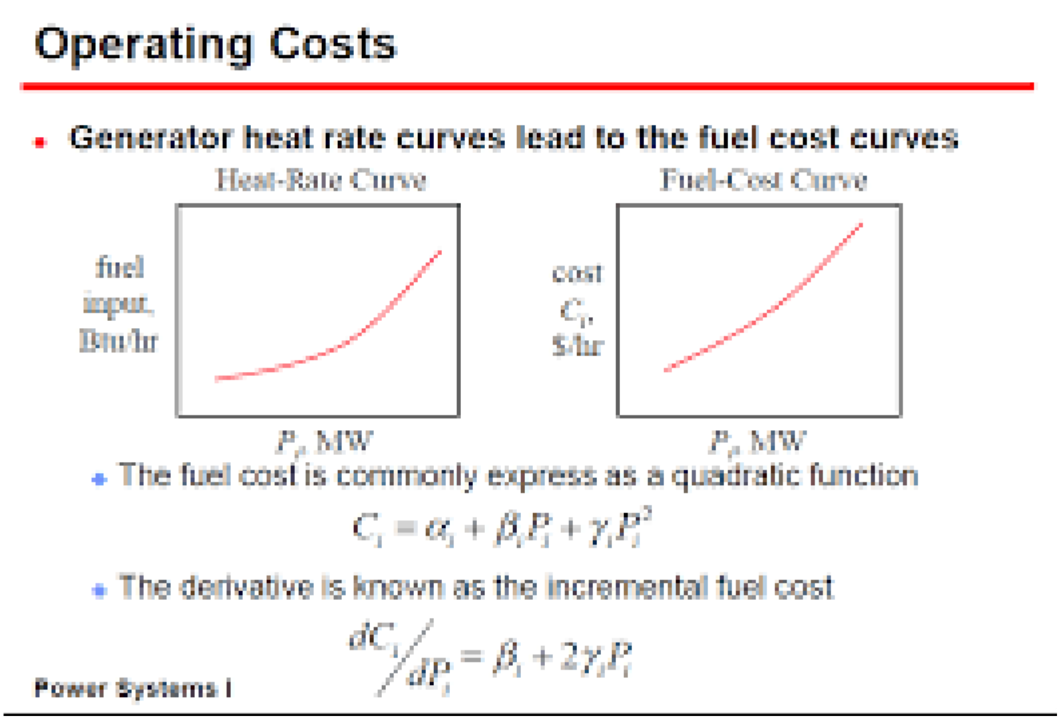
Unit V: Basic Pricing Principles: Generator Cost Curves, Utility Functions, Power Exchanges, Spot Pricing. Electricity Market Models (Vertically Integrated, Purchasing Agency, Whole-sale competition, Retail Competition), Demand Side-management, Transmission and Distributions charges, Ancillary Services. Regulatory framework

1. Topic: Generator cost curves

Generator cost functions in the state-of-the-art are derived based on input–output characteristics, efficiency, and fuel costs of the major energy contributors such as natural gas, coal, nuclear, and hydro/renewable. The input–output characteristic of a thermal generator is the ability to convert thermal energy into electrical energy; these data may be obtained from design parameters of that generator. The cost function for an ith thermal generator can be represented by equation (1), where a_{0i} ($/h) is its no-load cost to operate, and b_{1i} (MBtu/MWh) and b_{2i} (MBtu/MWh^2) are the quadratic coefficients of the thermal input–output curve of that generator with fuel cost F_i, expressed as $/MBtu. To obtain the quadratic cost coefficients for a generator, (1) relates to (2), where $F_i b_{2i}$ equals γ_i, $F_i b_{1i}$ equals β_i, and a_{0i} equals α_i. The cost function of hydro/ Renewable generators comprises only no-load cost because they are non-thermal units and do not have fuel costs associated with generating electricity.

$$C_i(P_i) = a_{oi} + F_i(b_{1i}P_i + b_{2i}P_i^2) \qquad (1)$$

$$C_i(P_i) = \alpha_i + \beta_i P_i + \Upsilon_i P_i^2 \qquad (2)$$



2. Topic: Utility functions

An **electric utility** is a company in the electric power industry (often a public utility) that engages in electricity generation and distribution of electricity for sale generally in a regulated market. Power & Utilities includes electricity power generation, transmission and distribution of a public service (Utilities), usually in the form of electricity, water and heating (gas), but depending on the jurisdiction, can include telecommunications and broadband services also. The major goals of an electrical utility can be broadly categorized into three: -

- Control the long-term costs of the electric system: The regulatory framework should promote a broad range of resources to increase the ratio of average to peak electric load, helping to right-size the electric system to customer's needs.
- Give customers more energy choices: The regulatory framework should allow customers to use emerging technologies and commercial arrangements to manage their energy production and use.
- Build a flexible grid to integrate more clean energy generation: The regulatory framework should promote the flexibility needed to allow the electric grid to incorporate an increasing proportion of variable clean energy through use of demand response and energy storage, for example.

Regarding the utility "Data Connectivity, i.e. telecommunications and broadband services" it can be stated that "the electric system of the 21st century will depend on operation of data networks to allow the utility to gain visibility and control of the electric system. Many of the functions associated with operation of a data network are outside the electric utility's traditional area of operations and include strategically important, but not capital intensive, software and service components. Taken together, these considerations may guide the inquiry into what the utility of the 21st century should do, how it should earn revenue, and what kind of metrics should shape its operation.

The potential functions of a twenty-first century electric utility may include:

- Reliability services, such as pole and line maintenance, circuit reconfiguration, supplemental power supply, undergrounding, power factor correction, distribution system engineering and voltage variation optimization.
- Connectivity services including operation of the communications backbone to support distribution line automation and to enable potential advanced metering functionality.
- Network integration services, such as scheduling, multi-directional power flow and management services, storage-based power "loan" services, electric vehicle charging services, and the necessary distribution system planning and data analysis for load,

voltage and hosting capacity.

- Transaction management services, such as aggregation, clearing and settlement among parties, integration of distributed energy resources and metering customers.
- Customer engagement services, such as home energy optimization, appliance automation, intelligent load management, backup energy services including energy storage, energy efficiency program delivery, customer support, low-income engagement and electric vehicle education.

Many of these functions are so connected with one another that they are best undertaken by a single enterprise. However, there may be functions that could be undertaken separately or which the electric utility may not be optimally organized to perform.

3. Topic: Power Exchange (PX)

A power exchange may refer to the entity that operates an electricity market at which electricity is traded. PX is a trading center where utilities, power marketers, and other electricity suppliers submit price and quantity bids to sell energy or services, and potential customers submit offers to purchase energy or services. Key points of a power exchange include:

• Facility for trading of electricity: This market place permits different participants to sell and buy energy and other services in a competitive way based on quantity bids and prices. Participants include utilities, power marketers, brokers, load aggregators, retailers, large industrial customers and co generators · PX is a new independent, non government and non profit entity which accepts schedules for loads and generation resources.

• Foster the development of competition: It provides a competitive market place by running an electronic auction where market participants buy and sell electricity and may do business quickly and easily. Through an electronic auction, PX establishes an MCP (marginal cost price) for each hour of the following day for trades between buyers (demands) and sellers(suppliers).

• Transparency: It submits balanced demand and supply schedules for successful bidders to ISO(Independent System Operator) and performs settlement functions with ISO as well as PX participants such as UDCs (Utility Distribution Companies), marketers, aggregators etc · It also submits ancillary service bids to ISO for maintaining system reliability , adjustment bids(may be used to relieve or eliminate congestion on transmission grid) · PX guarantees an equal and non discriminatory access and competitive opportunities to all participants.

• Liquidity: In this market place PX does not deal with small consumers. PX manages settlement and credit arrangements for scheduling and balancing of loads and generation resources.

4. Topic: Spot Pricing

There is a need for fundamental changes in the ways society views electric energy. Electric energy must be treated as a commodity which can be bought, sold, and traded, considering its time-and space-varying values and costs. A framework based on the use of spot prices is used for the establishment of such an energy marketplace. The spot price is the current market price at which an asset is bought or sold for immediate payment and delivery. That is a spot price is the price retailers pay when they buy electricity from the wholesale market. Spot prices change every hour and can vary quite dramatically depending on supply and demand balance.

In general terms: An hourly spot price (in dollars per kilowatt hour) reflects the operating and capital costs of generating, transmitting and distributing electric energy. It varies each hour and from place to place. The spot price based energy marketplace involves a variety of utility-customer transactions (ranging from hourly varying prices to long-term, multiple-year contracts), all of which are based in a consistent manner on hourly spot prices. These transactions may include customers selling to, as well as buying from, the utility. Some advantages of using spot pricing may be as follows:

- Any given level of system capacity will be used more efficiently, because price will reflect the operating cost of the marginal plant or the market-clearing price when demand would otherwise exceed capacity. When demand is slack, customers will benefit from the fall in price and be encouraged to expand consumption;
- when demand is high, price will rise to ration out available capacity. Because price can be used to ration capacity, less reserve capacity needs to be held to meet uncertain demand, so required investment is less and hence average costs and prices are lower.
- Because spot pricing more accurately reflects cost and demand conditions, it can be used as an efficient means of coordination in a decentralized system. Efficient merit order running can be secured without the need for integration of ownership and control.
- Large monopolistic generating companies can be replaced by smaller competitive ones, thereby securing the benefits of competition, notably greater efficiency and lower prices.
- In a less centralized system with spot prices, generating companies will acquire a better understanding of the needs and responsiveness of their customers, which will lead to better forecasting and investment policy.
- By flattening the load curve, spot pricing would facilitate system operations, and

thereby reduce operating costs.

- It would provide additional benefits, both to the utility and of a more general kind, via the establishment of a two-way communications network between utility and consumer.

The likely disadvantages of spot pricing have not been so clearly identified but the following may summarize a few:

- There will be the costs of repeatedly calculating and revising the spot price, informing customers, and metering and more finely billing usage.
- Many customers may initially be confused by the proposed approach.

5. Electricity Market Models

Market participants can avoid congestion charge by forming a pool and entering into financial contracts. A pool model with locational market prices defined for every node is often considered as an ideal market model as the nodal prices perfectly reflect all costs of supplying electricity at given nodes and, manage congestion at the same time.

Two main technical features determine the complexity of such models: the product ‘‘electricity’’ which cannot be stored and its transportation that requires a physical link (transmission lines). Proper market models, in most cases, must deal with imperfectly competitive markets, which are much more complex to represent. Some market models used in the power industry are as follows:

a. Vertical Market Model

The electric power industry has over the years been dominated by large utilities that had an overall authority over all activities in generation, transmission and distribution of power within its domain of operation. Such utilities have often been referred to as vertically integrated utilities. Such utilities served as the only electricity provider in a region and were obliged to provide electricity to everyone in the region. The typical structure of a vertically integrated electric utility is shown in figure 5.1 below. In the figure, the money flow is unidirectional, i.e. from the consumer to the electric company. Similarly, the information flow exists only between the generators and the transmission systems. In vertically integrated utilities, it was often difficult to segregate the costs involved in generation, transmission or distribution. So, the utilities often charged their customers an average tariff rate depending on their aggregated cost during a period.

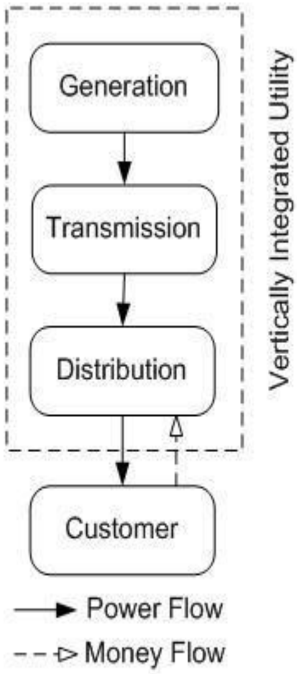


Figure 5.1: Vertically integrated market model

Demerits: -

- Generally one firm, once with a franchise.
- Regulators approve what utilities build. This may or may not be the lowest cost investment, and may or may not be technologically innovative.
- Traditional utility regulation accommodates the use of more debt, but limits innovation.
- Risk and return expectations will be relatively lower. This will affect what types of entities hold ownership stakes.
- Reduced need for marketing and business development. Largely focused on providing onesize-fits-all solutions for customers.

5.2 <u>Wholesale Competition Model</u>

This model is one step closer towards competition. There is an organized market in which the generators can sell their energy at competitive rates. The market may be organized either by a separate entity or may be run by the system operator itself. There is not much choice for the end user. The end user is still affiliated to the Discom (Distribution company) or retailer working in that geographical area of operation. The large customers or the bulk customers, so to say, are privileged to choose their energy provider. However, the definition of bulk customer is a subjective matter and changes from system to system.

This model, as shown in Figure 5.2, provides the choice of supplier to Discoms, along with competition in generation. Implementation of this model requires open access to the transmission network. Also, a wholesale spot market needs to be developed. Discoms can purchase energy for their customers either from a wholesale market or through long term contracts with generators.

The customers within a service area still have no choice of supplier. They will be served by a Discom in their area. With this model, the Discoms are under Universal Service Obligation (USO), as they have monopoly over the customers. They own and operate the distribution wires. The transmission network is owned and maintained either by government and/or private transmission companies. System operators manage the centrally accomplished task of operation and control.

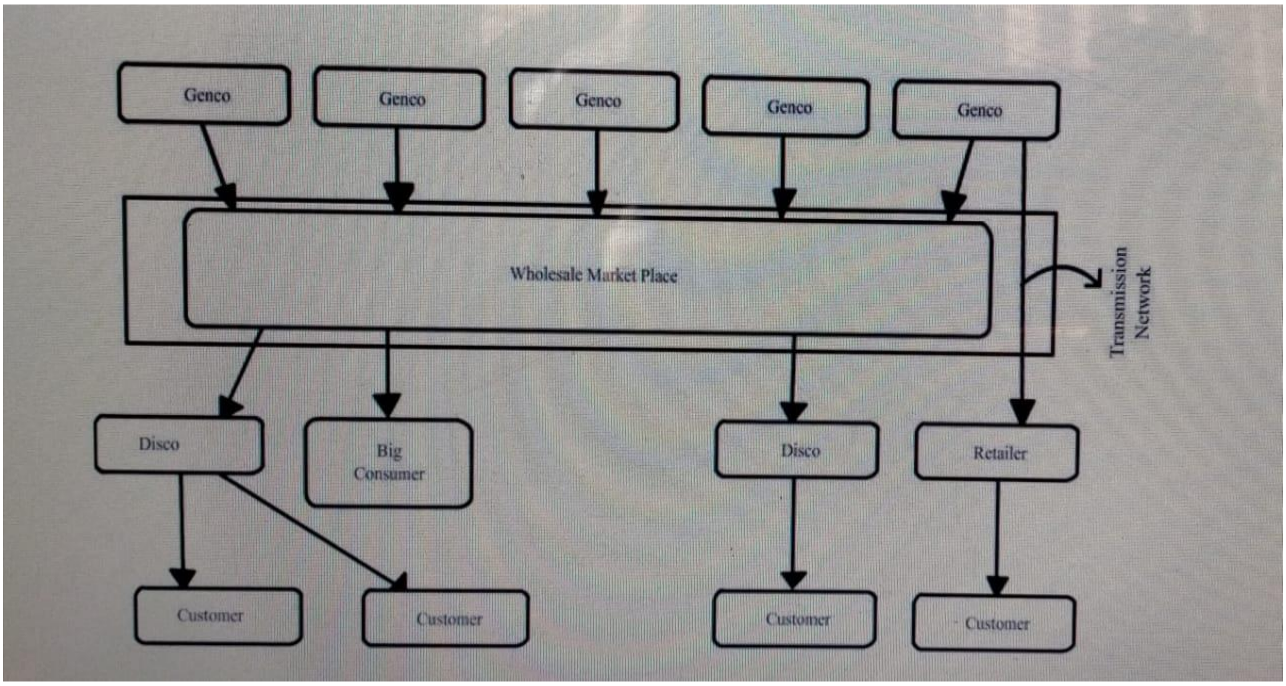


Figure 5.2: Wholesale Competition Model

The model provides a competitive environment for generators because the wholesale price is determined by the interaction between supply and demand. In contrast, the retail price of electrical energy remains regulated because the small consumers still do not have a choice for their supplier. The distribution companies are then exposed to vagaries of the wholesale price of the commodity. The merits and demerits of this model are as follows:

Merits: -

- Choice of seller provided for Discoms and bulk consumers.
- The buyers and sellers can make forward contracts or buy from a wholesale marketplace.
- The price is decided by interaction between demand and supply. Hence, indicates truly competitive price.

Demerits: -

- The end consumer still doesn't have a choice. It buys power from the affiliated Discom.
- Rates for end consumers are regulated rather than competitive.
- Discoms face competition at wholesale level, while their returns are regulated.
- Structural and institutional changes required at wholesale level.

5.3 Retail Competitive market

In this model, as shown in Figure 5.3, all customers have access to competing generators either directly or through their choice of retailer. This would have complete separation of both generation and retailing from the transport business at both transmission and distribution levels. Both, transmission and distribution wires provide open access in this model. There would also be free entry for retailers. In this model, retailing is a function that does not require the ownership of distribution wires, although, the owner of distribution wires can also compete as a retailer.

This model is a multi-buyer, multi-seller model and the power pool in this model acts like an auctioneer. It behaves like a single transporter, moving power to facilitate bilateral trading and this is achieved through an integrated network of wires. In this pooling arrangement, there is a provision for bidding into a spot market to facilitate merit order dispatch. The pool matches the supply and demand and determines the spot price for each hour of the day. It collects money from purchasers and distributes it to producers.

The advantage of this model over monopoly utilities is that competition is introduced in both wholesale and retail areas of the system. This model is supposed to be a truly deregulated power market model. The retail price is no longer regulated because small consumers can change their retailer for better price options. This model is economically efficient as the price is set by interaction of demand and supply. In wholesale competition model, with relatively few customers, all of them regulated Discoms, a spot market can be preferable but not essential.

However, in retail competition model, spot markets become essential, since contractual arrangements between customers and producers are carried out over a network owned by a third party. In retail competition model, metering becomes a major problem. If the number of customers is increasing and metering capability for all the customers is not sufficient, it may create logistical problem and provoke disputes.

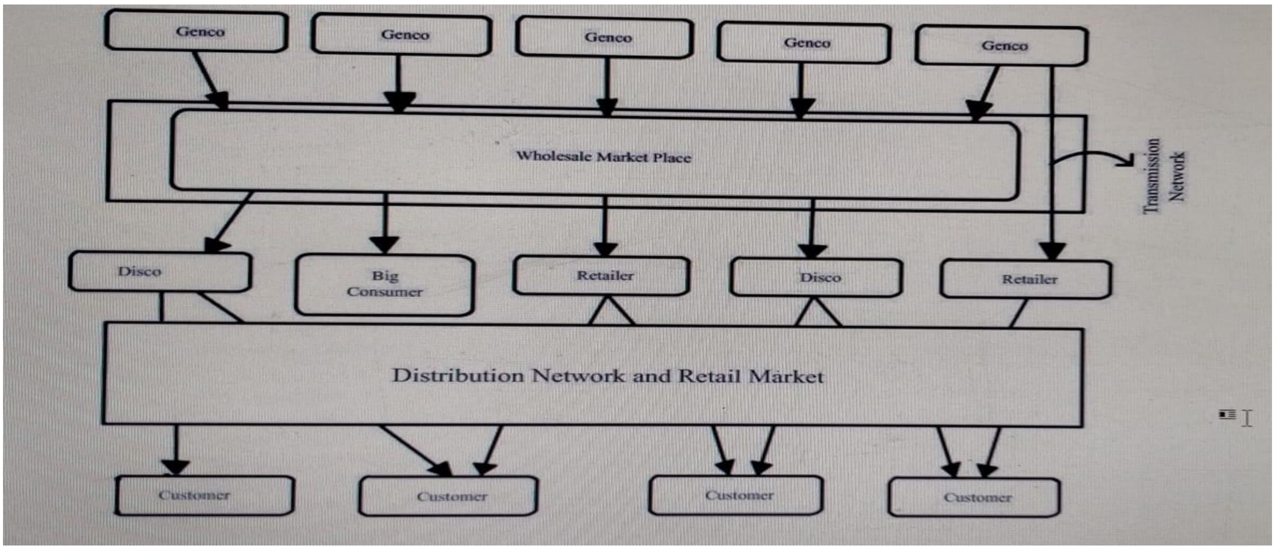


Figure 5.3: Retail Competition Model

Merits:

- Supposed to be 100% deregulated model.
- Every consumer has a choice of buying power.
- The price is decided by interaction of demand and supply. Hence, it is truly competitive price.
- There is no regulation in energy pricing.

Demerits:

- Need constitutional and structural changes at both, wholesale and retail level.
- Extremely complex settlement system due to large number of participants.
- Requirement of additional infrastructural support

6. Topic: Demand side Management

Demand Side Management (DSM) is used to describe the actions of a utility, beyond the customer's meter, with the objective of altering the end-use of electricity - whether it be to increase demand, decrease it, shift it between high and low peak periods, or manage it when there are intermittent load demands - in the overall interests of reducing utility costs. In other words, DSM is the implementation of those measures that help the customers to use electricity more efficiently and in doing so reduce the customers use and the utility costs.

DSM can be achieved through.

- Improving the efficiency of various end-uses through better housekeeping correcting energy leakages, system conversion losses, etc

- Developing and promoting energy efficient technologies, and

- Demand management through adopting soft options like higher prices during peak hours, concessional rates during off-peak hours seasonal tariffs, interruptible tariffs, etc.

DSM, in a wider definition, also includes options such as renewable energy systems, combined heat and power systems, independent power purchase, etc, that utility to meet the customer's demand at the lowest possible cost. Hence DSM can be achieved through energy efficiency by reducing energy consumption on the one hand and on the other hand by managing the load demand itself. The first may be achieved through awareness on use of energy efficient equipment on the part of consumer. Thus, it leads to conservation of energy. However, the latter calls for reduction in power demand or shifting it to off-peak hours. This can be achieved with utility providing incentive like time-of-use tariff giving rebate during off-peak. Of course, utility has a leading role always through its actions that effect quantity or pattern of energy consumption by the consumer through reduction of drawl during peak period. This will in turn help the utility to reduce investment for generation vis-à-vis transmission and distribution, as the case may be.

7. Topic: Transmission pricing

Federal Energy Regulatory Commission (FERC) recognized that transmission grid is the key issue to competition, and issued guidelines to price the transmission. The guidelines are summarized such that the transmission pricing would:

- Meet traditional revenue requirements of transmission owners
- Reflect comparability: i.e. a transmission owner would charge itself on the same basis that it would charge others for the same service.
- Promote economic efficiency.
- Promote fairness.
- Be practical.
- Even though transmission costs are small as compared to power production expenses and represent a small percent of major investor owned utilities' operating expenses, a transmission system is the most important key to competition because it would provide price signals that can create efficiencies

in the power generation market.

Transmission pricing methods:

1. Contract Path Method
2. MW-Mile method

1. **Contract Path Method:** · It has been used between transacted parties to price transmission where power flows are assumed to flow over a predefined path(s). · Despite its ease, this technique was claimed be a bad implementation of true transmission pricing as power flows would very seldom correspond to predefined paths. · Physically, electrons could flow in a network over parallel paths owned several utilities that may not be on the contract path. · Parallel path flows refer to the unscheduled transmission flows that occur on adjoining transmission systems when power is transferred in an interconnected electrical system. · As a result, transmission owners may not be compensated for the actual use of their facilities. · Added to parallel flows, the pancaking of transmission rates is another shortcoming of this method. · Pancaking is when contract path crosses a boundary defining transmission ownership, additional transmission charges would be added to a transaction, which in turn might increase the price of the transaction. · In-efficient method

2. **MW –Mile method:** · Several ISOs are using a MW-Mile approach to price transmission. · The MW-Mile rate is basically based on the distance between transacted parties (from the generating source to the load) and flow in each line resulted from the transaction. · This approach takes into account parallel power flows and eliminates the previous problem that transmission owners were not compensated for using their facilities. · This approach does not give credit for counter-flows on transmission lines. · The method is complicated because every change in transmission lines or transmission equipment requires a recalculation of flows and charges in all lines.

8. Topic: Ancillary Services

Ancillary services are defined as services which are required to support the transmission of capacity and energy from resources to loads while keeping a reliable operation of the transmission system of a transmission provider in accordance with Good utility practice.

Ancillary services are the specialty services and functions provided by the electric grid that facilitate and support the continuous flow of electricity so that supply will continually meet demand. The term ancillary services is used to refer to a variety of operations beyond generation and transmission that are required to maintain grid stability and security. These services generally include, frequency control, spinning reserves and operating reserves. Traditionally ancillary services have been provided by generators, however, the integration of intermittent generation and the development of smart grid technologies have prompted a shift in the equipment that can be used to provide ancillary services.

A large number of activities on the interconnected grid can be termed as ancillary services. However, in order to remove this large discrepancy, the North American Electric Reliability Council (NREC)
along with Electric Power Research Institute (EPRI) has identified 12 functions as ancillary services.

These are:

1. **Regulation:** The use of generation or load to maintain minute-to-minute generation-load balance within the control area.
2. **Load Following:** This service refers to load-generation balance towards end of a scheduling period.
3. **Energy Imbalance**: The use of generation to meet the hour-to-hour and daily variations in load.
4. **Operating Reserve (Spinning):** 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 for several minutes.
5. **Operating Reserve (Supplemental):** The provision of generating capacity and curtailable load to correct for generation-load imbalances, caused by generation and /or transmission outages, and that is fully available for several minutes. However, unlike spinning reserves, supplemental reserve is not required to respond immediately.
6. **Backup Supply:** This service consists of supply guarantee contracted by generators with other generators or with electrical systems, to ensure they are able to supply their consumers in case of scheduled or unscheduled unavailability.
7. **System Control:** This activity can be compared with the functions of the brain in the human body. System control is all about control area operator functions that schedule generation and transactions and control generation in real time to maintain generation load balance.
8. **Dynamic Scheduling:** It includes real-time metering, tele-metering along with computer software and hardware to virtually transfer some or all of generator's output or a customer's load from one control area to another.
9. **Reactive Power and Voltage Control Support:** The injection or absorption of reactive power

from generators or capacitors to maintain system voltages within required ranges.

10. **Real Power Transmission Losses:** This service is necessary to compensate for the difference existing between energy supplied to the network by the generator and the energy taken from the network by the consumer.
11. **Network Stability Services from Generation Sources:** Maintenance and use of special equipment (e.g., PSS, dynamic braking resistances) to maintain secure transmission system
12. **System Black Start Capability:** The ability of generating unit to proceed from a shutdown condition to an operating condition without assistance from the grid and then to energize the grid to help other units start after a blackout occurs.

It should be noted that identification and definition of a particular ancillary service is system dependent. There is no global definition of a particular ancillary service that is applicable in all systems.

References

1. Y. Bichpuriya, S. A. Soman, “Electric Power Exchanges: A Review”, NATIONAL POWER SYSTEMS CONFERENCE, 15th-17th DECEMBER, 2010.

2. Littlechild, S. C. (1988). *Spot pricing of electricity Arguments and prospects. Energy Policy, 16(4), 398–403.* doi:10.1016/0301-4215(88)90187-5.

3. K.Bhattacharya, M.H.J.Bollen and J.E.Daader, "Operation of Restructured Power Systems", Kluwer Academic Publishers, 2001.

4. Mukhopadhyay, S., & Rajput, A. K. (2010). *Demand side management and load control — An Indian experience. IEEE PES General Meeting.* doi:10.1109/pes.2010.5589589.

5. Dutta, G., Mitra, K. A literature review on dynamic pricing of electricity. *J Oper Res Soc* **68,** 1131–1145 (2017). https://doi.org/10.1057/s41274-016-0149-4.

6. https://www.tdworld.com/data-analytics/what-functions-should-electric-utilities-perform**, 2018**