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Working Group on Asian and Australian Electricity Infrastructure

PANEL SESSION: RELIABILITY COORDINATION IN A MARKET ENVIRONMENT – ASIAN AND AUSTRALIAN EXPERIENCE

(Nikolai Voropai and Tom Hammons)

2007 IEEE PES General Meeting, June 24-28, Tampa, Florida, USA
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Technical CC Room 5

Sponsored by: International Practices for Energy Development and Power Generation[#]

Chairs: Nikolai Voropai, Energy Systems Institute, Irkutsk, Russia
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PAPER 07GM0428

INTRODUCTION

The experience of power industry restructuring in many countries of the world showed the reliability-related difficulties and problems encountered. Transition to a competitive model of power industry organization called for thorough and comprehensive studies. As the result of restructuring there is money and subjects of relations with non-coincident criteria. The necessity of rational combination of market mechanisms of management and state regulation that should be indirect, "soft", was revealed. It turned out that competition mechanisms, though, enhance the commercial efficiency of electric power system (EPS) operation but may have an adverse impact on reliability of EPS and power supply to consumers.

Therefore it is important to analyze and to compare the experience of different countries considering:

- Specific features of economic interrelations between different subjects of relations – generations and network companies, power supply organizations and consumers;
- Principles of providing reliability of EPS and power supply;
- Economic mechanisms of coordinating the interests of different subjects of relations.

The Panelists and Titles of their Presentations are:

[#] Document prepared and edited by T J Hammons

1. Jin Zhong, University of Hong Kong and Kong Chongqing Kang, Tsinghua University, China. Transition of China Power Industry: Market Efficiency and Reliability Issues (Paper 07GM1052)
2. Subrata Mukhopadhyay and Sushil K Soonee, Reliability: from Load Forecasting to System Operation in Indian Power System (Paper 07GM0866).
3. Nikolai I.Voropai, Energy Systems Institute, Irkutsk, Russia. Reliability Coordination in Power Supply Problem (Paper 07GM0309)
4. Pradit Fuangfoo, Provincial Electricity Authority, Bangkok, Thailand; Wei-Jen Lee, Energy Systems Research Center, University of Texas at Arlington, TX, USA; and Khaled A. Nigim, University of Waterloo, Canada. Intentional Islanding Operation to Improve the Service Reliability of Thailand Electric Power System (Paper 07GM0313).
5. Asaf M. Gousseinov and Bagir S. Akhundov, Azerbaijan Research and Design Institute of Power Engineering, Baku, Azerbaijan. Impact of Distributed Generation on Stability of the Azerbaijan Power Supply System in Market Conditions (Paper 07GM0519).
6. Fushuan Wen, University Distinguished Professor, South China University of Technology Guangzhou, China. (Invited Discusser)
7. R.C. Bansal, School of Engineering and Physics, University of the South Pacific, Fiji; and T. J. Hammons, Glasgow University, UK. A Discussion on the Restructuring of the Indian Power Sector (Paper 07GM0197)
8. Jaeyoung YOON, Dongwook Park and Hoyong Kim, Korea Electrotechnology Research Institute; and Jae-seok Choi, Gyeongsang, National University Jinju, ROK, Korea. Possible Interconnection Scenarios and Impacts on Composite System Reliability between "ROK-DPRK-RF" (Paper 07GM0938).
9. Sang Seung Lee, Yu Chang Kim, Joong Kyo Han, Jong Keun Park, Seung Hun Lee, Masaharu Osawa, Seung Il Moon, and Yong Tae Yoon, Various Institutions Korea. Northeast Asia Power Interconnection Studies Trends and Prospects in Korea (Paper 07GM0884)
10. Invited Discussers

Each Panelist will speak for approximately 20 minutes. Each presentation will be discussed immediately following the respective presentation. There will be a further opportunity for discussion of the presentations following the final presentation.

The Panel Session has been organized by Nikolai Voropai (Director, Energy Systems Institute, Irkutsk, Russia) and Tom Hammons (Chair of International Practices for Energy Development and Power Generation IEEE, University of Glasgow, UK).

Tom Hammons and Nikolai Voropai will moderate the Panel Session.

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PANEL SESSION CHAIRS

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BIOGRAPHIES

Nikolai I. Voropai, Senior Member IEEE, was born in Belarus in 1943. He graduated from the Leningrad (St. Petersburg) Polytechnic Institute in 1966. N.I. Voropai received his PhD degree from the Leningrad Polytechnic Institute in 1974 and the Doctor of Technical Sciences degree from the Siberian Energy Institute in 1990.

His research interests include: modeling of power systems, operation and dynamics performance of large power grids; development of national, international and intercontinental power grids; reliability and security of energy systems, power industry restructuring. Prof. N.I. Voropai is Director of the Energy Systems Institute of the Russian Academy of Sciences, Irkutsk, Russia. He is also Head of Department at the Irkutsk Technical University, Corresponding Member of the Russian Academy of Sciences, IEEE R8 East Zone Representative, and Chairman of IEEE PES International Practice Subcommittee WG on Asian and Australian Electricity Infrastructure

Thomas James Hammons (F'96) received the degree of ACGI from City and Guilds College, London, U.K. and the B.Sc. degree in Engineering (1st Class Honors), and the DIC, and Ph.D. degrees from Imperial College, London University.

He is a member of the teaching faculty of the Faculty of Engineering, University of Glasgow, Scotland, U.K. Prior to this he was employed as an Engineer in the Systems Engineering Department of Associated Electrical Industries, Manchester, U. K. He was Professor of Electrical and Computer Engineering at McMaster University, Hamilton, Ontario, Canada in 1978-1979. He was a Visiting Professor at the Silesian Polytechnic University, Poland in 1978, a Visiting Professor at the Czechoslovakian Academy of Sciences, Prague in 1982, 1985 and 1988, and a Visiting Professor at the Polytechnic University of Grenoble, France in 1984. He is the author/co-author of over 350 scientific articles and papers on electrical power engineering. He has lectured extensively in North America, Africa, Asia, and both in Eastern and Western Europe.

Dr Hammons is Chair of International Practices for Energy Development and Power Generation of IEEE, and Past Chair of United Kingdom and Republic of Ireland (UKRI) Section IEEE. He received the IEEE Power Engineering Society 2003 Outstanding Large Chapter Award as Chair of the United Kingdom and Republic of Ireland Section Power Engineering Chapter (1994~2003) in 2004; and the IEEE Power Engineering Society Energy Development and Power Generation Award in Recognition of Distinguished Service to the Committee in 1996. He also received two higher honorary Doctorates in Engineering. He is a Founder Member of the International Universities Power Engineering Conference (UPEC) (Convener 1967). He is currently Permanent Secretary of UPEC. He is a registered European Engineer in the Federation of National Engineering Associations in Europe.

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1. TRANSITION OF CHINA POWER INDUSTRY: MARKET EFFICIENCY AND RELIABILITY ISSUES (PAPER 07GM1052)

Jin Zhong, University of Hong Kong and Chongqing Kang, Tsinghua University, China.

Abstract— With the deregulation of power industry, power system reliability becomes a critical problem. The impact of deregulation on system reliability is one of the concerns after the unbundling of the traditional integrated power companies. In this paper, the reliability situations in restructuring China power industry are 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 applied to guarantee the reliability operation in the restructured power systems. In the end, the reliability issues and challenges in Chinese power industry are discussed.

Index Terms— China power industry, reliability, deregulation, restructuring

I. INTRODUCTION

With the rapid economic growth in China since 1980s, the electricity generation and consumption have increased significantly in the past decades. To attract investment in generation, since 1985, China government provided a fixed high return rate to international investors and private investors for building new power plants. In 1997, the total generation capacity owned by international companies has reached 14.5% of the total installed capacity of the whole country. Due to the sufficiency of electricity, the policy of high return rate was abolished in 1999. About the same period, the power industry in China has started the restructuring procedures.

The China power system deregulation has experienced two stages. The first stage is an experiment stage, which started from 1998. In this stage, six provincial power companies are selected to participate in an experimental electricity market. The experimental program includes separation of generation and transmission, generation auction demonstration. Based on the experiences obtained from the demonstrated electricity markets, the program of the second stage of power system restructuring is determined by the National Development and Reformation Commission (NDRC) in the beginning of 2002. The structure of the electricity market in China is restructured to be regional electricity markets.

In the end of 2002, the state-owned generation assets were restructured, and five independent generation companies were established. At the same time, two power grid Corporations were established. They are State Grid Corporation and South China Grid Corporation. The State Grid Corporation has five subsidiary regional grid companies. They are North China Regional Grid, North East China Regional Grid, Central China Regional Grid, East China Regional Grid and North West China Regional Grid. Besides separation of generation and transmission assets, the State Electricity Regulatory Commission (SERC) is established to monitor and regulate the electricity markets 0.

With the restructuring of power systems, vertically integrated power companies are separated into various benefit entities. System reliability issue becomes one of the main concerns in electricity markets. In this paper, we will introduce the current situations of reliability management in the restructured power system of China. In Section II, latest data of China power industry and its market operation mechanism are both presented. In Section III, the reliability management organization and its functions are introduced. Some data of power system reliability is provided in Section IV. Reliability issues and challenges are discussed in Section V. Section VI is the conclusion.

II. CHINA POWER INDUSTRY AND ITS MARKET OPERATION

A. INSTALLED CAPACITY

By the end of 2005, the total installed capacity has reached 517.2GW. Compare to that in 2004, the installed capacity has increased 16.9% during one year. Thermal power capacity, 391.4GW, still hold a dominant position in the total installed capacity. It is about 75.67% of the total installed capacity. The hydroelectric power capacity is 117.4GW, about 11.5% of the total capacity. Nuclear power capacity is 6.84GW, 1.32% of the total capacity. Wind power capacity has reached 1.05GW, which is 0.2% of the total capacity. The installed capacities of various generation sources are shown in Fig. 1 [3][4].

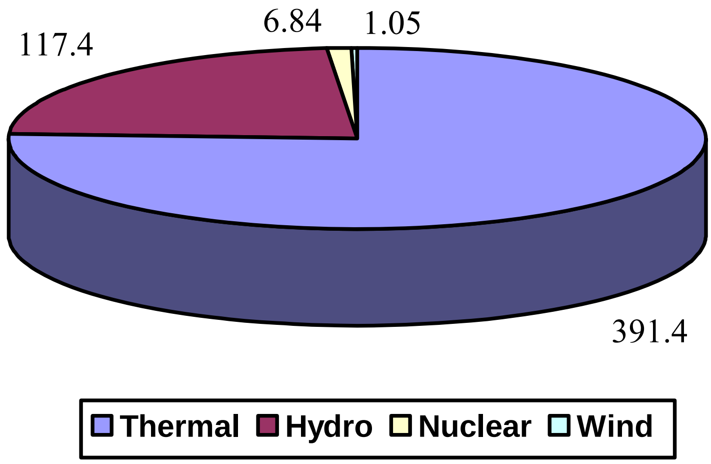

Fig. 1. Installed capacity (GW) by the end of 2005.

B. POWER GENERATION

The total annual power generation has reached 2,497TWh in 2005, which has increased by 13.82% compare to that of 2004. The average utilization hour of generation units is 5425h in 2005. The number has reduced 30h compare to 2004. The detailed data of generation and utilization hours is given in Table 1[3][4].

TABLE I. DATA OF POWER SYSTEMS IN 2005

	Installed Capacity (GW)	Generation (TWh)	Annual utilization hours (h)
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

C. TRANSMISSION FACILITIES

The data for transmission facilities over 220kV voltage level is given in Table 2 [3][4].

TABLE II. DATA OF TRANSMISSION FACILITIES OVER 220KV IN 2005

Voltage level	220kV	330kV	500kV-AC	500kV-DC
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

D. MARKET OPERATION

After the separation of generation and transmission assets, regional grid companies and provincial power companies have started the demonstrated operations of regional electricity markets.

Currently, most of the markets are single buyer markets, in which all generators sell their energy to the grid companies [1]. The NDRC and local government regulate the electricity sale prices charged from customers and the generation prices paid to generators. In some regions with long distance power transmissions, the transmission prices paid to grid companies are also regulated and decided by the NDRC.

Some systems have started demonstrated generation auction markets. Generators offer the amount of generation and its corresponding prices to the system operators. The system operators will select the generators for generation according to the merit order. Currently, the generation auctions are submitted only for yearly energy schedules and monthly energy schedules. The system operators are responsible for separating the long term schedules to daily and hourly power dispatch. Since it is a demonstrated market, the generators are still paid by the prices determined by the NDRC and local governments. The auction prices are used only when system operators select generators. The electricity prices maybe deregulated in the near future. Some large customers are seeking for the possibilities of purchasing electricity directly from generators with a lower price than regulated prices. This is one of the incentives to further deregulate the current pricing mechanism.

The reliability problems have been considered and discussed in the procedure of 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 are compulsory to follow the reliability requirement issued by the market regulator.

III. RELIABILITY MANAGEMENT IN CHINA

A. RELIABILITY MANAGEMENT ORGANIZATION

The Electricity Reliability Management Center (ERMC) was established in January 1985[2][3]. The ERMC has developed with the transition of Chinese power industry and the restructuring of power sectors. The statistical data of electric reliability was first published in 1985 by the ERMC in Electric Power Reliability Management Magazine, which later becomes the official magazine for reliability data publishing. In July 1987, the Electric Power Facility Reliability Statistical Code is issued. It is the start of the information technology management for electric power reliability in China. The first Power Reliability Index Release Meeting was held in 1994. After that, the meeting is held annually to release the reliability data of the year.

In 1998, the same year of the start of the first stage power system restructuring, the China Electricity Council and the former State Power Corporation initiated to establish the Electricity Sector Reliability Council, whose office was set in the ERMC. In the beginning of 2006, the ERMC was emerged to the State Electricity Regulatory Commission (SERC) undertaking the functions of reliability monitoring. Each power company has a reliability council under the ERMC. The relationship of reliability management organizations is shown in Fig. 2 [2][3].

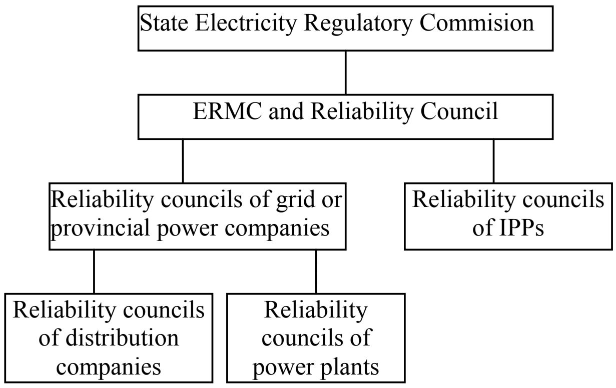

Fig. 2. Reliability management organizations

B. THE FUNCTIONS OF ERMC

The main functions of ERMC include [2][3]:

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

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

C. THE MEASURES FOR RELIABILITY MANAGEMENT

The reliability operation and management in China power system is implemented by administration measures. The ERMC acts an important role in the reliability operation. During last few decades, the most important reliability management measures include[2][3]:

- The ERMC has worked out an Electric Power Reliability Management Code in 1987. The Code is the basic criteria for reliability operation. The regulations issued later are more or less based on the Code.
- The reliability information management software was development by the ERMC. Generation and transmission companies are required to use the software for reliability management. This facilitated the power system reliability operation.

- The annually release of reliability operation indices for big units and transmission equipment bring pressures on power companies. They would try to improve the reliability indices for the next year index release.
- The ERMC monitors the potential reliability problems caused by power system planning, equipment manufacture and system operation. The reliability is improved from equipment reliability operation to system reliability operation.

III. RELIABILITY STATISTIC DATA IN THE PAST DECADES

To show the reliability situations after the power system deregulation, the reliability data is provided from 1985 to 2005 in this paper.

A. RELIABILITY DATA OF GENERATION

In 2005, the generation reliability data is based on the investigation on 1,329 large capacity generation units including thermal units larger than 100MW, hydroelectric power plants larger than 40MW and nuclear generation units. The total installed capacity of the investigated units is 285.5GW in 2005[3][4].

The unplanned outage hours per unit, Equivalent forced outage rates (EFORs) and Equivalent available factors (EAFs) of thermal units in the past five years are provided in Table III [3]-[8].

TABLE III. RELIABILITY DATA OF THERMAL GENERATION UNITS

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

The unplanned outage hours per unit, EFORs and EAFs of hydroelectric power units in the past five years are provided in Table IV [3-8].

TABLE IV. RELIABILITY DATA OF HYDRO 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

The trends of EFOR and utilization factors are shown in Fig. 3 and Fig. 4, respectively.

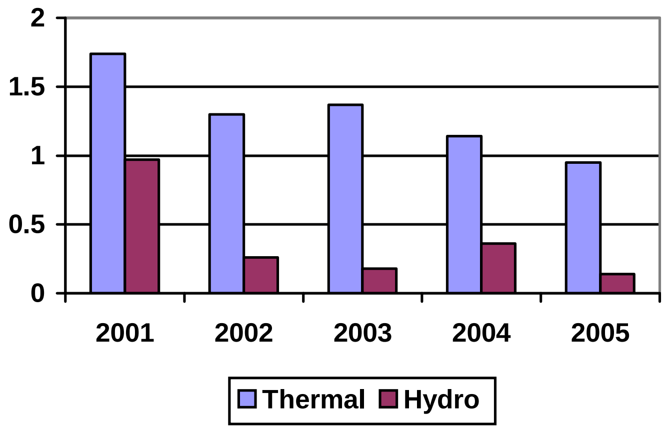

Fig. 3. EFOR of thermal and hydro units from 2001 to 2005

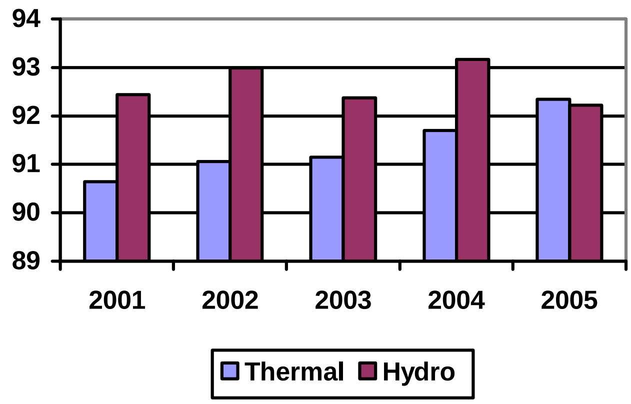

Fig. 4. EAF of thermal and hydro units from 2001 to 2005

Fig. 3 and Fig. 4 show that the trend of equivalent forced outage rate is going down in the past five years. The equivalent availability factors of thermal units keep going up in the five years.

In Table V, the reliability indices of thermal units (>100MW) are given from 1985 to 2005[3]-[8]. The trends of the EFOR and EAF changes are shown in Fig. 5 and Fig. 6, respectively.

TABLE V. RELIABILITY DATA OF THERMAL GENERATION UNITS

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

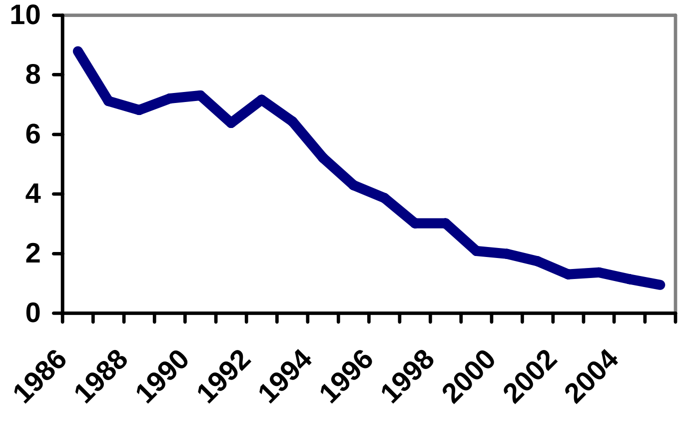

Fig. 5. EFOR trend (in %) from 1985 to 2005.

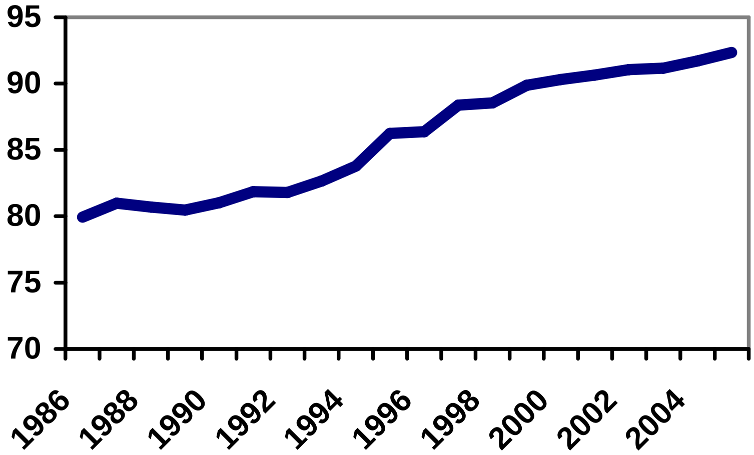

Fig. 6. EAF trend (in %) from 1985 to 2005.

It can be seen from the table and figures that, the reliability management in the past 20 years are effective, and the reliability of thermal units has improved significantly. On the hand, the improvement of the reliability, to certain extend, is because of the new installation of large capacity thermal units that have higher reliability operation levels than small capacity units.

B. RELIABILITY DATA OF TRANSMISSION SYSTEMS

The equivalent forced outage rates and equivalent availability factors are given for various transmission facilities in Table VI for year 2005[3][4].

TABLE VI. RELIABILITY DATA OF TRANSMISSION FACILITIES IN 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

It is seen from the table that transformers and circuit breakers have higher forced outage rates compare to other facilities.

In Table VII, five year outage-rate data is given for some main transmission facilities[3][4].

TABLE VII. ANNUAL OUTAGE RATE OF TRANSMISSION FACILITIES, 2001-2005

	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

C. POWER SUPPLY RELIABILITY

According to the data of 2005, the reliability on service in total (RS-1) is 99.766%, and the reliability on service except limited power supply due to generation shortage of system (RS-3) is 99.845%. The average interruption hours of customer (AIHC-1) is 20.491h. The historical statistical reliability data for large customers (>10kV) are given in Table VIII [3][4].

TABLE VIII. POWER SUPPLY RELIABILITY FOR LARGE CUSTOMERS

	RS-1(%)	AIHC1(h)	RS-3(%)	AIHC3(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

V. RELIABILITY COORDINATION IN RESTRUCTURED POWER SYSTEMS

A. RELIABILITY IMPROVEMENT UNDER ELECTRICITY SHORTAGE

Due to the fast economic growth and the lag of new generator construction, almost all provinces in China experienced electricity shortages from 2001 to 2005. It needs to stress that the reliability level during this period has improved faster than before. The annual utilization hours of different sizes of units are given in Table IX [3][4].

TABLE IX. UNIT UTILIZATION HOURS FROM 2001 TO 2005

Unit Capacity	100MW	125MW	200MW	300MW	350MW	600MW	Average
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

From the last column of the table, it shows that the number of the average unit utilization hours reached 6350h in 2004, which is extremely high in the past decades. Because of the electricity deficiency and high unit utilization hours, generation companies put lots of efforts on reliability operation on their own initiatives.

On the other hand, transmission and distribution lines are operated in high loading rate during the period 2001-2005 due to the high unit utilization and lagging of transmission planning. The outage rates of transmission systems increased for the period, and the reliability level reduced. The situation is shown by the data in Table VII and VIII.

B. RELIABILITY ISSUES UNDER MARKET ENVIRONMENT

In the traditional vertically integrated power system, the system reliability was regulated as well as system operation and planning. Power companies are obligated to follow the reliability operation criteria to reach guaranteed reliability levels.

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

Considering this issue, the SERC has emphasized the importance of reliability in their market regulations. The reliability requirements are listed as one of the main technical requirements when market participants determine electricity sale contracts or sign in grid-access agreements. The Generation Permit issued to generation companies also have reliability request. In 2006, the SERC starts to be responsible for the electric reliability management. This means the reliability will be regulated by the government regulatory bodies.

C. RESEARCH WORK ON RELIABILITY ISSUES IN CHINA

Regarding the research work on market and reliability issues of China power industry, following topics are stressed in recent researches.

First, some researches focused on power system operating reliability evaluation based on real-time operating state [9][10]. This is also one of the important issues in the Project supported by the State Key Development Program. The impact of real-time operating conditions such as power flow, bus voltage and system frequency on failure probability of components are introduced to build up the evaluation algorithm of power system operating reliability.

Second, power supply reliability is paid much attention to. Since traditional reliability management is lack of consumers' demands information and economic incentives, insurance mechanism and principal-agent mechanism are both introduced into power system reliability management[11][12]. New outage insurance mechanism is presented so as to manage the power supply reliability and reduce the outage loss more effectively. Principal-agent mechanism is applied in the relationship of customers and power enterprises, and then we can analyze the configuration of key parameters of incentive contract and the influence over the power companies' effort from the information perspective.

Third, the reliability management is also extended to consider operation risk assessment [13]. The main objectives of operation risk assessment are at two aspects. One is to assess the uncertainty factors in power system operation quantitatively and build the index systems of operation risk assessment; the other is to coordinate the security and economy of power system synthetically by taking the operation risk assessment indexes as the decision means.

VI. CONCLUSIONS

The paper has discussed the reliability issues in China electric power industry, from past to present restructuring system. The reliability management measures are described and the evolution of reliability levels is discussed by giving the detailed historical reliability data. In the end, the reliability issues and challenges in the current Chinese electricity market are discussed.

VII. ACKNOWLEDGMENT

The authors gratefully acknowledge China Electricity Reliability Management Center for their great support for providing complete statistical reliability data of China power industry.

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IX. BIOGRAPHIES

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2. RELIABILITY - FROM LOAD FORECASTING TO SYSTEM OPERATION IN INDIAN POWER SYSTEM (PAPER 07GM0866).

Subrata Mukhopadhyay, *Senior Member, IEEE*, and Sushil K Soonee, *Senior Member, IEEE*

Abstract--In this paper, in the background of evolution of power grids in India, establishment of regulatory framework and operational philosophy in vogue, first reliability aspect of long term, mid term as well as short term (operational / outage) planning has been dealt with. Thereafter issues on the day ahead scheduling of generation as associated with real time operation (linking frequency in particular) for implementation through unique real time pricing mechanism has been highlighted. It has been shown how effectively markets could take care of reliability with self-healing mechanism, particularly in a country like India having power shortages. At the same time important parameter like grid voltage too has figured in, although a lot more is expected in the time to come. Though immediately not tagged with pricing in the power market directly, finally grid security, restoration, mock trial for black start, etc. from reliability angle are the other pertinent aspects that have been touched to conclude. As such reliability coordination in every aspect is playing an important role right from load forecasting to system operation under the changing scenario with the development of power market in India[1].

Index Terms— Network Security, Planning - Long Term, Mid Term and Short Term, Real time Operation – Frequency and Voltage, Reliability, Restoration Procedure, Wide Area Network Measurement and Control.

I. NOMENCLATURE

APDRP	: Accelerated Power Development and Reform Program
ARR	Annual Revenue Return
CEA	: Central Electricity Authority
CTU	: Central Transmission Utility
DISCOM	Distribution Company
IEGC	: Indian Electricity Grid Code
IPP	: Independent Power Producer
IRP	: Integrated Resource Planning
NHPC	: National Hydroelectric Power Corporation
NTPC	: National Thermal Power Corporation
POWERGRID	: Power Grid Corporation of India
R & M	: Renovation and Modernization
SEB	: State Electricity Board
SLDC	: State Load Dispatch Center
SPS	: Special Protection Scheme
STU	: State Transmission Utility
UFRLS	: Under Frequency Load Shedding
UI	: Unscheduled Interchange
UVLS	: Under Voltage Load Shedding
WANMC	Wide Area Network Measurement and Control

II. INTRODUCTION

At the time of independence in 1947 Indian Power System with hardly a capacity not even two thousand MW was to serve the need for urban centers through isolated generation. Development of river-valley projects and formation of SEBs in the federal structure ushered in addition of generation through steam power plants of higher capacity also in fifties and sixties along with the interconnecting network, eventually forming the state grids. Seventies and eighties saw the inter-sate transmission development leading to five regional grids. Almost at the same time with Central Government venturing into thermal, hydro and nuclear generation it became a reality to have larger thermal units initially of 200 MW and then 500 MW in mine-mouth power stations with interconnection at 400kVlevel. Subsequent development in nineties and in the early part of this decade made it possible to connect even regions with HVDC system in back-to-back mode (primarily on account of mismatch in frequency) and with trunk lines (some being even intra-regional ones). Most recently it has been possible to connect four regions (excluding the southern region, which continues to be connected with the rest through various HVDC connections) in synchronous mode as a step towards formation of national grid.

Side by side with power sector reform taking place, since early nineties, it has been possible to add generation by the Independent Power Producer (IPPs) in some regions, unbundling of power sector with generation, transmission and distribution as separate distinct entities with private entrepreneurs taking over distribution system and forming DISCOMs. With the regularity bodies formed, both at Central and State level, for a large number of players in the field, tariff is fixed up the former. Transmission however still remains a natural monopoly, though joint sector venture has also been made. Regulation allowing open access [2] has made it possible to do trading in power with a number of entities joining the fray, from both public and private sector, and also under joint venture. Under such complex power system, reliability has assumed a great importance, be it right at load forecasting stage enabling planning, design and establishment of supply system (generation along with connectivity) commensurate with projected demand or subsequent operation of power system as a whole to balance continuously supply and demand depending upon reliability of each and every component of the system. Accordingly at first role of reliability at planning stage is being dealt with, followed by its impact during system operation and consequent effect in power market.

III. RELIABILITY ASPECT OF PLANNING

Truly speaking it 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.

A. LONG TERM PLANNING

With Central Electricity Authority (CEA) of Ministry of Power of Government of India at the helm of affairs, the basic work of planning starts with power survey. SEBs at the grass-root level do the spade work with different agencies involved through collection of data concerning new demand in commercial, industrial, domestic, public service and irrigation areas and also the growth for the existing systems in the corresponding areas. CEA consolidates the projected figures on all-India basis by working in close coordination with the SEBs and forecasts load and work 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 bar. Various components, such as, Transmission and Distribution (T & D) losses (both technical and commercial), load factor, diversity factor, etc. are also taken into account state / system-wise along with growth rate. With National Power Grid as a reality, long term projection takes care of regional diversity factor considering significant daylight time difference across the country from east to west. Recession in economy, restructuring of SEBs are the other pertinent factors that influence the overall scenario. These figures are, however, scrutinized by certain Departments of Government of India including Planning Commission keeping it mind the commensurate fund requirement vis-à-vis relative priority with respect to the other sectors of infrastructure of the country for investment under public sector. Having made the blue print, CEA further works out the details of generation corresponding to various scenarios of load projected for few five-year plans ahead. In all these projections computed availability based on planned outage, forced outage (partial and complete) are taken onto account. Then under Integrated Resource Planning (IRP), considering all possible sources to produce electricity in conventional ways including nuclear one, most optimum solution is attempted for meeting the load requirement. In the process of planning for addition of generation, issues of system improvement to minimize T & D losses, 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 overall supply. Having known the load points too, in the process it identifies the possible corridors of transmission of power vis-à-vis energy, though voltage level for it may be just an indicative one at this stage. As applicable for the planning of any system, the basic philosophy of configuring transmission system is to achieve a level of operating performance with adequacy and security, which 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 approach, later being based on most likelihood of occurrence vis-à-vis past experience to expect ultimately an acceptable system performance. Accordingly certain planning criteria have been evolved and are followed in India. Inputs in the form of possible generation sites with capacity available and so the loads in bulk, the process of transmission planning starts. It involves not only the corridors of transmission lines with voltage levels but also with the finding of locations of associated substations. Adequate transformation capacity in the substation with the possibility of future expansion, flexibility at the operation stage, etc. are the major guiding factors for such planning exercises.

Due to the enactment of Electricity Act 2003 [3], though generation has been de-licensed, expansion of electricity grids still has a good planning oversight from CEA (in perspective plans) to POWERGRID (in mid-term planning). With adequacy, a perennial problem as far as generation and distribution is concerned, thrust is being given to these through ultra mega power projects (4000 MW and above) as well as Central Government interventions through augmentation of distribution infrastructure through Accelerated Power Development and Reform Program (APDRP). Implementation of the latter is being monitored qualitatively by the time of energized state of 11 kV level bus, said to be reaching up to an average of about 99% time.

B. MID TERM PLANNING

Under this issue comes the natural question who would plan for 8760 hours in the entire year? Is it the Distribution Companies (DISCOMs), State Transmission Utilities (STUs) or the State Load Dispatch Centers (SLDCs)? Indian Electricity Grid Code (IEGC) talks about meeting demand without overdrawing from the grid, a need to trade-off between interrupting consumer load without compromising the security of the electricity grid. Annual Revenue Returns (ARRs) filed by DISCOMs have no mention of the quality of service in terms of how many consumers would have to suffer power cuts and for what duration in the 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.

C. 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 have only recently been unbundled. Outage planning of jointly owned units of National Thermal Power Corporation (NTPC), National Hydroelectric Power Corporation (NHPC) and other Central Government owned plants poses a more serious problem and it eludes consensus. On the other hand it suits the generating plants also who can get away with slippage in maintenance plans thus running the risk of forced outage.

IV. RELIABILITY ASPECT OF DAY AHEAD SCHEDULING

For the 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 also on base load and cannot go down below 70% due to poor quality of coal. Thus scheduling is quite rigid and predictive.

V. RELIABILITY ASPECT OF REAL TIME OPERATION

For the real time operation, two very pertinent parameters, voltage and frequency are worth consideration in general to describe the situation.

A. 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 under any yardstick. The frequency linked Unscheduled Interchange (UI) mechanism [4], a unique feature, encourages control areas to monitor and control their off take and thereby complement grid security. This unique real time pricing mechanism demonstrated effectively how markets could take care of reliability, particularly in a country like India having power shortages.

The uniqueness of UI, which is deviation from the schedule and its pricing is linked to frequency. The UI mechanism has a self healing property, brings in equilibrium and emulates all the properties of 'Non-Cooperation Game Theory' automatically. The mechanism while causing economy also complements reliability, yet maintaining the sovereignty of the utilities giving choice and freedom.

Besides long-term (25 yrs) and short-term day-ahead, spot / balancing market by way of UI mechanism where the prices are linked to the frequency has been created. The spot prices are linked to frequency which is said to be collectively controlled and effectively stabilized. It does not require elaborate calculations. Regulators tinker the UI vector from time to time in order to achieve economy and reliability by creating a pseudo competitor.

Unlike other Pools the Pricing Mechanism of Unscheduled Interchange, i.e., Schedule minus Actual is linked to frequency. The Central Regulator after public hearing and debate notifies the UI price curve. The slope of the curve, kinks, upper and lower ceilings are arrived at by the Regulator with a view to cause overall economy as well as quality in the grid.

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 only go to 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.

This was all right as long as each grid operated separately and had a strong intra regional transmission system. With the synchronization of 4 out of 5 regional grids, a fairly tight control is desirable if the network is to operate reliably.

B. 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.

VI. NETWORK SECURITY

From the point of view of network security real time contingency analysis for better situational awareness is another area of concern. Exceptional events like smog during winter, earthquake, weather related disturbance result in large number of line tripping. Provision of larger design margin, as adoptable for new lines, enhances chances of lesser failure. But with earlier constructed lines reliability is a big concern under such situations.

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

VII. RESTORATION PROCEDURES

In case of system black out or brown out, clear-cut procedure has been laid down for the restoration based on grid code. However, in order to check its effectiveness at the time of need, there is necessity of mock trial to see how reliable is the preparedness to meet such eventuality. Past experience, even with regional grid operation has shown that restoration process takes anything from an hour or two to even up to 18 to 24 hours to bring back complete normalcy. In case of national power grid though vulnerability may be more, at the same time possibility of restoration through the formation of large islands with the balancing of supply and demand reliably is possible through proper identification.

VIII. CONCLUSIONS

Indian power sector which has grown to a large size in the last sixty years after its independence in 1947, has opened up with unbundling into distinctive entities of generation, transmission and distribution. With both public and private participation, reliable load forecasting, planning and lastly system operation ensuring security to meet the demand at each instant have become the utmost necessity in the context of having electricity for all by the end of next five-year plan, March

2012. With the power market opened and power trading going on, in real sense though reliability could not be measured or assessed, at every sphere of activities its role and impact could be felt. Hence whether at component level or system-wise, and at every stage coordination is all the more necessary to achieve the goal.

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XI. BIOGRAPHIES

Subrata Mukhopadhyay (S'70, M'70, SM'80) was born in Asansol, India in 1947. He graduated in Electrical Engineering from Jadavpur University, Calcutta in 1968 and had his Master's and Doctorate Degrees from Indian Institute of Technology, Kharagpur and Roorkee in 1970 and 1979 respectively. His employment experience of 36 years includes teaching and research in Roorkee and power system planning, design and operation with the Central Electricity Authority of Government of India. He has authored two books and thirty papers, won IEEE Third Millennium Medal in 2000, PES Delhi Chapter Outstanding Engineer Award & PES Asia-Pacific Regional Outstanding Engineer Award for 2001, RAB Leadership & Achievement Awards in 2002 and 2004 respectively. He is also a Fellow of the Institution of Engineers (India) and the Institution of Electronics and Telecommunication Engineers, India.

Sushil K Soonee (M'99, SM'01) born in 1956 and currently heading Northern Regional Load Dispatching Center of Power Grid Corporation of India Ltd. as Executive Director, had his graduation in Electrical Engineering from the Indian Institute of Technology (IIT), Kharagpur, India in 1977. After a brief stint in private sector joined Central Electricity Authority and worked extensively in integration of State Grid to form a Regional Grid in Eastern and North-Eastern Region, carried out Research and Literature Survey in Power System Operation and Control at IIT

Kharagpur in 1981, traveled extensively Europe, USA and SAARC countries. He had first hand experience of Power System Operation of Eastern, Southern and Northern Grids, and also on Commercial Settlement, Restoration and entire gamut of Power Pooling and System. Frequency maintenance within permissible limits, voltage control, etc. achieved to a great extent during his tenure in Southern Region. Persuaded constituents to rejuvenate Inter-State Transmission lines, hitherto dormant. Worked for implementation of Availability Based Tariff (ABT) and on implementation, the scheme is recognized not only in India but worldwide. At present implementing the Intra-State ABT scheme also, and Free Governor Mode of Operation. Streamlined Open Access in Inter-State Transmission System. Authored 25 technical articles and presented in various forums, chaired many technical sessions in seminars / workshops, acted as Member of various committees for Regional Power System on disturbance and restoration. He is a Fellow of the Institution of Engineers (India) also.

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3. RELIABILITY COORDINATION IN POWER SUPPLY PROBLEM (PAPER 07GM0309)

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Abstrat- The paper addresses the problems of power supply reliability in a market environment. The specific features of economic interrelations between power supply organization and consumers in terms of reliability assurance are discussed. The principles of providing power supply reliability are formed. The economic mechanisms of coordinating the interests of power supply organization and consumers to provide power supply reliability are suggested.

Keywords- Power Supply, Reliability, Market Environment, Coordination, Principles, Mechanisms.

I. INTRODUCTION

The experience of power industry restructuring in many countries of the world showed the reliability-related difficulties and problems encountered [1-3, etc.]. Transition to a competitive model of power industry organization called for thorough and comprehensive studies. The necessity of rational combination of market mechanisms of management and state regulation that should be indirect, "soft", was revealed. It turned out that the competition mechanisms, though, enhancing the commercial efficiency of electric power system (EPS) operation may have an adverse impact on reliability of power supply to consumers.

In Russia the Federal Law "On electric power industry" [4] started the market transformations in electric power industry. Great attention has been paid to reliability problem. The law defines two notions: system reliability and power supply reliability. The system reliability is provided by EPS and it is a responsibility of System Operator. The power supply reliability is provided by 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 company using distribution electric network hereinafter will be called power supply organization.

Based on the above said it is sensible to consider:

- Specific features of economic interrelations between power supply organization and consumers;
- Principles of providing power supply reliability;

An economic mechanism of coordinating the interests of power supply organization and consumers.

The approaches to solution of the problems are considered below.

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II. FEATURES OF ECONOMIC INTERRELATIONS BETWEEN POWER SUPPLY ORGANIZATION AND CONSUMERS

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

Consumer that buys power from power supply organization understands that it has to pay for power supply reliability and is ready to pay. On the other hand, insufficient power supply reliability results in losses for the consumer. Therefore, consumers should weigh the payment for power supply reliability and losses from insufficient reliability. And if power supply organization is unable to provide the required reliability consumer will agree to get compensation for the losses due to insufficient power supply reliability.

This somewhat simplified reasoning characterizes the difference in interests of power supply organization and consumer and shows the need to find a compromise. To do this power supply organization and consumer should exchange information. In a general case consumer should show the damage due to unreliability *D(R)* and 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 [5]. Qualitatively this is illustrated in Fig.1.

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

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

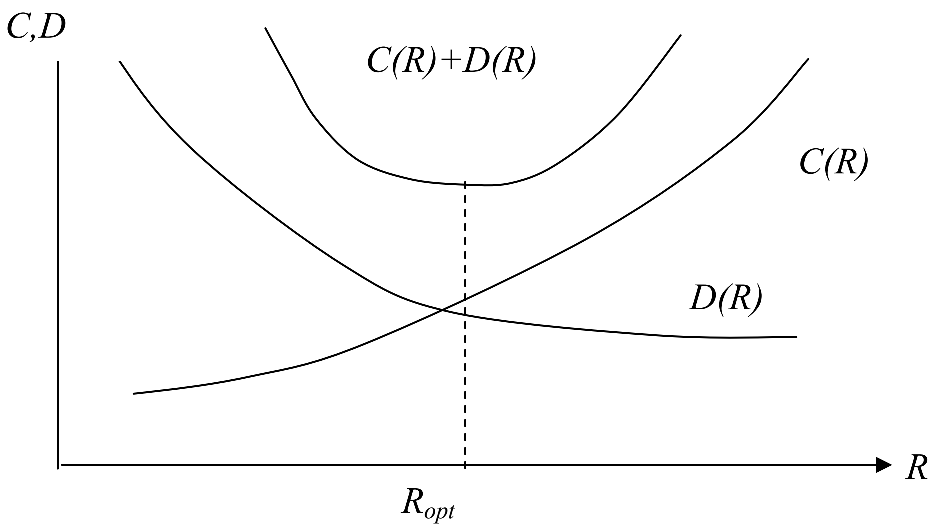

Fig.1. Classic reliability criteria

III. PRINCIPLES OF PROVIDING POWER SUPPLY RELIABILITY

In providing reliability consumer plays, in some sense, a leading ("active") role. Each consumer may formulate quite definite requirements to frequency, duration and magnitude of interruptions in power supply to their electrical facilities. Consumer may have several types of electrical facilities with different requirements to power supply reliability. This depends on the production process the consumer has: the more sophisticated and advanced technology the higher requirements to power supply reliability. Based on the requirements to reliability the concrete recommendations on power supply scheme are made for consumer (power supply from one, two or more independent sources, technical capabilities of meeting the requirements to duration of power supply interruption, i.e. the need of automatic transfer to reserve source, or manual switching to reserve source, or other, less stringent, requirements). All this leads to formation of categories of electric facilities in terms of reliability. This is a qualitative index of power supply reliability which is determined and provided at the stage of designing the power supply scheme [6].

Electric power system provides the required reliability level in the nodes of the main grid that supply power to the power supply scheme of consumer (supply nodes). The required reliability level in supply nodes should be sufficient to meet the consumer's integral requirements to reliability of power supply to its electrical facilities at the power supply scheme chosen by the consumer. Thus, it follows that the requirements to reliability in supply nodes of EPS should be formulated by consumer, whereas EPS should assess its capabilities of providing reliability in the supply nodes and estimate cost on their implementation. Then consumer will analyze the relationship between the 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 in supply nodes. Based on this analysis consumer will choose the most rational solution on power supply reliability.

In a market environment the reliability is the service that provides meeting the requirements to power supply reliability. The cost of this service is determined on a market basis, i.e. mutual obligations of power supply organization and consumer and responsibility for their discharge are expressed in economic terms and are 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 to power supply scheme and reliability levels in supply nodes and establishment of standards by categories of electrical facilities. Thus, there is a combination of market and normative approaches though the role of the normative component is auxiliary.

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

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

System Operator, responsible for system reliability, and power supply organization, responsible for power supply reliability, should analyze when the reliability cost should be included into the prices of system reliability services and prices of electricity sold to consumers, and when the losses should be compensated from insurance funds. A general principle here is payment for reliability through the prices in ordinary and quite probable situations and compensation for losses of EPS and consumers from insurance funds in improbable extraordinary situations. Quantitative evaluations of the boundary between the two aspects of providing reliability in electric power industry require specific studies.

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

IV. A MECHANISM TO COORDINATE INTERESTS OF POWER SUPPLY: ORGANIZATION AND CONSUMERS

As is seen from the above said, in a general case both subjects of relations – power supply organization and consumer – have different reliability criteria, which do not coincide. Unfolding [5] let us consider a possible mechanism of interrelations between the subjects in order to find a compromise solution of providing power supply reliability.

A most general criterion for all subjects is the criterion of the maximum net present value (NPV). Let us consider this criterion for power supply organization and consumer.

For power supply organization

$$NPV_s = I_e + I_R - C - D^*, \qquad (1)$$

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; D^* payments to consumers for insufficient level of power supply reliability in relation to the agreed level, stipulated in the contract on power supply between power supply organization and consumer over period T. D^* is like "damage" for supply organization.

For consumer

$$NPV_c = P_c - C_e - C_R - D + D^* \qquad (2)$$

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

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

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

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

However, for consumer

$$D^{*}- D - C_R \rightarrow max. \qquad (4)$$

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

$$I_R = C_R\,. \qquad (5)$$

Let us analyze the obtained relationships from the viewpoint of interests of power supply organization and the aggregate consumer.

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

However, consumer is interested in higher compensation D^* than cost of providing reliability C_R. If consumer states the required reliability by setting the values of specific damages d_p, ruble/kW (from a sudden power outage) and d_e, ruble/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^* power supply organization will try to increase reliability of this particular consumer.

Thus, the considered economic mechanism of interrelations between power supply organization and consumer provides economic balance of their interests, thus entitling consumer to choose any reliability level by setting its own characteristics d_p and d_e. Setting the fee to be paid by consumer for power supply reliability power supply organization may stimulate consumer to analyze its real characteristics d_p and d_e, without overstating them too much. This creates economic incentives for power supply organization to efficiently increase power supply reliability and allows consumers to rationalize their requirements to power supply reliability. Rationalization of the requirements comes down to the fact that it becomes profitable for consumer to set values of 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.

V. CONCLUSION

Assuring power supply reliability in a market environment requires coordination of non-coincident interests of power supply organization and consumers. Reliability of power supply is determined by reliability in supply nodes of the system, that is provided by system reliability of EPS, and by reliability of the consumer's power supply scheme. Based on the economic estimations consumer has to correlate its cost of maintaining a necessary level of system reliability, cost of providing reliability of its own power supply scheme and cost of compensating the damages from extraordinary emergencies. The economic mechanism of coordinating the interests of power supply organization and consumers is formed through the market efficiency criteria for these subjects.

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VII. BIOGRAPHY

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4. INTENTIONAL ISLANDING OPERATION TO IMPROVE THE SERVICE RELIABILITY OF THAILAND ELECTRIC POWER SYSTEM (PAPER 07GM0313).

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Abstract-- Following the steps of the gas industry, the traditional paradigm of the vertically integrated electrical utility structure has changed. The crisis in California has drawn great attention and sparked intense discussion within the utility industry. One general conclusion is to rejuvenate the idea of integrated resource planning and promote the distributed generation (DG) via traditional or renewable generation facilities for the deregulated utility systems [1, 2]. 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 of islanding of DG connected to radial subtransmission system could improve the system reliability and decrease outage cost during power outage or schedule maintenance [3-6]. In order to improve the service reliability of Thailand electric power system (EPS), this paper performs both quasi-steady state and dynamic studies of a sample substanmission system to explore possible arrangements and operation strategies to allow DGs to be continue operated under islanding conditions.

Index Terms–Distributed Generation, Reliability, and Intentional Islanding Operation.

I. INTRODUCTION

The power system operation will become more competitive and many challenges will arise after deregulation. After experiencing the price hikes and rotating blackouts in California, the disbursed or distributed generation (DG) via renewable generation facilities becomes one of the most attractive alternatives for the future utility industry. Researchers are trying to maximize the benefits of DGs in the system. To allow DGs operating in islanding mode is one of the main research topics in this area. 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 lost of supply [3-6]. However, utilities normally do not permit intentional islanding operation without thoroughly impact study. Since the islanding is formed after disconnected from the main grid, utilities cannot guarantee that the

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islanding system will remain stable, and it relies upon 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 aliven [8].

This paper discusses related issues for islanding operation. The procedures for proper landing operation to improve the service reliability for Thailand Electric Power System are proposed.

II. THAILAND ELECTRIC POWER SYSTEM [7]

Thailand, bordering the Andaman Sea and the Gulf of Thailand, is a developing country located on Southeastern Asia. As of 2006, estimated population is about 65 million. Three state enterprise utilities are responsible for the entire Thailand EPS. Electricity Generating Authority of Thailand (EGAT) is responsible for generation and transmission, Metropolitan Electricity Authority (MEA) and Provincial Electricity Authority (PEA) provide 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.

Thailand's EPS Structure

As shown in Fig. 1, EGAT controls bulk power generation and transmission and establishes power purchase agreement with Independent Power Producers (IPPs), Small Power Producers (SPPs) and neighboring countries (Lao People's Democratic Republic and Malaysia). EGAT sells electric power to the distribution utilities (MEA and PEA) and its direct customers. Energy Planning and Policy Office (EPPO) is at the core of the institutional structure in the Thai energy sector. EPPO is responsible for all policies related to IPPs and SPPs, privatization, investment, and tariff structure.

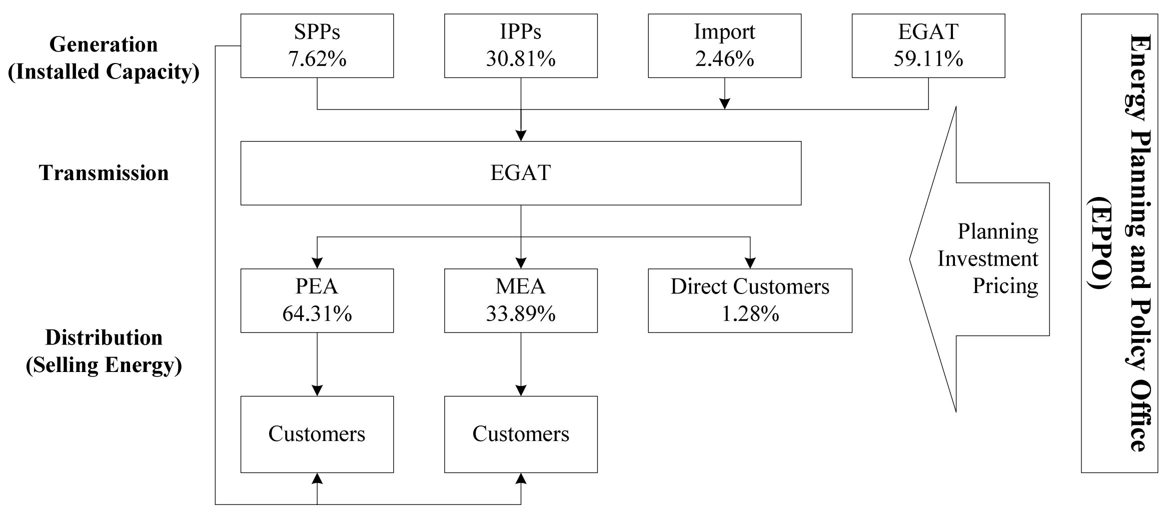


Fig. 1 Thailand's EPS structure as of 2004

2.2 Generating and Transmission System of Thailand

As of 2004, the total generating installed capacity of the whole country is 25,969 MW. Around 59.11% of installed capacity is owned by EGAT, 38.43% belongs to IPPs and SPPs, and 2.5%

imports from neighboring countries. Maximum total peak demand is 19,326 MW. EGAT's generating capacities consist of 24.53% thermal plants, 18.08% combined-cycle, 13% hydro power plants, and 3% gas turbine and other renewable energy. For system security purpose, the HVDC transmission line is linked between EGAT and Malaysia's transmission system.

All transmission lines with various voltage levels ranging from 69 kV to 500 kV are owned, controlled, and operated by EGAT. The 500 kV backbone transmission lines connect the northern and the central regions. The rest of inter-regional transmission lines are at 230 kV. Subtransmission systems to deliver electric power from the main transmission system to MEA and PEA system are operated at 115 kV and 69 kV.

2.3 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 research focuses on PEA's system, the detail of MEA system will not be included.

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

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

Fig.3 shows typical PEA's subtransmission and distribution systems. Each substation typically has two power transformers that carry up to 5 feeders. The capacitor banks are installed at the substation power factor correction, voltage profile improvement, and system losses reduction. Along with each feeder, switching devices (disconnecting switch) and protective devices (recloser and fuse cutout) are installed to transfer load to other circuit and to protect the system during fault. Automatic Voltage Regulator (AVR) is used for increasing voltage at the end of circuit with long feeder. DG can be connected to PEA's system at anywhere at point of common coupling (PCC).

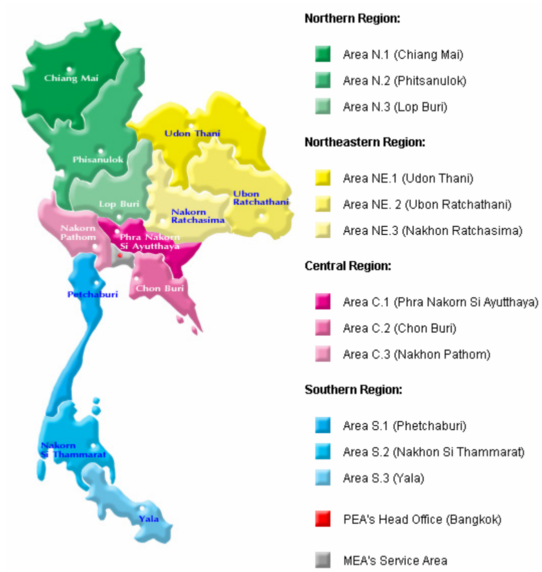


Fig. 2 PEA's service areas

2.4 Current Regulation for Interconnection of DG to PEA's System

The current regulation has been established since October 2000. The regulation targets small power producer (SPP), which is distributed generation (DG), with aggregated total generating capacity between 100 kVA and 90 MW to synchronize with PEA's system. DG is responsible for the costs of interconnection of the power systems, modification of PEA's system to facilitate synchronization, and equipment testing and installation of protective devices to prevent damage to the system. PEA may request DG applicant to perform the impact study. If the impact study is approved by PEA, PEA will consider connecting of DG to PEA's system. For generating capacity exceeding 10 MW, DG has to be connected to the 69 kV or 115 kV system. The criteria for synchronization of DG to PEA's system are summarized as follows:

- Voltage Levels: DG should maintain it 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
- Frequency: DG has to maintain the frequency level of its system at 50 ± 0.5 Hz. If this level cannot be maintained, DG has to be disconnected from PEA's system within 0.1 second.
- Power Factor: DG has to maintain power factor between 0.85 leading and 0.85 lagging at PCC.
- Harmonics: DG should not cause excessive voltage and current distortions as defined in the harmonic regulations for commercial and industrial.
- Voltage Fluctuation: DG should not cause excessive voltage fluctuation as defined in the voltage regulations for commercial and industrial.
- Isolation Transformer: DG should connect its system through either delta or wye-grounded transformer to the PEA grid.
- Islanding Operation: DG should be disconnected from the system during power outage to avoid inadvertent islanding operation.

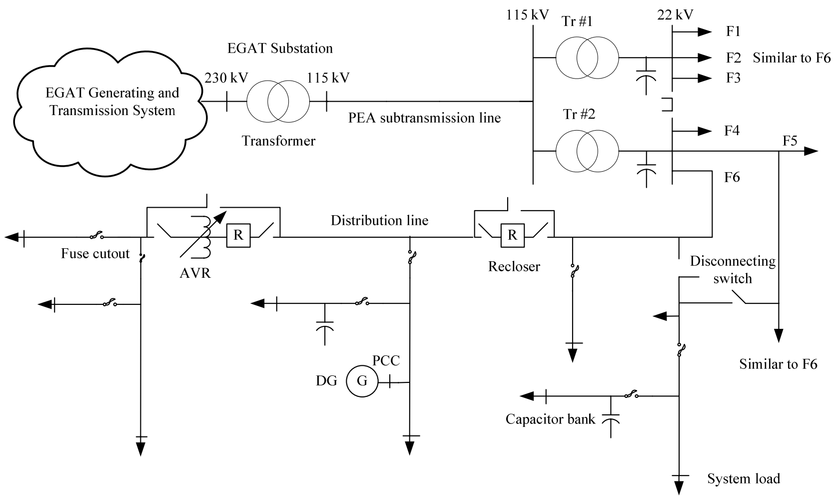


Fig. 3 Typical PEA's subtranmission distribution systems

III. ISSUES RELATED TO ISLANDING OPERATIONS

3.1 Sample Test System

As shown in Fig. 4, a 7 buses, 5 loads, and 2 DGs (DG1 = 90 MW and DG2 = 50 MW) subtransmission system (115 kV) is used as test system. In this study, it is assumed that the protective devices can separate the faulted part from the islanding area before DGs can perform intentional islanding operation. This paper will concentrate on only Synchronous Generator (SG) since Squirrel Cage Induction Generators (SCIG) cannot operate during islanding operation.

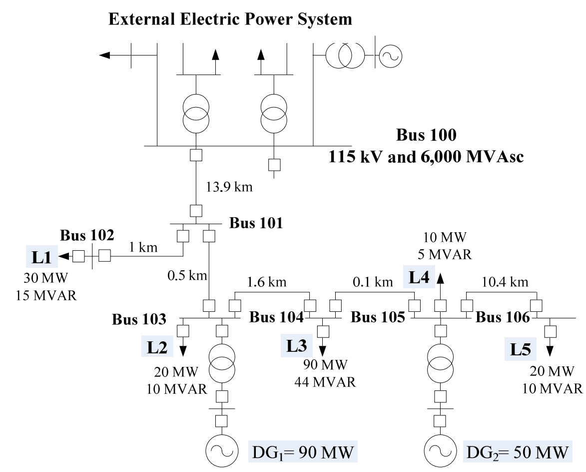


Fig. 4 One line diagram of the sample test system

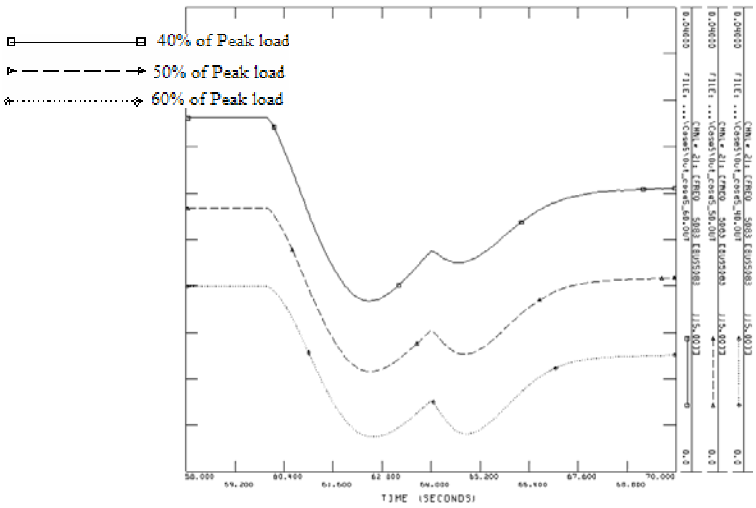
3.2 Quasi-Steady State Performance of Islanding Operation

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

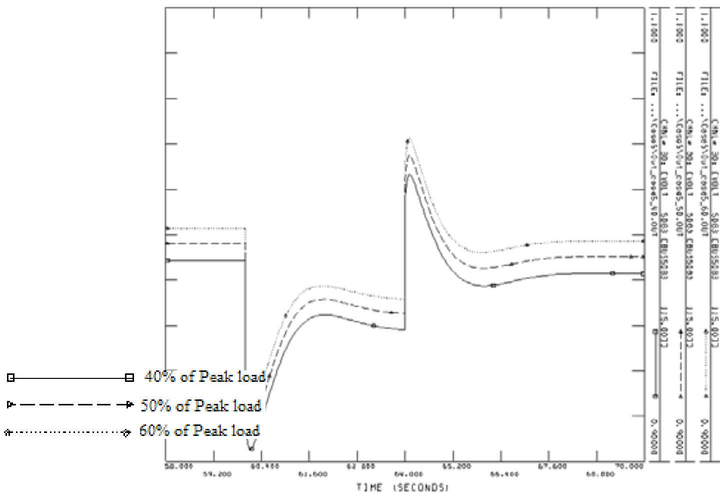
3.2.1 Large Motor Starting

Normally, it 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 the stiffness of the system. Since the islanding system is relative weak, the effect of starting a large motor requires further investigation.

The cases of load conditions, 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. The starting current of the motor is assumed to be 3.0 times of rated current at power factor of 0.30. Since the behavior of motor during starting depends on both the control device and the motor itself, the worst case scenario would represent the motor during starting as constant shunt admittance for 4 sec, and then change the motor load back to the normal condition. The initial shunt admittance is 0.140 – j0.445 pu relative to a 100 MVA base. Fig.5 shows that the frequency drops below 49.4 Hz for 4 sec, and the voltage is higher than 0.9 pu for all cases. Without proper coordination, underfrequency relay may be activated to trip loads from the islanded system in some cases.



(a) Frequency deviation



(b) Voltage at bus #103

Fig. 5 Quasi-Steady state performances of the islanding system during a large motor starting

3.2.2 Load Following and Load Rejection

It is normal that the electric energy demand does not remain constant all the time. The load following/rejection capabilities affect the performance of DGs during operating at islanding mode. The load following and load rejection patterns for the test system are shown in Fig. 6. Though Fig. 7 shows that system remain in synchronism, high frequency deviations and voltage fluctuation may prevent DGs from this operation because it may cause equipment failure or malfunctioning.

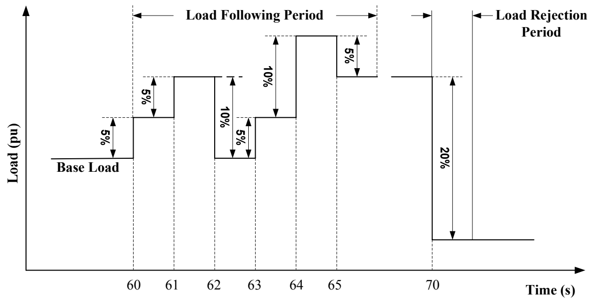
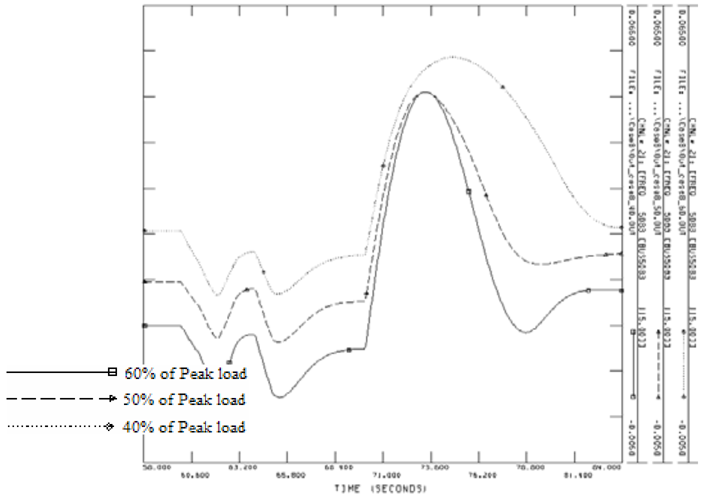
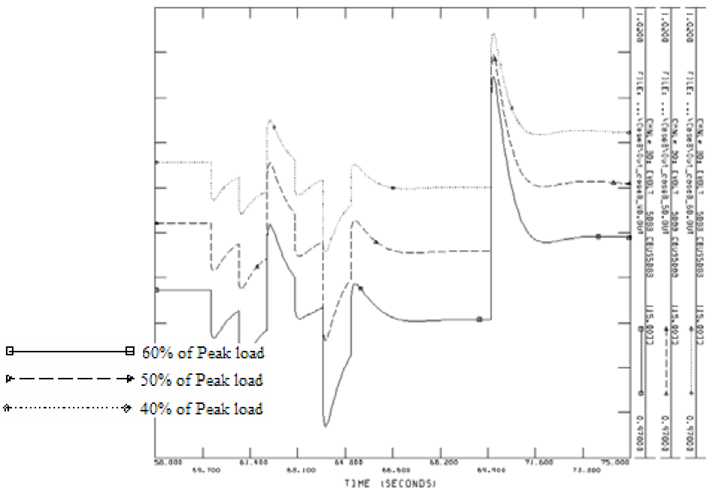


Fig. 6 Load following and load rejection patterns



(a) Frequency deviation



(b) Voltage at bus #103

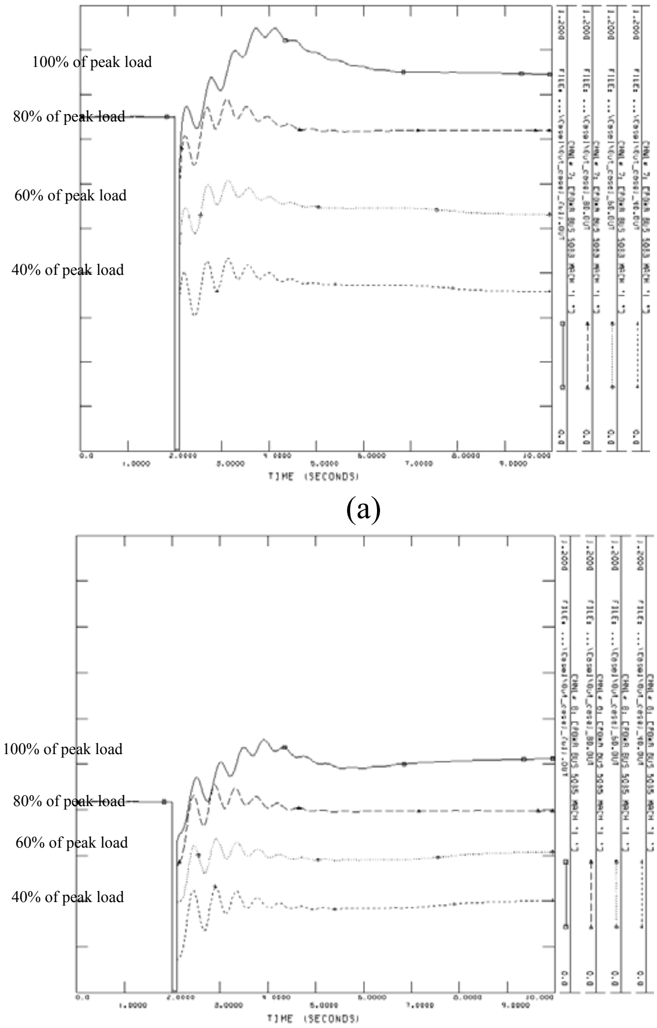
Fig. 7 Load following/rejection performance of SGs operated on islanding mode under different load conditions

3.3 Dynamic Performance of Islanding Operation

3.3.1 Islanding due to System Fault [9]

Islanding can be formed due to system faults or schedule maintenance. Since islanding due to maintenance will have less impact on the system, only the dynamic performance of the fault related islanding system is presented.

The islanding is formed when a fault occurs at line between #100 and #101. Fig. 8 shows that both DG1 and DG2 share the system load at 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.



(b)

Fig. 8 Power outputs of (a) DG1 and (b) DG2 at different load conditions operated on islanding mode after applying fault on line #100-#101 at t = 2 sec for 5 cycles

3.3.2 Fault within the Islanding System

Fault is a severe disturbance occurring in the system. System may still experience various fault conditions during islanding operation. It is important to ensure that system (both DGs and customers) are proper protected when a fault occurs during islanding operation. Depending upon the loading condition, one can see that the system may become unstable when the fault clearing time exceed 10 cycles in the sample test system [9-10].

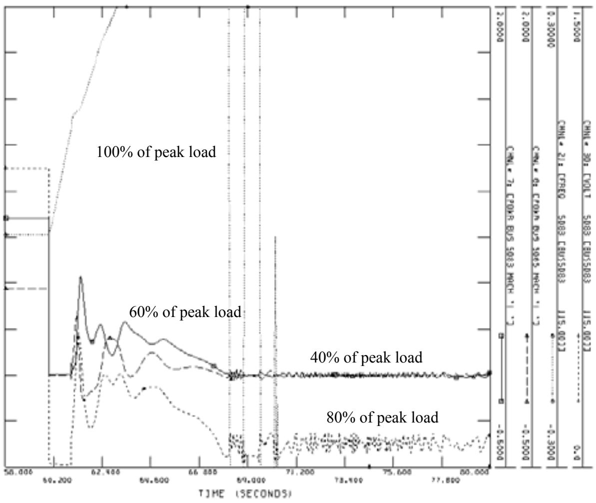


Fig. 9 Dynamic performances after applying fault at bus #101 for 10 cycles

IV. CONCLUSION

If loads cannot be transferred to the other circuit after a permanent fault, the outage cost from lost of energy of supply may be significant. Intentional islanding operation will be able to improve system reliability and service continuity for their customers. However, only DGs with proper control can be operated in islanding mode. Well planed 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. For re-synchronization, synchronization check relay is also required. The differences of voltage, frequency, and phase angle at re-synchronization should comply with IEEE 1547-2003 [10].

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VI. BIOGRAPHIES

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Khaled Nigim (SM) has a Ph.D. in Electrical Engineering from the University of Leicester, England, UK and B. Sc. in Electrical Engineering from Zagazig University of Cairo, Egypt. He is the Coordinator of the on-lineMaster of Engineering in Electric Power 'MEng and GDip graduate program' at the Department of Electrical & Computer Engineering, University of Waterloo. He has more than 24 years of experience in renewable energy system design and implementation, design and assembly of industrial units that incorporate PLCs, intelligent sensors, VSD's and decision-making, for infrastructure restoration. He is a registered professional engineer in Ontario, Canada.

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5. IMPACT OF DISTRIBUTED GENERATION ON STABILITY OF THE AZERBAIJAN POWER SUPPLY SYSTEM IN MARKET CONDITIONS (PAPER 07GM0519).

Asaf M. Gousseinov and Bagir S. Akhundov, Azerbaijan Research and Design Institute of Power Engineering, Baku, Azerbaijan. Impact of Distributed Generation on Stability of the Azerbaijan Power Supply System in Market Conditions (Paper 07GM0519).

Abstract -- The development of the fuel and gas industry, its movement towards international market arena and gradual change of economy sectors towards market conditions contribute to dynamic improvement and development of economy of the Republic of Azerbaijan. Under present condition the demand for electricity outstrips power supply capacity.

At least 5 regions of the republic have consumers located far away from the central power supply system, and they already express their interest in independent power sources due to interruptions in the power supply and its low quality. At the present moment, consideration is given to Distributed Generation principle.

Index Terms: critical disconnection time, distributed generation, power distribution reliability, power system transient stability.

I. INTRODUCTION

Introduction of Distributed Generation (DG) principle is one of a tendency that characterises development of the modern power supply systems. This tendency is demonstrated by a number of related factors:

- raise in price for primary energy sources;
- liberalization in the power energy sector;
- increased demand growth for secondary energy, especially in the regions remotely located from the transmission power grid;
- shortage of energy supply in the power systems;
- consumers’ disposition to have own available independent heat and power sources or at least, to be able to select amongst those, etc.

Principle of distributed generation is based on small-scale power stations from a wide range of technologies used, including renewable energy.

Factors listed above are mostly common for the power supply system of the republic of Azerbaijan.

The paper outlines factors affecting operating modes of the Azeri power grid in terms of introducing distributed generation principle. In spite of intensive growth in the energy generation it is still some tie o pass before the power system of Azerbaijan will experience shortage in power generation and have largely loaded power transmission lines, remote power consumers experiencing low voltage profiles and high power losses.

In that regard, the paper suggests introduction of distributed generation principles through provision of small power stations in 4 regions of the republic. A consideration is given to Wartsila’s engines (20 V 345 SQ) each rated at 8.73MW providing that the every station will have ten of those engine and be able to generate 87.3MW. Such a station is commonly known as modular station. Construction and commissioning of similar facilities normally takes 5 – 7 months.

The placing of the modular station is done following analysis of the power grid’s “generation-consumption” structure in the regions and identification of low voltage profile nodes.

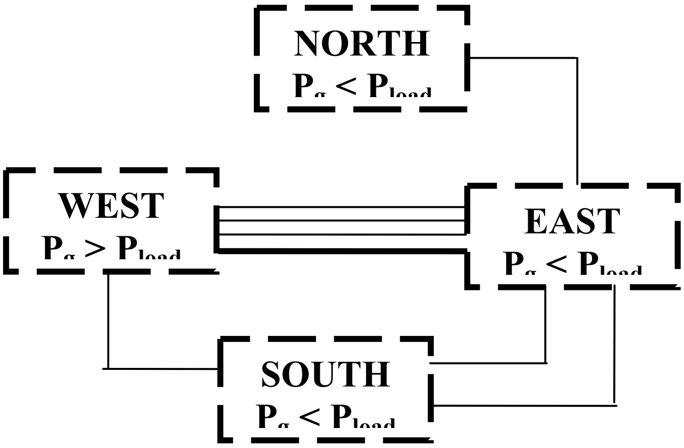

Figure 1. Simplified “generation-consumption” structure of the Azerbaijan power grid.

Mainly intended for connection into distribution power system to improve power supply reliability at consumer end, these stations are also connected to the transmission grid for parallel operation with other power stations in the system.

All 4 modular stations are connected to the power system of the republic of Azerbaijan and their total capacity accounts for 8-10% of the power system’s load.

However, it should be noted that difference in characteristics (both electrical and mechanical) of the modular engines based on dual-fuel internal-combustion engines may impact operating mode and reliability of the power system.

II. scope of reaserch

The research is mainly concentrated in the below stated main areas and supported by a number of design-experiment studies performed by the authors.

1. It was analytically proven that in a complex power system relative movement between synchronous generators caused by disturbances in the power system is defined by such factors as difference in inertia constants and direct or indirect (via system) interconnection. Below equation has been developed to analyze relative movement between synchronous generators.

$$\frac{d^2\delta_{ij}}{dt^2} = \left(\frac{P_{Ti}}{T_{Ji}} - \frac{P_{Tj}}{T_{Jj}}\right) - E^2\left(\frac{1}{T_{ji}} g_i - \frac{1}{T_{jj}} g_j\right) -$$

$$- E^2\left[\left(\frac{1}{T_{Ji}} - \frac{1}{T_{Jj}}\right) g_{ij} + \left(\frac{1}{T_{Ji}} + \frac{1}{T_{Jj}}\right) b_{ij} \sin\delta_{ij} - \left(\frac{1}{T_{Ji}} - \frac{1}{T_{Jj}}\right) g_{ij} \cos\delta_{ij}\right] -$$

$$- E^2 \frac{1}{T_{Ji}} \sum_{\substack{k=1 \\ k\neq ij}}^{n} \left[g_{ik} + b_{ik} \sin\delta_{ik} - g_{ik} \cos\delta_{ik}\right] -$$

$$- \frac{1}{T_{Jj}} \sum_{\substack{k=1 \\ k\neq ij}}^{n} \left[g_{jk} + b_{jk} \sin\delta_{jk} - g_{jk} \cos\delta_{jk}\right]$$

Three latter elements in the equation represent influence of static parameters (load, direct and indirect links between generators) and define initial reaction to disturbance. In turn, difference of inertia constants affects all components of the above equation and determine dynamics of the transient. In the existing power supply system inertia constant of generators are commensurable quantities (6–13 seconds), whereas, the modular stations do have units with lesser inertia constants in the range of (0.3-0.5 seconds) and the difference significantly affects the way transients take place.

It shall be noted that introduction of modular stations and their integration into the power system normally takes up to a year it is not always possible to conduct in-depth complex power system stability and protection studies to analyse impact of integration. In that regards it is necessary to develop and have available a methodology that would provide reliable indexes characterizing stability of power system.

The paper suggests that such the indexes could be:

Sensitivity Index identifying weak point in the system and characterizing nodes. Physically this represents reaction of synchronous generator's rotor to disturbance as a misbalance of active power. Mathematically this is a diagonal element of upper left block of the Jacob's inverse matrix.

$$J^{-1} = \begin{bmatrix} \frac{\partial \delta}{\partial P} & \frac{\partial U}{\partial P} \\ \frac{\partial \delta}{\partial Q} & \frac{\partial U}{\partial Q} \end{bmatrix}$$

From the transient stability standpoint the upper left block of the matrix J^{-1} attracts the most interest. The most sensitive elements can be derived on the base of maximum of diagonal elements. If one takes into account that a linear model is considered then $\frac{\partial \delta}{\partial P} \approx \frac{\Delta \delta}{\Delta P}$ can be used with a small acceptable error to facilitate computation in the Power System Operations Department. With that in mind it would be enough to set a small load increment of (5-10)% at i-generation node to analyze reaction of the system, and most importantly assess change in rotor angle as a result. Analytically this can be represented as follows:

$$\varepsilon_{\delta .i} = \frac{\Delta \delta_i}{\Delta P_i} = \frac{2\pi}{360\ P_{io}} \cdot \frac{\delta_{io} - \delta_i}{\Delta P_i}$$

$\varepsilon_{\delta i}$ – outlines initial reaction of generator's rotor angle (**$\Delta\delta i$**) to disturbance ΔPi. Regardless cause of disturbance in the power system, it comes to a generation node as a power misbalance, and the value of initial rotor's reaction depends on a set of static parameters of the power system, i.e. structure and operating mode.

System Heterogeneity Index characterizing state of a system. Mathematically this is dispersion of Sensitivity Indexes ($\varepsilon_{\delta i}$) as follows:

$$\varepsilon_H = \frac{1}{n}\sum_{i=1}^{n} \left(\varepsilon_{\delta av} - \varepsilon_{\delta i}\right)^2$$

where: n – number of generators

$\varepsilon_{\delta av}$ – average value of ($\varepsilon_{\delta i}$) of generators in the power system.

Any change in structure or operating mode of a power system impacts sensitivity indexes of every generation node in the system, and the changes are not equal for every node. A more comprehensive index is System Heterogeneity Index that describes power system dynamically. In particular, its reduction and tendency to zero is a clear indication of a system becoming more symmetrical.

The Azerbaijan power system is characterised for its geographical disproportion in "generation-consumption" structure, i.e. most of generation capacity is concentrated in the West of the country, whereas consumers are mainly located in the East, North and South. Computation of node sensitivity and system heterogeneity indexes for existing system identified, as expected, that the most sensitive generators are located on the AzGRES power station ($\varepsilon_{\delta i}$) = 2.6 and Shimal GRES 400MW ($\varepsilon_{\delta i}$) = 1.2, and also (ε_h) = 0.696 at 4300MW operating load.

In order to improve these indexes a number of options have been considered, their impact assessed and proposal made that 4 off modular station to be installed in the North, South, East and West nodes of the system. With new modular stations distributed in the regions of Azerbaijan power system the sensetivity and heterogeneity indexes were calculated and compared to a case when only a single power station of the same power capacity is installed in the most demanding node of the system. Results of the analysis are in the table below:

Operating Mode / Stations	4300MW	4800MW	4800MW
	Sensitivity Indexes ($\varepsilon_{\delta i}$)		
Ming HEPS	0,32	0,38	0,38
Ali-Bayr. GRES	0,32	0,38	0,38
AzGRES 500kV	1,8	2,4	2,3
AzGRES 330kV	2,6	2,26	1,96
Shimal GRES	1,2	1,44	1,54
Shamkir HEPS	0,32	0,66	0,62
Yenikend HEPS	0,28	0,48	0,46
Baku CHP	0,28	0,34	0,32
Astara MS	-	-	0,46
Sheki MS	-	-	0,34
Hachmas MS	-	-	0,42
Baku2 MS	-	-	0,32
ε_H	0,696	0,665	0,446
Notes:		2nd 400MW Unit at Shimal GRES	4 off 90MW modular station in the regions.

3. As far as the Azerbaijan power system is concerned the most sensitive nodes as well as impact of integrating modular stations on these nodes (sensitive nodes) have been identified. In particular, the paper demonstrates advantage of introducing 4 off modular stations in the regions as compared to commissioning just one station of the same total capacity in the central transmission system.

4. Transient stability calculations demonstrated that as a result of significantly different inertia constants of the generators normally utilised in the modular stations as compared to existing units at main power stations, critical disconnection time at nearby substations in the power system at 2ph faults to earth sharply reduces. This necessitates additional measures. Transient curves have been obtained: relative movement of rotor angles of the modular generators and main system generators, as well as, currents, voltage, active and reactive powers, frequencies. These parameters are important to make recommendations on transient stability of the electrical power system.

5. Considering peculiarities of connection of a modular station to the main power supply grid it is proposed to use alignment chart (nomograph) on the base of known “area theory”. The alignment chart allows identifying maximum load that can be applied to given modular station in order to maintain and not jeopardise transient (dynamic) stability of the node and system as a whole. Maximum load allocation is also performed with due regard for static stability indexes.

6. As a result of introducing and spreading 4 off modular stations between regions of the republic it becomes possible to reduce by 30% unloading capability required at emergencies, i.e. if before having modular stations in the system it was necessary to disconnect X MW of connected load to keep the system in operation and stable following any significant disturbance, after introduction and spreading modular stations within Azerbaijan it is only 0.7X MW to be isolated. It should also be mentioned that 4 off modular stations contribute to significant reduction of power losses in the main transmission lines (220-330-500kV) as well as allow unloading those lines.

III. CONCLUSIONS

1. Introduction of the modular stations improves voltage profiles in own and nearby regions;
2. The main transmission lines of the power grid as well as power stations involved in power load compensation are unloaded;
3. Power losses in the transmission grid are reduced
4. Emergency reserve is reduced;
5. Fault current disconnection time at nearby sub-stations is reduced.

The latter factor is indicative of reduction in the transient stability as a result of significantly lower inertia constants of the modular engines.

The paper outlines important steps towards provision of the transient stability.

As whole the transient stability is not disturbed – this is indicated on the curves showing relative movement of rotor angles of the modular station and existing generators in the power grid following severe faults.

IV. PRESENTATION MATERIALS

During presentation the following support data and comments will be provided:

- "Generation – Consumption" structural scheme for the Azerbaijan power grid;
- Analytical representation of factors affecting relative movement;
- Inverse Jacob's matrix and formulas used to calculate *Sensitivity Index and System Heterogeneity Index;*
- Data tables showing *Sensitivity Index* and *System Heterogeneity Index* when modular stations connected to the power grid;
- Data tables showing critical disconnection times needed to keep the power system stable with modular stations connected;
- Transient curves: relative movement of synchronous generators' rotor angles, voltages, currents, active and reactive powers, frequencies;
- Alignment charts to show maximum acceptable load allocation in the system in order to keep power system dynamically stable;
- Voltage profile comparison in the regions and at connection points to the power system with modular stations in and out of operation;
- Comparison of unloading requirements with modular stations in and out of operation;
- Quantitative indexes reflecting effective impact of introducing modular stations on static stability of power systems.

V. BIOGRAPHIES

Asaf Gouseynov was born in Baku (Azerbaijan) in 1937. He graduated from the Azerbaijan Industrial Institute (currently Azerbaijan State Oil Academy). At the present moment he is employed by the Azerbaijan Power Engineering institute of Design and research as Deputy Director.

In 1966 he was awarded PhD by the Moscow Energy institute following successful research in the area of utilization of computing machinery for stability study of power system containing long overhead transmission lines. In 1990 he was awarded Doctor’s Degree in Novosibirsk following completion of work on setting up methodical basis for simplification of mathematical models of the power system considering electromechanical transient processes.In 2005 he was awarded a medal for Technical Progress in Azerbaijan.

Baghir Akhundov was born in Baku (Azerbaijan) in March-1977. He graduated from the Azerbaijan State oil Academy in 1999 with Master’s Degree (honor) in Electrical Engineering. In 2000 became a member of Institution of Electrical Engineers in UK. Currently working towards becoming Chartered Engineer with IET.

He proceeded with research work in the area of power system optimization and stability and is currently concentrating efforts in studying impact of introducing Distributed Generation (DG) principle in the Azerbaijan power supply system.

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7. A DISCUSSION ON THE RESTRUCTURING OF INDIAN POWER SECTOR {PAPER 07GM0197}

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Abstract-- During the past few years Indian power sector has experienced major changes in power sector. This paper discusses the restructuring/privatization of Indian power sector addressing how it affects the reliability of power system. Key issues related with the performance of the power sector like privatization of power sector, renovation and modernization (R&M) of old plants, metering problems, increase of hydro power and non conventional energy sources to overcome pollution problems have been discussed in this paper. Advantages of information technology (IT) and major areas in which IT can be used, have also been discussed.

Index Terms-- Power Sector, Renovation and Modernization, State Electricity Boards, Transmission and Distribution, Information Technology**.**

I. INTRODUCTION

During the past two decades power sector over worldwide has experienced a rapid change in generation, transmission, and distribution system. These changes in the power sector have been mainly because of huge increase in the power requirement in developing countries and large investment required to meet the growing need of power, economical and environmental benefits, attaining the efficiency through competition etc.

Indian power sector has also experienced a rapid change. Power installed capacity of India, which was 1362 MW in 1947 rose to 127673 MW (Hydro 33600 MW, Thermal 83982 MW, Nuclear 3900 MW, Renewable Energy System 6191 MW) as on Oct. 2006. Transmission line length was 1831 km, 71149 km, and 111151 km for voltage levels of 765 kV, 400 kV, and 230 kV respectively as on Oct. 2006. High voltage diect current (HVDC) circuit length was 5872 km of ± 500 kV with installed capacity of 10000 MW. Substation capacity at 400 kV and 200 kV were 89477 and 149457 MVA respectively. There were 73.9 % of villages electrified (total village being 593 732) as on Oct. 2006. Still there is a shortage of power around 10 to 15%. If the same growth is maintained the installed capacity would go up to 2,30,000 MW by 2012 [1]. To achieve this target a generation capacity of about 10,000 MW per year would be required to be added. Addition of this capacity would require approximately Rs. 90,000 crores per year for generation, transmission and distribution works [2]. Government is unable to provide the required amount for power sector for which reforms/privatization is must. In India major part of electricity (about 65%) is generated through coal-fired plants, which cause air and thermal pollution. Air polluting agents consisting of particulates and gases such as Nox, SOx, etc., are emitted via the exhaust gases and thermal pollution due to the rejected heat transferred from condenser to cooling water. Transmission and Distribution (T&D) losses in India are 23% against the international average loss of 10%. Similarly there are revenue collection and metering problems in distribution systems.

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This paper focuses major problems of power sector in generation, transmission and distribution systems in India and discusses the restructuring/privatization of power sector. R & M of old plants, use of IT in power sector, revenue collection and metering problems in distribution systems, need of increase of hydro share and non-conventional energy sources to overcome environmental problems have been highlighted in this paper.

II. REFORMS/PRIVATISATION IN POWER SECTOR

During the past two decades the electric utility industry has experienced a rapid change [1]. These changes are aimed at attaining higher efficiency through competition. The competition is introduced by unbundling and divestitures. Unbundling means the functional decoupling of generation, transmission and distribution function, which were originally, integrated one. Wheeling of electrical services (transmission services) is one of the prevalent of such unbundled services provided by these utilities. Wheeling is the transmission of electric power from a seller to buyer through a transmission network owned by third party [3]. This section discusses the privatization in generation, transmission and distribution system.

1) Privatization in Generation

The 15th annual power survey of Central Electricity Authority (CEA) projects a power demand 2,30,000MW by the end of 11th five-year plan (2012-13). In order to meet this demand, every year a generation capacity of more than 10000 MW (10%) has to be added every year. The budget for addition of 1000 MW per year would require Rs 40000 crore. Budget provision for the entire power sector during 8th plan (1992-1997) was Rs. 79,589 crore meaning an annual budget of Rs.10,000 crore per annum for the entire power sector of the country. It means Government of India has huge shortage of funds, thus necessity of private sector in power generation is obvious. Joshi et al. [2] have presented the necessity of privatization in the field of power generation, its advantages, the precautions to be taken by energy planner. Necessity of eco-friendly, non-conventional sources of power generation, efficiency up-gradation in the field of utilization, statutory provisions essential for meeting the shortage of energy have also been discussed. Private sector participation in generation will increase the reliability of power system by making funds available for new power generation units and help in achieving the capacity addition targets.

The foremost strategy for power sector planning in the 21st century is to ensure the development of eco-friendly alternative sources of power. The conventional sources of electricity generation (coal fired plants) cause acid rains (SO_2), global warming (CO_2, N_2O, CH_4) and the problem in fly-ash disposal. They contribute pollution in more than one way. As per world bank estimates if power sector situation do not change in India, it will produce SOx, NOx, particulate emission and ash, three times more by the year 2015 and CO_2 emission would be 775 millions tons per year compared to the present compared to 1000 tons per year for the entire European countries [1].

Churchill, a Senior Advisor Washington International Energy Group has discussed the difficulties faced in private participation in thermal power generation in India [4]. Leaving alone the State Electricity Boards (SEBs), the Coal India, which handles coal activity in thermal power generation, is the most inefficient monopoly in India. The Indian Railways, which is mainly involved in the process of transportation of coal, has more employees than the population of the 23 countries in the world. Dealing with Coal India and Indian Railways Government departments is very difficult task, as they are not willing to be bound in the privatization of power sector. The capacity addition targets will require huge amount of fuel supply. Coal will remain the dominant primary source of commercial energy and total coal demand is expected to increase from 430 millions tones in 2005-6 to 670 to millions tones in 2011-12. Meeting these demand poses a formidable challenge in increasing coal production.

2) Privatization in Transmission

The transmission bill was passed by parliament in 1998, thus opening the way for private sector participation in transmission projects. The legislation allows private parties to invest in transmission facilities. The Central Electricity Regulator Commission (CERC) has been granted the powers to issue licenses for interstate transmission projects and the state electricity regulator commissions for intra-state license [4]. Karnataka and Madhya Pradesh are the first two states to invite private participation in transmission sector. Karnataka has also formed joint venture with National Grid of UK. The joint venture will set up transmission lines to evacuate power from independent power producers (IPP) projects planned in Mangalore area. The centre has also identified some projects for private participation. These projects will be taken up as joint ventures with power grid.

3) Privatization in Distribution

Over 95% of power distribution in the country is controlled by SEB. The only exceptions are the cities of Mumbai, Ahmedabad, Calcutta, Surat and Noida, which are distributed by the private companies. Private distribution companies have done well. They have been able to make profits and some portion of which they have ploughed back to improve the efficiency of the system. Their T&D losses are much lower and revenue collection is better. Whereas T&D losses of SEBs are exceptionally high. The losses are compounded by poor revenue collection, subsidy to agriculture farmers, inefficiency and corruption in the system. The net result is miserable state of SEB finances [4].

Many experts believe that private participation is very important and is the only way to reduce theft and corruption and improve the revenue collection, efficiency and reliability of distribution system. In fact multilateral funding agencies like World Bank and ADB (Asian Development Bank) are insisting on some form of private participation in distribution as an essential element of a reform and restructuring package.

Many States have initiated same sorts of privatization in the distribution system. Orissa is the first state to have introduced reforms in its power sector and its model is being followed by many other states. The generation, transmission & distribution activities of the board have been unbundled. As the part of restructuring exercise Power Grid Corporation was set up to look after transmission and distribution. It was decided that distribution would be privatized in phased manner. In 1997 the entire distribution network was divided into four zones and to transfer distribution to four companies (Cesco for central zone, Southco for the southern zone, Nesco for northern zone, and Wesco for western zone). The Orrisa government then decided to invite private sector participation through the joint venture for the purpose. Haryana and Andhra Pradesh are second and third states to undertake power reforms and they have also obtained financial assistance from World Bank. Other states, which have gone for power sector reform in distribution, are Gujarat, Delhi, Maharastra, Rajasthan, and Utter Pradesh. There have been instances where the billing for the consumers has increased by 40% in some area of Andhra Pradesh where electronic microprocessors-based meters have been used, and non-technical losses have been reduced from 10% to 0.5% [5].

III. RENOVATION AND MODERNIZATION

The objectives of R&M of power plants is generally to regain the capacity lost due to plant aging, availability and include environmental performance and to improve the reliability of plant. R&M of old power plants can deliver additional clean power, cheaper and faster. Nobody disagrees with this fact, but very less progress has been made in this area. The reason sited most often is the shortage of funds. The State Electricity Boards (SEBs) are not in position to invest in R&M even when institution like Power Finance Corporation (PFC) are willing to finance the R&M projects at concessional rates. Most of the SEBs are enable to qualify even for minimum loan requirements.

The CEA has estimated that during ninth, tenth and eleventh five-years plans, an investment of approximately Rs.225 million is required for R&M activities and live extension services. The total expected capacity increase would be 25,000 MW [6]. New plant installation would require over Rs.1000 million. Thus it is especially remarkably that these benefits can be just derived by investing just 20 to 25% of the investment required for installing new power plants. Additionally it will reduce the problems of finding new locations for power plants, reduction of pollution of old power plants, etc.

The scope of any R&M activities varies from plant to plant. Its range may vary from a simple replacement of components to complete the redesign of process. The specific scope of any R&M effort is generally determined after a comprehensive study of all the critical components and auxiliaries. Such study is often termed as residual life assessment (RLA). RLA exercise pinpoints the key weak points in the power stations [7]. Another objective of R&M plan may be to get more operational year from the power station. Such exercise is called life extension programme. Any major R&M drive involve some changes in the critical components of the power station. These may include turbo generator, steam generator, boilers and its auxiliaries, instrumentation and control (I&C) system, coal-handling plants, etc.

High steam temperatures and metallurgical imperfections can cause temperatures excursions turbines blades, which are especially vulnerable to these temperature variations as they lead to increase in heat consumptions and decrease the efficiency of conversation. Improved blading technologies/ complete replacement of old blades by new blades help in reducing in the rate of heat consumption and result in higher turbine efficiency. Hydroturbine may suffer from pitting and rusting problems. Steam generator and boilers are exposed to thermal and chemical stresses. Super-heater, economizers, furnished tubes and other parts of the boilers are often subjects to corrosion and metal fatigue. Most effective parts in a boiler are the tube and headers. Other auxiliaries could be cooling water pumps, boilers feed pumps, induced and forced fans, coal mills etc. R&M in boilers and their auxillies can lead to 10% increasing in the efficiency of the systems [8].

Coal handling is the most important component of any coal based thermal power station. Low quality of fuels like high ash content Indian coal can also cause wear and tear of metal surfaces, besides affecting the rate of heat transfer. Major parts that may require refurbishment in coal handling plant are wagon triplers, crushers, vibrating feeders, belts and electrical systems, etc.

Rapid advancement in electronics has necessitated the changes in the I&C systems. Instrumentation is the key to the smooth running of any power station. Retrofitting a new I&C system onto old plants is not easy and may require massive modifications in the basic design itself. However the importance of latest I&C system cannot be undermined. Monitoring and control of power plant leads to an improved efficiency.

IV. INFORMATION TECHNOLOGY (IT)

The level of computerization in Indian Power Sector is very low and makes system unreliable. Lake of automations at power systems especially those owned by SEBs, means low capacity utilization and high operational costs. Similarly, lake of computerization in the distribution management means wastage of power, fluctuation in frequency level, grid break down and low quality of service. Metering, invoicing and billing processors are not fully computerized. This leads to an inaccurate reading on one hand and long lead times (between reading and billing and between billing and collection) on the other. The main reason for low use of IT at the SEBs is not, as often claimed by top officials, the lake of funds but lake of awareness of the benefits of such use [9]. If SEBs have well plans for IT up gradations, agencies like PFC are willing to provide the money. Maharastra State Electricity Board (MSEB) is using an integrated system or an enterprise wide IT solution. States like Andhra Pradesh, Orissa and Haryana are making IT infrastructure a key aliment of their future plants and strategies. This section focuses the major areas of generation and distribution where use is very important.

A) Plant Automation

Computerization or automation has become critical to maximum generation efficiency and reliability. It is essential for collection of data from various parts of the plants and for remote control of equipments. In power plants automation may be require for power plants maintenance, fuel management systems, automatic generation control (AGC), supervisory control. The brief description of each system is presented as under [10].

1) Power Plants Maintenance

The power plants maintenance system store information for analysis of maintenance and evaluation of equipment performance. Maintenance information system has also to interface with other systems like material information systems for equipments stocking level, personal information systems for labour resources and general accounting systems for cost tracking.

2) Fuel Management Systems

Control of fuel cost is critical to the overall economy of power production. A key function of fuel management systems is to aid in the requirement of fuel. It also facilities the monitoring and control of fuel supply contracts. Accounting functions are used for fuel purchases, transportation cost, coal inventory values. The fuel management integrates the load forecast, generation scheduling and dispatch information. This information is used to optimize fuel allocation.

3) Automatic Generation Control

AGC adjusts generation against load. The objective of AGC is to maintain the quality and minimize the cost of energy production and transmission. This is done through load frequency control (LFC) and economy dispatch. Both these functions are done in real time. LFC maintains the frequency at specified value. It also maintains power interchange with neighbouring control areas at schedule values. Power system which draw energy from neighboring areas need to do so in specified manner such that neither the transmission lines nor generating units are over stressed.

4) Security Control

Power systems need to survive all possible contingencies. A contingency is an event that causes components such as transmission lines, generators and transformers to be unexpectedly removed from service. Survival means that system stabilizes and continues to operate at acceptable voltage and frequency levels without loss of load and increase the system reliability.

B) Distribution Automation

Major advantage of computerization is centralization of data collection. At a centralized load centre, data like current, voltage, power factors, circuit breaker status etc. is telemetered and displayed. This gives the operator an overview of the entire distribution network. Display of data would enable the operator to optimize the flow in the event the feeder overload or low/ high voltage. This is normally accomplished by switching in/out of capacitors and load management etc. This in-turn leads to improvement in voltage profile, reduction in power losses, improvement in reliability, quick deduction of faults and restoration of services.

Different generating units that are online have different costs of generation. It is therefore necessary to optimize the contribution of each of these units so that the load is met at minimum cost. The system takes into account not only the generation costs of power plats but also their geographical location. This enables the dispatch manager to minimize the transmission losses and thus achieve the minimum cost.

1) Load Management

The objective of load management is to improving the load factors and to shed load during emergency
conditions. Another important application is load survey. Nowadays load-forecasting can be done by electronic tariff meters.

2) Load Despatch

The purpose of load despatch system is to balance the overall supply and demands in power systems. It is especially important when there are simultaneous surplus and shortages of power in transmission grids. In addition to managing supply and demand the system also serves to monitor and control the quality of power delivered. It also ensures that key criterion like frequency and power factors are strictly adhered to the specified levels.

3) Supervisory Control and Data Acquisition (SCADA)

The purpose of SCADA is to allow to operator to observe and control the power systems. It supports both energy management and distributed automation. The specific task that SCADA performs are [11]:

- *Data Acquisition* - provides measurement and status information to operator.
- *Trending* - plots measurement on selected time scales.
- *Supervisory Control* - allows operator to remotely control devices such as circuit breaker and relays.
- *Training* - restricts operation of a device within specified parameters and prevents unauthorized operations.
- *Alarms* - inform operators of unplanned events and desirable operating condition and sorts them out critically.
- *Logging* - records all operator entries and all alarms specified information.
- *Load Shedding* - provides information for automatic and operator-initiated tripping of load in response to system emergencies.

V. METERING

In India T&D lossses are 21 %. Some states like Delhi, Jammu and Kashmir, Orissa etc. have T&D loss more than 45%. Many countries including China have losses less than 10% the reason for high T&D losses in India is very simple and clear. A large part of this loss is due to non-technical factors, i.e. theft and fraud. We lose 10% of electricity generated because of these factors. Energy loss on this account is in the range of 70 to 100 billion units and this translates into a revenue loss of Rs. 110 to 160 billion [12]. Technology can play an important roll in reducing these non-technical losses. There is need to switch from all electromechanical meters to new microprocessors based electronic meters. Microprocessors-based electronic meters are comparatively very difficult to tempter with. Table I shows the advantages of microprocessors based electronic meter over Ferraris wheel meters.

TABLE I
Comparison of Ferraris Wheel Meters with Microprocessor-based Electronic Meters

Description	Ferraris wheel meter	Microprocessor-based electronic meter
Accuracy	Can be affected by wear and tear, changing frequency, overloading, etc.	No such loss of accuracy
Meter reading	Manual and slow	Automatic and fast
Remote monitoring	Not possible	Possible
Tempering possibility	High	Very low
Billing process	Slow due to paper work	Fully computerized and fast
Load management capabilities	Not possible	Possible
Information on power factors, frequency, etc	Not available	Displayed on the meter
Multi tariff billing	Not possible with one meter	Possible
Uses of information on peak load, daily average, etc.	Not available	Recorded and stored over a period of time

VI. INCREASE OF HYDRO SHARE

It is the oldest and cheapest method of power generation that utilizes the potential energy of water. The energy obtained is almost free of running cost and is completely pollution free. Of-course, it involves high capital cost and more gestation period for which private participation is must. Hydroelectric power can be multi-purpose such as river flood control, storage of irrigation and drinking, etc. [13], [14]. In India there is huge potential for hydropower projects, and very less has been harnessed so far. So there is great need for increase of hydro share to get the clean power. In India if the coal reserves and population growth continues to be like previous years, the coal may not last for more than 150 years. In addition, higher transportation cost is incurred on transportation of coal over longer distances.

VII. INCREASE OF RENEWABLE ENERGY SOURCES

Mukunda [15] has presented a paper on need to increase the contribution of renewables from 2% to 10%, i.e. moving from 1800 MW to 9000 MW in 5 years. In fact, India is a country which has separate ministry for non-conventional energy sources (MNES) and a bank for development of renewables i.e. Indian Renewable Energy Development Agency (IREDA). There is a need to increase all renewables as much as possible. Major non-conventional energy sources where huge potential exists are solar photovoltaic, wind, and mini/micro hydro-systems. Non-conventional energy sources will produce the pollution-free clean power and remote areas can be electrified where it is very difficult to execute transmission lines.

Distributed generation (of capacity 2-50 MW) and dispersed generation (capacity less than 500 kW) need to come up again, because economy of scale for large generators over small generators has decreased [16]. The main reason for reduction in the economy to the scale is that distributed and dispersed generation avoid T&D cost in terms of initial cost (execution of long transmission lines) and running cost (T&D) losses.

VIII. GOVTERMENT FUTURE PLAN

Rapid growth of economy will place a heavy demand on electric power system and this is an area of weakness at present. Reforms in power sector have been under way for several years and they have bought several important institution changes, which were required to make power sector more efficient. Utility based generation is expected to rise around 30,000 MW in Tenth Plan (2002-03 to 2006-07) and there is plan to for increase of 60, 000 MW in 11th plan (2008-09 to 2012-13) with a growth rate between 8 to 9% per annum [17]. Addition of this capacity will require the availability of fuels such as coal or natural gas, etc. for new plants. There is need to pay special attention to exploit hydro potential and nuclear capabilities and various other renewable energy sources. State government must plan to bring down the aggregate technical and commercial losses from current level of 40% to at least 15% by end of 11thy Plan.

IX. CONCLUSIONS

This paper has shed some light on major problems of power sector in generation, transmission and distribution systems in India and discussed the restructuring/privatization of power sector. R & M of old plants, use of IT in power sector, revenue collection and metering problems in distribution systems, need of increase of hydro share and non- conventional energy sources to overcome environmental problems have been highlighted in this paper. Following are the important conclusions of this paper:

Huge investment is required in the power sector. So entry of privatization in generation, transmission, and distribution is must. It will create competition in generation and distribution. In distribution, use of microprocessor-based electronic meters is very important to avoid theft and for faster revenue collection. In transmission there is some type of monopoly due to its functional nature. R& M of plant will generate additional capacity at 25% of expenditure of new installed capacity of plant and will also increase the reliability of existing plant and reduce there shut down period. This will also reduce the pollution from old plants, and the problem of locating site for new plants. There is a need to increase hydropower, and non-conventional sources to overcome the environmental problem. Use of non-conventional sources would help in electrifying the difficult remote areas where execution of transmission line may not be technically/economically feasible.

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8. POSSIBLE INTERCONNECTION SCENARIOS AND IMPACTS ON COMPOSITE SYSTEM RELIABILITY BETWEEN "ROK-DPRK-RF (PAPER 07GM0938).

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Abstract--This paper presents possible interconnection scenarios and reliability analysis results on power exchange between “ROK-DPRK-RF”. Four possible scenarios on power system interconnection between “ROK-DPRK-RF” are proposed to compare pre-feasibility study results in technical, economic and marketable viewpoints. Among these topics, this paper deals with the composite system reliability on interconnected power system. NEAREL(NEAREST-RELIABILITY) program, HLII level composite system reliability program, is developed to analyze the reliability index such as LOLP and EENS for this interconnected system. This paper specifies four possible interconnection scenarios and presents the study results for composite system reliability variations based on these scenarios on NEAREST(North East Asian Region Electrical System Ties) between “ROK-DPRK-RF”.

Index Terms -- power system interconnection, possible interconnection scenario, reliability analysis, NEAREST.

I. POSSIBLE INTERCONNECTION SCENARIOS

Among NEAREST, this paper focuses on potential "RFE-DPRK-ROK" inter-ties because these countries have high mutual complementary characteristics over other countries when considering sufficient energy reserves of the RF, severe power shortage status of the DPRK and ROK’s current necessity of power cooperation. There are four possible scenarios on power system interconnection between "RFE-DPRK-ROK". Fig. 1 represents the basic diagram of (Scenario-1) and <Table 1> describes the comprehensive technical analysis results for each scenario in technical/economic viewpoints such as investment cost, max/min exchanging power, energy security and reliability.

(Scenario-1), which actively engages ROK, DPRK, and RF, can guarantee the energy security of ROK. When feasible minimum power exchange is concerned, at least 2 GW should be exchanged to secure the profitability. Based on power system configuration of year 2010, the maximum power exchange is 4 GW. It means that ROK’s power system is able to technically support up to 4 GW without reinforcing current power system facilities.

(Scenario-2) interconnects the ROK and the RF’s power system and DPRK only provides ROW(Right Of Way) of transmission line. This scenario requires only two converter stations in ROK and RF, whereas (scenario-1) requires three converter stations. Even though (scenario-2) has advantages in terms of construction cost and interconnected power system operating technology, power system interconnection passing through DPRK poses severe energy security threat. In terms of economic feasibility, the minimum power exchange is 2 GW, and maximum power exchange, in respect to ROK’s system, is 4 GW.

(Scenario-3) also establishes two-terminal HVDC system, but bypasses DPRK and passes through East Sea instead of DPRK territory. This scenario resolves the aforementioned energy security issue; however, construction cost soars from installing undersea transmission line. In terms of economic feasibility, the minimum and maximum power exchange is same as 3 GW. The minimum power exchange is comparatively high because of huge construction cost; and

conversely, maximum power exchange is low because AC network near interconnection bus in east coast is weaker than the one near interconnection bus in Seoul.
(Scenario-4) avoids using costly long distance transmission lines, and establishes power system interconnection via BTB(Back-To-Back) system at the border. Converter stations are set up at “DPRK-RF” and “ROK-DPRK” borders, and DPRK’s AC network transfers power from one converter station to another. Since interconnected transmission line is eliminated, this scenario is the most cost effective of all. However, DPRK’s poor AC network condition can negatively affect the reliability of interconnected power system. If ROK and RF have to financially partake in DPRK’s AC network reinforcement, economic and marketable feasibility may worsen. The minimum and maximum power exchanges for this scenario are 2 GW and 4 GW, respectively.

Of four possible scenarios, the (Scenario-1) is the most reasonable option when considering all of the requirements and conditions. This scenario involves three converter stations located in Vladivostok, Pyongyang and Seoul. In addition, VSC-HVDC system appears most appropriate when considering DPRK’s weak system.

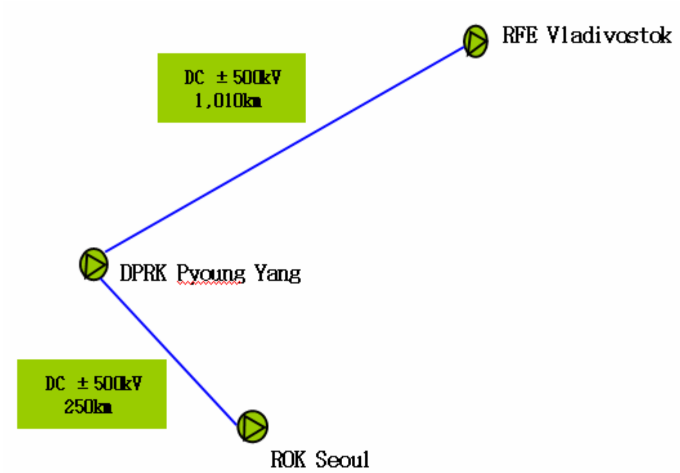

Fig. 1 Diagram of (Scenario-1)

Table 1> Results of technical analysis of each scenario

Category	Scenario 1	Scenario 2	Scenario 3	Scenario 4
HVDC System	3 terminal interconnection (‘‘ROK-DPRK-RF‘‘)	2 terminal (Seoul, Vladivostok, via DPRK)	2 terminal (Seoul, Vladivostok, via East Sea)	BTB
Cost	□	□	×	○
Min. power exchange	2GW	2GW	3GW	2GW
Max. power exchange	4GW	4GW	3GW	4GW
HVDC technology	VSC required	VSC or CSC	VSC or CSC	VSC required
Reliability	□	○	○	×
Energy security	□	×	○	×
Priority	1	2	3	4

*) Excellent: ○, average: □, poor: ×

II. RELIABILITY ANALYSIS OF INTERCONNECTED SYSTEM

Composite system reliability analysis program, NEAREL, is developed as a tool to analyze power supply reliability of interconnected system. Composite interconnected system encompasses all aspects of a power system that includes generation, transmission system, and interconnected power system to neighboring country. This program is a Hierarchical Level II (HLII) reliability analysis program of the composite interconnection system, which calculates the reliability index considering generation and transmission systems.

The interconnected power systems are divided into two categories: assisted system (receiver) and assisting system (supplier) during arbitrary period. This research proposes Tie line constrained Equivalent Assisting Generator model (TEAG) that incorporates forced outage rates of transmission lines. The two composite generation and transmission systems that are interconnected by one tie line are shown in Fig. 2.

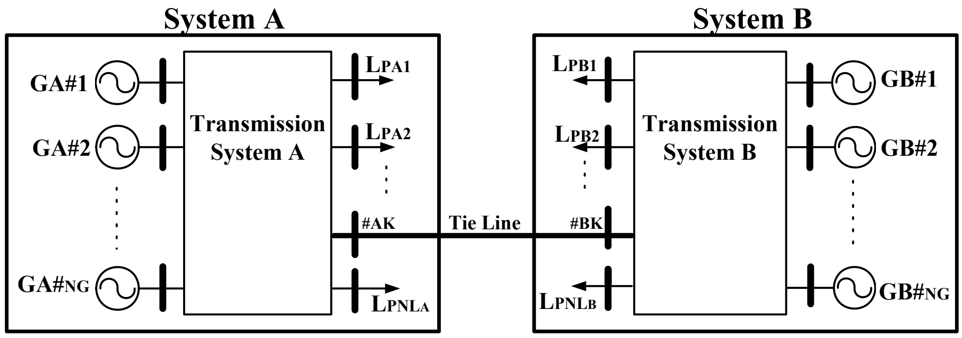

Fig. 2. Diagram of the composite interconnection system model with interconnected System A and B (System A: Assisted System, System B: Assisting System)

First, an arbitrary load point is identified from composite power system facilities (generation and transmission system) after considering capacity limit and forced outage rates (FOR). Then Synthesized Fictitious Equivalent Generator at arbitrary load point that uses composite power system's active load concept for Assisting System B can be modeled. Next, the load is removed from the load point #BK to yield the actual equivalent generator that System B can provide to System A. The revised equivalent assisting generator (EAG) can be expressed in capacity using a probability distribution function (PDF).

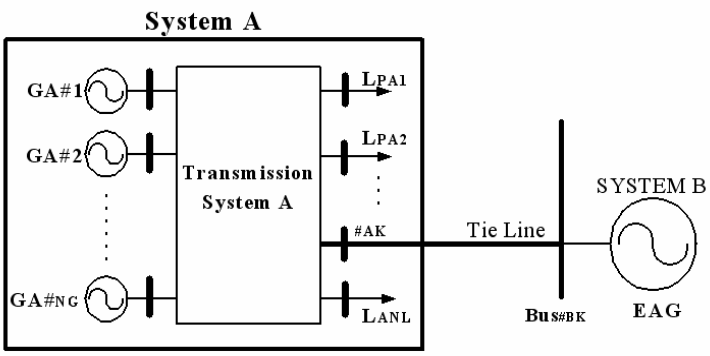

Fig.3. Equivalent assisting generator (EAG#BK) for System B connected to System A

The interconnected transmission line capacity constrain can further limit revised EAG capacity. The revised equivalent assisting generator, which took interconnection line capacity constrain into account, is the final practical version. This final version is called Tie Line Constrained Assisting Generator Model (TEAG), and it can be expressed in probability distribution function (PDF) as below Fig. 4.

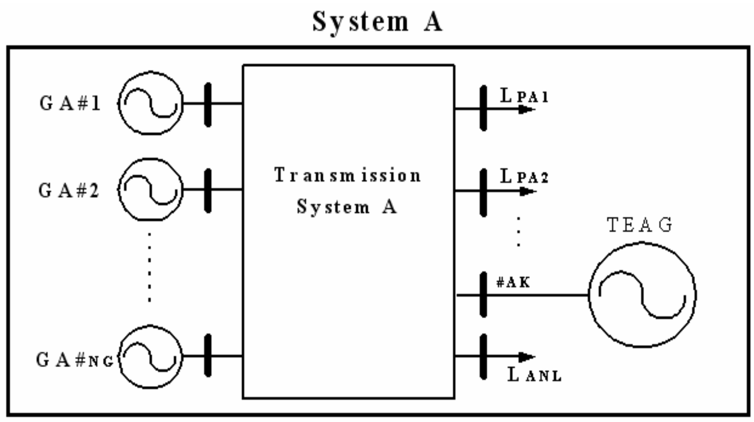

Fig. 4. Equivalent assisting generator model (EAG) (TEAGAK)

III. RELIABILITY ANALYSIS RESULTS

Table 2 shows the results of interconnected composite power system reliability analysis for each country in case of (Scenario-1). The overall system reliability improves in case of power system interconnection, even though the ROK's reliability slightly worsens. However, the ROK's reliability increases during the crucial summer season. The reason why the the ROK's reliability slightly drops is the DPRK's severe power shortage. If the DPRK meets the power balance in the future, the ROK's reliability will improve than independent system operation. This means that the DPRK's power system should be reinforced before power system interconnection with the ROK.

Table 2 Seasonal reliability index LOLE[Hrs/Yr] for each country (Comparisons of Independent and Interconnected operation)

ROK 2 0 1 0						
SEASON		SPRING	SUMMER	FALL	WINTER	Total
ROK	Indepen.	0.035873	0.116515	0.484491	0.046054	0.682933
	Intercon.	0.48210	0.01798	1.64678	2.33056	4.47742
DPRK	Indepen.	89.7729	9.98194	110.457	128.246	338.45784
	Intercon.	0.27375	0.00591	0.84476	1.46879	2.59321
RF	Indepen.	0.646775	0.080679	1.70401	2.47637	4.907834
	Intercon.	0.25213	0.00429	0.79334	1.31377	2.36353

*) LOLE(Loss of Load Expectation) [Hours/Year]

In (Scenario-2), both countries' overall reliability index will improve in case of power system interconnection than independent system operation. (Scenario-3) holds the same condition as (scenario-2) in terms of reliability analysis, thus it has the same reliability analysis results as (scenario-2).

Table 3. Result of reliability analysis for (scenario-2)

	Independent power system		Interconnected power system	
	LOLE [Hrs/Yr]	EENS [GWh/Yr]	LOLE [Hrs/Yr]	EENS [GWh/Yr]
ROK	0.682933	1.673132	0.301094	0.860168
RFE	4.907834	4.324243	0.138382	0.053989
Ave.	2.795384	2.998688	0.219738	0.457079

*) EENS(Electrical Energy Non Supplied) (GWh/Year)

(Scenario-4), interconnecting through DPRK's AC network negatively affects ROK's reliability because DPRK's AC network is in severe poor condition. Consequently, this scenario is undesirable in terms of reliability.

Table 4 Result of reliability analysis for (scenario-4)

	Independent power system		Interconnected power system	
	LOLE [Hrs/Yr]	EENS [GWh/Yr]	LOLE [Hrs/Yr]	EENS [GWh/Yr]
ROK	0.682933	1.673132	4.74965	29.8837
RFE	4.907834	4.324243	2.48566	2.43638
Ave.	2.795384	2.998688	3.617655	16.16004

*) LOLE(Loss of Load Expectation) [Hours/Year]

As a result, (scenario-2) or (scenario-3) is the best scenario if we think of only reliability terms. DPRK's AC network reinforcement is the basic necessary condition in case of DPRK's participation in the power system interconnection. Also, the reliability index of ROK, DPRK, and RF in respect to various interconnection capacities is studied. These findings indicate that improvement in reliability index is saturated at 3 GW. This means 3 GW is deemed optimum interconnection capacity for each scenario.

IV., CONCLUSION

This paper presents the possible interconnection scenarios and reliability analysis results on power exchange between "ROK-DPRK-RF". Four possible interconnection scenarios are proposed and evaluate pre-feasibility study results for several technical issues, especially for reliability viewpoints. As a study results, power system interconnection between "ROK-DPRK-RF" improves reliability in all scenarios in comparison to independent power systems. Among these possible scenarios, even though (scenario-1) is the most reasonable option when considering all of the technical/ economic requirements and conditions. But, (scenario-2) and (scenario-3), which exclude DPRK from power system interconnection, presents the most reasonable options if we think of only reliability terms. If DPRK would be involved, (scenario-4), which use DPRK's AC network, should be avoided to ensure reliability. As a summary, the average reliability index of all countries is greatly improved. But, ROK is slightly decreased in case of unidirectional supply from ROK to DPRK because of the severe electricity shortage of DPRK. Of course, after the DPRK status is stabilized, reliability index of the ROK will also be improved. Also, the optimum interconnection capacity appears to be 3 GW because the reliability index is saturated if the interconnection capacity over 3GW.

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VI. BIOGRAPHIES

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9. NORTHEAST ASIA POWER INTERCONNECTION STUDIES TRENDS AND PROSPECTS IN KOREA (PAPER 07GM0884)

Sang Seung Lee, Yu Chang Kim, Joong Kyo Han, Jong Keun Park, Seung Hun Lee, Masaharu Osawa, Seung Il Moon, and Yong Tae Yoon, Korea. Northeast Asia Power Interconnection Studies Trends and Prospects in Korea (Paper Pending)