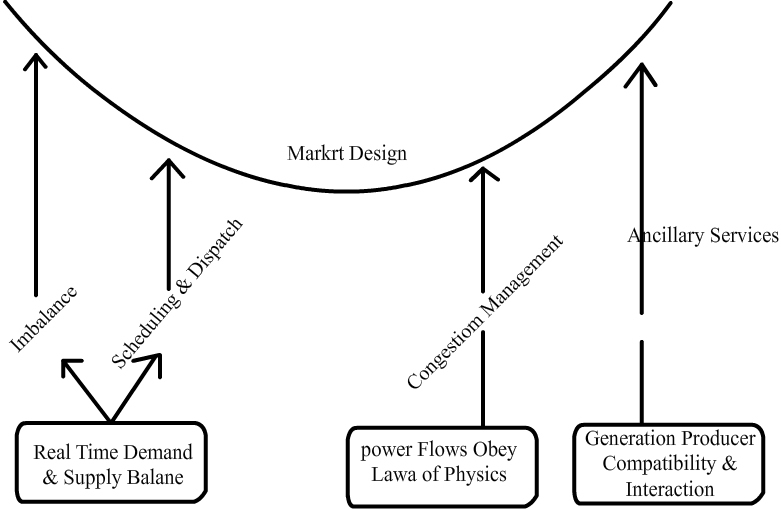
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| The classification of market models based on contractual agreements can be applied to most of the commodities that are traded in the market, if we assume a certain level of abstraction by presenting only the buyers and sellers. However, when it comes to ‘electricity' as a commodity, the same laws of economics or commercial trade arrangements may not hold good. This is because, electricity as a commodity bears different characteristics from other commodities, or rather, electricity is physically different from other commodities. This fact complicates the procedure of electricity trading. In other words, the trade is not as simple as an interaction between two entities: buyer and seller. The interdependencies of actions taken by various participants (primarily generators and loads), mandate somebody to take over the control of real time activities. This somebody is the system operator, who makes sure that the whole system runs reliably and thus kept in synchronism. Thus, it is worthwhile to understand the distinguishing features of electricity as a commodity,  D**istinguishing Features of Electricity as a Commodity** |
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| There are three basic distinguishing features of electricity. These are associated with electricity due to its physical nature. These three basic features effectively lead to one distinguishing feature of this commodity, the one that has commercial implications. Let us see these in details |
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| Real Time Demand Supply Balance |
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| Electricity can not be stored in bulk. Other commodities can be manufactured and kept in a warehouse until the demand for the same is sensed. A manufacturer of other commodities gets sufficient flexibility in planning the manufacturing activity and coordinating the dispatch. The same is not true for electricity. The demand for electricity needs to be satisfied on real time basis. |
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| The parties involved in electricity trade perhaps would like to do it through forward contracts . These can be contracts for physical delivery or financial in nature. In many power markets, bulk trade of electricity (> 80%) is done through forward contracts. Forward contracts can be done years ahead. When a certain amount of electricity is bought in the forward contract, it is the estimate of the buyer, how much it is likely to consume during actual delivery time. However, in real time, the actual consumption may not match the predicted consumption that had been forecasted at the time of doing forward trade. This difference is called as imbalance. Knowledge about this imbalance is exposed only during real time operation or slightly before that. In this case, the system operator or some other market mechanism stands ready to make up the imbalances (either on positive or negative side). |
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| Due to storage limitation, the supply-demand matching decision needs to be done on a competitive basis by letting supply and demand interact with each other. The operator buys and sells these imbalances through some commercial mechanism. Due to this feature of electricity, an issue related to the speed of operation pitches in. The system operator, while making a provision for imbalances, has to take into consideration various network interdependencies. The system operator always has to communicate with the active participants to tell them which generators should increase their output and which ones should decrease it. This activity is called scheduling in advance and dispatch in real time. Since the system operator has to work with seconds to spare, a delivery system to make up for imbalances has to be in place. In real time, the only time available with system operator is what is allowed by the energy stored in rotating masses of huge interconnected grid. |
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| Thus, this exceptional feature of electricity leads to two issues related to power market design: Imbalances and Scheduling and Dispatch. The question is how these difficult tasks get reflected in the rules of marketplaces. |

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| **Power Flows Obey Laws of Physics** |
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| The electric power can not be told as to where and how it should travel, once the injection and take-off points are decided. The electric power flow over transmission lines obey laws of physics. Effectively, electric power can not be stopped from flowing on a transmission line that is already hitting its power carrying capacity. The system operator has to ensure that none of the lines get overloaded. To do this, only freedom left with it is the selection of pattern of nodal injections (either generation or load). |
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| Thus, any arbitrary set of forward contracts can not be scheduled by the system operator as this may lead to exceeding of limits of physical parameters of some of the power system elements. Allowing only the practically feasible set of transactions during scheduling and further making corrections while dispatching so as to keep line loadings within limits is usually termed as congestion management. |
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| The concept of network congestion is shown by a simple lossless system in Figure 3.6. In this, generator A is a cheaper generator than generator B and hence, it gets a contract of satisfying the demand of load at bus 3 by generating 18 MW. The dispatch would be as shown in Figure 3.6(A). The power flow over all lines would be dictated by the reactance of parallel paths. In this case, let us assume that reactance of all three lines are same. Thus, two parallel paths are provided so as to transfer power of generator A to load at bus 3, with ratio of reactance 2:1. Obviously, the power will flow in opposite ratio on these paths. The flows are shown in Figure 3.6(A). However, if the physical properties of the line connecting nodes 1 and 2 state that it can carry only 3 MW, then the dispatch shown in Figure 3.6(A) left hand side is not practically feasible. To correct it, generator B is asked to generate 4.5 MW and generator A is asked to step down by 4.5 MW, leading to dispatch shown in Figure 3.6(B). This rearrangement of nodal injections is one of the means of congestion management, which is peculiar to electricity. |
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| https://nptel.ac.in/content/storage2/courses/108101005/philosophy%20of%20market%20models/image/6.jpg |
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| **Figure 3.6: Concept of network congestion** |
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| **Generator Product Compatibility and Interactions** |
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| To ensure reliable delivery of electricity, only generation by generators at injection points and take-off by loads at take-off points is not sufficient. The system operator must make arrangements for provision of allied services necessary to do this. These allied services are usually referred to as the ancillary services. Provision of reactive power, operating reserves are some of the commonly required ancillary services. Mostly, ancillary services are provided by generators. In this case, one is likely to witness the interdependencies involved in providing these services. In other words, the production of ancillary services is also dependent on production of energy. Then, the same generator is said to be providing two different products: energy and ancillary services. |
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| This complicates the matter because the single generator can be simultaneously needed to produce multiple outputs, or to produce ancillary service rather than energy. This complication is shown in Figure 3.7, where, a generator's capacity is divided into various products. The defining question is how much of capacity should be allocated to each product? In centralized markets (explained later), the system operator does a joint optimization, taking into account various technical and commercial parameters of a generator to allocate it's full capacity to each of the products. module 6 is devoted to ancillary service management where these issues will be discussed more elaborately. |
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| **Figure 3.7: Generation capacity allocation to various products** |

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| **Unusual Price Variation** |
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| The combined effect of various peculiarities of electricity is that it has large temporal variation in its price. It is not prudent to run all generators throughout the day. Rather, the most economical generators can be run throughout the day. Effectively, the price of electricity will be low during low demand period. However, during peak demand situation, the costly generators are brought on-line and the price of electricity goes high. Thus, marginal cost of producing energy will vary throughout the day. Such rapid cyclic variations in the price of a commodity are unusual, and arise due to peculiarities associated with electricity, basically, the characteristic of matching supply and demand on real time basis. It should be noted that this peculiarity of electricity has arrived because of one of the basic physical properties associated with it. |
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| **Effects of Peculiarity: Four Pillars of Market Design** |
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| We have seen the characteristic features of electricity when compared with other commodities. How do these affect the trading activities of this commodity? For example, what if network congestion does not allow a set of transactions to be feasible? Should the generator sell its generation capability in a single market that makes provision for energy as well as reserves, or should there be different markets for the same? Some subtle questions like these provide food for thought when designing criteria of markets are to be determined. |
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| Hunt in [1] has described the design issues arising out of characteristics of electricity as pillars of market design. These are: |
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| * Imbalance * Scheduling and Dispatch * Congestion Management * Ancillary Services |
| Figure 3.8 shows four pillars of market design arising due to the basic characteristics of electricity. |



The design of market revolves around the four pillars described above. It also depends on how and where these issues are accommodated in the whole process of market mechanism. Some of the pillars lead to creation of separate markets. Eventually, this gives rise to the issue of market architecture, which is nothing but arrangement and classification of these markets. Finally, these markets can be integrated into one efficient market or there can be cascaded markets.

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| **Framework of Indian power sector** |
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| India is a country with large geographical span with equally complex power network. Today’s power sector is a result of years of generation and transmission planning as well as the distribution development. A large number of government bodies is associated with the Indian power sector. Further, there are operational responsibilities which are entrusted with system operators at various levels. All these entities taken together form a framework for the power sector which is huge and complex in nature. This section elaborates on various aspects of the framework of Indian power sector. |
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| **Historical Developments** |
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| The power development in the country started with small isolated power systems. In the evolution of grid, these small power systems were interconnected to form state grids. In the seventies, the inter-connection of state grids with each other began in order to exchange surplus power available occasionally. |
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| In the eighties, the Government of India (GOI) stepped into power development on a regional basis by dividing the country into five regions. The GOI utilities had set up large pit-head power stations and allocations from these power stations were given to all the states within the region. These stations are typically known as Inter-State Generation System (ISGS). The Central utilities also developed the transmission network for evacuating the power from the Central stations to the state grids as well as inter-state / inter-regional network. This transmission network is known as Inter-State Transmission System (ISTS). The development of ISGS and ISTS led to continuous parallel operation of the state grids with each other, thus forming a synchronous regional grid. Subsequently, the opportunity available for exchanging seasonal surpluses as well as infirm power available during certain hours of the day due to diversity of peak demands induced the need for development of regional interconnections. Since different regional grids were operating at different frequencies which were widely varying, the favored regional interconnection mode is through HVDC back to back links. Such links enable the connection of two grids operating at different frequencies and the isolation of disturbances from one region to the other. |
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| The distribution system, right from its inception was owned and operated by respective State Electricity Boards (SEBs). However, the private sector has also existed in India in select cities like Mumbai, Kolkata and Ahmedabad which were run by private companies, continued to run by those private companies. Today, various private utilities like Tata Power Company Ltd. (TPC), Reliance Energy Ltd. (REL), Brihan-Mumbai Electric Supply and Transport (BEST), Calcutta Electric Supply Company Ltd. (CESC) and Noida Power Company Ltd. (NPCL) account for 5-10% of the total distribution market. Torrent Power has recently acquired 10 year distribution franchisee license in one of the lossy circles in Maharashtra . The end consumer, in sense, has remained indifferent to the activities / changes occurring at higher grid level like grid-inter-connections, regional exchange of power etc., largely due to vertically integrated structure and regulated tariff. |
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| **The Institutional Framework** |
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| In India, the governments at two levels, central government, i.e., GOI and various state governments have been vested with powers to make laws and regulations on various issues. The Ministry of Power (MoP) under the GOI formulates the national power policy for the entire country. The Central Electricity Authority (CEA) frames a national electricity plan (NEP) every five years and revises the same from time to time in accordance with the NEP. The NEP suggests locations for capacity additions in generation, transmission, and load center requirements. The plan deals with grid standards, security of supply, quality of power, and environmental considerations. It also coordinates the activities of various planning agencies for the optimal utilization of resources. The functions of various central sector institutions under the overall supervision of MoP are depicted in Table 1. |
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| |  |  | | --- | --- | | **Ministry of Power (MOP)** | | | Central Administrative Tribunal (CAT) | To adjust / arbitrate in any matter of dispute | | Central Electricity Authority (CEA) | National power planning | | Regional Electricity Board (REB) | Coordination, planning and security studies of SEBs | | Central Electricity Regulatory Commission (CERC) | Tariff, legal and regulatory issues | | Power Grid Corporation of India Ltd. (PGCIL) | Central transmission utility and grid operator | | National Load Dispatch Center (NLDC) | Operation of all regional links | | Regional Load Dispatch Center (RLDC) | Regional grid operation | | Power Finance Corporation Ltd. (PFCL) | Funding | | Rural Electrification Corporation (REC) | To finance and promote rural electrification | | Power Trading Corporation (PTC) | Power trading | | National Thermal Power Corporation (NTPC) | Thermal generation | | National Hydro Power Corporation (NHPC) | Hydro generation | | Neyveli Lignite Corporation (NLCL) | Lignite generation | | Nuclear Power Corporation of India Ltd. (NPC) | Nuclear generation | | Bureau of Energy Efficiency (BEE) | Estimate energy conservation and DSM potential | | Central Power Research Institute (CPRI) | Training and research | | National Power Training Institute (NPTI) | Training and research | | Ministry of New and Renewable Energy Sources (MNRES) | Renewable energy development | |
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| **Table 1: GOI owned / managed institutes / organizations** |
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| The National Thermal Power Corporation (NTPC) represents the largest generating company owning thermal generating plants (coal and gas). The responsibility of operating the regional grid is vested with the Regional Load Dispatch Centers (RLDC). The nuclear power generation is solely handled by the Nuclear Power Corporation of India Ltd. (NPCIL). The Central Electricity Regulatory Commission (CERC) regulates the tariff pertaining to central sector generation and transmission facilities. Similarly, the State Electricity Regulatory Commissions (SERC) regulate the end consumer tariff for that state, as well as the tariff of the state government owned generation and transmission facilities. The power development in the states is mainly handled by the vertically integrated state electricity boards (SEBs) or, recently, by the unbundled entities of SEBs in many of the states. In some states, private sector utilities (like Tata Power Company, Reliance Energy, etc.) have been given licenses for power generation, transmission, and distribution. Power trading is a licensed activity and the Central Electricity Regulatory Commission (CERC) has issued licenses to twenty two traders for the interstate trading of power. The PTC India is a government of India initiated public-private partnership trading company. |
| Operational Demarcation of the Power System |
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| So long as government owned assets are concerned, these are either owned by GOI or the State governments. The assets include generation, transmission and distribution facilities. Similarly, the operational activities are also demarcated into regional grid operation and state grid operation. The block schematic of ownership of assets and operational responsibilities is shown in Fig. 1. The figure shows hierarchy of grid operation and the owner of the corresponding segment. |
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| The Indian power system is operated with five regional grids as follows: Northern Regional (NR) grid, Western Regional (WR) grid, Eastern Regional (ER) grid, Southern Regional (SR) grid, and North-Eastern Regional (NER) grid. The regional grids demarcated on the map of India are shown in Fig. 2. Every region has a regional load dispatch center which operates the regional transmission grid as well as schedules the ISGS of that region. A regional grid comprises of many states. For example, the WR grid has seven constituent states: Gujarat, Madhya Pradesh, Chhattisgarh, Maharashtra, Goa, Dadra-Nagar-Haveli and Daman-Diu. The state owned grids are inter-connected via regional transmission grid, most of |
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|  |
| Figure 1: Hierarchical structure of Indian power sector |
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| https://nptel.ac.in/content/storage2/courses/108101005/reforms%20in%20indian%20power%20sector/images/2.jpg |
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| Figure 2: Five regional grids of India |
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| which is owned by the PGCIL, that acts as a CTU. The regional transmission grid is predominantly built up of 400 kV lines. Recently, some 765 kV lines also have been commissioned. Some of them are being operated on 400 kV. Most of the states have their own generating stations as well as transmission network. Except for some private utilities, most of the distribution network is owned and operated by state electricity boards or the unbundled companies of respective electricity boards. The state transmission grid forms the bottom most layer of the transmission network hierarchy. |
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| https://nptel.ac.in/content/storage2/courses/108101005/reforms%20in%20indian%20power%20sector/images/3.jpg |
|  |
| Figure 3: Regional interconnections in India |
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| The central sector power stations, i.e., ISGS are connected to ISTS. ISTS is alternatively known as regional transmission network. Finally, the topmost layer of the grid is the inter-regional transmission system. This is also owned by PGCIL. The inter-regional exchanges are coordinated and monitored by the NLDC. The regions are connected to each other, forming a national grid either through asynchronous links (HVDC back-to-back) or ac links to enable power exchange as shown in Fig. 3. |
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| National and Transnational Grids |
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| The plan of regional interconnection led to the formation of a national grid. As a first step in this direction, the 400-kV Raipur-Rourkela double circuit line connecting ER and WR was commissioned. In 2003, ER-NER grids were synchronously connected with the WR grid forming a central grid. Further, in 2007, WR and NR were interconnected synchronously and at the same time, ER and NR were connected through a synchronous tie-line. Hence, at present, two synchronous grids, NR-WR-ER-NER and SR operate in the country. SR is connected with various other grids with various asynchronous links. This national grid helps in tapping the least-cost energy resources, which are unevenly distributed over the various regions. In addition to this, the national grid facilitates the use of regional peak diversity. |
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| Currently, India and Nepal exchange power over a number of 33-kV and 132-kV lines connected to NR and ER in a radial manner. Plans are to develop hydro potential in Nepal in coordination with India and to export surplus power to India. Presently, the Chukka Power Project and Khirinchu Power Project in Bhutan are connected with ER for the evacuation of power. The 1,020-MW Tala Power Project in Bhutan connects NR and the central grid with Bhutan. Discussions are also under way for the formation of the South Asian Association for Regional Cooperation (SAARC) grid covering the power systems of India, Pakistan, Nepal, Bhutan, Bangladesh, Sri Lanka, and Maldives. Plans are also under discussion for the transfer of gas by pipelines from Bangladesh to India and from Iran/Central Asian countries to India through Pakistan and Afghanistan. |