Power Industry Reliability Coordination in Asia in a Market Environment

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Abstract: *This paper addresses the problems of power supply reliability in a market environment. The specific features of economic interrelations between the power supply organization and consumers in terms of reliability assurance are examined and the principles of providing power supply reliability are formulated. The economic mechanisms of coordinating the interests of power supply organization and consumers to provide power supply reliability are discussed. Reliability of restructuring China's power industry is introduced. Some reliability data is provided. The data shows that the reliability level has increased significantly in the past two decades. More and more measures are being applied to guarantee reliability of the restructured power systems. The reliability issues and challenges that are facing the Chinese power industry are considered The paper, then examines the evolution of power grids in India, the establishment of a regulatory framework, and operational philosophy in reliability aspects of long-, mid- as well as short-term (operational / outage) planning. Grid security, restoration, and mock trial for black start, etc. from the reliability angle are considered. Related issues for islanding operation to improve service reliability for Thailand's Electric Power System are then analyzed.*
Keywords: *Power supply reliability; power market environment; coordination; principles and mechanisms, China power industry deregulation and restructuring; India power restructuring; power network security; planning: long-, mid- and short-term; real time operation; restoration procedure; distributed generation; intentional islanding operation.*

1. Introduction

The experience of power industry restructuring in many countries of the world has highlighted the reliability-related difficulties and problems encountered (Casazza et al, 1999; Voropai, 2007; Chow et al, 2005). Transition to a competitive model of power industry organization has called for thorough and comprehensive studies. The necessity of rational combination of market mechanisms of management and state regulation that should be indirect has been indicated. It has turned out that those competition mechanisms, although enhancing the commercial efficiency of electric power system (EPS) operation may have an adverse impact on reliability of power supply to consumers.

This paper is a survey paper that considers power system reliability coordination in a market environment in Asia at present and future not presented in the literature in a convenient form heretofore. It examines power system reliability in Russia; transition of the Chinese power industry: market efficiency, reliability issues, reliability management, statistics, and reliability coordination in restructured power systems; and reliability from load forecasting to system operation in the Indian power system where reliability aspects of planning, day ahead scheduling, real time operation, network security, and restoration procedures are discussed. Also considered is intentional islanding operation to improve service reliability following a severe power system event. Here, issues related to islanded operation: quasi-steady state performance and dynamic behavior are considered.

2. Reliability Coordination in Power Supply

In Russia the Federal Law *On the Electric Power Industry* adopted by the state Duma on February 21 2003, started the market transformations in the Russian electric power industry. Great attention has been paid to the reliability problem. The law defines two notions: system reliability and power supply reliability. System reliability is reliability of power system as the technical or industrial object and includes adequacy and security. Power supply reliability shows the level of reliability of power supply of consumers and deals with reliability on service of consumers in power supply. System reliability is provided by EPS and it is a responsibility of the System Operator. Power supply reliability is provided by the power selling companies. However, these companies do not have their own funds to provide power supply reliability and, therefore, should coordinate their actions with the organizations that operate the distribution electric networks. The power selling companies using distribution electric networks hereinafter will be called power supply organizations.

It is sensible to consider:

- Specific features of economic interrelations between the power supply organizations and the consumers;
- Principles of providing power supply reliability;
- An economic mechanism of coordinating the interests of the power supply organizations and the consumers.

2.1. Features of Economic Interrelations between Power Supply Organization and Consumers

Reliability is one of the characteristics that determine quality of a commodity and for some level of reliability to be provided there should be resources and efforts that have a known influence for the power supply organization. The organization is ready to invest these resources and efforts since it understands that the consumers will pay for power provided the required power supply reliability is guaranteed. Otherwise, consumers will search for another power supply organization or put into operation its own power sources. On the other hand, the power supply organization should get some compensation for investing resources and efforts in power supply reliability.

Consumers that buy power from power supply organizations understand that it has to pay for power supply reliability and is ready to pay. Conversely, insufficient power supply reliability results in losses for the consumer. Therefore, consumers should weigh the payment for power supply reliability and the losses from insufficient reliability. This somewhat simplified reasoning characterizes the difference in interests of the power supply organizations and the consumers and shows the need to find a compromise. To do this the power supply organization and consumer should exchange information. In a general case the consumer should show the damage due to unreliability D*(R)* and the power supply organization, the electricity price as a function of reliability C*(R)*. After that each of them may plan their actions and determine a rational (compromise) level of reliability (Kucherov et al, 2005). Qualitatively this is illustrated in Fig.1.

Here *R* is reliability characteristics (indices) of a commodity (object), and *C(R)* are cost of providing reliability that will raise additionally the electricity price. Thus, point R_{opt} will characterize the sought efficient reliability of the object.

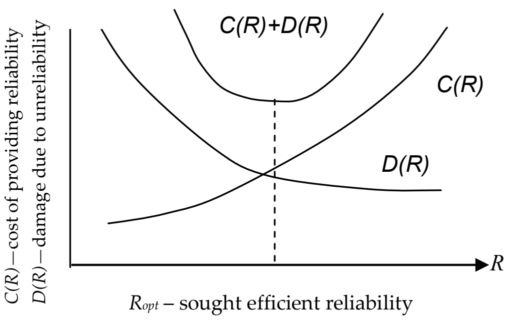


Fig. 1. Classic reliability criteria

The specific feature of the situation is based on each of the subjects has its understanding of the constituents presented in Fig.1, though they have a single objective base. For the power supply organization *C(R)* is the real cost of providing reliability. However, for the consumer it is the electricity price to be paid and in a market environment this price may not always correspond to real costs. Characteristic *D(R)* is perceived differently by the subjects. For the consumer it is damage due to insufficient reliability. For the power supply organization, it is payments to be made in the case that it cannot provide the required power supply reliability. The minima of the characteristic, i.e. R_{opt}, for these subjects may not coincide and this is an additional obstacle to finding the compromise.

2.2. Principles of Providing Power Supply Reliability

Each consumer may formulate quite definite requirements to frequency, duration and magnitude of interruptions in power supply to their electrical facilities. Consumers may have several types of electrical facilities with different requirements for power supply reliability. This depends on the production process the consumer has: the more sophisticated and advanced technology, the higher the requirements for power supply reliability. Based on the requirements for reliability, concrete recommendations on the power supply scheme for consumers (power supply from one, two or more independent sources, technical capabilities of meeting the requirements for duration of power supply interruption, i.e. the need for automatic transfer to reserve source, or manual switching to reserve source, or other, less stringent, requirements) are made. All this leads to formation of categories of electric facilities in terms of reliability. This is a qualitative index of power supply reliability that is determined and provided at the stage of designing the power supply scheme as stated in the rules for arrangement of electrical facilities published by the ENAS publishing house, Moscow, page 236 in 2004.

Electric power systems provide the required reliability level at nodes of the main grid that supply power to the power supply schemes of the consumers (supply nodes). The required reliability level at supply nodes should be sufficient to meet consumer's integral requirements for reliability of power supply to its electrical facilities at the power supply scheme chosen by the consumer. It follows that the consumers should formulate the requirements for reliability at supply nodes of EPS, whereas EPS should assess its capabilities of providing reliability at supply nodes and estimate cost implementation. Then the consumer will analyze the relationship between cost of providing reliability of power supply to its electrical facilities at the expense of power supply scheme capabilities and the cost of EPS services on providing some level of reliability at the supply nodes. Based on this analysis, consumers will choose the most rational solution for reliability of power supply.

In a market environment, reliability is the service that provides meeting the requirements of power supply reliability. The cost of this service is determined on a market basis, i.e. mutual obligations of the power supply organization and the consumers. Responsibility for its discharge is expressed in economic terms and is implemented through bilateral and multi-lateral contracts. The normative principle here suggests standardizing the requirements of specific electrical facilities to frequency, duration and magnitude of power supply interruptions which is then expressed in requirements for the power supply scheme and reliability levels at supply nodes and the establishment of standards by categories of electrical facilities.

System reliability is complex. It is provided by EPS structure, generating capacity reserves, transfer capability margins of tie lines, and control means in a wide sense (repairs of equipment, control of generation reserves, dispatching and automatic emergency control, etc.) Providing system reliability involves all segments of the electric power industry: generation, electric network, consumers, and system operator. The system operator that is responsible for system reliability has limited technical capabilities of providing system reliability, therefore the required means should be bought from other subjects: generating and network companies, and the consumers. This process can be organized by the System Operator on basis of multilateral contracts that stipulate economic obligations and economic responsibility of parties for system reliability.

Should pre-emergency conditions be revealed (a dangerous decrease or increase in frequency or voltage, occurrence of other threats in terms of reliability), emergency dispatching and automatic control priority before commercial management should be provided?

The System Operator (responsible for system reliability), and the power supply organization (responsible for power supply reliability), should analyze when reliability cost should be included in the prices of system reliability services and prices of electricity sold to the consumers, and when the losses should be compensated from insurance funds.

It is necessary to determine the relationship between reliability of elements of the EPS and power supply systems, and system means of providing reliability. Owing to technological progress, the reliability of both main and secondary (elements for diagnostics of state of equipment, control and management systems, etc.) EPS elements are increasing. This tendency may lead to decrease in *load* on system means of providing reliability if general requirements for power supply reliability do not rise simultaneously. Determination of such a rational relationship requires specific quantitative studies.

2.3 Mechanism to Coordinate Interests of Power Supply Organization and Consumers

In general, both subjects of relations (power supply organization and consumer) have different reliability criteria that do not coincide. Unfolding the rules for arrangement of electrical facilities, consider a possible mechanism of interrelations between the subjects to find a compromise solution of providing reliability of power supply (Kucherov et al, 2005).

Let us estimate the total value of income and cost for each subject as the criterion of its benefit. Consider this criterion for the power supply organization and the consumer.

For the power supply organization

$$IC_s = I_e + I_R - C - D^* \quad (1)$$

where I_e is the total reduced income from power sales over period T; I_R is the total reduced income from consumer's payment for reliability over period T; C is the total reduced cost of power supply organization operation (including a reduced share of capital cost and current costs over period T); and D^* is payments to consumers for insufficient level of power supply reliability in relation to the agreed level, stipulated in the contract on power supply between the power supply organization and consumer over period T. D^* is like "*damage*" for supply organization.

For the consumer

$$IC_c = P_c - C_e - C_R - D + D^* \quad (2)$$

where P_c is the total reduced profit of the consumer without power supply cost; C_e is the total reduced cost of power supply (taking into account that not only does the consumer buy electric power but also takes measures to receive it); C_R is the total reduced costs of providing reliability; and D^* is the payments from the supply organization (see (1)); D is the overall reduced damage of the consumer from unreliability of power supply.

It is seen from (2) that the consumer suffers overall damage from power supply unreliability (that equals D), but part of this loss (that equals D^*) corresponds to an insufficient level of power supply reliability in relation to the agreed level stipulated in the contract for power supply between the power supply organization and the consumer that is compensated by the power supply organization.

At given electric power sales and, hence costs, the interest of the power supply organization will be determined by the criterion

$$I_R - D^* \rightarrow max \quad (3)$$

However, for the consumer

$$D^* - D - C_R \rightarrow max \quad (4)$$

In this case for the aggregate consumer, representing all consumers that are served by this power supply organization,

$$I_R = C_R \quad (5)$$

Consider the obtained relationships from the viewpoint of interests of the power supply organization and the aggregate consumer. If the power supply organization is able to use efficiently the funds I_R and increase the power supply reliability by making cost of loss compensation lower than the reliability cost from I_R, it will gain an additional profit. Hence, the power supply organization gets an incentive to increase reliability efficiently.

However, the consumer is interested in higher compensation D^* than the cost of providing reliability C_R. If the consumer states the required reliability by setting the values of specific damages d_p, \$/kW (from a sudden power outage) and d_e, \$/kWh (from electricity undersupply), D^* can be raised, increasing d_p and d_e. However, this will increase the consumers' cost on providing reliability that should depend on d_p and d_e. Moreover, to decrease D^* the power supply organization will try to increase reliability for this particular consumer. Thus, the considered economic mechanism of interrelations between the power supply organization and the consumer provides an economic balance of their interests, thus entitling the consumer to choose any reliability level by setting its own characteristics d_p and d_e. Setting the fee to be paid by the consumer for power supply reliability, the power supply organization may stimulate the consumer to analyze its real characteristics d_p and d_e, without overstating them too much. This creates economic incentives for the power supply organization to efficiently increase power supply reliability and allows consumers to rationalize their requirements for power supply reliability. Rationalization of the requirements comes down to it becoming profitable for the consumer to set values for specific damages d_p and d_e that equal their real values. Overstatement of these values requires an increased payment for reliability, whereas their understatement compensates incompletely the damages from insufficient power supply reliability.

3. Transition of the Chinese Power Industry: Market Efficiency and Reliability Issues

The systems in China are basic conventional and not real deregulated systems. With rapid economic growth in China since the 1980s, electricity generation and consumption have increased significantly. To attract investment in generation, since 1985, the China government provided a fixed high rate of return to international investors and private investors for building new power plants. In 1997, the total generation capacity owned by international companies had reached 14.5% of the total installed capacity of the whole country. Due to surplus of electricity, the policy of a high rate of return was abolished in 1999. About the same period, the power industry in China started restructuring procedures.

Deregulation of the China power system has experienced two stages. The first stage was an experimental stage, which started from 1998. In this stage, six provincial power companies were selected to participate in an experimental electricity market. The program included separation of generation and transmission, and generation auction. Based on the experiences obtained, the program for the second stage of power system restructuring was determined by the National Development and Reformation Commission (NDRC) at the beginning of 2002. The structure of the electricity market in China has been restructured for regional electricity markets.

3.1. China Power Industry and Market Operation

Installed Capacity

By end of 2005, the total installed capacity had reached 517.2 GW. Compared to that in 2004, the installed capacity increased by 16.9% over one year. Thermal power capacity, 391.4 GW, is about 75.7% of the total installed capacity. Hydroelectric power capacity is 117.4 GW, about 22.7% of the total capacity and nuclear power capacity is 6.84 GW, 1.32% of the total capacity. Wind power capacity has reached 1.05 GW, which is 0.2% of the total capacity (http://www.cec.org.cn/) (Zhou & Zuo, 2006).

Power Generation

Total annual power generation reached 2,497 TWh in 2005. It increased by 13.8% compared to that of 2004. The average utilization of generation units was 5425 h in 2005. This has reduced by 30 h compared to 2004. Detailed data for generation and utilization hours is given in Table 1 (Zhou & Zuo, 2006).

	Installed Capacity (GW)	Generation (TWh)	Annual utilization (hrs)
Thermal	391.37	2,043.7	5,865
Hydro	117.39	396.3	3,663
Nuclear	684.6	53.1	N/A
Total	517.18	2,497.5	5,425

Table 1. Data of Power Systems in 2005

Transmission Facilities

The data for transmission facilities over 220kV is indicated in Table 2 (Zhou & Zuo, 2006).

Voltage level	220kV	330kV	500kV	500kV
Length of Overhead line (km)	178,730	13,384	56,523	5,821
Number of transformers	4,494	144	1,160	N/A
Number of circuit breakers	17,436	609	2,226	N/A

Table 2. Data for Transmission Facilities over 220kV in 2005

Market Operation

Currently, most of the markets in China are single buyer markets, in which all generators sell their energy to the grid companies (Zhong & Ni, 2006). The NDRC and local government regulate electricity sale prices charged from customers and generation prices paid to generators. In some regions with long distance power transmissions, transmission prices paid to the grid companies are also regulated and decided by the NDRC.

Reliability problems have been considered and discussed in the procedure for power system deregulation. Although generation assets have been separated, each regional grid company owns a few units for system frequency control and reliable operation. On the other hand, all generators and transmission companies follow compulsory reliability requirement issued by the market regulator.

3.2. Reliability Management in China

Reliability Management Organization

The Electricity Reliability Management Center (ERMC) was established in January 1985 (A brief introduction of Electric Reliability Management Center. Available: http://www.chinaer.org/zuzhi/english.asp). The ERMC has developed with transition of the Chinese power industry and restructuring of the power sectors. Statistical data for electric reliability was first published in 1985 by the ERMC in the Electric Power Reliability Management Magazine, which later became the official magazine for reliability data publishing. In July 1987, the Electric Power Facility Reliability Statistical Code was issued. It was the start of information technology management for electric power reliability in China. The first Power Reliability Index Release Meeting was held in 1994. After that, the meeting has been held annually to release reliability data for the preceding year.

The main functions of ERMC include (A brief introduction of Electric Reliability Management Center. Available: http://www.chinaer.org/zuzhi/english.asp):

- Formulate national reliability standard and related regulations.
- Collect electricity reliability data; establish comprehensive reliability information management system; and publish electricity reliability indexes.
- Monitor power system reliable operation.
- Formulate reliability criteria for the building of new generators and substations.

Currently, the work of ERMC is mostly based on reliability data collection and publishing, and reliability evaluation criteria formulation. More functions will be performed in the future with the development of electricity markets.

Measures for Reliability Management

Reliability operation and management for the China power system is implemented by administration measures. The ERMC enacts an important role in the reliability operation. During the past few decades, the most important reliability management measures include:

- ERMC formulated an Electric Power Reliability Management Code in 1987. The Code is the basic criteria for reliability operation. The regulations issued later have more or less been based on the Code.
- Reliability information management software has been development by ERMC. Generation and transmission companies are required to use the software for reliability management. This has facilitated reliable operation of the power system.
- Annual release of reliability operation indices for large units and transmission equipment bring pressures on power companies. They try to improve the reliability indices for the next year index.
- ERMC monitors potential reliability problems caused by power system planning, equipment manufacture and system operation. Reliability is improved from reliable operation of equipment to reliable operation of the system (A brief introduction of Electric Reliability Management Center. Available: http://www.chinaer.org/zuzhi/english.asp).

3.3. Reliability Statistic Data for Past Decades

Reliability Data for Generation

To indicate reliability following power system deregulation, reliability data from 1985 to 2005 is discussed. In 2005, generation reliability data is based on 1,329 large-capacity generation units including thermal units larger than 100 MW, hydroelectric power plants larger than 40 MW and nuclear generation units. The total installed capacity of the investigated units in 2005 was 285.5 GW (Zhou & Zuo, 2006).

The unplanned outage hours per unit, equivalent forced outage rates (EFORs) and equivalent availability factors (EAFs) for thermal units in the past five years are indicated in Table 3 (Zhou & Zuo, 2006; Zhao et al, 2005; Chen et al, 2004; Wu et al, 2003; Wang, 2002).

The unplanned outage hours per unit for EFORs and EAFs for hydroelectric power units in the past five years are given in Table 4 (Zhou & Zuo, 2006; Zhao et al, 2005; Chen et al, 2004; Wu et al, 2003; Wang, 2002). The unplanned outage hours per unit for EFORs and EAFs for hydroelectric power units in the past five years are given in Table 4. The trends for EFOR and utilization factors EAF are shown in Fig. 2 and Fig. 3, respectively. Fig. 2

Year	Unplanned outage hours per unit	EFOR (%)	EAF (%)
2001	141.69	1.74	90.64
2002	128.75	1.30	91.06
2003	113.02	1.37	91.15
2004	96.09	1.14	91.70
2005	79.21	0.95	92.34

Table 3. Reliability Data for Thermal Generation Units

Year	Unplanned outage hours per unit	EFOR (%)	EAF (%)
2001	81.15	0.97	92.44
2002	39.77	0.26	92.99
2003	30.07	0.18	92.37
2004	28.56	0.36	93.17
2005	22.4	0.14	92.22

Table 4. Reliability Data for Thermal Generation Units

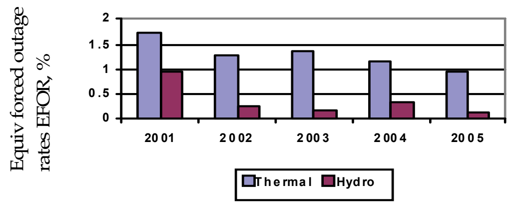


Fig. 2. EFOR for thermal and hydro units from 2001 to 2005

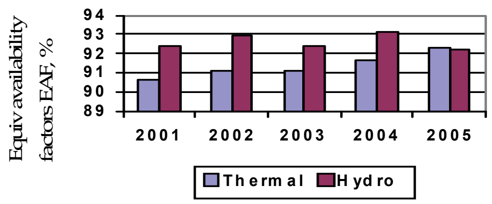


Fig. 3. EAF for thermal and hydro units from 2001 to 2005

and Fig. 3 show that the trend of equivalent forced outage rate has been going down over recent years. The equivalent availability factors for thermal units has been going up in the period.

In Table 5, the reliability indices for thermal units (>100 MW) are given from 1985 to 2005 (Zhou & Zuo, 2006; Zhao et al, 2005; Chen et al, 2004; Wu et al, 2003; Wang, 2002). The trends of the EFOR and EAF changes are shown in Fig. 4 and Fig. 5, respectively.

It can be seen from the table and figures that reliability management in the past 20 years has been effective, and reliability of thermal units has improved significantly.

Year	Average capacity of investigated units (MW)	EFOR (%)	EAF (%)
1985	139.46	5.55	84.02
1986	145.99	8.79	79.93
1987	148.85	7.12	80.98
1988	152.72	6.82	80.70
1989	158.36	7.20	80.47
1990	162.43	7.31	81.02
1991	169.08	6.38	81.85
1992	174.62	7.16	81.79
1993	180.75	6.43	82.66
1994	184.50	5.21	83.78
1995	186.23	4.29	86.24
1996	190.26	3.87	86.38
1997	196.68	3.02	88.38
1998	201.11	3.02	88.54
1999	206.82	2.09	89.86
2000	211.30	1.99	90.30
2001	216.10	1.74	90.64
2002	219.47	1.30	91.06
2003	223.94	1.37	91.15
2004	226.53	1.14	91.70
2005	233.94	0.95	92.34

Table 5. Reliability Data for Thermal Generation Units

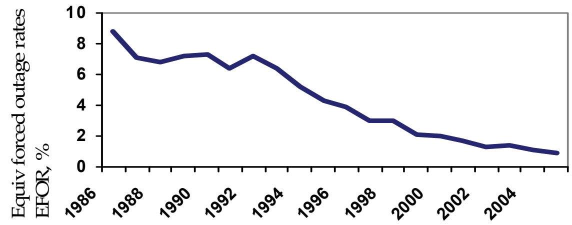


Fig. 4. EFOR trend for decade 1985 to 2005, %

	EFOR (%)	EAF (%)
Overhead line	0.282	99.089
Transformer	2.009	99.332
Reactor	0.256	99.356
Circuit breaker	2.007	99.634
Circuit transducer	0.136	99.799
Potential transducer	0.093	99.844
Switch	0.223	99.886
Lightning arrester	0.016	99.848
Capacitor	0.029	99.905
Bus bar	0.147	99.892

Table 6. Reliability Data for Transmission Facilities

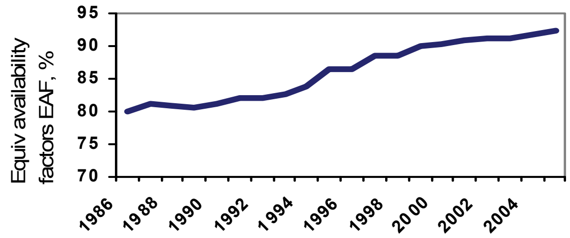


Fig. 5. EAF trend from 1985 to 2005, %

Improvement of reliability, to a certain extent, is on account of installation of new large capacity thermal units that have higher reliability operation levels than small capacity units.

Reliability Data of Transmission Systems

The equivalent forced outage rates and equivalent availability factors for year 2005 are given for various transmission facilities in Table 6 (Zhou & Zuo, 2006).

Power Supply Reliability

According to data of 2005, the reliability on service in total (RS-1) is 99.77%, and the reliability on service except limited power supply due to generation shortage of system (RS-3) is 99.85%. The average interruption hours of customer (AIHC-1) is 20.49 h and the average interruption hours of customer on service except limited power supply due to generation shortage of system (AIHC-3) is 13.54 h. The historical statistical reliability data for large customers (>10kV) are given in Table 8 (Zhou & Zuo, 2006).

	Overhead line (no./ 100km)	Cable (no./ 100km)	Transformer (no. per unit)	Circuit breaker (no. per unit)
2001	8.932	4.744	0.511	2.852
2002	9.674	4.447	0.640	3.077
2003	8.343	4.059	0.485	2.237
2004	9.408	4.148	0.468	2.535
2005	9.61	4.27	0.562	2.67

Table 7. Annual Outage Rate for Transmission Facilities

	RS-1 (%)	AIHC-1 (h)	RS-3 (%)	AIHC-3 (h)
2001	99.897	8.999	99.898	8.944
2002	99.907	8.171	99.916	7.375
2003	99.866	11.724	99.929	6.241
2004	99.820	15.806	99.927	6.388
2005	99.766	20.491	99.845	13.539

Table 8. Power Supply Reliability for Large Customers

3.4. Reliability Coordination in Restructured Power Systems

Reliability Improvement under Electricity Shortage

Due to fast economic growth and lag of new generator construction, almost all provinces in China have experienced electricity shortages in the period 2001 to 2005. It should be stressed that the reliability level during this period has improved faster than before. Annual utilization hours for different sizes of units are given in Table 9 (Zhou & Zuo, 2006).

Reliability Issues under Market Environment

The deregulation of power systems results in inconsistency of market mechanisms and reliability operation. Without a proper mechanism, reliability may become the trade-off of generation revenue. One of the challenges for transmission companies is to provide the mechanisms for facilitating reliable operation in a market environment.

Considering this issue, the State Electricity Regulatory Commission (SERC) has emphasized the importance of reliability in their market regulations.

Research Work on Reliability Issues in China

1. Research has been focused on power system operating reliability evaluation based on real-time operating state (Sun et al, 2005; Cheng et al, 2006).
2. Power supply reliability is being given much more attention.
3. Reliability management has been extended to consider operational risk assessment (Feng et al, 2006).
4. Reliability: From Load Forecasting to System Operation in Indian Power System

The Indian power sector has also experienced a rapid change. Installed power capacity of India, was 1,362 MW in 1947. It rose to 127,673 MW (hydro 33,600 MW, thermal 83,982 MW nuclear 3,900 MW, renewable energy system 6,191 MW) as of Oct. 2006. Transmission line length was 1,831 km, 71,149 km, and 111,151 km for voltage levels of 765 kV, 400 kV and 230 kV, respectively, as of Oct. 2006.

Unit Cap-acity	100 MW	125 MW	200 MW	300 MW	350 MW	600 MW	Avera ge
2001	5264.24	5591.59	5477.64	4996.71	5043.99	5287.73	5185.75
2002	5701.07	5794.01	5743.14	5349.99	5451.08	5276.1	5529.53
2003	6224.17	6283.58	6235.18	5908.26	5949.87	6114.14	6079.72
2004	6551.87	6439.79	6312.18	6272.7	6468.99	6342.1	6350.96
2005	6445.45	6187.15	6179.73	6229.38	6233.36	6297.69	6259.24

Table 9. Unit Utilization Hours

High voltage direct current (HVDC) circuit length was 5,872 km at ± 500 kV with installed capacity of 10,000 MW. Substation capacity at 400 kV and 200 kV was 89,477 and 149,457 MVA, respectively. 73.9 % of villages were electrified (total villages being 593,732) as of Oct. 2006.

There is a shortage of power of around 10 to 15% at this time. If the same growth were maintained the installed capacity would go up to 230,000 MW by 2012 (Palanisamy et al, 1999). To achieve this target a generation capacity of about 10,000 MW per year would be required to be added each year. Addition of this capacity would require approximately Rs. 90,000 crores per year for generation, transmission and distribution works (Joshi et al, 2000)

The Government is unable to provide the required amount of capital for the power sector for which reforms/privatization is essential. In India, the major part of electricity (about 65%) is generated through coal-fired plants, which cause air and thermal pollution. Transmission and Distribution (T&D) losses in India are 23% compared with the international average of 10%. Similarly, there are revenue collection and metering problems in the distribution systems.

4.1. Reliability Aspect of Planning

Generation and transmission planning can be divided into long-term, mid-term and short-term (to deal with scheduling of generation and transmission operation vis-à-vis outage) considering the period for which demand vis-à-vis supply is concerned.

Long-Term Planning

In India, the basic work of planning starts with a power survey that is undertaken by the Central Electricity Authority (CEA) of the Ministry of Power of Government of India. State Electricity Boards (SEBs) do the spadework with the different agencies involved through collection of data concerning new demand in commercial, industrial, domestic, public service and irrigation areas and also growth for the existing systems in the corresponding areas. CEA consolidates the projected figures on an all-India basis by working in close coordination with the SEBs. CEA forecasts load and works out total requirement of electric energy and peak load to be met for the next few five-year plan periods based on a combination of partial end use technique and trend analysis, and computing long term projection by extrapolating the energy requirement at power station bus bars. Various components, such as T & D losses (both technical and commercial), load factor, diversity factor, etc. are also taken into account state/system-wise along with the rate of growth (Mukhopadhyay & Soonee, 2007)

Long-term projection takes care of regional diversity factors considering the significant daylight time difference across the country from east to west. Recession in economy and restructuring of SEBs are the other pertinent factors that influence the overall scenario. These figures are scrutinized by certain Government Departments in India including the Planning Commission keeping in mind commensurate fund requirement vis-à-vis relative priority with respect to other sectors of infrastructure of the country for investment under the public sector. Having made the blue print, CEA works out details for generation corresponding to various scenarios of load projected for a few five-year plans ahead.

In all these projections computed availability based on planned outage, forced outage (partial and complete) are taken into account. Then under Integrated Resource Planning, considering all possible sources to produce electricity in conventional ways including nuclear, the optimum solution is derived for meeting the load requirement. In the process of planning for the addition of new generation, issues of system improvement to minimize T & D losses, the raising of plant load factor, renovation and modernization (R & M) of old but still running power plants, and also generation from renewable and non-conventional sources, etc. are considered to augment the overall supply.

Having known load points in the process, the possible corridors for transmission of power vis-à-vis energy are identified, though voltage level may be just indicative at this stage. The basic philosophy of configuring the transmission system is to achieve a level of operating performance with adequacy and security. This in turn requires a trade-off between cost and risk with the level of uncertainty taken care of. It is based on a combination of deterministic as well as probabilistic approaches, later being based on the most likelihood of occurrence vis-à-vis past experience to expect ultimately acceptable system performance.

Accordingly, certain planning criteria have evolved over the years and are followed. The process starts with inputs in the form of possible generation sites with capacity available and bulk loads. It involves not only the corridors for transmission lines with voltage levels, but also finding locations for the associated substations. The major guiding factors for such planning exercises are adequate transformation capacity in the substation with the possibility of future expansion, and flexibility at the operation stage, etc.

Mid-Term Planning

Under this issue is the question: who is responsible for planning for 8760 hours in the year? Is it the Distribution Companies (DISCOMs), State Transmission Utilities or the State Load Dispatch Centers (SLDCs)? The Indian Electricity Grid Code (IEGC) talks about meeting demand without overdrawing from the grid, and a need to trade-off interrupting consumer load without compromising the security of the electricity grid. Annual Revenue Returns filed by DISCOMs have no mention of quality of service in terms of how many consumers would have to suffer power cuts and for what duration in an entire year. This is despite the known shortage of power and energy in the country. So at this stage reliability of supply is commensurate not only with availability, but also with the issue of grid security.

Outage Planning

State Grid Codes have come into existence. There is not much of a problem in coordinating outages within a state, as the SEBs has only recently been unbundled. Outage planning of jointly owned units of the National Thermal Power Corporation, the National Hydroelectric Power Corporation and other Central Government owned plants poses a more serious problem and eludes consensus. On the other hand, it suits the generating plants that can get away with slippage in maintenance plans thus running the risk of forced outage.

4.2. Reliability Aspect of Day Ahead Scheduling

For hydro generation there is very little flexibility on account of irrigation requirement having an overriding effect. Only a few plants are having a high level of flexibility in respect of scheduling and real time operation. On the other hand, coal fired stations are operated on base load and cannot go below 70% due to poor quality of coal. Thus scheduling is quite rigid and predictive.

4.3. Reliability Aspect of Real Time Operation

For real time operation, two pertinent parameters, voltage and frequency, are considered to describe the situation.

Frequency

Operating philosophy is based on the fact that states are considered as notional control areas and tight control is not mandated. Frequency is also allowed to vary from 49.0 to 50.5 Hz, a fairly large band in comparison to developed countries. The frequency-linked unscheduled interchange (UI) mechanism (Mukhopadhyay & Dube, 2005), a unique feature, encourages control areas to monitor and control their off take and thereby complement grid security. This unique real time pricing mechanism demonstrates effectively how markets could take care of reliability, particularly in a country like India where power shortages occur.

Different imbalance or UI prices for each regional grid, a cap on UI volumes by control areas (with provision for fines by the regulator) and a dynamic variation in UI ceiling rates and slope along with fuel prices have to be introduced to complement reliability. Some of these have been taken up with the regulator. These show that markets can work and support reliability only if the design is such that it is self healing and does not require frequent interventions by the regulator.

With synchronization of 4 out of 5 regional grids, fairly tight control is desirable if the network is to operate reliably.

Voltage

For voltage control, a simple scheme operates at inter-utility level, which again needs to be reviewed. Generators are obliged by law to provide reactive power requirement and are not compensated for the same separately. The value of static and dynamic reactive reserves in this respect is yet to be appreciated by stakeholders.

4.4. Network Security

Real time contingency analysis for better situational awareness is an area of concern. Exceptional events like smog during winter, earthquake, and weather related disturbance result in a large number of line tripping. Provision of larger design margins enhances chances of lesser failure. Earlier constructed lines reliability is of concern under such situations.

Under-Frequency Load Shedding and Under-Voltage Load Shedding with pre-determined settings under code of practices avert catastrophic failure of the grid. In context of formation of a national grid, deliberations are going on for the implementation of Special Protection Schemes (SPSs), such as Wide Area Network Measurement and Control, again to contain the widespread effect of system disturbance and improving reliability of large integrated systems.

4.5. Restoration Procedures

In case of system black out or brown out, clear-cut procedures have been laid down for restoration based on the grid code. Past experience, even with regional grid operation, has shown that the restoration process takes anything from an hour or two to up to 18 to 24 hours to bring back complete normality.

The Indian power sector, opened up with unbundling into distinctive entities of generation, transmission and distribution, has grown to a large size in the last sixty years. With both public and private participation, reliable load forecasting, planning and system operation ensuring security to meet demand at each instant have become an utmost necessity in context of having electricity for all by the end of next five-year plan (March 2012).

5. Intentional Islanding Operation to Improve the Service Reliability of Thailand Electric Power System

Integrated resource planning and distributed generation (DG) via traditional or renewable generation facilities for deregulated utility systems should be rejuvenated to enhance reliability of power systems (Davis, 2002a; Davis, 2002b). Traditionally, interconnection standards avoid islanding operation of distributed generation, DG, due to the concerns of equipment failure and safety issues. However, in some cases, allowing islanding of DG connected to radial sub-transmission system could improve system reliability and decrease outage cost during power outage or schedule maintenance (Pilo et al, 2004; Zeineldin et al, 2005; Nigim & Hegazy, 2003; Hsu & Chen, 2005). To improve service reliability of the Thailand electric power system, both quasi-steady state and dynamic, studies of a sample sub-transmission system to explore possible arrangements and operation strategies to allow DGs to continue to be operated under islanding conditions have been performed.

With proper arrangement, an islanded faulted area with DGs can still be operated in islanding mode if the fault can further be isolated. This operation can improve system reliability and reduce the outage cost from loss of supply (Pilo et al, 2004; Zeineldin et al, 2005; Nigim & Hegazy, 2003; Hsu & Chen, 2005). Since the islanding is formed after disconnection from the main grid, utilities cannot guarantee that the islanding system will remain stable, and it relies on DGs to control voltage and frequency within the normal operation ranges. The protection and safety issues are also critical since line crews may not know the faulted part is still alive (Anderson, 1998).

Related issues for islanding operation are now examined. The procedures for proper islanding operation to improve service reliability for the Thailand Electric Power System as a case study are summarized.

5.1. Thailand Electric Power System (Fuangfoo, 2006).

Three state enterprise utilities are responsible for the entire Thailand EPS. They are (i) the Electricity Generating Authority of Thailand (EGAT) that is responsible for generation and transmission; (ii) the Metropolitan Electricity Authority (MEA); and (iii) the Provincial Electricity Authority (PEA) that provides services to the Metropolitan (Bangkok, Nonthaburi and Samut Prakan) and Provincial (rest of the country) areas, respectively. EGAT is also responsible for supplying some large customers (Fuangfoo, 2006).

Thailand's Distribution System

MEA and PEA are responsible for the distribution system. MEA delivers electric power to Bangkok, Nonthaburi, and Samut Prakan, whereas PEA serves the customers for the rest of the country. Since this study focuses on the PEA's system, detail of the MEA system is not included.

PEA had total peak load demand of 12,878 MW with 12,377,483 customers in 2003. PEA's service area covers 510,000 km^2, which includes 73 provinces or 99% of the country.

Originally, PEA had only distribution substations at 22 kV and 33 kV levels. Recently, EGAT has asked PEA to construct its own sub transmission system linking EGAT's substation to PEA's substation. PEA's sub transmission system uses a radial configuration at 115 kV or 69 kV (only very short lines in Prathumthanee province), of length 1-40 km. In the future, PEA plans to use a loop configuration sub transmission system in some areas to increase system reliability.

Current Regulations for Interconnection of DG to the PEA System

Current regulations for interconnection of DGs to the PEA system were established in October 2000. The regulations target small power producers that have DG with aggregated total generating capacity between 100 kVA and 90 MW for synchronization onto the PE system. DGs are responsible for the costs of interconnection to the power system, modification of the PEA system to facilitate synchronization, and equipment testing and installation of protective devices to prevent damage to the system. PEA may request a DG applicant to perform the impact study. If the impact study is approved by PEA, PEA will consider connecting the DG to PEA's system. For generating capacity exceeding 10 MW, DG has to be connected to the 69 kV or 115 kV systems. The criteria for synchronization of DG to PEA's system are summarized as follows:

- Voltage Levels that DGs should maintain should be the terminal voltage within the following ranges:
  - Voltage Level 115 kV - Maximum 120.7 kV, Minimum 109.2 kV
  - Voltage Level 69 kV - Maximum 72.4 kV, Minimum 65.5 kV
  - Voltage Level 33 kV - Maximum 34.6 kV, Minimum 31.3 kV
  - Voltage Level 22 kV – Maximum 23.1 kV, Minimum 20.9 kV
- DGs have to maintain the frequency of its system to 50 ± 0.5 Hz. If this level cannot be maintained, the DG has to be disconnected from PEA's system within 0.1 second.
- DGs have to maintain the power factor between 0.85 leading and 0.85 lagging at point of common coupling.
- DGs should not cause excessive voltage and current distortions as defined in the harmonic regulations for commercial and industrial consumers.
- DGs should not cause excessive voltage fluctuation as defined in the voltage regulations for commercial and industrial consumers.
- DGs should connect their system through either delta or wye-grounded transformer to the PEA grid.
- DG should be disconnected from the system during power outage to avoid inadvertent islanding operation.

5.2. Issues Related to Islanding Operations

To improve the service reliability of Thailand EPS, a sample substanmission system to explore possible arrangements and operation strategies to allow DGs to continue operation under islanding conditions has been studied.

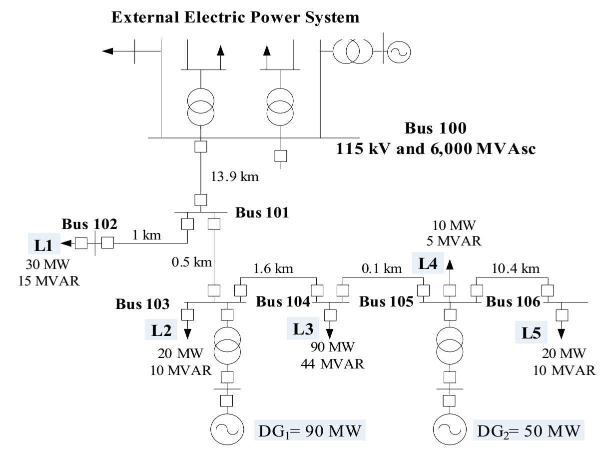


Fig. 6. Single-line diagram of the sample test system

Sample Test System

This is shown in Fig. 6. A 7-bus, 5-load, and 2 DGs (DG1=90 MW and DG2=50 MW) sub transmission system (115 kV) is used as the test system. In this study, it is assumed that the protective devices can separate the faulted part from the islanding area before the DGs can perform an intentional islanding operation. Only the Synchronous Generators will be considered since Squirrel Cage Induction Generators cannot operate during islanding operation.

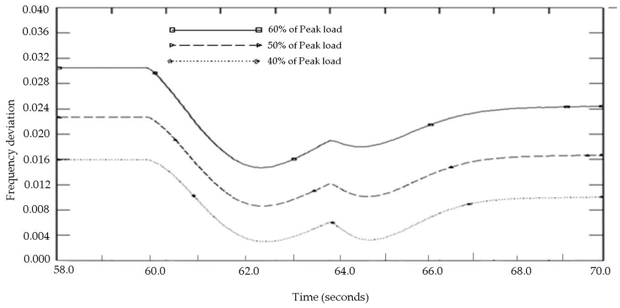
Quasi-Steady State Performance of Islanding Operation

The impact of disturbances during islanding operation is very important since the islanding system is a weak system. Large motor starting, load following, and load rejection create significant impacts on performance of the islanded system and should be studied.

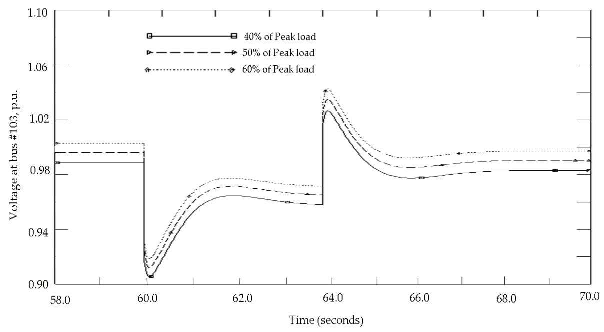
Large Motor Starting

Normally, large motor starting would cause voltage sag for a short period because of the high starting current (2~4 times of rated current) with low power factor when starting a large induction motor. The level of voltage sag depends on stiffness of the system. Since the islanding system is relative weak, the effect of starting a large motor requires further investigation.

Cases for load conditions of 40%, 50%, and 60% of peak load are used in the study to avoid overloading conditions during simulation. The motor capacity is assumed to be 14 MW (20% of total islanding load) at power factor 0.90 (running) and is connected to bus #103 (Fig. 6). The starting current of the motor is assumed to be 3.0 times the rated current at power factor of 0.30 (lagging). Since behavior of the motor during starting depends on both the control device and the motor itself, the worst-case scenario would represent motor starting by constant shunt admittance for 4 sec, and then change the motor load to the normal condition. The initial shunt admittance is (0.140–j0.445) pu relative to a 100 MVA base.



(a) Frequency deviation



(b) Voltage at bus #103

Fig. 7. Quasi-Steady state performances of the islanding system during large motor starting

Fig. 7 shows quasi-steady state performances of the islanding system during large motor starting. It shows that the voltage is higher than 0.9 p.u. for all cases. Without proper coordination, the under-frequency relay may be activated to trip loads from the islanded system in some cases.

Load Following and Load Rejection

It is normal that electric energy demand does not remain constant at all times. The load following/load rejection affects performance of DGs during operation in the islanding mode. The load following and load rejection patterns for the test system are indicated in Figs. 8 and 9.

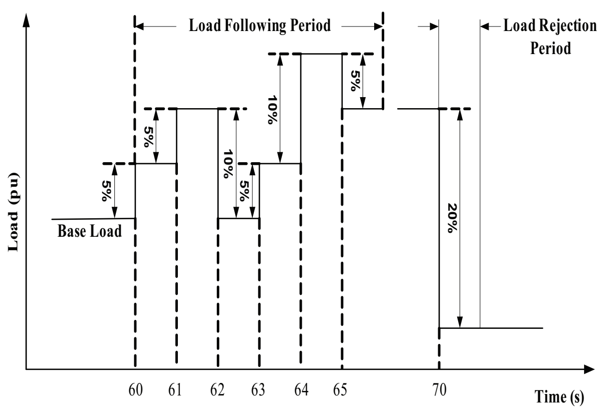
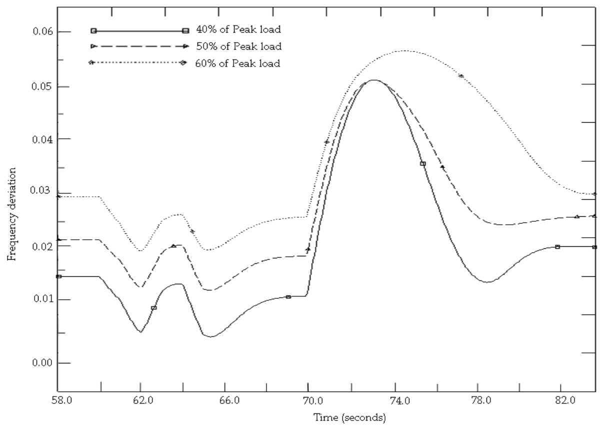
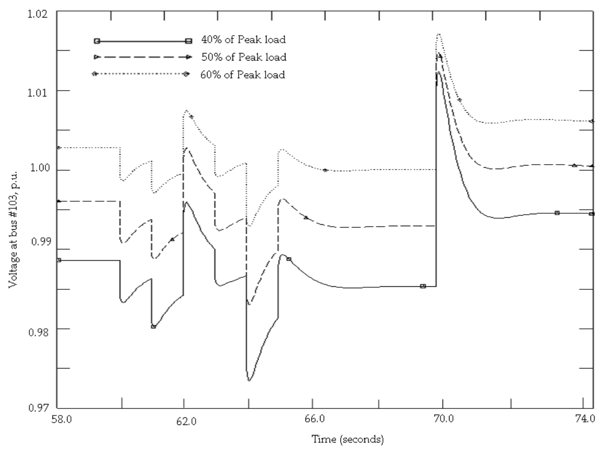


Fig. 8. Load following and load rejection patterns



(a) Frequency deviation



(b) Voltage at bus #103

Fig. 9. Load following/rejection performance of SGs operated in islanding mode under different load conditions

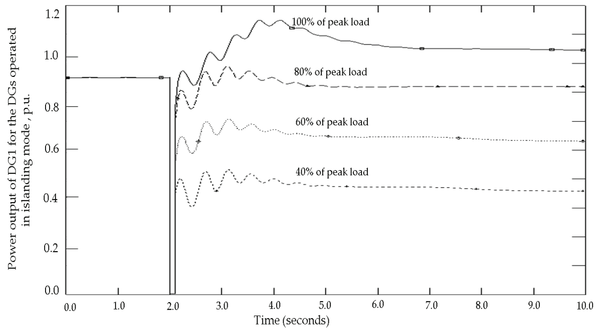
Fig. 9a depicts frequency deviation; Fig. 9b indicates voltage at bus-bar #103 of the test system shown in Fig.6. Although Fig. 9 shows that the test system remains in synchronism, high frequency deviations and voltage fluctuations may prevent DGs from operation because it may cause equipment failure or malfunctioning.

Dynamic Performance following Islanding Operation

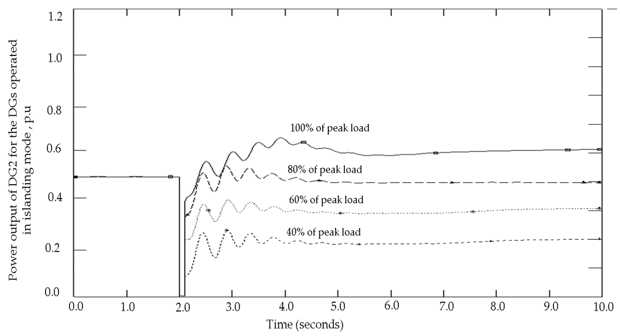
Islanding due to System Fault

Islanding can be formed by system faults or scheduled maintenance. Since islanding due to maintenance will have less impact on the system, only dynamic performance of the fault-related islanding system is presented (Kundar, P. (1994)).

Islanding is formed when a fault occurs on a line between busbars #100 and #101. Fig. 10 shows that both DG1 and DG2 share the system load in the same ratio due to the same speed droop. There are possibilities that the protective devices may disconnect DGs due to load generation mismatch. To avoid disconnecting of DGs under islanding operating mode, load shedding scheme and protective relay settings have to be studied to accommodate this situation.



(a) DG1



(b) DG2

Fig. 10. Power output of (a) DG1 and (b) DG2 under different load conditions for the DGs operated in islanding mode after applying fault on line #100-#101 at t=2 sec for 5 cycles

Fault within the Islanding System

The System may still experience various fault conditions during islanding operation. It is important to ensure that the system (both DGs and customers) is properly protected when a fault occurs during islanding operation. Depending on loading condition, the system may become unstable when the fault clearing time exceeds 10 cycles for the sample test system (Kundar, 1994; IEEE, 2003).

In summary, if loads on the test system cannot be transferred to other circuits after a permanent fault, the outage cost from lost energy supply may be significant. Intentional islanding operation will be able to improve system reliability and service continuity for their customers. Generation rejection or load shedding may be needed to achieve the goal. For re-synchronization, a synchronization check relay is also required. The differences in voltage, frequency, and phase angle at re-synchronization should comply with IEEE Standard D1547TM-2003 for Interconnecting Distributed Resources with Electric Power Systems.

6. Conclusions

1. Assuring power supply reliability in a market environment requires coordination of non-coincident interests of the power supply organization and the consumers. Reliability of power supply is determined by reliability in supply nodes of the system that is provided by system reliability of the EPS, and by reliability of the consumer's power supply scheme. Based on economic estimations, the consumer has to correlate its cost of maintaining a necessary level of system reliability, the cost of providing reliability for its own power supply scheme, and cost of compensating for damages from extraordinary emergencies. The economic mechanism of coordinating interests of the power supply organization and the consumers is formed through market efficiency criteria for these subjects.
2. The deregulation of power systems results in inconsistency of market mechanisms and reliability operation. Without a proper mechanism, reliability may become the trade-off for generation revenue.
3. Only DGs with proper control can be operated in islanding mode. Well-planned protection and operation schemes are required for intentional islanding operation. Load and generation balancing is the prerequisite for islanding operation. Generation rejection or load shedding may be needed to achieve the goal.

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