics as well as the ownership of the system are maximized in one corporate entity.

In the new market structures there is a variety of arrangements for the system operator and since the operator must be disassociated from all participants the name Independent System Operator is a natural choice. The ISO has three objectives: security maintenance, service quality assurance and promotion of economic efficiency and equity. To achieve these objectives the ISO performs one or more of the following functions:

(i) **Power system operations function**: This fundamental function includes the operation-planning function and real time control. The operation planning function includes power system scheduling, co-ordination with energy markets, power system dispatch, ATC determination, calculation of short-run costs and hourly prices for transmission-related services.

Real time control includes monitoring power system operation, monitoring system security, conducting physical network operations and network switching, dealing with outages and emergencies.

(ii) **Power market administration function**: There are two types of energy markets: the pool market and the contract (bilateral and multilateral transactions) market. The former is coordinated by the PX or an ISO-PX combined while the latter may be coordinated by one or more SC’s. In the pool market a power pool is run where parties can bid to buy and sell energy, develop a preferred schedule for the pool, submit
the supply and load schedule to the ISO according to pre-specified protocols (this is for the case when the PX is separated from the ISO). The contract market manages bilateral and multilateral transactions, coordinates submission from SCs, submits preferred schedule to the ISO according to pre-specified protocols.

(iii) Ancillary services provision function: The ISO own certain ancillary services for satisfactory grid operation, and also purchase ancillary services transactions from market participants according to pre-specified protocols. The ISO provides ancillary services to transmission users, and allocates the cost of ancillary services among all users.

(iv) Transmission facilities provision function: The ISO maintains the transmission network, provides transmission facilities for all suppliers and loads, plans transmission, reactive power and FACTS expansion and ensures that resources for future investments are generated.

4.5 TRADING ARRANGEMENTS

Trading arrangements that are followed in different parts of the world can be grouped into the following four categories.

4.5.1 The Pool

In the pool model, competition is initiated in the generation business by creating more than one Genco and is gradually brought to the distribution side where retailers could be separated from Discos and where consumers could be allowed to phase in a choice of retail supply. The
transmission system is centrally controlled by a combination of (ISO+PX) which is disassociated from all market participants and ensures open access. The (ISO+PX) operates the electricity pool to perform a price-based dispatch and provides a forum for setting the system prices and handling electricity trades.

4.5.2 Bilateral Trade

Bilateral model promotes free market competition and therefore is a good way to achieve competition in an electricity market. In this model, suppliers and consumers independently arrange trades, setting by themselves the amount of generation and consumption and the corresponding financial terms, with no involvement or interference by the system operator.

4.5.3 Pool and Bilateral Trades

The most likely arrangement, which will emerge in practical systems, is that a pool will exist simultaneously with bilateral and multilateral transactions. The significant difference between this model and the pool model is that the transmission sector is unbundled into a market sector and a security sector. In the market sector, there are multiple separate energy markets, containing a pool market taken care of by the PX and bilateral contracts established by the SCs. The ISO is responsible for system operation and guarantees system security and in operational matters holds a superior position over the PX and SCs. The existence of a power pool is not mandatory in this model but will invariably be the case. Market participants may not only bid into the pool but also make bilateral contracts with each other. Therefore this model provides more flexible options for transmission access.
4.5.4 Multilateral Trade

Multilateral trade is a generalization of bilateral transactions where a scheduling coordinator or power broker puts together a group of energy producers and buyers to form a balanced transaction. In practice, multilateral and bilateral transactions will coexist with a power pool. Conceptually the extreme case is where the concepts of pool and the PX disappear into this multi–market structure. Each market is managed by an SC or a broker under its individual rules.

4.6 GENERALIZED FRAMEWORK FOR POOL AND MULTILATERAL TRANSACTIONS

The operation of a competitive electricity market (pool and multilateral) takes place, in two different approaches. The first approach is a one step optimal power model that dispatches the pool in combination with the privately negotiated multilateral contracts while minimizing cost and accounting for both losses and congestion (Francisco Galiana et al 2002). In the second approach, trading of electricity and scheduling of the transmission services are independent tasks that are performed sequentially in two separate stages (Paul Gribik et al 1999). In the first stage, electricity is traded via transactions between selling and buying entities. All the transmission constraints are ignored at this stage. The resulting outcomes are referred to as the preferred schedules. Then, in the second stage, these preferred schedules are submitted to the ISO to assess the capability of the grid to accommodate the transmission requirements and procure the required transmission services. When the transmission network fails to simultaneously accommodate all these preferred schedules, the ISO invokes congestion relief procedures to ensure that the system is operated within operating constraints under both normal and contingency conditions. An example of such sequentially performed
procedure is the market-based scheme using incremental/decremental offers in the first California ISO design (Harry Singh et al 1998). In this scheme, each participating generator provides an incremental/decremental offer for raising/lowering its output at the specified prices so as to effectuate a change in the preferred schedule. The ISO adjusts the outputs of participating generators to relieve the network congestion with the objective of minimizing the total re-dispatch costs. In this thesis, the second approach is adopted. A generalized multi-transaction framework used for multilateral market is adopted from Shu Tao et al (2002). This is explained below:

A multilateral transaction is a set of selling entities supplying a specified amount of real power ‘t’ to a set of buying entities.

A transaction \( m \in M \), that is \( m = 1,2 \ldots NT \) is denoted by a triplet, \( T_m \), and given by

\[
T_m = \{ t^{(m)}, S^{(m)}, B^{(m)} \} \tag{4.1}
\]

\( S^{(m)} \) is a set of selling entities (Gencos) supplying a specified amount of real power \( t^{(m)} \) to \( B^{(m)} \), a set of buying entities (Discos).

The set \( S^{(m)} \) is a collection of 2-tuples

\[
S^{(m)} = \left\{ (s_i^{(m)}, g_i^{(m)}) ; i = 1,2,\ldots N_s^{(m)} \right\} \tag{4.2}
\]

where \( N_s^{(m)} \) is the number of selling entities in transaction \( m \)

\( s_i^{(m)} \) is the Id number of the bus to which the selling entity \( i \) is connected.
$\sigma_i^{(m)}t^{(m)}$ is the MW supplied by the selling entity $i$

Similarly the set $B^{(m)}$ is a collection of 2-tuples

$$B^{(m)} = \left\{(b_j^{(m)}, \beta_j^{(m)}); \ j = 1, 2, ... N_b^{(m)} \right\} \quad (4.3)$$

where $N_b^{(m)}$ is the number of buying entities in transaction $m$

$b_j^{(m)}$ is the Id number of the bus to which the buying entity $j$ is connected

$\beta_j^{(m)}t^{(m)}$ is the MW bought by the buying entity $j$

The above multi-transaction framework is used for combined pool and multilateral market. For this purpose, all the pool transactions already settled by the ISO using market-clearing procedure are treated as a single multilateral transaction between the group of pool sellers and the group of pool buyers. This equivalent multilateral transaction is taken within the set as the first multilateral transaction, $t^{(m)}$; $m=1$ and the other multilateral transactions take the later position, $t^{(m)}$; $m=2, 3, ... NT$. The quantum of this transaction is given by

$$t^{(1)} = \sum_{i=1}^{NPS} PG_i = \sum_{j=1}^{NPB} PD_j \quad (4.4)$$

where $NPS$ is the number of pool sellers and $NPB$ is the number of pool buyers. The pictorial representation of multi-transaction framework (Gianfranco Chicco et al 2002) is shown in Figure 4.2.
4.7 CONGESTION MANAGEMENT

Existence of transmission system constraints dictate the finite amount of power that can be transferred between two points on the electric grid. In practice, it may not be possible to deliver all bilateral and multilateral contracts in full and to supply all pool demand as it may lead to violation of operating constraints such as line overloads and violations of bus voltage limits. The presence of such network or transmission limitation is referred to as congestion. Congestion in a transmission system, cannot be tolerated, since this may prevent the existence of new contracts, lead to additional outages, increase the electricity prices in some regions of the electricity markets, and can threaten the system security and reliability.

Congestion management comprises two tasks congestion relief and congestion cost allocation. Congestion management is identified as one of the
critical and important tasks of the ISO for the smooth functioning of competitive electricity markets. There are two broad paradigms that may be employed for congestion relief. These are the cost-free means and the non-cost-free means. The former include actions like operation of transformer taps, phase shifters, or FACTS devices. These means are termed as cost-free only because the marginal costs involved in their usage are nominal. It is not always possible for cost free means and some non-cost free methods such as rescheduling generation and prioritization and curtailment of loads/transactions have to be exercised to relieve congestion. Congestion cost allocation is the equitable allocation of congestion charges incurred during congestion relief to those transactions causing congestion.

4.7.1 Congestion Management Methodologies

Based on the literature review, the congestion management methods can be categorized as auction based congestion management, nodal pricing based methods, re-dispatch and willingness to pay methods. The method used for congestion management is based on re-dispatching.

Re-dispatching: When transactions exceed ATC, transaction based methods require the curtailment of transactions, and physical boundaries then become a limit to trade. In this situation, the re-dispatching of generation may help to relieve part of the congestion. Re-dispatching generally creates additional costs to ISO, which could be allocated to the responsible parties for the sake of economic efficiency. In this re-dispatch, congestion relief means available to ISO are the acquisition of incremental/decremental injections from every willing participant at a cost, be it a generating or a load entity. While a uniform price auction is typically used in the forward energy markets, the adjustment auction for the transmission market is a pay-as-bid auction. To do so, the ISO runs an auction of incremental/decremental adjustments to
select the most economic means to provide overload relief. The participants in
the adjustment auction are not limited to be participants in the proposed
transactions.

4.8 REACTIVE POWER MANAGEMENT

In vertically integrated electricity system, providing reactive power
support is part of the system operator’s activities and the expenses incurred in
providing for such services is included in the electricity tariff charged to
customers. In deregulated electricity markets, provision for reactive power
support are to be made by the ISO in order to meet the contracted transactions
in a secure manner. Among the ancillary services, the reactive power support
is essential for the system operator to maintain an acceptable system voltage
profile. Since it is not desirable to transport reactive power over a long
distance, procurement of reactive power services should be done taking into
account the perceived demand conditions and availability of reactive power
resources. Most often, the independent generators own the resources for
reactive power support such as synchronous generators, synchronous
condensers, capacitor banks, reactors, static VAR compensators and FACTS
devices. According to FERC Order 888 (FERC Order No.888, 1996), and
NERC White Paper on Proposed Standards for Interconnection Services
(NERC, 1999), only reactive power support from synchronous generators is
considered as an ancillary service and is eligible for financial compensation.
However, this may change in the near future to recognize other reactive power
support sources, particularly FACTS controllers (e.g. static VAR
compensators or SVC), as per the recent recommendations of FERC (FERC
Staff Report, 2005). In view of the existing FERC guidelines, only reactive
power support from synchronous generators is considered as an ancillary
service. The ISO needs to enter into contracts with them for such provision.
Reactive power management has to be carried out by the ISO. Reactive power management includes procuring reactive power support required by the primary transactions and the associated reactive power load of DISCOS economically and allocating the resultant charges among the transaction participants and DISCOS in a transparent manner.

4.8.1 Cost of Reactive Power Supplied from Synchronous Generator

Generators provide reactive power support by producing or consuming reactive power when operating at lagging or leading power factors respectively. When a generator is supplying lagging reactive power, it is over excited. When a generator consumes lagging reactive power or supplying leading reactive power, it is under excited. Unlike fuel costs that represent the operating cost of active power production there is only a small operating cost in the case of reactive power production which can be ignored. To supply the reactive power, a generator has to reduce the active power supplied to the market because of generator’s capacity constraint. The capacity constraint is the restriction on the operation of the generator, imposed by the armature current limit, the field current limit and the under excitation limit (Figure 4.3). Because of these limits, the production of reactive power may prevent some other alternative capacity usages. Assuming that the capacity of a generator is used only for producing active and reactive power, the value of alternative capacity usage for reactive power is the profit of active power that cannot be achieved by producing reactive power. The profit corresponding to the decreased active power production (implicit financial loss to generator) is modelled as the reactive power opportunity cost.
Assuming reactive power support is provided only by synchronous generators, the following simple model for opportunity cost derived from the loading capability diagram (Figure 4.3) is adopted (Chung et al 2004).

Figure 4.3 Loading Capability Diagram
where

\[
C_{Q,i}(QG_i) = \left[ C_{i}(SG_{i,max}) - C_{i}(\sqrt{SG_{i,max}^2 - QG_{i}^2}) \right] kG_i \tag{4.4}
\]

\[
C_{i}(PG_i) = \left[ a_iPG_i^2 + b_iPG_i + c_i \right] \tag{4.5}
\]

4.8.2 Reactive Power Management in Different Deregulated Markets

Reactive power management and payment mechanisms differ from one electricity market to another, and no uniform structure or design has yet evolved. In most cases, the ISO enters into contracts with the reactive power providers for procurement of their services. These contracts are usually bilateral agreements based on ISO experience, rather than on well formulated optimal procedures. Brief review on reactive power management in different deregulated power system (Zhong, J 2002) is discussed.

Currently in North America, according to NERC’s Operating Policy 10, only synchronous generators are compensated for reactive power
provision. The New York ISO (NYISO) uses an embedded cost based pricing to compensate generators for their reactive power services, and it also imposes a penalty for failing to provide reactive power.

Generators are also compensated for their lost opportunity costs if they are required to produce reactive power by backing down their real power output. Such opportunity cost payments also exist in PJM Interconnection and California ISO (CAISO).

Provision of reactive power services in the California system is based on long-term contracts between CAISO and reliable must-run generators; generators are mandated to provide reactive power within a power factor range 0.9 lagging to 0.95 leading. Beyond these limits, the generators are paid for their reactive power including a lost opportunity cost payment.

The Independent Electric System Operator (IESO) in Ontario, Canada, requires generators to operate within a power factor range of 0.9 lagging to 0.95 leading and within a +/-5% range of its rated terminal voltage. The IESO signs contracts with generators for reactive power support and voltage control, and generators are paid for the incremental cost of energy loss in the windings due to the increased reactive power generation. The generators are also paid if they are required to generate reactive power levels that affect their real power dispatch, receiving an opportunity cost payment at the energy market clearing price for any power not generated.

Among other international practices, in Australia, synchronous condensers also receive payments for providing reactive power apart from generators. On the other hand, Sweden follows a policy wherein reactive power is supplied by generators on a mandatory basis and without any financial compensation.
In the Netherlands, individual network companies have to provide for their own reactive power, usually through bilateral contracts with local generators, who are only paid for the reactive capacity but not for reactive energy.

In the United Kingdom, the Transmission System Operator (TSO)-National Grid Electricity Transmission (NGET) invites half-yearly tenders for both “obligatory reactive power services” which correspond to the base reactive power each generator is required to provide, and “enhanced reactive power services” for generators with excess reactive power capabilities. There are two payment mechanisms: a default payment agreement, where both the generator and NGET enter into an agreement for service provision and payments; and a market-based agreement, where generators submit their reactive power bids to the NGET.

From the brief review of utility practices given above, it is clear that there is no fully developed structure for competition or pricing of reactive power services in any system. Moreover there is no unified framework, universally acceptable, for reactive power management practices that have developed post-deregulation. In some cases the pricing is based on fixed contractual payments, and in other cases based on gross system usage (embedded cost), while in other markets there is no mechanism for payments. Even the classification of the obligatory reactive power band is quite an ad hoc process that varies across ISOs without following any well defined criterion, apart from the operator’s experience.

Moreover, the ISOs do not have any well defined reactive power management system in their operational portfolio that could create an optimal provision of reactive power service considering all the issues arising from competition.
4.9 CONCLUSION

The electricity industry is to become completely deregulated in the presence of significant market competition. One of the principal characteristics of a competitive structure is the identification and separation of the various tasks which are normally carried out within the traditional organization so that these tasks can be open to competition whenever practical and profitable. In this deregulated structure generation, transmission and distribution are unbundled and offered as discrete services. The structural components representing various segments of this deregulated electricity market and the new trading structures are presented in this chapter. Technical issues such as congestion management and reactive power management are also discussed.