ENHANCING POWER QUALITY AND RELIABILITY IN Deregulated environment

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ABSTRACT

This paper presents power quality and reliability in deregulated power system. System reliability and power quality are important concerns associated with deregulation. Deregulation of the electric power sector offers the possibility of improving the system operational efficiency. This efficiency requires the development of an infrastructure that can address the information needs of the sector in a less centralized and more organized sense. The importance of Captive power plants (CPPs) is likely to increase further as power from the State Electricity Boards (SEBs) is becoming less reliable and more expensive. Both maintenance scheduling and fuel resource scheduling are long term operational planning.

Keywords: Reliability and power quality; Deregulation; infrastructure; load forecast; Captive and co-generation plants.

INTRODUCTION

‘The Electricity Act 2003’ has liberalized the setting up of captive power plants. Captive and co-generation plants have therefore become popular in the country not only for quality power generation but also for cost reduction. Electricity is one of the most vital infrastructure inputs for economic development of a country and therefore the growth of power sector is implicitly related to the growth of a nation. Since independence, the Indian power sector has grown many folds in size and capacity. The generating capacity has increased from 1362 MW in 1947 to more than 91000 MW till date, a gain of more than 60 times in capacity addition. In addition, the Indian power sector has been characterized by shortage of supply vis-à-vis demand because the supply side management was mainly through power programme financed by State/Central government through plan funds until early nineties. The power development programme in our country was more resource oriented than being need based and as a result addition of generating capacity as well as the transmission & distribution networks in successive plan periods were lower than the actual need primarily due to paucity of fund. This was the main reason behind acute shortage of power in the country. In 1990-91, the country faced peaking shortage of around 16% and energy shortage of about 8%. The position was worsened with peaking shortage
of 18% and energy shortage of about 12% at the end of 8th Plan period for capacity addition during the 8th Plan (1992-97) was much below the target. At the commencement of the 8th Five Year Plan (April 1992), the total generation capacity was 69,075 MW. This increased to 85,744 MW by March 1997 and is currently more than 91000 MW. The growth of economy calls for a matching rate of growth of power infrastructure. In order to support a sustained high rate of growth of gross domestic product (GDP) of nearly 6 per cent per annum, demand for power is expected to grow at around 9% annually. Central Electricity Authority (CEA), with active participation of State Electricity Boards (SEBs), has assessed the energy and peaking demand as shown in Table 1.1.

Table 1.1 Energy and peaking demand:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY DEMAND (Billion KWH)</td>
<td>469.06</td>
<td>569.65</td>
<td>781.86</td>
</tr>
<tr>
<td>PEAKING DEMAND (MW) ANNUAL</td>
<td>78,936</td>
<td>95,757</td>
<td>130,944</td>
</tr>
<tr>
<td>LOAD FACTOR (%)</td>
<td>67.83</td>
<td>67.91</td>
<td>68.16</td>
</tr>
</tbody>
</table>

RELIABILITY STUDY IN CAPTIVE POWER PLANTS

With the amendment in Electricity (supply) Act of 1948, Independent Power Producer (IPPs) and Captive power plants (CPPs) became viable options for adding new generation capacity. With the failure of IPP segment to take off, most lenders are looking for CPP option [9] as an effective tool for supply side management [10]. In addition, the demand-supply gap in the country is constantly rising and is currently at 8%. The peak demand supply gap is currently about 14%. It is estimated that India would be requiring additional 100,000 MW in the next ten years. The inadequate availability of quality power have prompted organizations to make adequate arrangements on their own to overcome their operational problems. Captive and cogeneration plants have therefore became popular in the country not only for quality power generation but also for cost reduction. As many as 65 captive power plants are in the offing at present and many are in the planning stage, representing a market of worth $20 billion [11]. Captive power plants are focused source of continuous and quality power within the total control of the user, thereby isolating them from any adverse effect on their production processes due to power shortages. Such plants easily supply quality power which denotes reliability of supply [12],[13] through the existence of an adequate and secure power supply. The captive power plants are set up by the user industry itself, for power intensive industries like aluminium extraction plant, steel plant, cement manufacturing, sugar manufacturing, chemicals preparation laboratories etc. to supply continuous power. As much as 35% of the electricity consumed by Indian Industry, estimated to be at least 20,000 MW [14], comes from these captive power plants. [15]. Since financing captive projects is free from issues like payment securities, power purchase agreements and off take risks, this sector is a much safer bet as compared to IPP financing or SEB financing. The recent cuts in interest rate has made financing in this area ever more attractive. In the past, captive power plants were installed primarily as a back-up arrangement but now more and
more businesses are looking at them as base-load stations. It is less out of choice and more out of compulsion that the power intensives industries in various states are moving more towards generating for its own input power. The reason for this shift is plenty. The first and the foremost reason is the increasing cost of electric power in the High Tension (HT) segment. Each time the electricity tariffs are revised, the industrial segment has to bear the major part of such hikes. In effect, the HT sector covers up for the concerned SEB’s inefficiencies. In most states, the HT segment is chosen to cross-subsidie the agricultural and the domestic options. The cost is lower as compared to IPP projects as the return on equity is not a consideration, less expenditure on the infrastructure, no additional transmission and distribution cost, the overheads are lower and there is no scope for pilferage of power.


<table>
<thead>
<tr>
<th>State</th>
<th>HT tariffs (paisa per kWh)</th>
<th>State</th>
<th>HT tariffs (paisa per kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andhra Pradesh</td>
<td>350-410 + fixed charges</td>
<td>Kerala</td>
<td>190-205 + fixed charges</td>
</tr>
<tr>
<td>Assam</td>
<td>230-270 + fixed charges</td>
<td>Maharashtra</td>
<td>345-370 + fixed charges</td>
</tr>
<tr>
<td>Bihar</td>
<td>169-178 + fixed charges</td>
<td>Orissa</td>
<td>230-250 + fixed charges</td>
</tr>
<tr>
<td>Delhi</td>
<td>350-450 + fixed charges</td>
<td>Punjab</td>
<td>243-275 + fixed charges</td>
</tr>
<tr>
<td>Gujarat</td>
<td>159 + fixed charges</td>
<td>Rajasthan</td>
<td>339-395 + fixed charges</td>
</tr>
<tr>
<td>Haryana</td>
<td>392 + fixed charges</td>
<td>Tamilnadu</td>
<td>340-390 + fixed charges</td>
</tr>
<tr>
<td>Himachal Pradesh</td>
<td>200-230 + fixed charges</td>
<td>Uttar Pradesh</td>
<td>360-390 + fixed charges</td>
</tr>
<tr>
<td>Karnataka</td>
<td>340-390 + fixed charges</td>
<td>West Bengal</td>
<td>260 + fixed charges</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>122-144 + fixed charges</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PLANNING TASK

A new favorable policy for captive power projects has given a boost for development in captive power generation. In consultation with the Central Electricity Authority (CEA), the power ministry has recently circulated draft guidelines to the state governments, which call for massive changes in state-level captive power policies [16]. The center’s initiative is primarily aimed at bringing in an estimated amount of 10,000 MW of unutilized captive power into the state grids. Under the new guidelines, setting up of power stations with a capacity lesser than 25MW will require no clearance from any agency. To attract more captive power into the grid, the new guidelines specify the price which the states should pay for it: It is a single-part tariff based on the highest variable cost of any plant in the state or the actual variable cost of the captive power producer, which ever is lower. The maintenance scheduling for thermal generating units in power system is a long-term scheduling problem of planned outages for regular maintenance. The role of such planning from the perspective of overall power system planning has to be properly understood to appreciate the level of advancement in this field. The general overview of power system planning is presented in following figure.
EXPANSION PLANNING AND LOAD FORECASTING

The process of selecting the type and location of new generation and transmission equipment and the installation date so that desired electricity supply is provided at the right time and at an economic cost, is termed as expansion planning. The additional processes include incorporation of load forecast in terms of annual peaks and energy needs for the entire utility area as well as for each region consisting of many utilities. The expansion planning can be segregated as generation planning and network planning. Generation planning aims at bringing about most economical generation expansion schedule as a blending of required system reliability level as ordained by the forecast of increase in demand after a certain interval of time. This planning mode decides where and when to invest for the installation of new generating units, their types and capacity. Network planning aims at bringing about optimal power system network configuration keeping in view load growth and generation planning for a certain planning horizon so as to meet the requirement of delivering electrical energy economically and in a safe mode. Both maintenance scheduling and fuel resource scheduling are long term operational planning. It aims at bringing about planned outage of generating units for maintenance purposes at a desired security level. It aims at bringing about cost-optimized use of fuels and delivery contracts meeting all long-term constraints. It aims at bringing about allocation of available water for hydro units throughout the year. The unit-commitment aims at bringing about optimum start-up and shutdown schedules for individual generating units. For this all technical as well as operational constraints must be fulfilled and outcomes of maintenance scheduling and fuel resource scheduling must be incorporated. The economic dispatch aims at bringing about optimal output from individual generating units. The maintenance of
the thermal generating units is absolutely related to power system reliability and hence to the overall operation of power system to satisfy the system load at a reasonable cost and with a reasonable assurance of continuity and quality. The recognition of “reasonable assurance” is the basis for a wide range of studies generally designated as reliability assessments [18] for ensuring quality power. The ever-increasing demand of electrical energy has manifested in the form of larger units to generate energy. In turn, such large units are opting for high-pressure turbo-generators operating at higher voltage levels and the enforcement of statutory norms must be followed for minimization of industrial hazards. With the incorporation of statutory safety regulations for maintenance of boilers, turbines and generators, a multi-class maintenance scheduling in terms of mathematical formulations necessitates a planning horizon of five years for maintenance scheduling. There are normally two categories of objective functions in power system maintenance e.g. reliability and cost. Since the captive power plants are set up by the user industries themselves, for power intensive industries like aluminium extraction plant, steel plant, cement manufacturing plant, sugar manufacturing plant, chemicals preparation laboratories etc. to supply continuous and quality power else leading to adverse effects. Reliability objective function, therefore, need be is considered for problem formulation. In this context, a brief exposition of generation reliability evaluation is appended below. The fundamental operating feature of any electrical power system is that the electrical energy production and consumption are simultaneous. Therefore, the reliability requirement within the electric industry is very high. The maintenance of power system equipment and especially the maintenance of generating units are implicitly related to power system reliability and have a tremendous bearing on the operation of the power system. Therefore, the maintenance problem has always been investigated together with system reliability engineering research [12] and historically has been assessed using deterministic as well as stochastic criteria and indices. Accordingly, for maintenance scheduling problem formulation, the reliability objective function can be either deterministic or stochastic. The deterministic reliability objective function maximizes the system’s net reserve. The main drawback of this approach is that it neglects the randomness in the capacities of the available generating units. This would mean that a system fulfilling the minimum reserve requirements may not be completely reliable. The random reliability objective function removes the above defect by taking into account the stochastic factors that influence the reliability of the system. [4]

GENERATION RELIABILITY EVALUATION
A power system, as any other system, consists of a set of components interconnected in some purposeful way. The flowchart for generating system reliability analysis including the effect of maintenance scheduling is shown as below.
The object of reliability study is to derive suitable measures of successful performance on the basis of information regarding components failures and on the system configuration. For generation reliability studies the components of interest are the generating units while system configuration refers to the specific units scheduled to serve the load. Since maintenance schedule is a long-term scheduling problem of planned outages, for regular maintenance of generating units, therefore such scheduling brings about a change in system configuration and affects the reliability of the system. Although the indices used in reliability evaluation are probabilistic and consequently they do not provide exact predictions but such information are extremely important to complement with proper policy decisions regarding the acceptable level of risk during real-time operation. The system is deemed to operate successfully as long as there is sufficient generation capacity to supply the load. In evaluating generation adequacy, the mathematical representations of generation and load are combined to model the risk of supply shortages in the system. The probabilistic estimates of the ability of a particular generation configuration to supply the load demand are used as indices. This approach, however, only considers bulk generation and the aggregate load in the system. Evidently, the transmission and distribution grids are very important to evaluate the reliability offered to a single customer. This model is sufficient for the purpose of comparing the adequacy of generation configurations for captive power plants as utility industries, which serve as load for such generating units, are located nearby. The ever growing complex nature of thermal unit maintenance scheduling problem in power system has made it necessary to develop an intelligent tool for its practical solution. High reliability requirement at reasonable cost for power system operation has made the problem of maintenance scheduling more important even before. Since an appropriate maintenance scheduling would help to increase the system reliability, reduce the generation cost, extend generator lifetime and relax new installation pressure, it has to
be carefully investigated using better solution techniques. Many maintenance scheduling methods have been proposed using conventional optimization techniques and such approaches suffer from the ‘curse of dimensionality due to the complex multidimensional nature of the problem. These approaches also tend to suffer from the requirement of excessive computational time with the increase of variables. Also, these methods may not generally lead to the global optima for a complex problem, i.e., the procedure tends to fall into a local minimum if the starting point is not carefully chosen. The ever growing complex nature of thermal unit maintenance scheduling problem in power system has made it necessary to develop an intelligent tool for its practical solution. High reliability requirement at reasonable cost for power system operation has made the problem of maintenance scheduling more important even before. Since an appropriate maintenance scheduling would help to increase the system reliability, reduce the generation cost, extend generator lifetime and relax new installation pressure, it has to be carefully investigated using better solution techniques.

INFRATECHNOLOGIES IN THE DEREGULATED POWER SECTOR
Deregulation of the electric power sector offers the possibility of improving the system operation efficiency. This efficiency requires the development of an infrastructure that can address the information needs of the sector in a less centralized and more organized sense. This infrastructure includes new and sophisticated measurement techniques and standards for tracking transaction in electricity markets and monitoring the performance of the electric power system[6],[8]. Major dynamics for the deregulation of the power sector include the following: The rate differences among the regions providing more efficient use of the existing generation resources by transmitting power longer distances than was typical in the era of industry regulation; the new, low cost techniques for electricity generation; the complexity of establishing a regulated sector with the incentives of making socially efficient investment choices; the difficulty of building a responsive regulatory body that will adjust the rates and conditions of services with respect to the dynamically changing marketing conditions; the complexity of monitoring utilities, establishing cost based rates for all consumer classes that will promote economic efficiency, while at the same time addressing the equity concerns of regulatory commissions((2),(5)). The main economical benefits expected from deregulation include improved quality of electricity service by allowing rates, that more closely track the true cost of service and by differentiating the product quality. The potential benefits associated with deregulation are significant because the system and hence the economic inefficiencies are large. Potential costs associated with deregulation include increased transaction costs for market transaction, increased bulk power transmission requirements, increased costs for the monitoring and control systems to enhance the system reliability and power quality and potential decreases in overall system reliability and power quality. System reliability and power quality are important concerns associated with deregulation[1],[7]. Reliable, high quality electric power is one of the main objectives of the industry. To study and identify the measurement and standards for the electric power sector, a data collection procedure with two stages was carried out [4],[5]. First, an extensive literature review was carried out and data were collected from various commercial publications, professional journals and statistical resources, and then extensive e-mail and telephone communications were carried out by various companies, i.e.; SIEMENS, ABB, Corporate research, ISO to investigate the evolving
structure of the electric power sector and to identify the potential areas, where measurement and standards play important role.

INFORMATION FLOW IN A DEREGULATED SECTOR

To maintain system reliability, system coordinators monitor inflows and outflows from grid, as well as other conditions, such as voltage profile, throughout the system. Some of the technical information flows for system operations are as follows.

- Generation monitoring and control;
- Transmission system real-time monitoring and control.
- Real-time communication links to end users to support demand-side management activity for deregulated sector.

Deregulation has dramatically changed the characteristics, type and number of measurements to be made, although there is no physical change in the actual system.

Voltage and current are two fundamental variables to be measured. Potential Transformers (PTs) and Current Transformers (CTs) are used for this task and careful attention must be paid in choosing their ratings in order to avoid saturation and distortion.

<table>
<thead>
<tr>
<th>Service</th>
<th>Measured variable</th>
<th>Measurement period</th>
<th>Deployment period</th>
<th>Reporting period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonics</td>
<td>V and I</td>
<td>&lt; 1s</td>
<td></td>
<td>Periodic measurements when problems are reported</td>
</tr>
<tr>
<td>Voltage, flicker, sag</td>
<td>V</td>
<td>-1s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage regulation</td>
<td>W</td>
<td>-1 min</td>
<td>-1 min</td>
<td>Periodic</td>
</tr>
<tr>
<td>Voltage</td>
<td>Watt and/ or vars</td>
<td>&lt; 1s</td>
<td>&lt; 1s</td>
<td>Periodic</td>
</tr>
</tbody>
</table>

This table presents measurements required for various purposes in a deregulated power sector. System control and data acquisition (SCADA) systems collect data sequentially by polling the measurement points every few seconds. A time-stamping convention must be developed and these stamps must be sent along with the measured data.

TRANSMISSION SYSTEM IN DeregULATION

Deregulation introduces further complications by making it more difficult to argue that the transmission system is built exclusively for reliability purposes and then to use the power of eminent domain to obtain right-of-way. In a deregulated energy sector, the main reason for expanding the transmission system is operational economy, rather than security in other words, to provide a more economical alternative to installing a new generation plant closer to the load. In a deregulated energy sector, not only the measurement system but also the operational principles on how to deal with customers is changing. Because customers that use similar transmission services require different ancillary services, bundling these services with the basic transmission service would result in some customers having to pay different amounts for ancillary services. Transmission system overloading and congestion problems can be solved by redispatching the generations with all the customers paying the increased costs associated with off-economic dispatch, through slightly higher average rates.
STANDARDIZATION FOR DEREGULATION

Standardization is directly related to measurements and is needed for establishing a minimum set of activities and to obtain proper pricing information for the transmission services. Some of the key areas where standards may be helpful in system operation are as follows:

- Standardization of information will be an important factor for competition. At present, some purchasers may have certain operational advantages in competition, because the asymmetrical information flow may be in their favor.
- Measurement and transmission of the operational data concerning the dynamic system performance (e.g. the transient performance of the system, and monitoring of the voltages) to the system operators,
- More frequent measurement and data transmission from the generating plants to system operators. For example, standards are needed to increase the amount of information received from the generating plants. In addition system operators need more accurate and correct information concerning load characteristics,
- Measurement and data transmission services provided to system operators for ancillary services concerning generations and loads,
- Requirements for maintaining system security, stability and integrity as the market opens up and Design and development of real-time software with a proper help system to assist the system operators manage the incoming data display information in a form so as to avoid information overloading on system operators and facilitate decisions.

The main contribution of standardization for market transactions will be:
- To assure compatibility among equipment in different systems and to provide reliable and accurate information for contracts (e.g., billing, performance evaluation and friction) and to resolve disputes,
- To develop pricing systems that reflect proper incentives and to support the development and enforcement of non-compliance penalties.

Technological areas where new standards may improve wholesale and retail activities include the following:

1. Development of a data exchange system (EDI) among metering, communication software and equipment, so that the retail market players (e.g., generation suppliers, distribution utilities and sales companies) can easily obtain and exchange data needed for their activities.
2. Tracking of generations; whether they are supplied as agreed in contracts,
3. Tracking of loads shed by retail customers and power marketers/brokers,
4. Tracking of actions on power marketers/brokers whether they apply load relief by providing ancillary services as agreed in contracts,
5. Tracking of power flows to assign responsibilities on the cost concerning cognition on lines that exhibit overloading or congestion. More accurate measurement of standard billing parameters for contracts that were neither previously needed nor explicit,
6. More precise measurement of power quality, especially harmonics, voltage flicker, sags and surges for contracts that were neither previously needed nor explicit.
ECONOMIC IMPACTS OF MEASUREMENT STANDARDIZATION

Measurement standardization for the electric power sector will have a significant impact on the sector, as presented in Table 2. In fact, reliable, low cost power is one of the main objectives in every sector of the economy. Power reliability and power quality are related to factors that affect customers. Power quality requirements affect customers by encouraging them to be sensitive to changes in system reliability and to install backup system equipment and protective devices.

Table 2. Impact areas associated with deregulation

<table>
<thead>
<tr>
<th>Concerns associated with deregulation</th>
<th>Potential economic impact</th>
<th>Importance of measurement standardization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power quality after deregulation</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Diagnostic tool from the monitoring system conditions and identifying problems</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Cost, complexity and vendor diversity of metering equipment for market transactions</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Development of power markets at different levels of quality</td>
<td>Medium</td>
<td>Medium</td>
</tr>
</tbody>
</table>

POWER QUALITY AFTER DEREGULATION

Potential Economic Impact (High): The importance of power quality will increase with the number of pieces of consumer equipment sensitive to power quality. The cost of low power quality will be paid by the failure of consumer equipment and lost productivity, labor and capital. An estimate of the annual loss to U.S. industry arising from power quality problems in terms of loss of productivity or equipment damage is about $26 billion/year. A single shutdown in the electric power system costs as much as $500,000/hour, which is why U.S. companies impose conditions concerning power quality in their contracts. The present estimate of the loss due to power quality problems in European industry about 10 billion euros/year. In 2000, 50% of electricity customers in the information technology sector in Germany were found to suffer from data loss due to equipment and computer lockup.

CONCLUSIONS

Many real-time services will be unbundled, each to be charged independently to the side that benefits from the services. It will be possible to calculate the revenue at a faster rate in terms of the transactions and compare the requested and realized responses. A faster response will be required from the transmission system, and the technological achievements that will increase the speed of this response will valuable. The study of measurement requirements and the needs for standardization is underway in several areas to assess the benefits that are potentially available in a deregulated electric power sector. A decision on whether to pursue standards in an area requires a prospective assessment of the benefits and costs of standards for that area. A retrospective assessment of these benefits is also valuable, not so much to affirm or withdraw the original decision, but to help refine the techniques and areas of investigation in future assessments. Both maintenance scheduling and fuel resource scheduling are long term operational planning.
REFERENCES
[8] IndiaCore Information on Indian Infrastructure & Core Sectors, 2004 (info@indiacore.com)