Power Flow Management And Pricing In Restructured Power System

A Project Report

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AKHYAY DEURI, EE13B066

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THESIS CERTIFICATE

This is to certify that the thesis titled **Power Flow Management And Pricing In Restructured Power System**, submitted by **Akhyay Deuri, EE13B066**, to the Indian Institute of Technology Madras, for the award of the dual degree of **Bachelor of Technology and Master of Technology**, is a bona fide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Dr. K. Shanti Swarup
Professor
Dept. of Electrical Engineering
IIT Madras, 600036

Place: Chennai

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I would like to begin by thanking my guide, Prof. K. Shanti Swarup for all his help, support and patience throughout the course of my project work. His approach and dedication to research has been incomparable and has always inspired me to keep pushing myself. All the students in the Power Systems Lab have been immensely cooperative, friendly and accommodating and have greatly inspired my own work.

ABSTRACT

The power flow through a transmission network must happen in an optimal way.The optimal power flow must follow the constraints of the network and the power supply and at the same time it should minimize the cost of operation of the generators. It becomes an optimization problem with objective of minimizing the cost of operation and constrained by network and power supply parameters. We use power world simulator to solve this optimization problem.

We also calculate various circuit parameters such as power transfer distribution factor,line outage distribution factors available transfer capacity. Power transfer distribution factors (PTDFs)describe how the real power flows change if power injection is shifted from one node to another. Correspondingly, line outage distribution factors (LODFs) describe the flowchanges when one line fails. PTDFs and LODFs are heavily used in the planning, monitoring and analysis of power systems, for instance like security analysis and contingency screening. PTDF is also called a sensitivity because it relates the amount of one change - transaction amount - to another change - line power flow. Available Transfer Capability (ATC) is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses.

The last chapter deals with electricity transmission pricing based on tracing based point-of-connection tariff for Indian power system. Point-of-connection tariff is payment at one point, the point of connection, gives access to the whole network system, and thus the whole electricity market place. Those entities who take part in power market activity (generators, loads), pay a single charge in Rs/MW towards network usage.

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ABBREVIATION

1. PTDF - Power Transfer Distribution Factor
2. LODF - Line Outage Distribution Factor
3. ATC - Available Transfer Capacity
4. GenCos - Generation Companies
5. TransCos - Transmission Companies
6. DisCos - Distribution Companies
7. PX - Power Exchange
8. ISO - Independent System Operator
9. AC - Alternating Current
10. DC - Direct Current

CHAPTER 1

Introduction

Electricity markets throughout the world continue to be opened to competitive forces. The underlying objective of introducing competition into these markets is to make them more efficient. Ideally, if fair and equitable market structures are created, which give all market participants incentives to maximize their own individual welfare, then the market as a whole should behave in a manner which maximizes the net welfare to society. However in order to access the efficiency of the markets and to forecast energy prices throughout the market it is expedient to be able to model the expected optimal behavior for these markets.
Determination of the optimal solution of power markets requires the need to consider the numerous physical constraints imposed on the market by the transmission system. The solution of this problem requires the use of an optimal power flow (OPF) algorithm. The goal of the OPF is the minimization (or occasionally maximization) of some objective function, subject to a variety of equality and inequality constraints. Often the objective function consists of the total generation cost in some set of areas, while the equality and inequality constraints include the power flow equations, generation/load balance, generator Mvar limits, branch flow limits, and transmission interface limits.Overall the LP based methods iterate between solving the power flow to take into account system non-linearities and solving an LP to redispatch the control variables subject to certain equality and inequality constraints.

Next part of the thesis deals with valuating market power in congested power system.A linear programming algorithm is used for determining a measure of market concentration in congested transmission systems. The linear program uses the effects of the congestors on the system to derate the line limits of each transmission line. The derated line limits allow for the congestor's contribution to the system flows to be taken into account when examining the available market for additional buyers and sellers in the system. The linear program uses transmission line constraints with derated line limits and generation constraints to calculate the maximum simultaneous interchange capability for a group of buyers and sellers on the system. The results of the linear program provide information regarding the maximum amount of power the buyers can import, as well as the amount of generation each seller can provide towards the simultaneous interchange.

In a vertically integrated market, the inter-area tie lines are designed only to address the reliability, system security and system restoration purposes. This integration of various systems becomes a market need in the deregulated era. Thus, inter-area tie lines become means of bulk power transfers on a regular basis from sources of cheap generation to loads. In other words, due to deregulation, the paradigm of grid integration has shifted from regional self-sufficiency to optimal utilization of resources across large geographical areas. Thus, it becomes imperative on the part of system operator to quantify the Available Transfer Capability (ATC) of the network and allocate the same to the market participants in an efficient manner.We use power world simulator to model calculate Available Transfer Capability of the network.

Congestion is also central to the issue of transmission tariffs, that is, how much is paid, and by whom, for the use of the transmission system. There are three aspects to the tariff issue in transmission management. The first is to ensure that there is sufficient revenue to cover the costs of the transmission system operators and the transmission system owners (who may not be the same). While covering operating costs is generally not a problem, the revenue stream must also motivate efficient transmission construction, a problem that is not as easily solved. The second aspect of transmission tariffs is that they can be used in various ways to manage congestion. They can send real time or ex ante price signals to transmission system users to control congestion operationally, and they can send long term price signals to motivate siting of new generators or major loads. The final aspect of transmission tariffs is that they can be used to bias the decentralized, unconstrained optimization process in the energy market to account for the physical phenomenon of transmission losses.

Losses are the last, but not the least, concern in transmission management. While they may be included in tariffing, they can also be treated separately, and a variety of approaches to loss management have appeared. Although loss effects may appear small compared to other potential sources of market inefficiency, they should certainly be handled as efficiently as possible.

Congestion management remains the central issue in transmission management in deregulated power systems. Without firm control of congestion, the operation of the transmission system can be compromised by the actions of market participants who do not have an economic stake in its security and reliability. Without careful attention to the interaction of congestion management and the economics of the energy market, market inefficiencies can take away the savings deregulation promises to society.

The last section of the thesis deals with electricity transmission pricing of tracing based Point-of-Connection tariff for Indian power system.Two commonly employed philosophies for transmission pricing in the de-centralized markets are: Point-to-point tariff and the point-of-connection (POC) tariff. The point to point tariff is also called transaction based tariff which is specific to a particular sale of power from named seller to a named buyer. Various versions of MW-Mile, postage stamp and contract path methods essentially represent the class of point-to-point ex-ante transmission pricing schemes.POC tariff is employed in the Nordic pool [6]. The basic principle of POC tariff is that payment at one point, the point of connection, gives access to the whole network system, and thus the whole electricity market place. Those entities who take part in power market activity (generators, loads), pay a single charge in Rs/MW towards network usage. This charge is decided by the connection level of that particular entity. The POC tariff depends on the characteristics of the individual seller or buyer. The distinguishing feature of POC tariff is that it can be applied to power exchange (PX) trades as well as bilateral transactions between two parties.

CHAPTER 2

Deregulated Power System and Power Flow Management

2.1 Introduction

Electric deregulation is the process of changing rules and regulations that control the electric industry to provide customers the choice of electricity suppliers who are either retailers or traders by allowing competition. Deregulation improves the economic efficiency of the production and use of electricity. Due to competition in the electric industry, the power prices are likely to come down which benefits the consumers. The main objectives of the deregulated power market are:

1. To provide electricity for all reasonable demands.
2. To encourage the competition in the generation and supply of electricity.
3.To improve the continuity of supply and the quality of services.
4. To promote efficiency and economy of the power system.

The important concepts of deregulation are :

1. Competition: The competition is at two levels in deregulated power industry: Wholesale (generation) and retail (distribution).
2. Deregulation: The rules governing the electric power industry are changed. The new structure introduces competition into the market, in place of a few large regulated companies.
3. Open Access: In deregulation of power system the Independent Power Producers (IPP) are permitted to transmit the power using utility transmission and distribution systems.

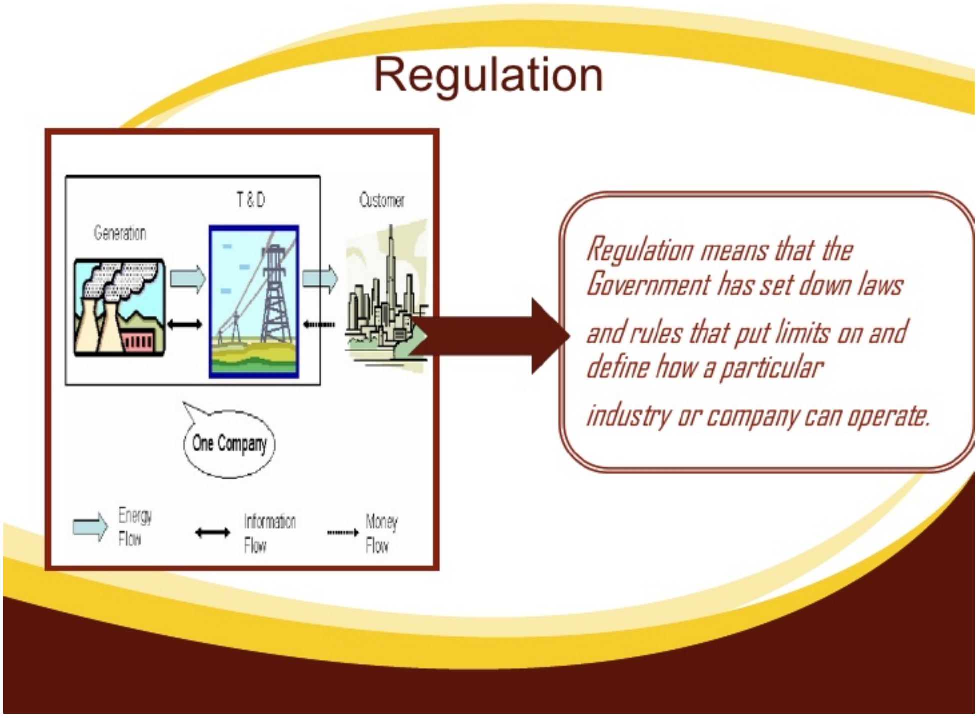

Figure 2.1: Regulated Power System

2.2 Reasons for Deregulation

If the power industries worked successfully with the regulated monopoly framework for over 100 years, what was the need for deregulating or changing the business framework of the system? There are many reasons that fuelled the concept of deregulation of the power industry. One major thought that prevailed during the early nineties raised questions about the performance of monopoly utilities. The takers of this thought advocated that monopoly status of the electric utilities did not provide any incentive for its efficient operation. In privately owned utilities, the costs incurred by the utility were directly imposed upon the consumers. In government linked public utilities, factors other than the economics, for example, treatment of all public utilities at par, overstaffing, etc. resulted in a sluggish performance of these utilities. The economists started promoting introduction of a competitive market for electrical energy as a means of benefit for the overall powerector. This argument was supported by the successful reform experiences of other sectors such as airlines, gas, telephone, etc.

Another impetus for deregulation of power industry was provided by the change in power generation technology. In the earlier days, cost-effective power generation was possible only with the help of mammoth thermal (coal/nuclear) plants. However, during the mid eighties, the gas turbines started generating cost effective power with smaller plant size. It was then possible to build the power plants near the load centers and also, an opportunity was created for private players to generate power and sell the same to the existing utility. This technology change, supposed to have provided acceleration to the concept of independent power producers, supported the concept of deregulation further. This technology change is supposed to have provided acceleration to the concept of independent power producers. This further supported concept of deregulation. This was specifically true where the financial losses were apparently high which was prevalent in some of the developing countries.

It should be noted that these are the indicative or major reasons for introducing the concept of deregulation in power industry. There are many other reasons as well. One of the important reasons is the condition under which power systems were regulated, did not exist any more. There was no wind of skepticism about the electrical technology and all the initial investments in infrastructure were already paid back. Further, the deregulation aims at introducing competition at various levels of power industry. The competition is likely to bring down the cost of electricity. Then, the activities of the power industry would become customer centric.

2.3 Benefits of the Deregulated Power System

1. Systems capacity will be used efficiently.
2. Optimization of energy supply will takes place.
3. Price of the electricity will become clearer.
4. Consumer choice will be improved.
5. Bad technologies are ignored and good technologies are replaced in their place.
6. Electricity prices are reduced.
7. The usage efficiency is improved due to restructuring in price signals.
8. Power flow will takes place from surplus areas to shortage areas.
9. The cost of ancillary services is reduced by reserve sharing.

In the deregulated electricity market, increased infrastructure utilization increases capital returns and increased competition increases economic energy transactions. Due

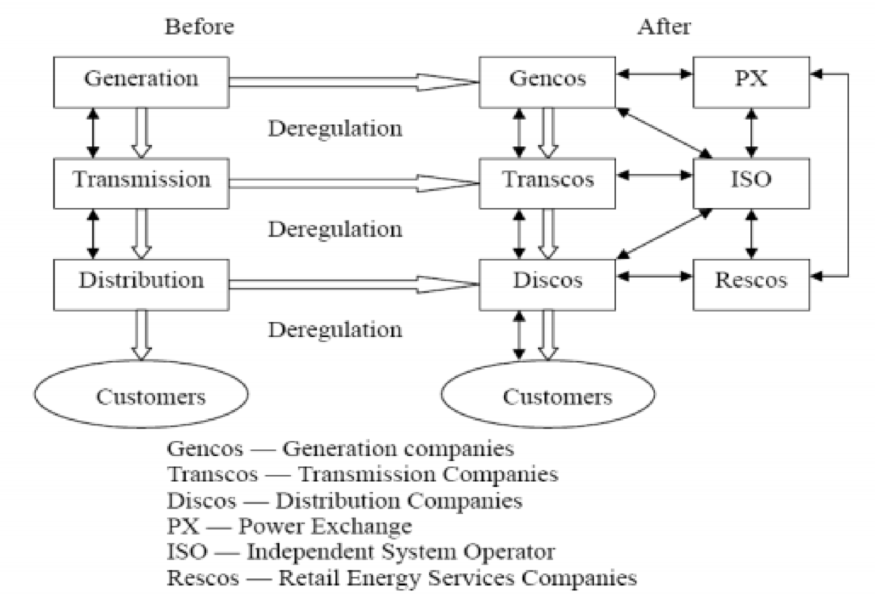

Figure 2.2: Deregulated Power System

to introduction of less costly sources, there will be new power flow patterns. New transmission difficulties will be created and some existing transmission constraints will be binding more often and with more economic significance. The interconnections are used at their capacity due to increased interchanges in power markets. This reality has brought into focus the practical limitations of interconnections and the associated problem of transfer capability. All these issues will have to be considered when transmission planning for a project is undertaken.

The word "deregulation" is relatively new to most of the countries. Due to the fact that it had only been in place in the power market for the past decade, and with the limited number of countries experiencing it, it is yet to be seen whether it is an opportunity or threat to the market. It can be a trend that is beneficial to one country and create problems for another. Constant review and monitoring of all the different markets is done to track the advancement of the power market. Up to date, the future of the market looks encouraging meeting the aims of deregulation.

2.4 Transmission Management

Around the nineties, almost all electric power utilities around the world operated with an organizational model in which there was only one controlling authority - the utility - operated the generation, transmission, and distribution systems located in a fixed geographic area. Economists always questioned whether this monopoly organization was efficient. With the example of the economic benefits to society resulting from the deregulation of other industries such as telecommunications and airlines, countries slowly started restructuring its nationally owned power system, creating private owned companies to compete with each other to sell electric energy. The arguments made for deregulation can be found in any undergraduate microeconomics textbook, and are as applicable to an industry of factories producing generic "widget" as they are to an industry of generators producing electric energy measured in MWh.

2.5 Power Flow on Transmission Networks

Electric energy cannot be stored. If we are given a set of source and destination power entry and removal sites, the ability to control which transmission paths the electric power takes is extremely limited. While power system apparatus like phase shifting transformers or high voltage power electronics (a family of equipment known as flexible ac transmission systems, or FACTS) can control the power flow over an individual link, such equipment is presently expensive and rare.

Better flow control would be useful because every link in the transmission system has a limit on the amount of power it can transfer at a given time. Several phenomena can impose these transfer limits, including thermal limits, voltage limits, and stability limits, with the most restrictive, of course, applying at any given time. Limits must be set to encompass both normal operation and the possibility of the unplanned disconnection of links or generators, called outages or contingencies, so that the power system can continue to deliver power when such contingencies occur.

2.6 Congestion Management

When the producers and consumers of electric energy desire to produce and consume in amounts that would cause the transmission system to operate at or beyond one or more transfer limits, the system is said to be congested. Congestion management, that is, controlling the transmission system so that transfer limits are observed, is perhaps the fundamental transmission management problem.

In the deregulated power system, the challenge of congestion management for the transmission system operator is to create a set of rules that ensure sufficient control over producers and consumers (generators and loads) to maintain an acceptable level of power system security and reliability in both the short term (real-time operations) and the long term (transmission and generation construction) while maximizing market efficiency. The rules must be robust, because there will be many aggressive entities seeking to exploit congestion to create market power and increased profits for themselves at the expense of market efficiency. The rules should also be fair in how they affect different participants, and they should be transparent, that is, it should be clear to all participants why a particular outcome has occurred. The form of congestion management is dependent on the form of the energy market, and congestion management itself cannot be separated from market considerations.

2.7 Market Economics and Congestion

The performance of a market is measured by its social welfare. Social welfare is a combination of the cost of the energy and the benefit of the energy to society as measured by society's willingness to pay for it. If the demand for energy is assumed to be independent of price, that is, if demand has zero price elasticity, then the social welfare is simply the negative of the total amount of money paid for energy. It can be shown that a perfect market has maximum social welfare. Real markets always operate at lower levels of social welfare. The difference in social welfare between a perfect market and a real market is a measure of the efficiency of the real market.

The conditions required for perfect competition are:

1) there are a large number of generators, each producing the same product.

2) each generator attempts to maximize its profits.

3) each generator is a price takerâĂŤit cannot change the market price by changing its bid

4) market prices are known to all generators.

5) transmissions are cost less.

Arguably none of these conditions ever exist in a real market.

When a generator bids other than its incremental costs, in an effort to exploit imperfections in the market to increase profits, its behavior is called strategic bidding. If the generator can successfully increase its profits by strategic bidding or by any means other than lowering its costs, it is said to have market power. The obvious example of market power is a non-regulated monopoly with zero elasticity demand, where the generator can ask whatever price it wants for electric energy. Market power results in market inefficiency.

let us consider a simple example of a two zone system connected by an interface, shown in Fig. 2.2. Let each zone have a 100-MW constant load. Zone A has a 200 MW generator with an incremental cost of $10/MWh. Zone B has a 200 MW generator with an incremental cost of $20/MWh. Assume both generators bid their incremental costs. If there is no transfer limit between zones, all 200 MW of load will be bought from generator A at $10/MWh, at a cost of $2000/h, as shown in Fig. 2.2(a). If there is a 50 MW transfer limit, then 150 MW will be bought from A at $10/MWh and the remaining 50 MWh must be bought from generator B at $20/MWh, a total cost of $2500/h. Congestion has created a market inefficiency of 25% of the optimal costs, even without strategic behavior by the generators. Congestion has also created unlimited market power for generator B. B can increase its bid as much as it wants, because the loads must still buy 50 MW from it. Generator B's market power would be limited if there was an additional generator in zone B with a higher incremental cost, or if the loads had nonzero price elasticity and reduced their energy purchase as prices increased.

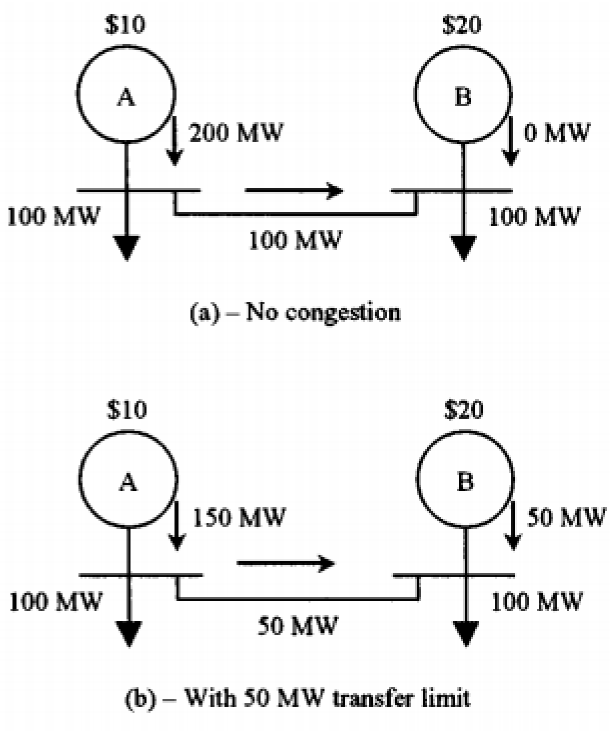

Figure 2.3: Two Zone System

Congestion management remains the central issue in transmission management in deregulated power systems. Without firm control of congestion, the operation of the transmission system can be compromised by the actions of market participants who do not have an economic stake in its security and reliability. Without careful attention to the interaction of congestion management and the economics of the energy market, market inefficiencies can take away the savings deregulation promises to society.

2.8 Optimal Power FLow

2.8.1 Introduction to OPF

OPF is a technology that has been used in the electric power industry for over 35 years. It gets its name from the fact that an optimization is performed to minimize generator operating costs. This is the exact same objective as the simpler economic dispatch (ED) function, but with an added set of constraints that represent a model of the transmission system within which the generators operate. When the transmission system is uncongested, the OPF solution is the same as the ED solution, so the explanation of OPF starts with ED.

1) ED: Conventional ED can be represented as a minimization of total generation cost as follows:

$min \sum_{Geni} C_i(P_{G_i})$

subject to constraints

$P_{G_i}^m in \leq P_{G_i} \leq P_{G_i}^m ax$

and

$\sum_{Geni} P_{G_i} = P_D$

where

P_{G_i} power output of generator ;

$P_{G_i}^{min}$ *and* $P_{G_i}^{max}$ generator's output limits;

P_D total system load;

$C_i(P_{G_i})$ individual cost function for generator .

The cost function is found from a heat rate curve, also called an input - output characteristic, which gives the generator electric power output in MW as a function of the thermal energy input rate (in MBTU/h or MJ/h) times the fuel cost per thermal energy unit. The heat rate curve is obtained from measured data. The resulting units for the cost function are then $/h as a function of MW. Generally the fit to measured data gives a monotonically rising function. The above problem formulation ignores the real power losses in the transmission system. Several methods can be used to add the effects of losses. Historically, ED has been performed by each electric utility's control computer systems. The total load in the ED calculation is modified by adding the total export power or subtracting the total import power so that the result is actually the total generation MW desired within the utility's system.

2.8.2 Optimal Power Flow(OPF)

The true OPF uses a formulation wherein the entire set of ac power flow equations are added to the economic dispatch as equality constraints so that as the calculation is run the cost of delivery of energy is minimized and a complete ac power flow solution (all complex voltage values) is reached. In addition, inequality constraints involving such things as the flow of MW, MVA, or current on a transmission line or the voltage at a substation bus can be incorporated in the OPF, and this makes it far more useful. Last of all, engineers have developed OPF calculations with ac power flow equations as equality constraints, inequality constraints on system flows and voltages, and then added constraints on flows and voltages that would be seen during contingency conditions. This OPF is then referred to as a security constrained OPF-or SCOPF. The difficulty in making a useful SCOPF is the fact that the system may not exhibit contingency problems at the start of the calculation, but only as the OPF adjusts generation do contingency constraints appear.

We use a very simplified approach :-

1) The ED formulation is augmented with the dc power flow equations.

2) A set of constraints is added.

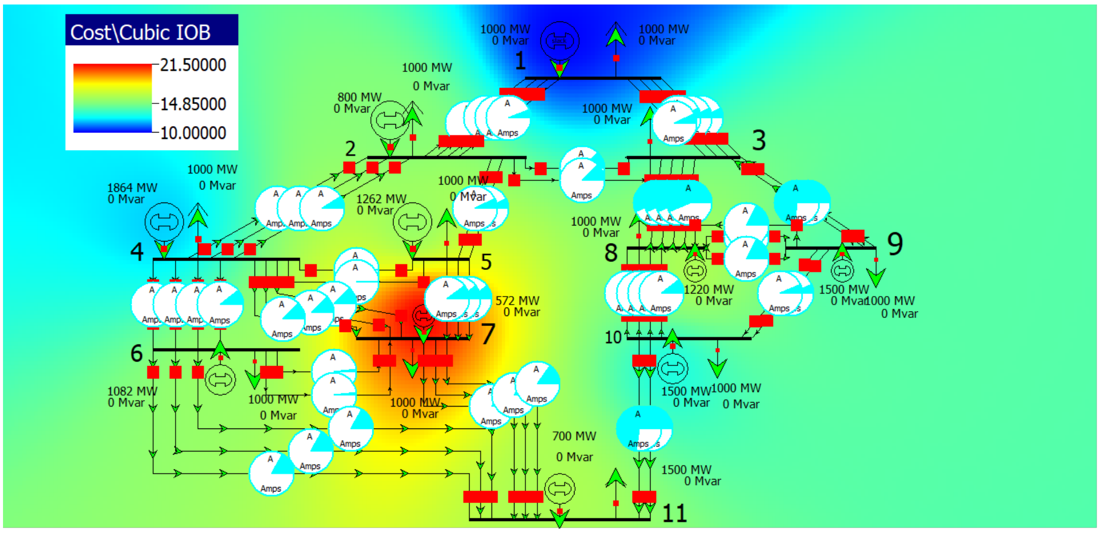

Figure 2.4: Different generator pricing for 11 bus 5 zone system

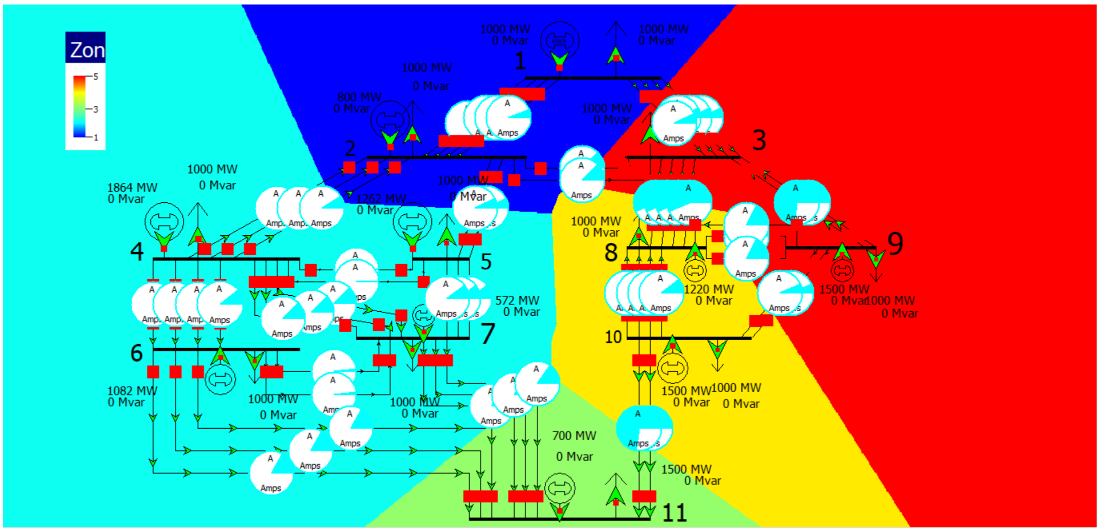

Figure 2.5: Optimal Power Flow for 11 bus 5 zone system

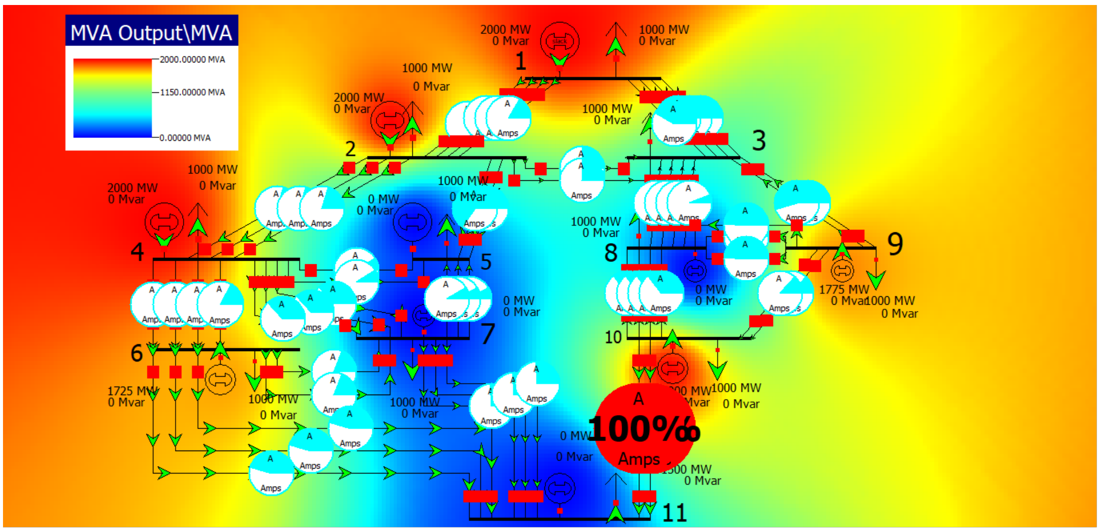

Figure 2.6: Output of various generators in MW calculated using Optimal Power Flow (OPF)

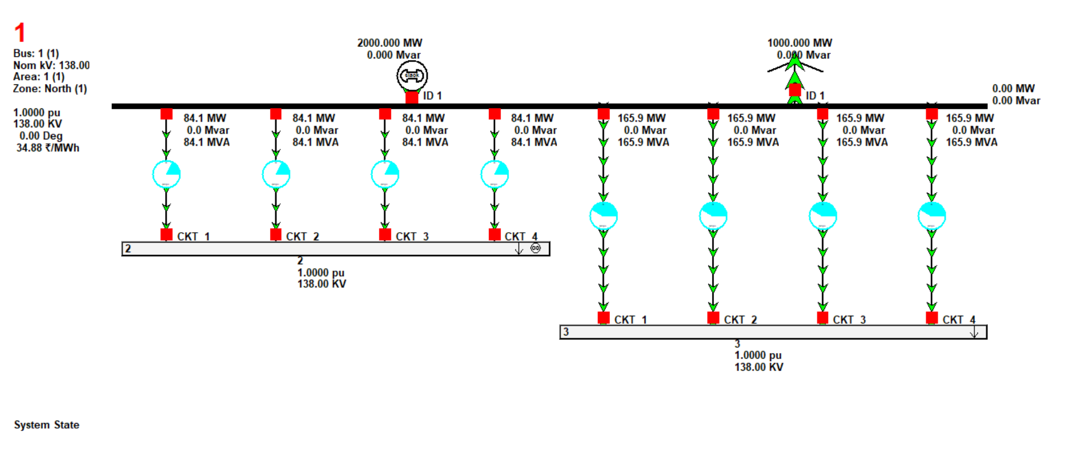

Figure 2.7: Bus view of Bus 1. It shows power flow between all the bus which are connected to bus 1

Number of Bus	Gen MW	Cost ₹/Hr (generation only)	Initial MW	Max MW	Profit ₹/hr
1	2000	60100	1924.6	10000	9662.04
2	2000	70100	1886.9	10000	243.95
4	2000	64100	1909.6	10000	6617.02
5	0	100	171.8	10000	-100
6	1725.1	56596.47	1612	10000	4642.96
7	0	100	240.5	10000	-100
8	0	100	183.2	10000	-100
9	1774.9	56453.56	1669.4	10000	3894.59
10	2000	66100	1902	10000	1157.48
11	0	100	0	10000	-100

Figure 2.8: Power flow of each generator after Optimal Power Flow calculation

Number	MW Marg. Cost	Congestion ₹/MWh	Area 1 MW Constraint
1	34.88	0	34.88
2	35.17	0.29	34.88
3	34.52	-0.36	34.88
4	35.36	0.48	34.88
5	35.36	0.48	34.88
6	35.5	0.62	34.88
7	35.45	0.57	34.88
8	33.98	-0.9	34.88
9	34	-0.88	34.88
10	33.63	-1.25	34.88
11	35.75	0.87	34.88

Figure 2.9: Marginal price of each bus calculated using optimal power flow

CHAPTER 3

Power Flow Management in Indian Scenerio

3.1 Power Transfer Distribution Factors

Introduction

The supply of electric power is essential for the function of the economy as well as for our daily life. Because of their enabling function for other infrastructures such as traffic or health care, power systems are considered to be uniquely important. The rise of renewable power sources puts new challenges to grid operation and security, as they are typically strongly fluctuating and often located far away from the load centers such that power must be transported over large distances. Thus efficient numerical methods are of great importance to analyze and improve the operation of power grids. An important method to assess the security of a power grid and to detect impending overloads is given by the linear sensitivity factors. Power transfer distribution factors (PTDFs) describe how the real power flows change if power injection is shifted from one node to another. Correspondingly, line outage distribution factors (LODFs) describe the flow changes when one line fails. These elementary distribution factors can be generalized to reactive power flow and multiple line outages . PTDFs and LODFs are heavily used in the planning, monitoring and analysis of power systems, for instance like security analysis and contingency screening.

From the power flow point of view, a transaction is a specific amount of power that is injected into the system at one zone by a generator and removed at another zone by a load. The linearity property of the dc power flow model can be used to find the transaction amount that would give rise to a specific power flow, such as an interface limit. The coefficient of the linear relationship between the amount of a transaction and the flow on a line is called the PTDF. PTDF is also called a sensitivity because it relates the amount of one change - transaction amount - to another change - line power flow. The PTDF is the fraction of the amount of a transaction from one zone to another that flows over a given transmission line. PTDF is the fraction of a transaction from zone to zone that flows over a transmission line connecting zone and zone . The equation for the PTDF is

$$PTDF_{ij,mn} = \frac{X_{im} - X_{jm} - X_{in} + X_{jn}}{x_{ij}}$$

where

X_{ij} reactance of the transmission line connecting zone and zone ;

X_{im} entry in the th row and the th column of the bus reactance matrix ;

The change in line flow associated with a new transaction is then

$$\Delta P_{ij}^{NEW} = PTDF_{ij,mn} * P_{mn}^{NEW}$$

where

i and j buses at the ends of the line being monitored;

m and n "from" and "to" zone numbers for the proposed new transaction;

P_{mn}^{NEW} new Transaction MW amount;

Interface PTDF's are found by summing the PTDF's for all of the circuits in service on that interface. The PTDF's can be used to calculate the effect any transaction from one zone to another will have on any interface.

3.2 PTDF calculation and results

3.2.1 Available Transfer Capacity

Introduction

The restructuring of the electric industry throughout the world aims to create competitive markets to trade electricity and generates a host of new technical challenges to market participants and power system researchers.

For transmission networks, one of the major consequences of the non-discriminatory

From Bus	To Bus	% PTDF From	% PTDF To
1	2	17.85	-17.85
1	3	7.15	-7.15
2	3	-2.23	2.23
2	4	18.98	-18.98
2	5	9.46	-9.46
3	8	4.36	-4.36
3	9	3.35	-3.35
4	6	7.2	-7.2
4	7	9.39	-9.39
5	7	6.3	-6.3
6	7	-5.01	5.01
6	11	12.93	-12.93
7	11	12.35	-12.35
8	10	4.53	-4.53
9	10	3.01	-3.01
10	11	12.07	-12.07

Figure 3.1: PTDF from bus1 to bus11

open-access requirement is a substantial increase of power transfers, which demand adequate available transfer capability (ATC) to ensure all transactions are economical.

With the introduction of competition in the utility industry, it is possible for customers to buy less expensive electrical energy from remote location. As a result, system operators face the need to monitor and coordinate power transactions taking place over long distances in different areas. Therefore, it becomes essential to evaluate multi-area ATC.

ATC Definition

Available Transfer Capability (ATC) is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses.

ATC and Related Terms

Transfer capability is the measure of the ability of interconnected electric systems to reliably move or transfer power from one area to another over all transmission lines (or paths) between those areas under specified system conditions. The units of transfer capability are in terms of electric power, generally expressed in megawatts (MW).

Limits to transfer capability

The ability of interconnected transmission networks to reliably transfer electric power may be limited by the physical and electrical characteristics of the systems including any one or more of the following:

Thermal Limits - Thermal limits establish the maximum amount of electrical current that a transmission line or electrical facility can conduct over a specified time period before it sustains permanent damage by overheating or before it violates public safety requirements.

Voltage Limits - System voltages and changes in voltages must be maintained within the range of acceptable minimum and maximum limits. For example, minimum voltage limits can establish the maximum amount of electric power that can be transferred without causing damage to the electric system or customer facilities.

Stability Limits - The transmission network must be capable of surviving disturbances through the transient and dynamic time periods following the disturbance.

ATC for base case

From Bus	To Bus	Transmission Limit(MW)	% OTDF	Pre-Trans Estimation (MW)	Limit Used(MW)
10	11	0	12.07	250	250
10	11	0	12.07	250	250
2	5	1824.05	9.46	327.45	500
2	5	1824.05	9.46	327.45	500
6	11	2102.51	12.93	228.05	500
6	11	2102.51	12.93	228.05	500
6	11	2102.51	12.93	228.05	500
1	2	2329.81	17.85	84.14	500
1	2	2329.81	17.85	84.14	500
1	2	2329.81	17.85	84.14	500

Figure 3.2: ATC for base case from bus1 to bus11

3.2.2 Contingency Analysis

Contingency analysis is a well known function in modern Energy Management Systems (EMS). The goal of this power system analysis function is to give the operator information about the static security. Contingency Analysis of a power system is a major activity in power system planning and operation. In general an outage of one

ATC for contingency

Transmission Limit(MW)	Limiting Element	% OTDF	Pre-Trans Est(MW)	Limit Used(MW)
-608.51	Line 10 (10) TO 11 (11) CKT 1	17.1	354.03	250
-608.51	Line 10 (10) TO 11 (11) CKT 2	17.1	354.03	250
-88.38	Line 10 (10) TO 11 (11) CKT 1	12.39	260.95	250
-88.38	Line 10 (10) TO 11 (11) CKT 2	12.39	260.95	250
-88.38	Line 10 (10) TO 11 (11) CKT 2	12.39	260.95	250
-81.26	Line 10 (10) TO 11 (11) CKT 1	11.78	259.57	250
-81.26	Line 10 (10) TO 11 (11) CKT 1	11.78	259.57	250

Figure 3.3: ATC for contingency case from bus1 to bus11

transmission line or transformer may lead to over loads in other branches and/or sudden system voltage rise or drop. Contingency analysis is used to calculate violations. Contingency analysis is a vitally important part of any power system analysis effort. Industry planners and operators must analyze power systems covering scenarios such as the long-term effects on the transmission system of both new generation facilities and projected growth in load. Market analysts and planners must make informed decisions regarding transactions for energy trade - whether that trade is for the next hour or months down the road.

Contingency analysis is abnormal condition in an electrical network. It puts the whole system or a part of the system under stress. It occurs due to the sudden opening of a transmission line, or generator tripping, or sudden change in generation. Sudden change in load value. Contingency analysis provides tools for managing, creating, analyzing, and reporting lists of contingencies and associated violations.

Contingency analysis is therefore a primary tool used for preparation of the annual maintenance plan and the corresponding outage schedule for the power system.

3.2.3 Economics and Transmission Management

The ideal of economists is to create a marketplace that is "efficient"- by which it means a marketplace in which producers make products that consumers want and do so at the least possible cost. In the electric power open marketplace this would imply that all consumers of electric energy could purchase energy at the same price no matter where they were. If the transmission systems had unlimited capacity to transfer energy, generation companies would all have to operate with nearly the same technological level so that they would all be producing electric energy at nearly the same price and could send their energy to any load customer no matter where that customer was located. Obviously, the transmission system limits the ability to transfer energy. Energy from generation that is low priced cannot always be transferred to load customers wanting to make purchases, and those customers are then forced to purchase from higher priced generation which is located so as not to be subject to limitation by the transmission system. Therefore the transmission system is said to introduce a degree of inefficiency into the electric power marketplace. A generation company that frequently finds itself within a region or zone of the power system that is limited in ability to bring in less expensive energy is said to be able to exercise "market power"-meaning that it can raise prices almost to any level and customers will pay those prices if they need the electric energy badly enough. Use of the OPF and contract network rights go a long way toward mitigating market power and making the transmission system efficientâĂŤas long as there is normally enough transmission capacity to sell contracts to any customer or generation company that desires them.

CHAPTER 4

Power Evacuation between two operators

4.1 Introduction

Power evacuation is a critical function that allows generated power to be immediately evacuated from the generator to the grid for distribution.The phrase Power Evacuation Studies is a generic term associated with plans for evacuating power generated from a generating source to a load centre. In the simplest form, it may mean only load flow studies with proposed transmission and distribution plans. When complete engineering is involved, the entire spectrum of power system analysis/studies may have to be performed.

With the widespread establishment of electrical grids, power transmission is usually associated most with electric power transmission. Alternating current is normally preferred as its voltage may be easily stepped up by a transformer in order to minimize resistive loss in the conductors used to transmit power over great distances; another set of transformers is required to step it back down to safer or more usable voltage levels at destination.

Power Evacuation Studies may mean, studies related to new generation facility and its connectivity to the grid for evacuation of the power or may mean studies related to existing facilities to study alternative plans of power evacuation for operational purposes.

High-voltage power transmission allows for lesser resistive losses over long distances in the wiring. This efficiency of high voltage transmission allows for the transmission of a larger proportion of the generated power to the substations and in turn to the loads, translating to operational cost savings.

4.2 Implementation in 11 Bus system

Figure 4.1 shows the optimal power flow in the 11 bus model.We want to send 1500MW from bus 11 to bus 1 optimally.

Figure 4.2 shows the difference case optimal power flow with sending end at bus 11 and receiving end at bus 1. We can find out all the power flows that are happening in the system. With that information we can be prepared for contingency.

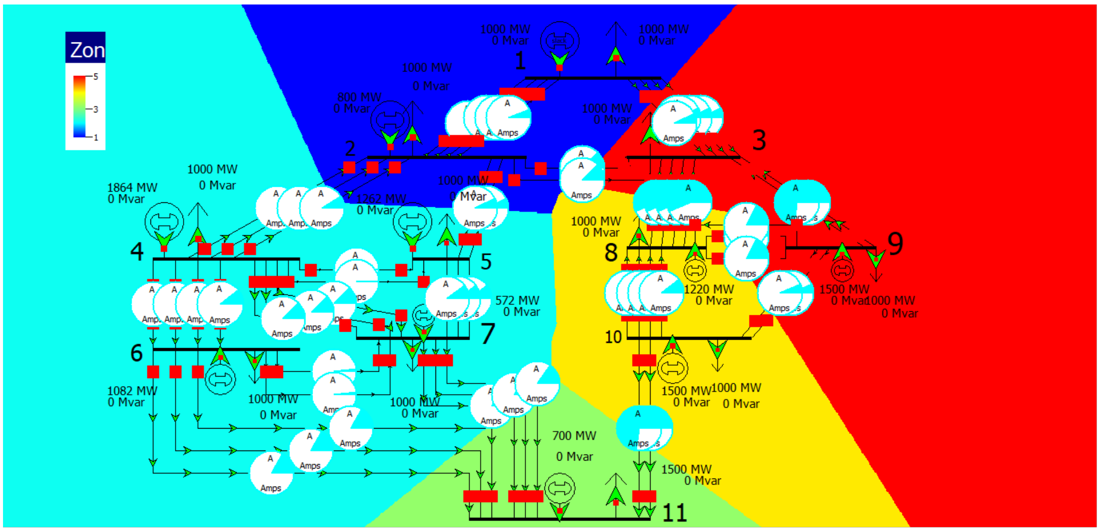

Figure 4.1: Optimal Power Flow for 11 bus 5 zone system

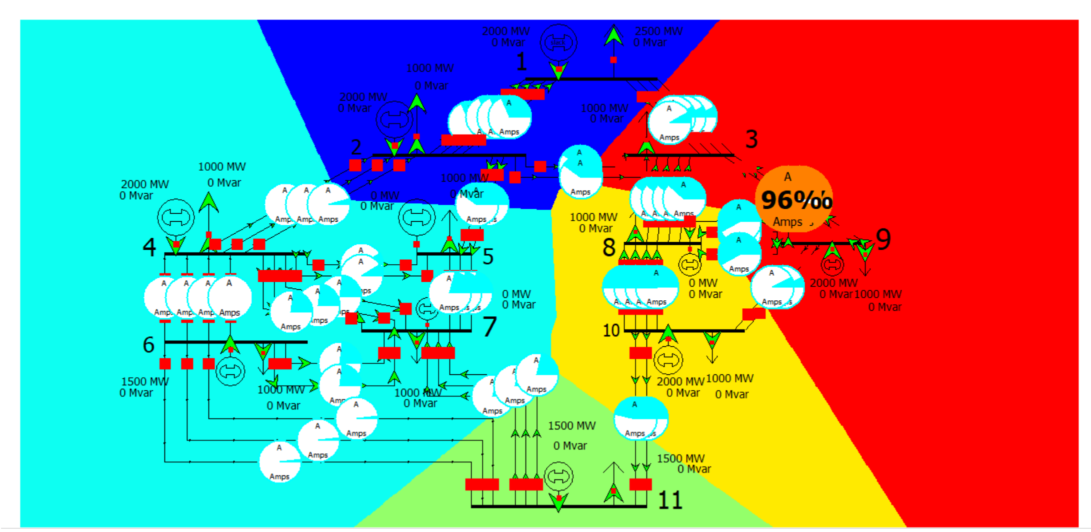

Figure 4.2: 1500 MW power transfer from bus 11 to bus 1 difference case

CHAPTER 5

Electricity Transmission Pricing in Indian Power System

5.1 Introduction

Two commonly employed philosophies for transmission pricing in the de-centralized markets are: Point-to-point tariff and the point-of-connection (POC) tariff. The point-to-point tariff is also called transaction based tariff which is specific to a particular sale of power from named seller to a named buyer. POC tariff is employed in the Nordic pool. The basic principle of POC tariff is that payment at one point, the point of connection, gives access to the whole network system, and thus the whole electricity market place. Those entities who take part in power market activity (generators, loads), pay a single charge in Rs/MW towards network usage. This charge is decided by the connection level of that particular entity. The POC tariff depends on the characteristics of the individual seller or buyer. The distinguishing feature of POC tariff is that it can be applied to power exchange (PX) trades as well as bilateral transactions between two parties.

One of the important tasks that a transmission pricing scheme has to accomplish is that of providing appropriate price signals. To promote economic efficiency, social welfare and least-cost operation, the pricing scheme should follow the marginal costs. However, due to economies of scale, transmission networks consists of long term investments. Hence, the short run marginal costs are unable reflect these investments while, the long run marginal costs are difficult to determine.

We determine the transmission usage charges based on POC principle for the power exchange (PX) trades in India. Recent reforms initiatives in the vertically integrated Indian power sector have mandated evolution of PX in the near future. While de-centralized market model is being suggested for PX trades, the POC tariff is evolving as the most favored candidate for transmission pricing scheme. Even though the POC scheme will be introduced for PX trades initially, in the later stages, it is expected to replace the current point-to-point tariff scheme for short term bilateral trades.

5.2 Overview of Indian Power Sector

Indian power system is divided into five regional grids, viz., Northern, Western, Eastern, North-Eastern and Southern. A region consists of number of state owned utilities, which are also separate control areas within that region. The power plants set up by central government enterprizes have allocations to the state utilities in a region. The backbone of transmission network in the country is provided by POWERGRID (Central Transmission Utility) which is primarily built to evacuate the power of central sector power plants and to inter-connect the state utility grids as well as regional grids. The interstate transmission system (ISTS) connects all central sector and inter-regional injection points with drawl points of the states similar to a LAN system with multiple computer nodes. The owner of state utility grid, i.e., State Electricity Board of each state acts as a State Transmission Utility (STU).

5.2.1 Various Power Transactions

The power transaction practices among the power utilities can be classified into three categories viz., long term transactions arising out of central sector allocations, short term transactions which are traded among the utilities under open access through forward contracts and UI power (Unscheduled Interchange) which is essentially the balancing power. In the near future with the setting up of the PX at the national level, some o the day-ahead transactions would be dealt through the PX.

1. Long Term Transactions: The central sector power plant allocations to the state utilities are termed as long term transactions irrespective of duration of the transactions. In case of other transactions, those exceeding 25 years are termed as long term transactions. The transmission network was built by CTU mainly for catering to the long term power requirements. Similarly, the transmission network owned by STUs caters to the power evacuation of state owned generating stations and IPPs in the state.

2. 2) Short Term Transactions: Surpluses and deficits on seasonal basis, daily variation of load, weather effects, diversity etc., necessitate trading of power between the power utilities on a short term basis. The short term transactions include those covering up to next three months which are approved in the current month, transactions approved on first cum first served basis, day-ahead transactions and same day transactions. As per the regulations in force, the short term open access transactions are approved by Regional Load Dispatch Center (RLDC) of the region in which the buyer is situated.

5.2.2 Current Transmission Pricing Scheme

The network operators like CTU, STU recover annual transmission costs through tariff regulated by the respective regulatory commissions. The transmission licensee is allowed to recover full transmission charges from long term customers. The regulatory commissions decide upon the tariff norms such as interest on loan, return on equity, debt-equity ratio, O&M charges, interest on working capital, depreciation etc. The transmission licensees earn revenue from the short term open access customers out of which 75% is passed on as credit to the long term customers.

The short term rate for each of these transmission systems is determined as 25% of the long term rate and the long term rate in turn is determined based on the annual transmission costs to be recovered by the transmission licensees and the average power demand catered by the network during the year. The short term open access rate is given as Rs/MW/day and is charged on six hourly time blocks.

5.3 Point of Connection Tariff

The basic principle of POC tariff is that payment at one point, the point of connection, gives access to the whole network system, and thus the whole electricity market place. It is commonly used in the Nordic pool where, the charges are devised so as to recover the costs for managing the transmission network and are controlled by country specific regulatory offices. The consumers or producers connected to a local network pay only to the owner of that network. This payment allows them to trade electricity with any other player within the entire national network system.

In Nordic pool, three levels of grids exist: Local grid, Regional grid and Main grid. The charge at a local grid also embeds the charges of its next upstream grid i.e., the regional grid. The regional grid in turn embeds charges of next upstream grid, i.e., the main grid. The advantage of the scheme is that free trade across the region is possible and the transmission tariff does not become a hurdle in the way of trade.

There are other advantages associated with this type of pricing scheme. First and the most important from the market participants point of view is that they know the transmission cost to be paid towards a particular sale or purchase of energy, apriori. Secondly, since the market participant pays just one charge proportional to MW injected or drawn, the contract path for a particular transaction is not required to be determined and hence pancaking of charges is avoided. Another important aspect of this pricing scheme is that it can be employed for both PX and bilateral trades.

Fixing POC rates for a system is a challenging task. The simplest version consisting of charging flat fee for all customers towards transmission usage makes it unfair to small customers or sellers. Application of postage stamp, i.e., a single charge throughout the zone is the most simplified form of POC tariff. However, grossly aggregated zonal postage stamp damps out the locational signals associated with the network usage costs. Moreover, this scheme may not correctly accommodate the usage costs of the other inter-connected grids in its own stamp. The most efficient way of satisfying desired features is to fix the POC rates that follow the Locational marginal Price (LMP) pattern. However, the sunk costs of transmission network are not included in the formulation of the short run marginal costs and hence, the cost component associated with the sunk costs of transmission is not directly accounted for.

The POC tariff being suggested for Indian power system should satisfy some features which are described as follows:

1. The POC tariff should reflect the possible network usage if power is injected or drawn on a particular node.
2. Both, generators and loads should share the costs of transaction.
3. The pricing scheme should create locational signals so as to provide incentives for generation investments in deficit areas and incentives for load growth in surplus areas.
4. The price signals should not be oversensitive so that they create hurdle for free trade across the regions; rather, these should be in tune with the degree of deficiency or adequacy of power in that region.
5. It is expected that in the Indian model, the PX and short term bilateral trades would co-exist and compete with each other. However, the PX would be mainly used for balancing the net position in a day ahead market. The price reference for bilateral trades, however, would be derived from the PX price. Hence, the POC tariff should be comparable with the current practice of pricing short term bilateral transactions.

5.4 Point of connection charges based on real power tracing

In this section, we float the concept of Locational Transmission Price (LTP) based on real power tracing, which takes into account the transmission sunk cost and represents the spatial distribution of network usage prices. The basic concept aims at finding the participation of each generator and load in each transmission element flows and thereby decide its locational weight towards network usage.

5.4.1 Concept of Locational Transmission Price (LTP)

The Locational Transmission Price (LTP) for each node is decided by the results of real power tracing. In simple words, LTP of a node reflects usage of various transmission lines and elements by load or generator on that node. In the discussion to follow, we develop the concept of LTP for loads. Same discussion holds true for generators.

Let the cost of line lm per MW per unit length be given by C_{lm} and let L_{lm} denote the length of the transmission line. Then,

$\overline{c}_{lm} = c_{lm} L_{lm}$

is usage price per MW associated with the line. The usage cost of the transmission line is known from the power flow solution. Consequently, total transmission system usage cost

$TC = \sum_{\forall\ lm} \overline{c}_{lm} P_{lm}$

is also known. Real power tracing makes it possible to distribute this cost accurately among all the constituents of the system including utility's native loads and generators. Since,

$P_{lm} = \sum_{i=1}^{n_L} y_{lm}^{i} P_{L_i}$

the transmission usage cost for load P_{L_i} of the line lm is given by ($\overline{c}_{lm} y_{lm}^{i} P_{L_i}$). Thus, the total transmission system usage cost for a load i is given by

$TC_{P_{L_i}} = P_{L_i} \sum_{\forall\ lm} y_{lm}^{i} \overline{c}_{lm}$

The locational transmission price (LTP) is obtained by dividing the above by P_{L_i}.

$LTP^{i} = \sum_{\forall\ lm} y_{lm}^{i} \overline{c}_{lm}$

5.5 Application on Indian System

In Indian power system, transmission systems can be categorized into three classes: Class A, class B and class C. Class A represents an inter-regional link, class B represents regional grid owned by CTU, while class C represents state utility owned (STU) grid.

The short term transmission usage rates for each class of network are predefined. From this, depending upon its voltage class and line length, the short term rate for each line in that class of network is calculated. Later on after carrying out real power tracing, the load and generator entities using these lines are charged in proportion to their participation in the line flows. Thus, the POC tariff rate at a node reflects the extent of use of all classes of network by a load or generator entity. This act of transformation of network usage into prices is facilitated by virtue of real power tracing.

5.5.1 Calculation of Rate of a Line in particular Class of network

Total fixed charges to be recovered from a particular class of network are known a priori. These are denoted as TSC_{long}^{A},TSC_{long}^{B}, TSC_{long}^{C}. These costs are supposed to be recovered from the customers of long term contracts. Our main interest is in the short term rates, as the POC tariff has to be made comparable with the same. Hence, the short term TSC for various classes of networks is calculated as follows: Let these be TSC^{A},TSC^{B}, TSC^{C} for class A, B and C networks respectively. Then

$TSC^{A} = 0.5 * TSC_{long}^{A}$

$TSC^{B} = 0.25 * TSC_{long}^{B}$

$TSC^{C} = 0.25 * TSC_{long}^{C}$

The participation of line lm in TSC^{A} is calculated by: $TSC_{lm}^{A} = \frac{l_{lm}^{A} Q_{lm}^{A}}{\sum_{\forall lm \epsilon A} l_{lm}^{A} Q_{lm}^{A}} TSC^{A}$ l_{lm}^{A} be length and Q_{lm}^{A} be a factor reflecting voltage class for a particular line lm in class A. Similarly ,TSC_{lm}^{B}, TSC_{lm}^{C} can be calculated.

5.5.2 Calculation of Locational Transmission Price

As a subsequent step, real power tracing is carried out on the system data. Real power tracing finds out the participation of each nodeâĂŹs load or generator in the transmission line real power flows. Based on results of real power tracing, the locational transmission price for i^{th} load is calculated by,

$$LTP^i = (\frac{\sum_{\forall\ lm\epsilon A} \frac{P^i_{lm}}{P_{lm}} TSC^A_{lm}}{P_{L_i}}) * 0.5 + (\frac{\sum_{\forall\ lm\epsilon B} \frac{P^i_{lm}}{P_{lm}} TSC^B_{lm}}{P_{L_i}}) * 0.5 + (\frac{\sum_{\forall\ lm\epsilon C} \frac{P^i_{lm}}{P_{lm}} TSC^C_{lm}}{P_{L_i}}) * 0.5$$

where, P^i_{lm} is obtained by upstream tracing. Similarly, the LTP for kth generator is calculated by,

$$LTP^k = (\frac{\sum_{\forall\ lm\epsilon A} \frac{P^k_{lm}}{P_{lm}} TSC^A_{lm}}{P_{G_k}}) * 0.5 + (\frac{\sum_{\forall\ lm\epsilon B} \frac{P^k_{lm}}{P_{lm}} TSC^B_{lm}}{P_{G_k}}) * 0.5 + (\frac{\sum_{\forall\ lm\epsilon C} \frac{P^k_{lm}}{P_{lm}} TSC^C_{lm}}{P_{G_k}}) * 0.5$$

where,P^k_{lm} is obtained by downstream tracing.

5.5.3 Aggregation of Locational Transmission Prices to form Zones

The aggregate locational transmission price of a zone is done by load and generation weighted averaging for each state. For qth state, load weighted aggregated locational transmission price for all loads,

$$LTP^q_L = \frac{\sum_{i\epsilon q} P_{L_i}}{L} TP_i \sum_{i\epsilon q} P_{L_i}$$

Similarly, for qth state, generation weighted aggregated locational price for all generators,

$$LTP^q_G = \frac{\sum_{i\epsilon q} P_{G_k}}{L} TP_k \sum_{k\epsilon q} P_{G_k}$$

To calculate the aggregated rate for a particular state q,

$$LTP^q = \frac{P^q_G LTP^q_G + P^q_L LTP^q_L}{P^q_G + P^q_L}$$

5.5.4 Implementation

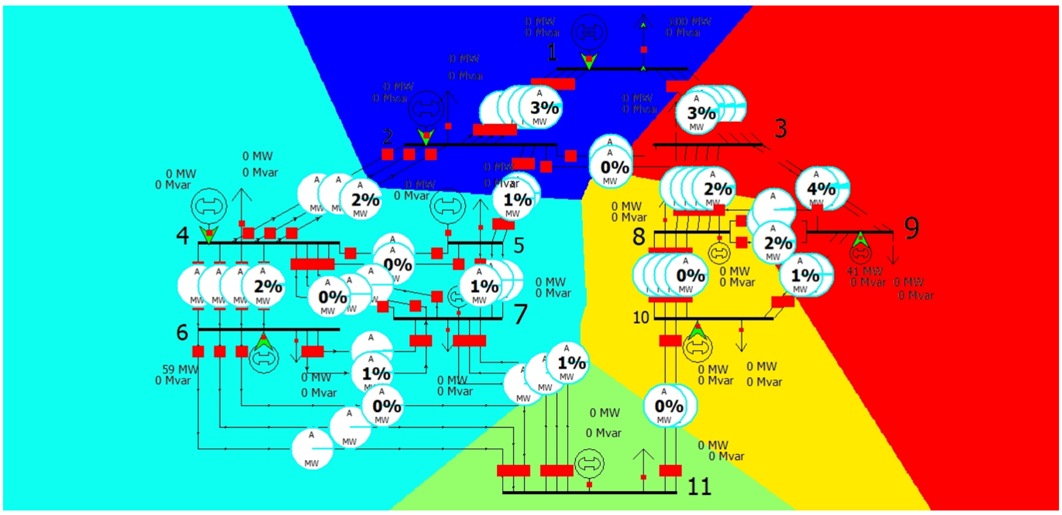

Figure 5.1: Difference case for optimal power flow if 100MW load is added at bus1

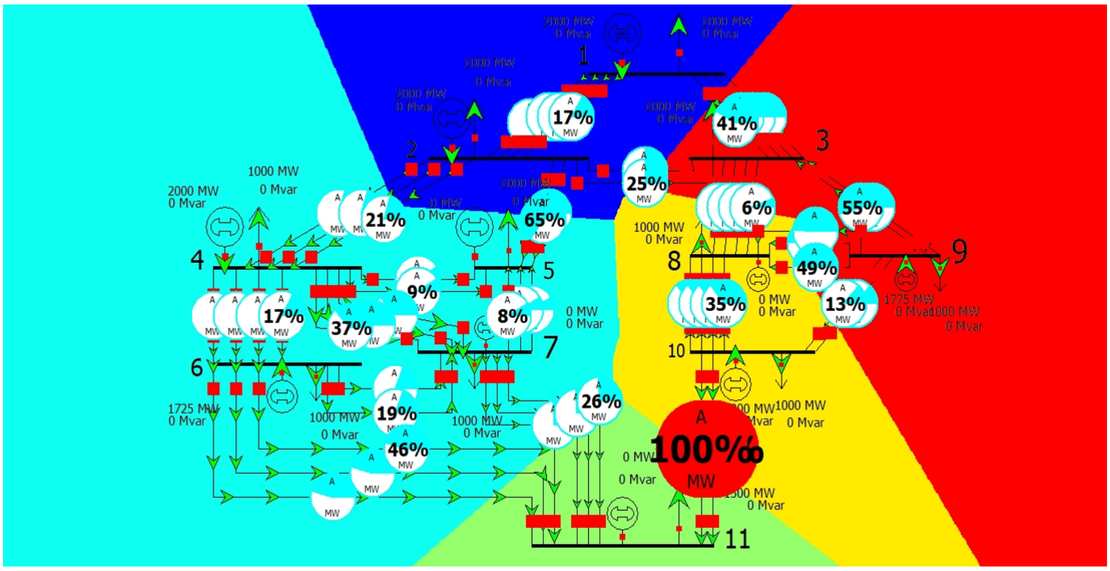

Figure 5.2: Base case optimal power flow

Calculation of LTC for blue zone:

$TSC^{A} = 5000Rs/MW$

$TSC_{B} = 3000Rs/MW$

$TSC^{A}_{lm} = \frac{1}{10} * 5000$

$TSC^{B}_{lm} = \frac{1}{8} * 3000$

$LTP^{1} = (\frac{\frac{3}{39}+\frac{2}{19}+\frac{1}{64}+\frac{1}{26}+\frac{1}{15}+\frac{2}{51}+\frac{3}{39}}{100}) * \frac{5000}{10} + (\frac{\frac{3}{14}+\frac{2}{16}+\frac{1}{20}+\frac{1}{9}+\frac{4}{59}}{1000}) * \frac{3000}{8}) = 0.4 + 0.26 = 0.66Rs/MW$

$LTP^{2} = (\frac{\frac{2}{19}+\frac{2}{64}+\frac{2}{23}+\frac{1}{40}+\frac{1}{46}+\frac{1}{26}+\frac{1}{7}+\frac{1}{14}}{100}) * \frac{5000}{10} + (\frac{\frac{1}{18}+\frac{2}{15}+\frac{1}{36}+\frac{1}{21}+\frac{1}{9}\frac{2}{57}}{1000}) * \frac{3000}{8}) = 0.41 + 0.14 = 0.55Rs/MW$

$LTP^{q}_{L} = \frac{100*0.66+100*0.55}{200} = 0.605Rs/MW$

CHAPTER 6

Conclusion and Future Work

The optimal power flow of a network saves a lot of power and at the same time it optimizes the cost of operation and maintain the line limits. It can be implemented in all kind of power flow scenario from small to big network. Available transfer capability can be used in a lot of power flow scenario. It gives us the limits on how much more power we send without violating the line limitation. It can also be used to analyze lots of contingency, with which we can analyze the performance of the network during adverse condition. Last section we have dealt with how to collect tariff based on the tracing based point of connection for Indian power system. Fixing POC rates for a system is a challenging task.

The simplest version consisting of charging flat fee for all customers towards transmission usage makes it unfair to small customers or sellers. Application of postage stamp, i.e., a single charge throughout the zone is the most simplified form of POC tariff. However, grossly aggregated zonal postage stamp damps out the locational signals associated with the network usage costs. Moreover, this scheme may not correctly accommodate the usage costs of the other inter-connected grids in its own stamp. It is expected that in the Indian model, the PX and short term bilateral trades would co-exist and compete with each other. However, the PX would be mainly used for balancing the net position in a day ahead market. The price reference for bilateral trades, however, would be derived from the PX price. Hence, the POC tariff should be comparable with the current practice of pricing short term bilateral transactions.

Four possible paths to the future of transmission management suggest themselves: Transaction based, OPF based, price area, and distributed. Each needs research to move along the path to better tradeoffs between system reliability and market economics. The transaction-based approach must be changed to take its effect on market efficiency into account, and perhaps to allow for spot markets with multiple, unpaired bidders in its operating mechanism. Improvements in the ATC calculation algorithm that take the nonlinearities of the power system into account can be expected to improve accuracy at the expense of computation time and complexity.

For OPF-based approaches, the immediate challenge is to implement the continent-wide OPF mechanisms that will be needed to cope with networked systems that accept long distance transactions. Continent-wide OPF faces some significant engineering challenges. Run time for systems with tens of thousands of buses and real time performance requirements merits attention. The robustness, data maintenance, communications, and reliability issues raised in Section VI will have to be addressed. Given the necessary legal, administrative, and organizational support, these challenges should yield to good engineering.

A somewhat different challenge is to determine whether a centralized optimization algorithm such as OPF, even with participant bidding, is economically as effective as simpler market mechanisms such as those used in price areas. If the use of centralized optimization creates excessive market inefficiency, then alternative structures that enable more efficient markets must be found. What these structures will be is not clear.

Price area approaches, while less technically complex than OPF approaches, still have challenges. One is to determine when a transmission system is sufficiently radial to employ price areas instead of OPF. Another is to provide an analytical method of determining where the boundaries should be drawn between price areas, and how inter-area transfer limits should be set. Price areas must also face questions about their economic efficiency, in comparison with centralized OPF.

The path to decentralized transmission management is less clear. Some sort of autonomous or hierarchical cooperative transmission management algorithm is needed that provides for robust and secure operation of the transmission system and also optimizes market efficiency in the presence of bilateral transactions that span a number of autonomous regions in a networked system. No immediate answer presents itself to the authors!

CHAPTER 7

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