IEEE POWER ENGINEERING SOCIETY
ENERGY DEVELOPMENT AND POWER GENERATING COMMITTEE
International Practices for Energy Development and Power Generation Subcommittee

PANEL SESSION: STATUS OF ASIAN AND AUSTRALIAN ELECTRICITY INTERCONNECTIONS AND EFFORT TO IMPROVE EFFICIENCY AND LIMIT GREENHOUSE GAS EMISSIONS[#]

EXTENDED FULL LENGTH PAPERS

IEEE 2003 General Meeting, Sheraton Centre Toronto Hotel, Toronto, Canada, Wednesday, July 16, 2003, Room Hilton/Toronto IIIC, 9:00 a.m.

Chair: Tom Hammons, Chair, International Practices for Energy Development and Power Generation, University of Glasgow, Scotland, UK; E-mail: T.Hammons@ieee.org
Co-Chair: Nikolai I. Voropai, Energy Systems Institute (ESI), Russian Academy of Sciences, Irkutsk, Russia. E-mail: voropai@isem.sei.irk.ru

This Panel Session discussed the Status of Asian and Australian Electricity Interconnections and Effort to Improve Efficiency and Limit Greenhouse Gas Emissions. Presented were the views of renowned international authorities on electricity infrastructure, international interconnections, and alternative energy resources and renewable energy to limit greenhouse gas emissions in Asia and Australia. Reviewed was the present status and future prospect of electricity infrastructure from the viewpoint of Research and Development (R & D) in Japan; power system interconnection of Far-East Russia, the Korean peninsular and Japan; South Korea and North-East Asia interconnection; the status of interconnection of power grids in South Asia; the proposed HVDC bus Siberia-Russia Far East; and increasing the dispatch ability of wind energy through interconnections in Asia and Australia.

Interconnection of electric power systems of regions, states and individual territories is acquiring a growing scale of importance in world practice. There are many benefits of this tendency because of the so-called system effects that lead to improving economical, ecological and technological efficiencies of the joint operation of electric power systems. The efforts to limit GHG emission are one of such benefits.

Asia and Australia are very favorable regions for electric power grid creation and using the above system effects on account of different levels of economic development in different countries of the region, different placement of fuel and energy resources, and consumers, etc. Therefore, the analyses of the present status and prospective trends of Asian and Australian Electricity interconnections and efforts to improve efficiency and limit GHG emission are very important problems.

The Session presented the results of some studies in this area to date.

[#] This document has been prepared and edited by Tom Hammons, Chair of International Practices for Energy Development and Power Generation, University of Glasgow, 11C Winton Drive, Glasgow G12 0PZ, UK.

The Presenters and Titles of their Presentations were:

1. Takeichi Sakurai (Japan). Present Status and Future Prospect of Electricity Infrastructure in Japan: from the View Point of R&D;
2. Sang-Seung Lee, Jong-Keun Park, and Seung Il Moon (Korea). Power System Interconnection Plan in Far East Russia, Korean Peninsula and Japan
3. Dong-Wook Park, Jae-Young Yoon (Korea). Activities in South Korea for the Northeast Asia Power System Interconnection;
4. Subrata Mukhopadhyay (India). Interconnection of Power Grids in South Asia: Present Status and Expectations in Future;
5. Nikolai I. Voropai (Russia). The High Voltage Direct Current Bus: Siberia-Russian Far East;
6. Dennis Woodford (Canada). Increasing the Dispatch ability of Wind Energy through Interconnections in Asia and Australia.

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

The Panel Session was organized by Nikolai I. Voropai, Director of the Energy Systems Institute (ESI) of the Russian Academy of Sciences (Irkutsk, Russia) and T. J. Hammons, Chair of International Practices for Energy Development and Power Generation (University of Glasgow, UK).

Tom Hammons and Nikolai Voropai moderated it.

The first presentation was on the present status and future prospect of electricity infrastructure in Japan in respect of Research and Development. Takeichi Sakurai, Technical Advisor, Tokyo Electric Power Company (TEPCO), Japan presented it.

The major electric power companies in Japan celebrated their fiftieth anniversary in 2002. As privately owned and virtually integrated utility companies, TEPCO constructed much of the infrastructure for generation, transmission and distribution. They have developed new technologies for rapid growth of demand, which has reached about 20 times the initial value in half a century.

Saturation of growth is coming to the Japanese Power Industry. Following deregulation of power generation, deregulation of retail started in 2000, and the new scheme for the free market is under discussion in government committees. In the competitive world, R&Ds for cost reduction is given priority.

This presentation focused on the present status and future prospects of R&D for the infrastructure, such as HVDC transmission, UHV transmission, etc.

Takeichi SAKURAI joined TEPCO in 1960 after graduating in Electrical Engineering from the University of Tokyo. His early work with TEPCO was in R&D for HVDC transmission and UHV AC transmission, along with the design and construction of the Shin-Shinano frequency converter station. During 1989-95 he was the General Manager of the Engineering Research and Development Center. During 1995-2002 he was TEPCO Fellow. He is a Senior Member of IEEE, and Member of the Engineering Academy of Japan (EAJ).

The second presentation was entitled: Power System Interconnection Scenario and Analysis between Korean Peninsula and Japan. It was given by Sang-Seung Lee, Jong-Keun Park, and Seung Il Moon, from Korea. The presenters discussed and analyzed a map for power flow for the interconnections of Northeast Asia: between South Korea and North Korea, between South Korea and Japan, and between North Korea and Far East Russia. These interconnections are to satisfy power shortages in the regions where load is concentrated in both two parts of South Korea and one part in North Korea. In South Korea, nearly 43% of the total electricity generated is consumed in the Seoul metropolitan area and nearly 33% in the southeast area. Large-scale power plants have been constructed, however, in the southern area. Multiple routes for connecting the network were established to supply the Seoul metropolitan area, and a significant quantity of the power flows northwards, Supply and demand in the future will be greatly unbalanced because the two regions of South Korea have a greater supply of power than demand.

The presentation proposed scenarios and presented a power flow analysis for the interconnections to solve the problem of power shortage in the Korean Peninsular.

Sang Seung Lee received his Ph.D. degree in Electrical Engineering in 1998 from Seoul National University, Seoul, Korea. Currently, he is Senior Researcher at the Electrical Engineering and Science Research Institute (EESRI). His interests are in the areas of Power system interconnection, control, and power system economics.

Jong Keun Park received his B.S. degree in Electrical Engineering from Seoul National University, Seoul, Korea in 1973; and his M.S. and Ph.D. degrees in Electrical Engineering from University of Tokyo, Japan, in 1979 and 1982, respectively. Since 1983, he has been with the School of Electrical and Computer Engineering at Seoul National University. His present interests are power system interconnection, application of intelligent systems to power systems, and power system economics.

Seung Il Moon received his B.S. degree in Electrical Engineering from Seoul National University, Seoul, Korea in 1985; and his M.S. and Ph.D. degrees in Electrical Engineering from Ohio State University in 1989 and 1993, respectively. Currently he is with the School of Electrical and Computer Engineering at Seoul National University. His present research interests are power system modeling and control.

The third presentation discussed Activities in South Korea for the Northeast Asia Power System Interconnection. Dong-Wook Park, and Jae-Young Yoon, both from Korea, prepared the presentation. Dong-Wook Park is Vice President of R&D and Testing at the Korea Electro technical Research Institute (KERI) and Jae-Young Yoon is Head of the Power System Research Group at the Korea Electro technical Research Institute. Hoyong Kim, Director of the Institute, presented it.

The Power System in the Korean Peninsula has been split in two since 1948. The two systems have developed separately from each other and have been isolated from other power systems except that the North Korean power system had been connected to the Chinese network for a limited period about 30 years ago. This presentation evaluated the advantages of system interconnection, identified barriers and countermeasures, and suggested the setting up of an international body to discuss future plans for system interconnection. Cooperation of all the countries in the Northeast Asia region is required and the help of international organizations such as APERC and UNESCAP is indispensable.

Dong-Wook Park received a B.Sc. degree in Electrical Engineering from Seoul National University in 1978, a M.Sc. from Busan National University, and a Ph.D. from UMIST in England. He has worked in high power testing, system insulation coordination, and reliability assessment; and is interested in Northeast Asia System Interconnection.

Jae-Young Yoon received his B.Sc. M.Sc. and Ph.D. degrees from Busan National University. Since 1987, he has worked in the research field of power system analysis. Currently, he is managing a research project; application of HTS-equipment such as cables, current limiting reactors, and transformers.

The fourth presentation was entitled: Interconnection of Power Grids in South Asia---Present Status and Expectations in Future. Subrata Mukhopadhyay, Central Electricity Authority, New Delhi, India made it.

India is the most populous country in Southeast Asia and has the highest installed capacity for power generation. The installed capacity for power generation is about 106GW and meets a peak load of about 70GW. There exist five distinct regions, namely: Northern, Western, Southern, Eastern, and Northeastern so far as regional power systems are concerned. Only the last two are connected synchronously, while connection between the others are by HVDC back-to-back links. On average, all India peak load deficit is about 12.6%, while the corresponding energy figure is 7.5%. Major exchange takes place from surplus Eastern Region to Southern, Western, and Northern Regions either through back-to-back HVDC connectors or through radial ac systems.

The presentation highlighted an ambitious plan for adding 100GW to its installed capacity to meet a peak load of about 157 GW. Discussed was a plan to form the national grid with overlay of 765 kV ac and HVDC transmission systems for the optimization of resources using diversity of load both from time of day as well as variation in types of load.

Subrata Mukhopadhyay graduated in Electrical Engineering from Jadavpur University, Calcutta in 1968 and gained his Master's and Doctorate Degrees from the Indian Institute of Technology, Kharagpur and Roorkee in 1970 and 1979, respectively. His employment experience of 32 years includes teaching and research in Roorkee and power system planning, design, and operation with the Central Electricity Authority of the Government of India. He has authored two books and twenty-two papers He was awarded the IEEE Third Millennium Medal in 2000, the PES Delhi Chapter Outstanding Engineer Award and PES Asia-Pacific Regional Outstanding Engineer Award for 2001, and in 2002 the IEEE Regional Activities Board (RAB) Leadership Award. He is also a Fellow of the Institution of Engineers (India).

The penultimate presentation was entitled: The High Voltage Direct Current Bus---Siberia-Russian Far East. It was prepared by L. S. Belyaev, L.Yu. Chudinova, L. A. Koshcheev, S. V. Podkovalnikov, V. A. Savelyev, and N. I. Voropai. Nikolai I. Voropai presented it.

The presentation addressed a HVDC bus comprising transmission lines and converter stations that is proposed to connect prospective hydro and tidal power sources and tie interconnected electric power systems of Siberia and the Russian Far East to supply domestic electricity and for export. Discussed was typical winter and summer operating modes of the proposed HVDC bus together with the required transfer capacities of converter stations and transmission lines. Also presented was a comparative economic and environmental assessment of effectiveness of the bus Siberia--Russian Far East.

Lev. S. Belyaev graduated from the Moscow Energy Institute in 1950. At present he works as Chief Researcher at the Energy Systems Institute in Irkutsk. His main fields of interest are development, simulation, and optimization of energy systems. He is the author and co-author of more than 200 scientific papers.

Lyudmila Yu. Chudinova graduated from Leningrad Polytechnic Institute as a Hydropower Engineer in 1990. She is also a researcher at the Energy Systems Institute. Her fields of interest are interstate electric ties and hydropower; She has published 10 scientific papers.

Lev A. Koshcheev graduated from Leningrad Electrotechnic Institute in 1955. He is Deputy Director General of the Direct Current Research Institute. His main research interests are problems of stability and reliability of electric power systems and long-distance DC and AC ties. He is a winner of the USSR State Prize, and has authored/co-authored more than 150 scientific publications and inventions.

Serguei V. Podkovalnikov graduated as an Electrical Engineer from Irkutsk Polytechnic Institute in 1980 and is currently a Senior Researcher at the Energy Systems Institute. His research interests include methods for decision-making in energy uncertainty and multiple criteria, interstate electric ties, and electric power industry liberalization. He has authored/co-authored almost 60 scientific papers, and books.

Vladimir A. Savelyev graduated from Moscow Power Institute in 1955 and is now a Senior Researcher at the Energy Systems Institute. His research interests include long-term development, optimization and scheduling of power systems. He is the author and co-author of 90 scientific papers and books.

Nikolai I. Voropai is Director of the Energy Systems Institute and Head of the Electric Power Systems Department at the Institute. He is also a Professor at Irkutsk Technical University.

The Final presentation was on the dispatchability of wind energy through interconnections in Asia and Australia. Dennis Woodford, President, Electranix Corporation, Winnipeg, Manitoba, Canada, made it.

Both North East Asia and Australia have exhibited reluctance for electrical interconnections between states. As they progress towards doing so, opportunities are created for improved use of renewable energy. Not only are additional markets opened up, but also in both regions there will be greater access to hydroelectric dams by wind farms. It is the hydroelectric systems that provide excellent opportunities for storing the intermittent energy from wind farms. The end result is that the energy generated by wind farms can be dispatchable and thus be of greater value. In the presentation, this was discussed.

Dennis Woodford was born in Melbourne, Australia and graduated from the University of Melbourne with a B.E. degree and from the University of Manitoba with a M.Sc. degree. He was Special Studies Engineer in Transmission Planning of Manitoba Hydro, and Executive Director of the Manitoba HVDC Research Centre. He is a registered Professional Engineer with the Province of Manitoba and an Adjunct Professor at the University of Manitoba

The presentations are summarized below:

1. PRESENT STATUS AND FUTURE PROSPECT OF ELECTRICITY INFRASTRUCTURE IN JAPAN: FROM THE VIEW POINT OF R&D

Takeichi Sakurai, Advisor, TEPCO, Japan, E-mail: sakurai.takeichi@tepco.co.jp

Abstract. The major electric power companies in Japan celebrated their 50th anniversary in 2001. As privately owned and virtually integrated utility companies, we constructed much infrastructure for generation, transmission and distribution. We have developed new technologies for the rapid growth of demanded power, which reached about 20 times the initial value in a half-century. After full growth, saturation of the power growth comes to the Japanese Power Industry. Following the deregulation of power generation, deregulation of retail started in 2000, and the new scheme for the free market is under discussion in the governmental committees. In this presentation, I would like to talk about the present status and future prospect of infrastructure in Japan and related R&D work, such as HVDC transmission, UHV transmission, etc.

Index Terms—Interconnections, HVDC transmission, Power generation economics, Power system security, UHV transmission.

1. Introduction

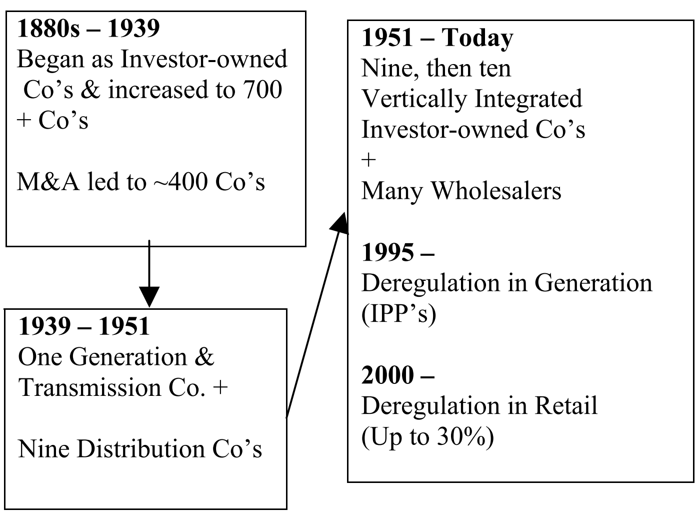


Fig. 1. History of Japanese Utility Industry

At the beginning of the utility industry in Japan, from 1880s to 1939, there were many Investor-owned companies, in competition with each other in the free market.

The number of the companies reached to more than 700 and then M&A led to about 400 companies.

From 1939 to 1951, the Japanese electric power industry was reformed into one Generation and Transmission Company plus nine Distribution Companies.

In 1951 the Japanese electric power industry was reformed again into a more effective style, and it has worked very well until now.

Deregulation in generation started in 1995, and in retail (up to 30%) in 2000.

The History of the Japanese Utility Industry is illustrated in Fig. 1

2. Present Power System

From 1951 up to today, the Japanese utility industry has been made up of nine, then ten vertically integrated investor-owned companies. In addition to this, many wholesalers existed, and supplied electricity to the ten major companies.

Fig.2 shows the present power system in Japan.

As for interstate interconnection, the systems of 9 companies are interconnected through 500kV, 275kV ac, BTB dc, or dc lines. One system, Okinawa is isolated.

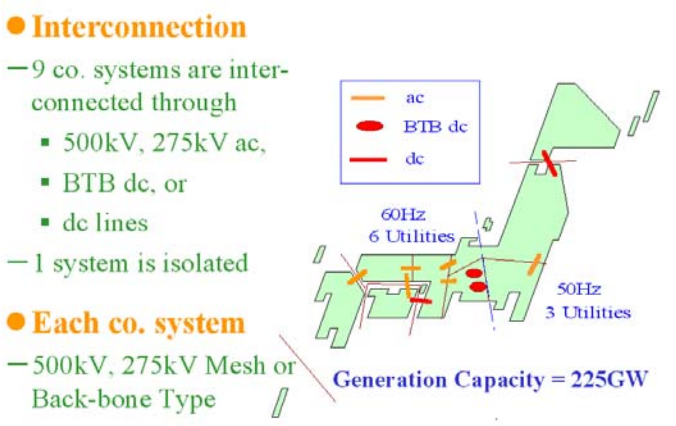


Fig. 2. Present Power System

Each company system is 500kV, 275kV mesh or backbone type.The Japanese economy has been slowing since 1995, after the rapid growth lasting more than 40 years.

In the 1960s the growth rate reached three times in ten years, but in these past 7 years the growth has been zero.

3. Power System in Future

Fig.3 shows the transmission system of Japan around the year 2010 to 2015.

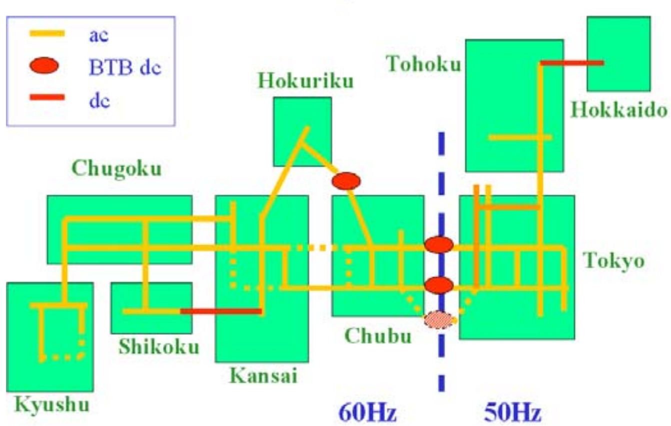


Fig. 3. Transmission System-2010-15

Because of power growth saturation in these 7 years, we are not sure when is the precise date of these expansions. And hopefully the UHV transmission line of TEPCO may be up rated to 1,000 kV around 2010-15.

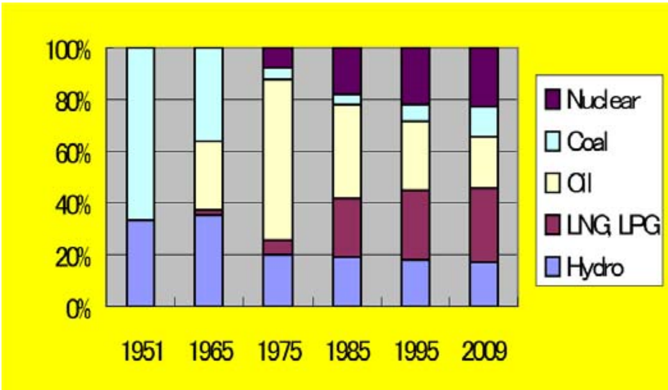


Fig. 4. Generation Capacity Ratio by Energy Source

Fig. 4 shows the generation capacity ratio by energy source. In 1951, coal-fired thermal power and hydropower were used in Japan. In the 1970s, more then 50% of power was supplied by oil-fired thermal generation, but after the first oil crisis in 1973, the security of energy supply became a very important issue. At present, the best mixture of energy supply, nuclear, LNG and other fuels is realized.

Table I shows the power supply targets in the year of 2010, referred from the interim report of the supply and demand division, Electric Utility Industry Council, 1998.

Following this target, 45% of power will be supplied by nuclear in 2010, and new energy such as wind power and solar power will supply 1%.

Comparing with the present situation, increase of nuclear power is from 35% to 45%. The reason for this is the mitigation of CO_2 emission, one of the measures for the Kyoto protocol.

In December 1997, in Kyoto Japan, the COP3 Protocol of Global Climate Change was approved.

TABLE I. POWER SUPPLY TARGETS-ELECTRICITY GENERATED

FY / Power Sources	1996		2010	
	TWh	%	TWh	%
Nuclear	302.1	34.6	480.0	45
Coal	123.7	14.2	136.0	13
LNG	203.7	23.3	213.0	20
Hydro	83.8	9.6	119.0	11
Oil	154.7	17.7	87.0	8
Geothermal	3.6	0.4	12.0	1
New energy	1.3	0.1	9.0	1
Total	872.9	100	1056.0	100

Interim Report of the Supply and Demand division, electric Utility Industry Council, 1998

The main points are summarized below:

- Reduce aggregate emissions of six greenhouse gases by at least 5% below 1990 levels during 2008-2012.
- Key target: U.S.A.=7%, European Union=8%, Japan=6%, Russian Federation=0%
- Six greenhouse gases: CO_2, CH_4, N_2O (1990), HFCs, PFCs, SF6 (1995) Scenarios for the Mitigation of CO_2 in line with the Kyoto Protocol are very difficult for Japan.

The following items are the major ways.

1. Supply side
   Increased use of nuclear power
   Appropriate use of low-carbon fossil fuels
   Improved power generation efficiency
   Development & dissemination of renewable energy
   Development of CO_2 removal technology

2. Demand side
   Energy conservation
   Load leveling

4. Technical Features of Japanese Infrastructure

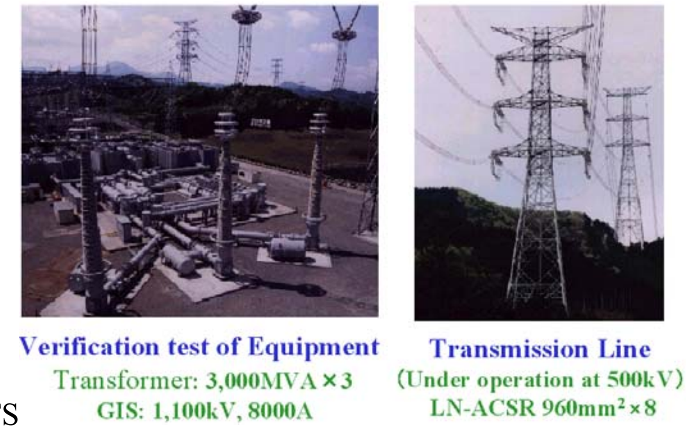
Technical Features of Japanese Infrastructure is summarized as follows:

1. 500kV ac transmission
   2cct large capacity transmission lines
   Multiple phases reclosing

2. UHV (100kV) ac transmission
   Transmission lines were constructed and now operated at 500 kV
   Substation equipments are under verification test

3. HVDC transmission
   Light triggered thyristor valve

Voltage sourced self-commutated inverter for HVDC &



FACTS

Fig. 5. UHV (1,000kV) Transmission

Fig.5 show the UHV substation equipment and trans-mission line.

Substation equipment has been under verification test at Shin-Haruna substation since 1996. Test will continue until 2003.

Transmission lines are already constructed and operated at 500kV, first line named Nishi-Gunma line in 1992, the total length reached about 500km. Fig. 6 shows the energy availability and energy utilization of HVDC systems. As for the availability, the value for the Japanese system is between 97.5% and 99.0%, much better than the world average of 94.6%. As for the utilization factor, the value is not high because Japanese HVDC systems are mainly used for operation in emergency in the ac power system, and are usually operated floating, that means zero output operation.

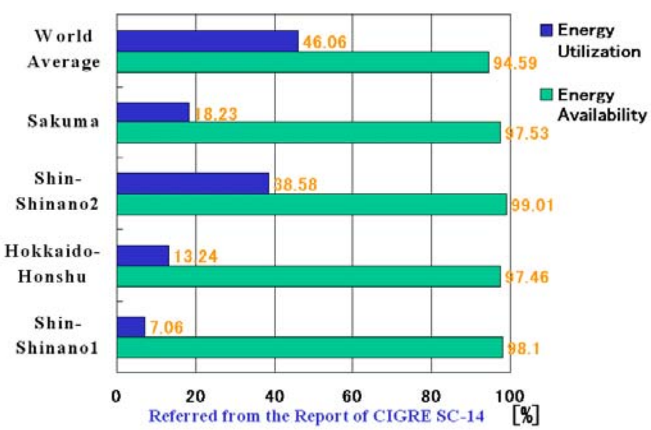


Fig. 6. Operational Data of HVDC Systems

The features of Japanese thyristor valves are:

1. Light triggered thyristor
   Reduces the number of parts to 1/10 and realizes the high reliability
2. Large sized thyristor elements

The world's largest thyristor elements (6 inch, 8 kV-3, 500A) were used in Kii-channel project

Electric power companies, CRIEPI, and manufacturers in Japan jointly carried out research to develop a future dc link between power systems using multiple terminals of voltage-sourced converters.

Three converters rated at 53MVA (37.5MW and 37.5MVar) were manufactured and tested.

The GTO thyristor element has a diameter of 6 inches, and a nominal capacity of 6kV and 6kA.

5. Interconnection with Foreign Countries

It is said that very large amounts of renewable energy, hydropower and tidal power, exist in Siberia and Far East of Russia.

We made a preliminary study of the interconnection with Russia for the future expected development of such renewable energy as large-scale hydro and/or tidal power, and importing the surplus power.

For the interconnection with Russia and Japan, HVDC transmission is the key technology. In the study, voltage & Capacity: ±500kV, ±800kV, □10G□

Distance: submarine cable (about 50km×2)+transmission line (more than 2,000km) is considered.

Security, economy, new technology (multi terminal) etc. are discussed

At present, the Japanese power industry is facing saturation of power growth, having much reserve generating facility. And so few people are interested in this issue.

But in the future, because of the limited resource of energy and for improvement of the global environment, importance of the renewable energy will be reviewed.

Biography

Takeichi Sakurai (M'1996, SM'2000) was born in Tokyo, Japan, in 1937. He graduated from the University of Tokyo and joined Tokyo Electric Power Company (TEPCO) in 1960, as an Electrical Engineer.

His early work in TEPCO was R&D for HVDC transmission and UHV AC transmission, along with the design and construction of the Shin-Shinano frequency converter station.

During 1989-95 he was the general manager of the engineering research and development center, during 1995-2002 he was TEPCO Fellow, and from 2002 up to present technical advisor of TEPCO.

He is a life member of IEEJ (Institute of Electrical Engineers of Japan), a member of EAJ (Engineering Academy of Japan)

2. POWER SYSTEM INTERCONNECTION SCENARIO AND ANALYSIS BETWEEN KOREAN PENINSULA AND JAPAN

*Sang-Seung Lee**, Jong-Keun Park, and Seung Il Moon **
*EESRI, 130, Building, Seoul National University, San 56-1, Shilim 9-dong, Kwanak-gu, Seoul, 151-742, Rep. of Korea, e-mail: sslee@er.snu.ac.kr
**School of Electrical Eng, Seoul National University, Rep. of Korea

Summary - The power system interconnection in North East Asia discussed has a goal to settle the problem of power shortage in the regions where the load is concentrated in both two parts in South Korea and one part in North Korea. In the case of South Korea, nearly 43% of the total electricity generated is consumed in the Seoul metropolitan area and nearly 33% in the southeast area. But large-scale power plants have been constructed mostly in the southern area. Multiple routes of connection network were established to supply the Seoul metropolitan area, and a significant amount of the power flows relatively northward. The supply and demand of the power in the future will be greatly unbalanced because the two regions in South Korea have a greater quantity in supply power than that of demand power. Here we will discuss three cases of the assumed scenarios between Russia, North Korea, South Korea, and Japan.

In the first scenario, the interconnection assumed is to connect the 765kV HVAC between the Kyeongin area in the northwestern region of South Korea and Shinpo in the middle-east region of North Korea. There are shortages of power in the metropolitan areas in South Korea (around Seoul) and in North Korea (around Pyongyang). However, because North Korea has a weak power system and is suffering from a severe shortage of electricity, the power transmission from Shinpo's nuclear power plant, which has a capacity of 2,000MW, is also currently faced with a certain number of problems. A new construction plan of the 765kV transmission line between the two countries is to solve the problem about this weak power system.

In the second scenario, the interconnection assumed is to connect the HVDC between the Busan area in the southeastern region of South Korea and the Kyushu area in the northwestern region of Japan. This interconnection is to solve the shortage of power in the southeastern region of South Korea (a.k.a. Yeongnam area).

In the third scenario, the assumed scenarios is a case without connecting the Shinpo's nuclear power plant to be constructed with 2,000MW capacity in future. Here the proposed scenario is to provide for the interconnection plan of the electric power grids between Far-East Russia and Wonggi in North Korea, between Pyoungsan in North Korea and Yangju in South Korea and between Busan in South Korea and Kyushu in Japan. The first scenario involves the interconnection of the HVDC power transmission system. The second scenario concerns the interconnection of the 765kV HVAC power transmission system. The third scenario concerns the interconnection of the HVDC power transmission system.

1. Power System in South Korea

In the case of South Korea, the metropolitan area situated in the central parts consumed nearly 43% of the total electricity generated, and the southeast area consumed about 33%.

Taking into account geographical boundaries, the South Korean electricity generation system can be divided into 7 geographical areas, as indicated in Table I.

TABLE I. REGIONAL DIVISION IN SOUTH KOREA

Region	Main Province
1. Kyungin area	Seoul Kyunggi province
2. Kangwon area	KangWon1 province
3. Jungbu area	ChungCheong province
4. Honam area	Jeolla province
5. Kyungbuk area	KyungBuk province
6. Kyungnam area	KyungNam province
7. Jeju area	Jeju province

As shown in Table II, the transmission voltages used are 345kV for the major networks, and 154kV or 66kV for the local systems. Most 66kV lines are now either being removed or replaced by higher voltage lines.

The power system on Jeju Island is now connected to the mainland via a 100km-long submarine transmission system, comprised of HVDC (High Voltage Direct Current) cables.

Because demand for power is increasing rapidly in the metropolitan area, 765kV facilities are in the process of being constructed and were supposed to come into operation sometime in 2002, in order to provide large-scale stable power transmission between the large power generation plants and the areas where the consumers are located.

TABLE II. TRANSMISSION LINE (AS OF 2001)

Transmission voltage	Circuit length
765kV	662 c-km
345kV	7,345 c-km
154kV	17,576 c-km
66kV and less	1,540 c-km
180kV (HVDC)	232 c-km
Total	27,355 c-km

* This information was provided by KPX.

2. Power System in North Korea

This study assumes that the power system in North Korea is divided into 5 areas as shown in Table III. The power system in North Korea is smaller than that in South Korea. Most of the hydroelectric power plants are located in the hilly region of the northern areas in North Korea and most of the thermoelectric power plants are located in the metropolitan area. Moreover, power capacity in North Korea has been estimated to be approximately 7,000MW. Currently, it is known that transmission line voltage is composed of 110kV lines and 220kV lines.

TABLE III. REGIONAL DIVISION IN NORTH KOREA

Region	Main Province
1. Northwest area	Pyunganbukdo-Province
2. Northeast area	Hamkyungdo-Province
3. Central area	Pyungannamdo-Province
4. Southwest area	Hwanghaedo-Province (Pyoungyang)
5. Southeast area	Kangwon2-Province

3 *Power System of Kyushu in Japan*

Japan's power system is divided into 9 regional companies serving the areas of Hokkaido, Tohoku, Tokyo, Chubu, Hokuriku, Kansai, Shikoku, Chugoku, and Kyushu, and transmission consists of 500kV, 220kV, 110kV, and DC 250kV lines. The frequency used is 60Hz in the western part and 50Hz in the eastern part of the country. According to statistics published in 2001, the total generating capacity of the nine power companies is 33,765MW due to hydropower, 118,112MW due to thermal power, and 42,300MW due to nuclear power. The total capacity is therefore 194,177MW.

The overhead transmission system consists of 46,692km of lines with a voltage of less than 110kV and 16,048km of lines with a voltage of more than 110kV, and 19,324km of lines with a voltage of more than 187kV. The total length of these overhead lines is 82,065km. The underground system consists of 9,333km of cable with a voltage of less than 110kV, 909km of cable with a voltage of more than 110kV, and 624km of cable with a voltage of more than 187kV. The total cable length is a 10,865km.

Among these regions, Kyushu has a total land area of 42,163 km^2 and is located in the southernmost part of Japan. The generating capacity of Kyushu's Electric Power Company is approximately 30,200MW. The backbone of its transmission system consists of 500kV, 220kV, and some 110kV lines.

Kyushu's infrastructure is composed of nuclear, thermal, hydro, and geothermal power generating plants. The nuclear power plants are located both in the southwest coastal region and at the furthermost tip of Kyushu's northwest coast. The thermal power plants are located mainly on Kyushu's northeast and the northwest coasts. The hydro power plants are randomly distributed within the north and south central regions. The geothermal power plants are located in the north and south central regions.

TABLE IV. REGIONAL DIVISION OF KYUSHU IN JAPAN

Region	Main Province
1. Northern area	Kita Kyushu Province
2. Northeast area	Higashi Kyushu Province
3. Northwest area	Nish Kyushu Province
4. Central area	Kumamoto Kyushu Province
5. Southwest area	Minami Kyushu Province
6. Southeast area	Hitotsuse Kyushu Province

4. *Power System of Far East Russia*

The South-Yakutia hydroelectric plants in Far East Russia are named, because it is advisable to use the rich waterpower resources of Russia. For this problem to be solved, as well as the intersystem effects on the whole to be realized before 2015, it is necessary to create an interstate electric tie between the interconnected electrical power systems of Far East Russia and South Korea.

This tie must be the HVDC one because of the different operating frequencies in the systems between the two countries considered. After 2015, it is possible to increase the delivered power and energy at the expense of building a South-Yakutia hydroelectric plant complex. This complex will consist of four HPPs on the Uchur and Timpton rivers.

Their total capacity can be increased to 5 GW and the mean multiyear-electricity production will be 23.5 TWh. The primary component of this complex is the Sredne-Uchurskaya HPP with the installed capacity of 3,300 MW and an average annual energy output of about 15 TWh.

The electric tie of Sredne - Uchurskaya HPP - South Korea will pass through the territories of Russia, North Korea, and South Korea. Its total length is approximately 2,500 km.

5. Load Flow Results for the Interconnection in Far East Russia, North Korea, South Korea, and Japan

TABLE V. LOAD FLOW RESULTS OF N.K. AND S.K. INTERCONNECTION WITHOUT SHINPO' NPP INJECTION

Load increase in N.K.	Northward power injection (**S.K.→N.K.**) [MW]
2%	387
5%	613
10%	1,017

TABLE VI. LOAD FLOW RESULTS OF N.K., S.K. AND JAPAN INTERCONNECTION WITH SHINPO' 2,000MW NPP INJECTION

Load increase in S.K.	Southward power injection (**N.K.→S.K.**) [MW]
5%	259
7%	506
10%	877

TABLE VII. LOAD FLOW RESULTS OF S.K. AND JAPAN (HVDC)

Power injection	(**Japan→S.K.**) [MW]
50MW	50
200MW	192

TABLE VIII. LOAD FLOW RESULTS OF FAR-EAST RUSSIA, N.K., S.K. AND JAPAN INTERCONNECTION WITHOUT SHINPO' NPP INJECTION

Load increase in S.K.	Southward power injecti (**N.K.→S.K.**) [MW]
5%	258
7%	506
10%	877

Source*: The data needed for this presentation have been provided by the Korea Electric Power Corporation, the Korea Power Exchange, and the Kyushu Electric Power Corporation.*

Biography

Sang Seung Lee was born in Kyung-Nam, Korea on April 2, 1960. He received a Ph. D. degree from the School of Electrical Engineering at the Seoul National University, Seoul, Korea in 1998. Currently, he is Senior Researcher with the Electrical Engineering and Science Research Institute (EESRI). His areas of interest are power system interconnection, control, and power system economics.

Jong Keun Park was born in Taejeon, Korea on Oct. 21, 1952. He received a B. S. degree in Electrical Engineering from Seoul National University, Seoul, Korea in 1973, and M. S. and Ph. D. degrees in Electrical Engineering from University of Tokyo, Japan, 1979 and 1982, respectively. Since 1983, he has been with the School of Electrical and Computer Engineering of the Seoul National University as a Professor. His present research interests are power system interconnection, application of intelligent systems to power systems and power system economics.

Seung Il Moon was born in Jeollanam-Do, Korea on Feb. 1, 1961. He received B. S. degree in Electrical Engineering from Seoul National University, Seoul, Korea in 1985, and the M. S. and Ph. D. degrees in Electrical Engineering from Ohio State University, 1989 and 1993, respectively. Currently, he is an Associate Professor with the School of Electrical and Computer Engineering at Seoul National University, Korea. His present research interests are power system modeling, analysis, and control.

3. ACTIVITIES IN SOUTH KOREA FOR THE NORTHEAST ASIA POWER SYSTEM INTERCONNECTION

Park, Dong-wook; Yoon, Jae-young; Korea Electro technology Research Institute

The power system in the Korean Peninsula had been divided two systems, i.e. North Korean and South Korean power systems, in 1948. These two power systems had been developed separately from each other and also isolated from any other power systems except that the North Korean power system had been interconnected to the Chinese network for a limited time period about 30 years ago.

The total generating capacity in the Korean peninsula is known to be approximately 59 GW at the end of 2001; 50.9 GW in South Korea and 7.6 GW in North Korea. South Korea has enough generating capacity to supply the power demand and has reserve capacity equivalent to a reserve rate of larger than 15%. However, the peak demand is still expected to increase by the rate of 3.4% per year. In other words, the peak demand in 2015 is expected to be 67.8 GW and the generating capacity must be 78.7 GW to supply this peak demand based on LOLE of 0.5 days/yr. This means that the generating plants of about 34.4 GW must be newly constructed by 2015 considering closedown capacity of 6.6 GW. Considering that about 97.7% of primary energy domestically consumed must be imported and 70% of its territory is covered with mountains, there might be great difficulty in developing new generating resources in the viewpoint of sitting, financial investment and import of primary energy.

However, as well known, North Korea is suffering from a shortage of generating capacity. Because of lack of information about the North Korean power industry, it is difficult to clearly describe the present status of the power demand and supply in North Korea but there are many indications that show the shortage of electricity in North Korea. According to the research report, their potential power demand is about 3.0 GW and available generating capacity is about 2.5 GW. This means that the shortage of electric power is approximately 0.5 GW and can be overcome by the commitment of the nuclear power plant of 2.0 GW under construction as a KEDO project. However, the construction schedule of this generating plant is so sensitive to the international political relationship and, so far, has been delayed due to various reasons. Furthermore, experts are suspicious about the stable operation of this nuclear power plant mainly due to three reasons as follows; (1) bad power quality, (2) low reliability of transmission lines and (3) too large capacity compared to the potential power demand of North Korea.

The inter-state system interconnection might be one of the best solutions to alleviate the difficulties that the electricity industry in the Korean peninsula is confronting and will do. However, there seems to be various barriers against the inter-state system interconnection in Northeast Asia including Russia, China, Mongolia, Japan, North and South Korea. These barriers are caused from different status and institutional structure of the electricity industry, unstable political and economic condition in this region, conflict due to the historical background and so on. In order to overcome such barriers, the South Korean Government will launch a project titled “Enhancement of Cooperation in The System Interconnection among The Northeast Asian Countries”.

The objective of this project is to evaluate the advantages of the system interconnection, to identify the barriers and to find out the countermeasures and, finally, to give birth to an international organization for discussing the future plan for system interconnection. In order to accomplish this objective, it is required to build a database for analyzing the technical and economic effects of the system interconnection on system operation and long term power supply planning and, in addition, to evaluate technical, economic and market feasibility. This means the cooperation of all the countries in this Northeast Asia region, and also the help of international organizations such as APERC and UNESCAP are indispensable.

BIOGRAPHY

Park, Dong-wook is Vice President of R&D and Testing at the Korea Electro technology Research Institute [KERI]. He received a B.Sc. Degree in Electrical Engineering from Seoul National University in 1978, a M.Sc. Degree from Busan National University, and Ph.D. Degree from the University of Manchester Institute of Science and Technology [UMIST] in England. Since 1978, he has been with KERI. He has mainly worked in the field of high power testing, system insulation coordination, and reliability assessment, and he is very interested in Northeast Asia System Interconnection, including North Korea.

Yoon Jae-Young is Head of the Power System Research Group at the Korea Electro technology Research Institute [KERI]. He received his B.Sc., M.Sc., and Ph.D. Degrees in Electrical Engineering from Busan National University. Since 1987, he has been working in the research field of power system analysis including custom power systems at the Korea Electro technology Research Institute (KERI). Currently, he is managing a research project, application of HTS-equipment such as cables, current limiting reactors and transformers and also playing a key role in the research project related to the Northeast Asia System Interconnection, including North Korea. jyyoon@keri.re.kr

4. INTERCONNECTION OF POWER GRIDS IN SOUTH ASIA: PRESENT STATUS AND FUTURE EXPECTATIONS

Subrata Mukhopadhyay, *Senior Member IEEE,* Central Electricity Authority, New Delhi, India

Abstract**—**In an effort to improve efficiency and limit greenhouse gas emissions, while lesser and lesser dependence on the use of fossil fuel based power stations is necessary, at the same time harnessing hydro-potential and other non-polluting form of generation is desired to meet increasing demand. This may, however, call for a good amount of interconnection of such sources that may be quite dispersed geographically with respect to the load centers. In this presentation in this context two such examples have been taken up. In India its five power regions are in the process of getting interconnected to form the national grid. With some neighboring countries, though India has few interconnections at present, eventually in a full-fledged manner it may lead to what could be termed the SAARC (South Asian Association for Regional Cooperation) Grid. Similarly in the South Eastern part of Asia also, in formation is an interconnected grid of ten ASEAN (Association of South East Asian Nations) member countries, known as the ASEAN Power Grid.
Index Terms**--** Interconnection, grid, HVDC back-to-back, SAARC, ASEAN

1. Introduction

In South Asia, the most populous country India is also having the highest installed capacity for power generation. At present (as on May 31, 2003) it is about 108,200 MW and meets a peak load of about 71,500 MW with an annual energy generation figure of about 550 billion units of electricity.

So far as history goes, at the time of independence of the country (in 1947), with an overall installed capacity of about 1,360 MW only, there used to be smaller localized utilities operating isolated systems to supply power in and around urban and industrial areas. Thereafter with the gradual formation of state level utilities (known as State Electricity Boards) in the fifties, it became a reality to interconnect various power utilities to form the state grid at 132 and 220 kV levels by the mid-sixties. Units of sizes more than 100 MW were embedded in the state-owned utilities. Then came the era of integration of these state grids to evolve the regional ones basically with the idea of optimizing the natural resources available and even out surplus/deficit of one with the other in the same region. However for certain contiguous states, even if they are in different regions, due to common river-valley projects, sharing of power continues to take place. Examples of this are the ones of Damodar Valley Corporation on the river Damodar in the Eastern Region, Bhakra Beas Management Board run power projects in Beas-Satluj basin in and around Bhakra Dam in the Northern Region, Machkund power project between the state of Orissa in the Eastern Region and the state of Andhra Pradesh in the Southern Region, etc.

In the seventies when the consolidation of regional grids started, regional power stations were planned under the aegis of Central Government. The philosophy in that case has been in favor of allocation of power to various State Electricity Boards of the region from such regional power stations following certain norms. The load of the state in such case has to be met from its own generation and allocation from centrally owned stations in the region. At the initial stage in the absence of an adequate network to deliver power directly to all the states of the region, a method of displacement through the state grids was used. Very often this mechanism fails on account of over-drawl by one state, physically nearer to the source, at the cost of other. Particularly, during high demand condition with low operating frequency, it sometimes resulted in grid collapse too. This in turn led to the development of massive 400 kV intra-regional transmission networks, which hitherto were very much restricted in skeleton form within a state to deliver bulk power from point to point.

Similarly, need-based 500 kV level bipolar HVDC transmission lines were added subsequently to the power map of India over long distances for bulk power supply. Also a large number of generating units of size 200 MW were installed and a few of 500 MW capacity, both at the state level and regional level.

At present there exist thus five distinct regions, namely, Northern, Western, Southern, Eastern and North Eastern so far as regional power systems are concerned as shown in Fig. 1. Out of these, the last two have been interconnected in synchronous mode over a decade and the combination has recently been synchronized with the Western Region too. Interconnections with the rest rely on HVDC links, either back-to-back or in point-to-point bulk supply mode over a long distance, primarily on account of large variation in the operating frequency regime and limited variation

Fig. 1. Five power regions of India with 28 states, 6 union territories and national capital territory of Delhi

in the operating frequency regime, and limited exchange of power is possible. On an average all-

India peak load deficit is about 12%, while the corresponding energy figure is about 8%. Major exchange takes place from surplus Eastern Region to Southern, Western and Northern Regions through both, HVDC and ac systems having maximum inter-regional transfer of about 2,200 MW (against 8,000 MW of available capacity) and 45 million units in a day. Heavily shunt-compensated (reactive) synchronous link between Eastern and North Eastern Regions is primarily a double-circuit 400 kV line, though in parallel a 220 kV double-circuit line exists for a section. Recently commissioned synchronous link between Eastern and Western Regions is also at 400 kV, which is being provided with dynamic series compensation. This is being made as back-up support for the outage of a pole of the 2,000 MW, 500 kV HVDC bipolar long distance (1,370 km) interconnection between Eastern and Southern Regions that has been in existence since last year (2002). In case of such eventuality, power is to be re-routed through the synchronous tie between the Eastern and Western Regions and then finally from the Western to Southern Region through the 1,000 MW HVDC back-to-back link between them. Interconnections between the Eastern and Northern, Northern and Western (both of capacity 500 MW), Western and Southern (of capacity 1,000 MW), Southern and Eastern (of capacity 500 MW, constructed prior to the long distance HVDC bipolar line) for the time being will continue through HVDC back-to-back mode.

2. Electricity for All by 2012

By the year 2012 (i.e., in the next nine years) India has taken an ambitious plan to make available electricity for all by adding more than 100,000 MW in its installed capacity to meet a peak load of about 157,000 MW and annual energy consumption of 975 billion units of electricity [1], [2]. With the process of consolidation of regional grids already completed, it has further raised the hope for optimization of resources at national level considering certain physical constraints, like possibility of exploring hydro-potential in the North Eastern and Northern Regions only, availability of fossil-fuel mainly in the Eastern Region, etc. Accordingly, side-by-side, there is a plan to form the national grid with extensive overlay of 765 kV ac and HVDC transmission systems for the optimization of resources using diversity of load, both from time of the day point of view as well as variation in types of load. Fig. 2 shows an alternative with extensive use of 765 kV transmission lines forming the backbone of national grid [3].

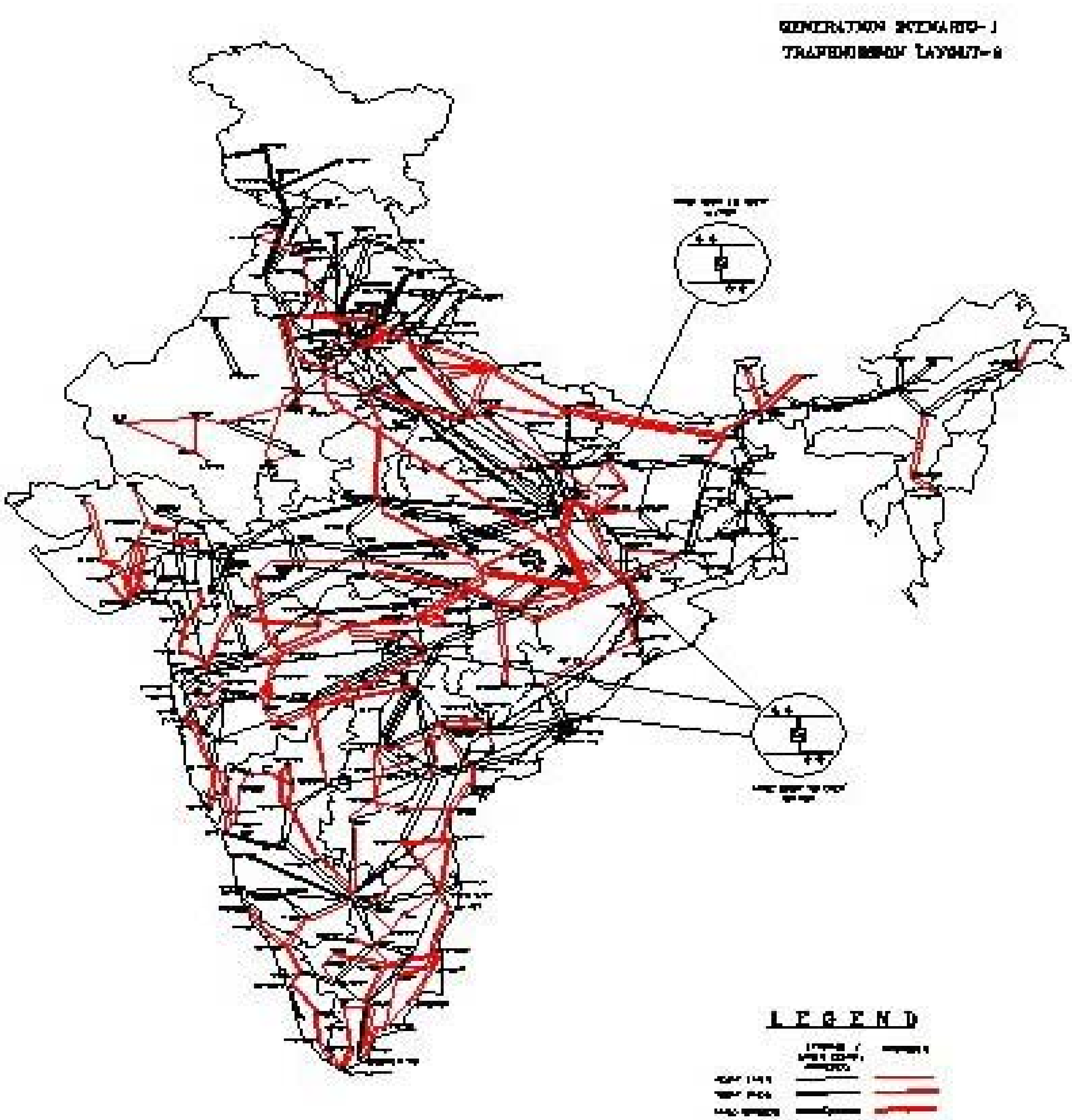


Fig. 2. 765 kV transmission lines forming the backbone of national grid

With this, the saving in installed capacity is expected to be more than 13,000 MW, mostly in fossil fuel based generation and by haulage of power on harnessing large hydroelectric generation potential in the North Eastern Region. In fact this region, the smallest of all in load, is already having excess power, which when further pooled with that of the neighboring Eastern Region, provides a good amount of surplus for exporting to the remaining three large regions, namely the Northern, Western and Southern Regions. The path of transmission of power in this case has the option of HVDC, 765 kV ac or series compensated 400 kV ac systems. Overall combination of generation and transmission in this manner, as worked out, shows a substantial amount of saving in operating cost per annum too (estimated at 12 billion Indian Rupees per annum).

3. Interconnection of Grids

The power scenario envisaged corresponding to the above-mentioned condition allows huge and almost unrestricted inter-regional exchanges of power. As per the studies concerned with the power flow pattern, it is estimated a united national grid when formed may enhance this capacity to the level of 30,000 MW or so from the present level of 8,000 MW with maximum transfer going up to 15,000 MW. Effort is being made to configure suitable location of the interconnection through identification of transmission highways from different angles, based on feasibility (right-of-way, terrain, etc.), development of bulk load, maintenance of system operating parameters, stability, reliability (based on credible static/dynamic contingencies and some degree of uncertainty in the generation front), etc. Side by side to these technical aspects, attention is being given to the use of newer technology options, and commercial mechanisms (for investment return) as well as institutional arrangements. The latter involve agencies, like independent power transmission service providers, national system coordinator, etc. All these are meant to have the system viable from construction, operation and maintenance points of view on a long term basis, particularly in the context of power sector reforms resulting in unbundling of power utilities vis-à-vis decentralized approach to this important infrastructure of economy.

4. Development of Non-Conventional and Non-Polluting Generation

In parallel is an effort also to develop non-conventional forms of generation that are a non-polluting source of electrical energy. As against present combined installed capacity of about 1,900 MW (wind, solar, etc.) it is aimed at increasing this by 6 to 7 times during this period. This will further enhance the system capacity for utilization.

5. Interconnection With Neighboring Countries

So far as other neighboring countries are concerned, Bhutan with a very high perennial source of hydro-resources even at present is well connected (at 220 and 132 kV levels, besides at 11 and 33 kV in the border areas) with the combined grid of the Eastern and North Eastern Region, and now of the Western Region. Major amount of power from its Hydro Power Stations at Chukha (4 of 84 MW) and Kurichu (4 of 15 MW) is exported to India. Furthermore, in the downstream of Chukha, construction is in the advance stage for the 1,020 MW (6 of 170 MW) Tala Hydro-Electric Project (HEP). Available power from this source after pooling with that available from other sources in the Eastern and North Eastern Regions of India is being hauled to the Northern Region through a major trunk line forming an essential part of the national grid. This route is basically planned to operate initially with a high degree of reactive compensation to contain high voltage for transfer of a much lower amount of power. Subsequently with the development of load and pooling of generation, while this type of compensation may be removed, ultimately provision exists for extensive use of dynamic series/shunt compensation to increase further load transfer capability of the corridor.

With Nepal at present there exist few connections mostly of radial type at voltage of 11, 33 and 132 kV levels in the Eastern and Northern Regions of India. Operating a 132 kV level interconnection for exchange of power is also being prioritized between two sources of hydro-generation in Nepal and the Eastern Region. Effort is on to enhance power transfer from 50 to 150 MW by adding a few more 132 kV interconnections. Also in the pipeline is development of 750 MW West Seti HEP in Nepal to deliver power to the Northern Region of India at Bareilly through 400 kV transmission systems. 5,600 MW Pancheshwar HEP on the Mahakali river basin with two 2,800 MW power stations on either side of the river for Nepal and India, also considered for development, is proposed to be supplemented by the downstream project either at Rupaligad (240 MW) or Purnagiri (1,020 MW). Evacuation through 765 kV transmission systems to interconnect with the Northern Region of India at Moradabad, Meerut and with 220 (to Bareilly) or 400 kV for the smaller station is envisaged.

At present Bangladesh is not electrically connected to India. However, there is possibility of a good amount of exchange between the countries for mutual benefits. While India is in a position to supply power from its surplus Eastern Region to the western side of Bangladesh by a 220 kV line from Farakka (India) to Ishurdi (Bangladesh), on a reciprocal basis utilizing natural gas resources, similarly power may flow from the eastern part of Bangladesh to the North Eastern Region of India by 220 kV line from Shahji Bazar (Bangladesh) to Kumarghat (India). Of course establishment of the latter path depends much on the development of further load in the North Eastern Region, for which, however, scope exists in future.

Myanmar, geographically situated south of the North Eastern Region of India, has a proposal to exploit its hydro potential in the northern part for exporting its surplus to India after meeting its own demand. For this, one identified project is concerned with the development of Tamanthi HEP of capacity 1,200 MW, out of which 800 MW of power is proposed to be delivered to North Eastern Region of India at the 400 kV Misa substation.

Linking Srilanka and Pakistan too in the Power Grid of South Asia, as discussed a number of times in the past for limited interconnection, is also a possibility that needs to be explored further. Interconnection with Srilanka may be through submarine cable from the Southern Region of India for 1,000 MW capacity in HVDC mode of transmission. From Pakistan, depending on mutual convenience, possibility lies with interconnection from the developed Sindh river-valley projects to the Northern Region of India. For power transfer of up to 500 MW it may be through a 220 kV link from Dinanath (near Lahore, Pakistan) to Patti (near Amritsar, India) and for more power, by 400 kV links to Moga (Punjab) and Sirohi (Rajasthan) of India. Again, distant future may also see joint tidal power development in the gulf of Kutchch, once the proposition is found viable and economic.

In fact except Myanmar, all the other six countries (Bangladesh, Bhutan, India, Nepal, Pakistan and Srilanka) come under the group known as SAARC (South Asian Association for Regional Cooperation) and formation of a SAARC grid too has been thought of (leaving, of course, Maldives).

6. ASEAN Power Grid

Side by side to developments in the Indian Sub-continent area, the South Eastern part of Asia too is going through important developments in the power sector. The ASEAN Power Grid (APG) is the major energy infrastructure mandated in 1997 by the ASEAN (Association of South East Asian Nations) Heads of States/Government under the ASEAN vision 2020 [4]. It envisages interconnecting 10 ASEAN member countries - Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam. As many as 14 electricity interconnections are planned under the ASEAN Power Grid (APG) – 6 in Greater Mekong Sub-region (GMS) with Cambodia, Lao PDR, Myanmar, Thailand and Vietnam, 4 in Brunei, Indonesia, Malaysia, Philippines - East ASEAN Growth Area (BIMP-EAGA) Sub-region, and 4 in Indonesia, Malaysia, Singapore, Thailand - Growth Area (IMST-GA) Sub-region. Fig. 3 shows the ASEAN Power Grid as planned.

Philosophy of interconnection is based on a cross-border bilateral basis, on a Sub-regional basis, and then on a totally integrated basis.

7. Master Planning

It has been formulated on the basis of the ASEAN Interconnection Master Plan Study - Working Group (AIMPS-WG) of Heads of ASEAN Power Utilities and Authorities (HAPUA). Studies were completed in 2001 and presented in July 2002 in Brunei. Decisions have been taken in favor of pursuing matter for GMS interconnections with the Asian Development Bank (ADB) and the World Bank (WB). For the BIMP-EAGA Sub-region, Business Council and respective power utilities are to make effort and a Trans-Borneo Power Grid Interconnection is planned. For the IMST-GA Sub-region the respective power utilities are to coordinate cross-border interconnections.

8. Progress of Interconnection Projects

As per the 14th Meeting of the ASEAN Power Utilities/Authorities Cooperation Project No. 3 - Interconnections, April 4-6, 2002, Luangprabang, Lao PDR progress is summarized below:

1. **Peninsular Malaysia - Singapore Interconnection Project:** Since December 1985 operating interconnection via 2x250 MVA, 275/230 kV transformers, double-circuit 2x300 sq. mm overhead line and double-circuit submarine cable rated at 250 MVA each between Plentong 275 kV substation in Johor of Tenaga Nasional Berhad (TNB) of Malaysia and Upper Jurong 230 kV substation of Power Grid Limited (PGL) of Singapore is beneficial for system emergencies with availability of 99.45%.
2. **Thailand - Peninsular Malaysia Interconnection Project:** Sadao substation of Electricity Generating Authority of Thailand (EGAT) interconnected to Chuping substation of TNB through 115/132 kV transformer energized in 1981 stands now as back-up to Stage - II HVDC interconnection designed for power transfer of 300 MW initially completed in October 2001 (upgradeable to 600 MW).
3. **Sarawak - Peninsular Malaysia Interconnection Project:** With Sarawak Electricity Supply Corporation (SESCO) coordinating, it has been conceived under Bakun HEP, but deferred due to high cost.
4. **Peninsular Malaysia - Sumatra Interconnection Project:** With TNB coordinating, pre-feasibility study has been carried out jointly by TNB and PLN of Indonesia with feasibility in favor of HVDC.
5. **Batam - Bintan - Singapore - Johor Interconnection Project:** With PLN of Indonesia coordinating, PLN conducted preliminary study and made report available to TNB of Malaysia and PGL of Singapore for review. Batam-Singapore interconnection is being studied by AIMS-WG.
6. **Sarawak - West Kalimantan Interconnection Project:** With SESCO coordinating, PLN of Indonesia completed basic design study for 275 kV transmission lines and West Kalimantan substation in May 2000 and SESCO is expected to complete study for their portion.

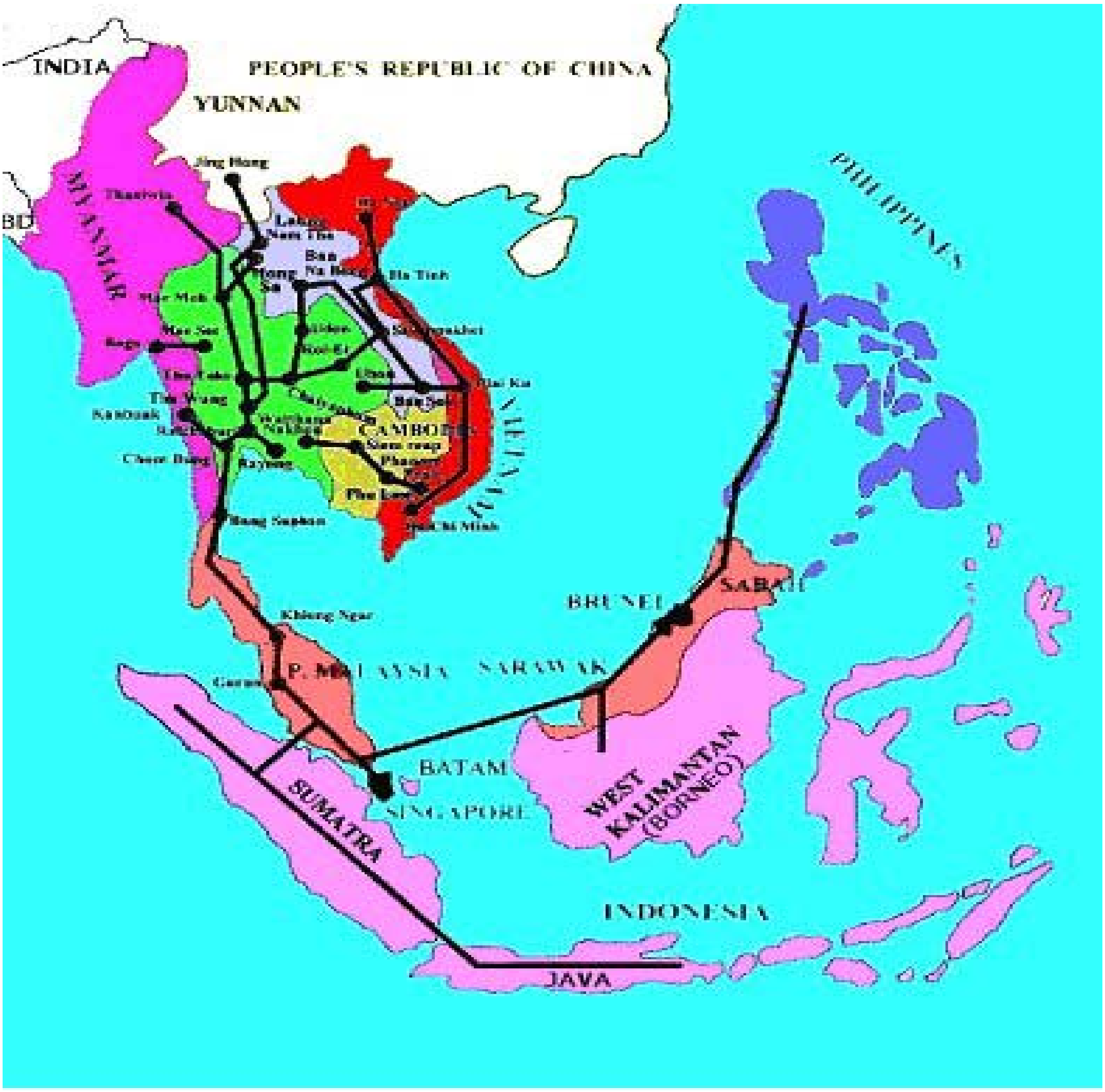


Fig. 3. ASEAN Power Grid as planned involving 10 member countries

7. **Philippines - Sabah Interconnection Project:** With TRANSCO of Philippines coordinating, initial results of AIMS indicated project not viable for 500 MW transfer capacity.
8. **Sarawak - Sabah - Brunei Darussalam Interconnection Project:** With SESCO coordinating, (i) Sarawak - Sabah Interconnection is expected to be commissioned by 2007 with the commissioning of Bakum HEP and (ii) for the remaining part of Interconnection, progress has been reported to be slow and study made available to BIMP-EAGA Working Group for implementation in private sector.
9. **Thailand - Lao PDR Interconnection Project:** With EGAT coordinating, under changed scenario by the end-2006 and mid-2008 export from Lao PDR to Thailand is to be enhanced from 1,500 to 3,000 MW requiring 500 kV line between Roi Et and Savannakher (for power from Nam Theun 2 Project, initially directly and later on by

pooling in power from other projects in the substation). It would be the first interconnection with completion by end-2007.

10. **Lao PDR - Vietnam Interconnection Project:** With Vietnam Power Mission coordinating, a 500 kV transmission line from Ban Sok 500 kV Substation in Lao PDR to Pleiku in Vietnam is to come as approved in February 2002.
11. **Thailand - Myanmar Interconnection Project:** With EGAT coordinating, for export to Thailand up to 1,500 MW by the year 2010 through 500 kV Ta Sang - Mae Moh3 transmission lines from Ta Sang HEP, feasibility study has been carried out by Tokyo Electricity Power Company (TEPCO) and Mitsui Company.
12. **Vietnam - Cambodia Interconnection Project:** With Electricity of Vietnam as the coordinating utility, it has been aimed to provide power supply to the areas along the border by medium voltage lines (35, 22 or 15 kV) and high voltage interconnection with 127.6 km of transmission line in Cambodia covering southern region via Takeo.
13. **Lao PDR - Cambodia Interconnection Project:** With Electricity du Lao (ELD) coordinating, a double-circuit 115 kV transmission line from Ban Yo substation (Lao PDR) to Lao PDR-Cambodia border of length 150 km is aimed at electrification of southern provinces of Lao PDR and border area of Cambodia, extendable further to Strung-Streng and is scheduled to be completed by 2006.
14. **Thailand - Cambodia Interconnection Project:** With EGAT coordinating, study of system interconnection was completed in 2001 for exporting power by 2004 to three provinces in Cambodia, namely, Battambang, Siem Reap and Banteay Meanchey.

9. Conclusions

From the foregoing analysis, it may be observed that to cope up with the ever-increasing demand of electricity, as evident for the developing countries, there is requirement of commensurate addition of generating capacity. Environmental restrictions, depleting reserve vis-à-vis non-availability of fossil-fuel of desired quantity obviously puts thrust on the harnessing of hydro-potential in spite of a long gestation period, and other non-conventional and non-polluting sources of electrical energy, like, wind, solar, tidal, etc. Further, geographical disposition of the available sources has forced evolution of the grid from state to regional and then to national level in a country that ultimately is leading to interconnecting neighboring national grids for mutual benefits.

10. Acknowledgement

The author is indebted to his organization, Central Electricity Authority of Union Ministry of Power, Government of India and IEEE PES Thailand Chapter for making available valuable inputs in the form of published and working documents. The author gratefully acknowledges also contribution of his colleagues in the Central Electricity Authority and Power Grid Corporation of India Ltd. during the preparation of this presentation.

11. References

[1] "Sixteenth Electric Power Survey of India", Central Electricity Authority, New Delhi, India, Sep 2000.
[2] "Fifth National Power Plan", Central Electricity Authority, New Delhi, India, Feb 2001.
[3] "Perspective Transmission Plan 2011-2012", vol. I & II, Central Electricity Authority, New Delhi, India, June 1999.

[4] Koomchoak Biyaem, "ASEAN Power Grid", *Newsletter, PES Chapter of IEEE Thailand Section*, vol. 1, no. 1, Apr 2003.

2. Biography

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 gained his Master's and Doctorate Degrees from Indian Institute of Technology, Kharagpur and Roorkee in 1970 and 1979, respectively. His employment experience of 32 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 twenty-three papers, was awarded an IEEE Third Millennium Medal in 2000, the PES Delhi Chapter Outstanding Engineer Award & PES Asia-Pacific Regional Outstanding Engineer Award for 2001, and the 2002 RAB Leadership Award. He is also a Fellow of the Institution of Engineers (India).

5. THE HIGH VOLTAGE DIRECT CURRENT BUS"SIBERIA-RUSSIAN FAR EAST

L.S. Belyaev, L.Yu. Chudinova, L.A. Koshcheev, S.V. Podkovalnikov, V.A. Savelyev, N.I.Voropai

Abstract--The high voltage direct current (HVDC) bus comprising transmission lines and converter substations is proposed to connect prospective hydraulic and tidal power sources and tie interconnected electric power systems (IEPSs) of Siberia and the Russian Far East (RFE) to supply domestic electricity needs and concentrate export potential. Typical winter and summer operating modes of the HVDC bus are analyzed and the required transfer capabilities of the converter substations and transmission lines are determined. A comparative economic and environmental effectiveness of the bus is studied.
Index terms--Interconnected electric power systems, HVDC bus, power plants, power export, costs.

1. Introduction

The paper addresses the HVDC bus intended to tie the interconnected electric power systems of Siberia and the Russian Far East as well as large hydropower complexes: Tugur tidal power plant (TPP) to be constructed on the Okhotsk sea coast, the Uchur hydropower plants (HPPs) in South Yakutia and the Moksk HPP on the Vitim river. Creation of such a bus along with construction of the above power plants is likely by 2025-2030. The main objectives of the HVDC bus are:

1) to get the bulk of electricity generation from environmentally friendly renewable energy sources;
2) to balance output of Tugur TPP by using hydro power plants of Siberia and the RFE;
3) to attain system benefits from connection of IEPSs of Siberia and the RFE and from their subsequent connection with electric power systems (EPSs) of the countries in Northeast Asia (NEA);
4) to concentrate electric power potential of Siberia and the RFE to meet growing demands of the region and export demands in the future;
5) to improve stability and reliability of parallel AC ties.

The considered HVDC bus may become a very powerful and important link in the future electric power grid of Northeast Asia. It can serve as starting points for the interstate electric ties (ISETs) with China, Japan, North and South Korea.

2. A HVDC Bus Configuration

An important factor that affects the HVDC bus configuration, transfer capabilities of its sections and capacities of the converter substations (CS) is the need to balance output of the Tugur TPP that changes from zero to a full installed capacity of the plant irregularly during a 24-hour period during lunar and solar cycles. Actually at any hour of the day the plant generating capacity may turn out to be zero (due to no head when the levels of the TPP reservoir and sea are equal) or any other value

---

Belyev L.S., Chudinova L.Yu., Podkovalnikov S.V., Saveliev V.A., Voropai N.I. are with Energy Systems Institute, Irkutsk, Russia (e-mail: spodkovalnikov@isem.sei.irk.ru)
Koshcheev L.A. is with Direct Current Research Institute, St-Petersburg, Russia (e-mail: niipt@solaris.ru)

up to the installed capacity. Therefore the TPP output can be used in two ways: a) only to save fuel (unloading thermal power plants) without being involved in the balance of EPS capacities or b) to replace capacity of other power plants after balancing TPP output to firm power by means of some energy storage systems. The second way is more preferable.

With sufficient capacities (and size of water reservoirs) of HPPs in EPS, it is expedient to balance the TPP output by installing additional hydropower units that would require the least capital investments. In this case during the working hours of the TPP the main HPP capacities will be unloaded and the water will be accumulated in their water reservoirs whilst in the hours of the TPP "standstill" the additional HPP units will be loaded providing some firm output of the TPP. This, the most efficient way of balancing Tugur TPP output, becomes possible owing to the construction of the HVDC bus.

The installed capacity of the Tugur TPP was taken equal to 8 GW and average annual generation - to 19.5 TWh as was designed by the Design Hydropower Institute "Hydroproekt". TPP firm capacity was taken equal to 4 GW. Thus, the annual utilization hours of this firm capacity is equal to nearly 5000 which supposes the TPP to meet cycling loads of consumers in the IEPSs of Siberia and the RFE. For this purpose, about 4 GW of additional capacities mentioned above are to be installed at HPPs of Siberia and the Russian Far East.

A part of these additional units are expedient to be installed at the Uchur and Moksk HPPs that are planned to be constructed in parallel with the HVDC bus construction. It was assumed that the installed capacity of the Uchur HPPs would increase by 1.5 GW (from 3.5 GW under the available project to 5 GW) and the capacity of the Moksk HPP - by 0.5 GW (from 1.5 to 2 GW). The rest of the necessary 2 GW of additional units are supposed to be equally split among IEPSs of Siberia and the RFE - 1 GW at the Angara hydropower plants (the Ust-Ilimsk and Bratsk HPPs) and 1 GW at the Zeya and Bureya HPPs. As already mentioned the cost of these additional units are considerably (several times) lower than that of the main units as their construction does not need erection of dams, sluices, preparation of water reservoir bed, etc.

The converter substations of the HVDC bus are located at the points of receiving power from the Moksk HPP, Uchur HPPs and Tugur TPP as well as at the ends of the main line in the cities of Bratsk and Khabarovsk. An emphasis should be placed on the fact that the Khabarovsk converter substation is not a terminal. It serves as a linkage between the bus and IEPS of the RFE and is connected to a main line. It is supposed that after Khabarovsk CS the main line of HVDC bus may have extensions to China, Japan and South Korea.

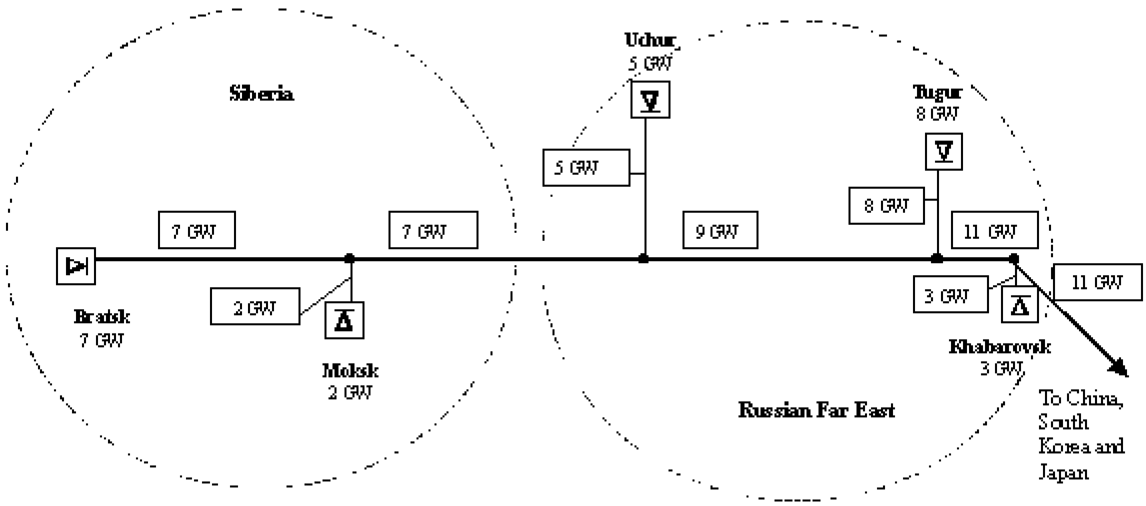


Figure 1. Block diagram of the HVDC Bus " Siberia-Russian Far East"

Based on the above, Figure 1 presents the block diagram of the considered HVDC bus. The main line of the bus is likely to run along the Baikal-Amur railway. Its length is about 3200 km. The HPPs and TPP are connected to the main line by branches. The total length of the bus including these branches is above 4800 km. According to the Direct Current Research Institute (NIIPT) the voltage of the bus was accepted to be ± 750 kV. The same institute conducted conceptual design of the HVDC bus.

3. TypicalL Operation Modes of the Bus

The power flows via the HVDC bus are mainly determined by the operation of Tugur TPP, therefore below they are considered with account for the operating modes of this plant. Selected were five typical operating modes of the HVDC bus important in terms of determining transfer capabilities of its different sections and CSs:

1) Power output of Tugur TPP coincides with annual winter load maximum in Siberia and the RFE;
2) Power output of Tugur TPP coincides with winter load minimum in Siberia and the RFE;
3) No power output of Tugur TPP at the time of maximum load in Siberia and the RFE;
4) Power output of Tugur TPP coincides with annual summer load maximum in Japan and South Korea;
5) No power output of Tugur TPP at the time of maximum load in Japan and South Korea.

The HVDC bus operating modes differ essentially in various seasons of a year. In summer the power flows via the bus are quite intensive and may reach 9-11 GW in some operating modes. The flows are mainly from the west to the east. In winter their volume lessens and their direction changes to a reverse one on a number of sections. Thus, though the summer loads in the IEPSs of Siberia and the RFE decrease, the power flows via the HVDC bus grow. This shows that though the bus plays an important role in meeting electricity demand of Siberia and the RFE, its key task is also to concentrate the surplus power of the IEPSs of these regions, taking place mainly in summer period, for export.

The transfer capabilities of different sections of the HVDC bus were determined by maximum flows via the corresponding sections. The capacities of the converter substations that connect the Uchur and Moksk hydropower plants and Tugur TPP with the bus were determined by the capacity of these power plants. The capacities of converter substations that connect the bus with IEPSs of Siberia and the RFE were determined by the maximum exchange flows between the bus and the IEPSs. The obtained transfer capabilities of the HVDC bus sections and converter substations are presented in Figure 1.

An export potential concentrated by "Siberia – Russian Far East" HVDC bus was determined from the analysis of its typical operating modes. In summer it made up 11 GW and in winter - 2 GW.

4. A Preliminary Study of Economic and Environmental Effectiveness of the Bus

Construction of the above tidal and hydro power plants will replace commissioning of new thermal power plants in the IEPSs of Siberia and the RFE that should be taken into account when estimating the HVDC bus effectiveness.

There is an important peculiarity of EPSs in the NEA region - some countries have annual load maxima in winter (Russia, DPRK, North of China) and other countries - in summer (Japan, South Korea, South of China). In the study, the summer surplus power in the IEPSs of Siberia and the RFE was supposed to be exported to Japan and South Korea to substitute local power plants there and winter surplus power - to China. The benefit gained from such an export supply was also taken into account when estimating the HVDC bus effectiveness.

A comparative economic and environmental effectiveness of the HVDC bus was estimated by comparing the annualized cost for the bus, HPPs and TPP connected to the bus and export lines, with the costs that would take place without the bus (and the above power plants and export lines) at development of competing (alternative) power plants in Siberia, RFE, Japan, South Korea and China. Obviously, in the case when the latter exceed the former the bus is economically effective (gives a positive economic effect) and vice versa.

It should also be noted that to correctly estimate effectiveness of environmentally friendly power sources on the base of hydraulic and tidal energy, environmental damage from fossil fuel combustion at competing thermal power plants must be taken into account. Therefore the costs are to include environmental damage from fossil fuel combustion.

Technical and economic data on transmission lines and power plants to be connected to the HVDC bus and to be replaced by the flows from it were based on the data of NIIPT, Design Power System Institute "DalESP", Hydroproekt, Korea Electro technology Research Institute and Tokyo Electric Power Company.

An economic estimate of environmental damage from fossil fuel combustion at thermal power plants was taken from [1].

The calculations show that the HVDC bus construction requires nearly $5 Billion. Besides the construction of export transmission lines to South Korea, China and Japan is estimated at more than $11 Billion The high cost of the latter is caused by the need to use a submarine cable to pass through the straits between the mainland and the Japanese islands in the case of power export to Japan. Thus, the total capital investments into the bus and export transmission lines exceed $16 Billion

Capital investments into HPPs and TPP connected to the HVDC bus exceed $ 26 Bill. Thus, the construction of the bus, export transmission lines and power plants will require huge investments in the amount of nearly $43 Billion.

Capital investments into the competing power plants are large and make up $23 Billion yet they are almost two times lower than the capital investments into the HVDC bus, HPPs, TPP and export transmission lines.

At the same time yearly costs for the bus, export transmission lines and power plants are almost two times lower than those of the competing power plants. Fuel cost make up more than 50% of yearly costs of the competing power plants. Construction of the bus along with HPPs and TPP will make it possible to replace annually about 14 Million tce of fossil fuel at thermal power plants of Siberia, the Russian Far East, China, South Korea and Japan.

The results of the preliminary studies on economic and environmental effectiveness of the HVDC bus showed that its construction would enable a positive economic effect at a discount rate of 8-9%. The account for the environmental damage substantially increases the bus effectiveness.

Thus, the HVDC bus "East Siberia-Russian Far East" that concentrates the electric power potential of Siberia and the RFE to supply local loads and export power is considered to be effective.

5. Conclusions

1. The HVDC bus " Siberia-Russian Far East" can be an important link of the IEPS of Russia and interstate EPS of the NEA countries. The bus is multi-functional and allows one to gain different benefits from interconnecting the power systems.
2. Connecting new HPPs and TPP to the bus can attain a substantial environmental benefit. Without the bus their construction and involvement into the energy balance of Russia and the NEA countries become uncertain in the coming decades.
3. An important feature of the considered bus is its capability to concentrate Siberian and the RFE power resources to meet domestic electricity needs and supply power for export both in winter (for export to China and DPRK) and particularly in summer (for export to South Korea and Japan). Such a "multi-purpose" function of the bus substantially enhances its effectiveness.
4. The studies have shown potential effectiveness of the HVDC bus " Siberia-Russian Far East".

6. References

[1] L. S. Belyaev, L. A. Koshcheev, and N. I. Voropai et al. “Potential role of hydropower resources of South Yakutia in the power interconnections of the NEA countries”, Proc. *2000 International Conference on Physical and technical problems of the North,* Yakutsk, Russia, pp.9-22.

[2] C. Flavin, “The US national energy strategy: a critique,” Proc. *1991 Conference on Global collaboration on a sustainable energy development*, Snekkersten, Denmark, pp. 173-181.

7. Biographies

Lev S. Belyaev was born in 1928. He graduated from Moscow Energy Institute in 1950 with a degree in Electrical Engineering. He is Professor (1986) and Doctor of Technical Sciences (1969). At present he works as a Chief Researcher of Energy Systems Institute (ESI). In 1975-1976 he was with the Energy Program at the International Institute for Applied Systems Analysis – IIASA (Luxenburg, Austria). His main fields of scientific interest are: development, simulation and optimization of energy systems including global ones, energy technology assessment, interstate electric ties, and methodology of decision-making under uncertainty. He is the author and co-author of more than 200 scientific papers and books.

Lyudmila Yu. Chudinova was born in 1966. In 1990 she graduated from Leningrad Polytechnic Institute as a hydropower engineer. At present she is a Researcher of ESI. Her fields of interest are: interstate electric ties and hydropower. She has published 10 scientific papers.

Lev. A. Koshcheev was born in 1932. He graduated from Leningrad Electrotechnic Institute in 1955. He is Doctor of Technical Sciences (1987) and Professor (1989). For the time being he is Deputy Director General of the Direct Current Research Institute and Professor at St.-Petersburg Technical University. His main research interests are: problems of stability and reliability of electric power systems, and long-distance DC and AC electric ties. He is winner of a State Prize of the USSR. He is the author and co-author of more than 150 scientific publications and inventions.

Serguei V. Podkovalnikov was born in 1958. In 1980 he graduated from Irkutsk Polytechnic Institute as an electrical engineer. In 1989 he defended his thesis on the application of mathematical methods for decision-making under uncertainty and multiple criteria to energy studies. In 1993 he participated in the Young Scientists Summer Program of IIASA (Austria). In 1997 – 1998 he was with Pace University (USA) as a Fulbright Scholar. He is a Member of IEEE. For the time being he is a Senior Researcher of ESI. His research interests are: methods for decision-making in energy under uncertainty and multiple criteria, interstate electric ties and interconnected power systems, expansion planning of electric power industry in a market environment, and electric power industry liberalization. He is the author and co-author of nearly 60 scientific papers and books.

Vladimir A. Savelyev was born in 1932. In 1955 he graduated from the Moscow Energy Institute as a hydropower engineer. He is a Senior Researcher of ESI now. His research interests are: long term development, optimization and scheduling of power systems and cascades of hydropower plants, hydropower safety, and methods for electricity tariffs setting for power systems with substantial hydropower capacities. He is the author and co-author of 90 scientific papers and books.

Nikolai I. Voropai is Director of ESI. He is also the Head of the Electric Power System Department of the Institute and Professor at Irkutsk Technical University. He was born in Belarus in 1943. He graduated from Leningrad Polytechnic Institute in 1966. N.I. Voropai received degree of Candidate of Technical Sciences in 1974 and Doctor of Technical Sciences in 1990. His research interests include: modeling power systems; operation and dynamic performance of large interconnections; reliability, security and restoration of power systems; development of national, international and intercontinental interconnections. N.I. Voropai is a Member of CIGRE, a Senior Member of IEEE and a Member of PES.

6. INCREASING THE DISPATCHABILITY OF WIND ENERGY THROUGH INTERCONNECTIONS IN ASIA AND AUSTRALIA

D.A. Woodford, Electranix Corporation, 107-865 Waverley Str., Winnipeg, Canada, R3T 5P4

Abstract-- Both North East Asia and Australia have exhibited reluctance for electrical interconnections between states. As they progress towards doing so, opportunities are created for improved use of renewable energy. Not only are additional markets opened up, but also in both regions there will be greater access to hydroelectric dams by wind farms. It is the hydroelectric systems that provide excellent opportunities for storing the intermittent energy from wind farms. The end result is that the energy generated by wind farms can be dispatchable and thus be of greater value.

Index Terms—Interconnections, renewable energy, wind farms.

I Introduction

There has been much written and studied on the benefits for international electric power interconnections in North-East Asia. The Nations of North East Asia have either large economies or extensive energy resources. At present the economic potential of these countries is held back in part because of the inability to properly exploit electric energy. The countries with large economies in the region are unable to trade a-kilowatt hour between them. This is not the trend of other developed and growing regions of the world.

The states in Australia have traditionally avoided interconnections for historical reasons. It is only in recent years that there has been progress towards interconnecting the power systems of the eastern states – Queensland, New South Wales, Victoria, Tasmania and South Australia. Queensland and New South Wales are now interconnected, and so to are Victoria and South Australia. A dc link between the island of Tasmania and Victoria on the mainland is being constructed and will interconnect these two states.

As electric power interconnections in North East Asia and Australia are contemplated, there is a new dimension that should be factored in. This is the growing need and demand for renewable energy. The pressures to restrict greenhouse gases are opening up opportunities for investor owned developments of very large renewable energy generation systems. Almost every developed or developing country in the world is undertaking serious studies and initiating projects. Wind power is the cheapest source of renewable energy besides some hydroelectric projects. Other renewable sources are solar and tidal power.

A technical challenge with large renewable energy generators is the intermittent nature of the power available. It is only when there is wind that electricity can be generated. This is not a problem for small renewable generators, but when the projects propose several thousand megawatts, then the resulting impact may be unfavorable to the operation of the power system unless a form of storage of electricity is available.

2. Mongolian Wind Energy

There are many options for interstate interconnections in North East Asia. The proposed interconnection from Bratsk, past Irkutsk, then on through Mongolia past Ulaan Baatar to Beijing (the China-Mongolia-Russia or Trans-Asia project [1]) has had considerable attention and negotiation without success. The initial designs were for 2000+ MW capacities with a smaller tap into Mongolia near Ulaan Baatar.

However, Mongolia has the potential for wind generation with large wind farms that can be located across the ideal terrain of the steppes. The renewable energy could be transmitted to Beijing and beyond using the Trans transmission line with a large tap (up to full rating of the transmission line of 2000+ MW). The transmission needed to collect the wind energy could strengthen and add to the rural distribution system. A modern wind turbine manufacturing plant in Mongolia could be established to supply the wind farms, thus bringing increased economic activity to the country.

3 Energy Storage

The Trans-Asia interconnection offers great technical advantages for large wind generation in Mongolia. First of all, consider the energy storage problem. The wind does not always blow when electrical energy is required most. However, with the northern termination of the interconnection at Bratsk where there are large hydroelectric resources, some degree of energy storage is possible. Energy from water flow through the hydro generators can be reduced and supplanted by wind energy. Then when energy is required at times of greater demand and there is no wind blowing in

Fig. 1. Visual image of part of a wind farm in Mongolia

Mongolia, the unused water can be released through the hydro generators and the resulting energy transmitted across the interconnection to supply the demand. This in effect allows intermittent wind energy to be dispatchable, thereby adding value to the wind energy generated. Visual image of part of a wind farm in Mongolia is shown in Figure 1.

There are other hydroelectric resources in the region that could be used for energy storage for the wind energy. These include the Three Gorges project when transmission is completed up to the Beijing area, and North Korea when the Trans-Asia interconnection is extended through to Japan.

In South East Australia there are significant hydroelectric resources in the Snowy Mountains in New South Wales (shared with Victoria), Hydro Tasmania and smaller plant such as Kiewa, Eildon and Hume. There is also good wind energy potential, particularly in Tasmania, which is conveniently located in the "Roaring Forties" trade winds.

Applying the inherent energy storage capability of hydroelectric generators and dams provides greater economic use of both the wind generation and the hydroelectric systems

Fig. 2. Eucumbene Dam in the Snowy Mountains in Australia

Interconnections provide access for the wind farms to hydroelectric resources. When the Bass Link interconnection between Tasmania and Victoria is operational, it will theoretically be possible for a wind farm in Victoria to use the hydroelectric generators of Hydro Tasmania for energy storage. Capacity of the interconnections, key transmission lines and the water conditions of the hydro systems will determine how effective energy storage will be.

Manitoba Hydro in Canada, for example, is firmly interconnected with the United States. The Northern Great Plains area in the US just south of Manitoba has good wind energy potential. Manitoba Hydro has evaluated its capabilities for using its hydroelectric system for energy storage and may be able to store and release up to 1000 MW of intermittent wind energy, thus making it dispatchable. One simple means of payment for such service is to keep a percentage of the energy stored, say 10% to 15%.

4 Interconnections as an Economic Driver

The economically developed regions of the world have strong interconnections to allow trade in electrical energy. Because North East Asia has no significant interconnections between countries, they are depriving themselves of additional trade opportunities and the resulting incremental increase in economic benefits for all countries in the region. The Trans-Asia interconnection shown in Fig. 3 will provide the electric energy super highway to allow trade in electricity to be profitable.

Broadening the electricity markets to all countries of North East Asia will increase profitability for wind energy and indeed all electric energy trading.

5. Conclusions

There is a great need for renewable energy that can offset greenhouse gases from generators derived from fossil fuels. The Trans-Asia interconnection from Russia extended through to Japan will offer a means of trading wind energy generated in Mongolia. Hydroelectricity in Russia, China and North Korea can serve as energy storage for best use of the intermittent nature of wind generation.

Interconnections will be the means to accomplish trade in electricity throughout North East Asia. The end result will be increased economic benefits for all countries involved. Mongolia in particular can benefit from the large-scale wind energy developments possible.

In South Eastern Australia, increased interconnection capacity between states will also allow wind farms to access the reasonably large hydroelectric systems in the region to generate green, dispatch able energy. Incentives are probably needed to overcome the interests that inhibit such developments at present [5].

6. References

[1] Barthold, L.O., Hoville, W.G., Selman, S., McKay, I.H., Kazachkov, Y.A., Flisberg, G., Ushakov, A.E., Westerlund, S., Baby, A., Borovski, V.M., Kuimov., S.V., Svidchenko, A.N., "Privately Financed Transmission: The Trans-Asia Example," Proceedings of the Conference on Eastern Energy Policy of Russia and Problems of Integration into the Energy Space of the Asia-Pacific Region," Irkutsk, 1998.

[2]. Belyaev L.S., Voropai, N.I., Podkovalnikov, S.V., Shutov, G.V., "Ways of Creating International Connections in East Asia and Environmental Implications," *IEEE Power Engineering Review*, 1998, Vol 18, No.8, pp. 7-10.

[3] Belyaev L.S., Voropai, N.I., Lagerev, A.V., Podkovalnikov, S.V., Popov, S.V., Saveliev, V.A., Sokolov, A.D., Trufanov, V.V., Ushakov, A.E., Chudinova, L.Yu. Shutov, G.V., "Prerequisites and Directions in Formation of the Interstate Interconnected Electric Power System in North East Asia," *Proceedings of the International Conference on Eastern Energy Policy of Russia*

and Problems of Integration into the Energy Space of the Asia-Pacific Region, September 22-26, 1998, Irkutsk, Russia, pp. 342-355.
[4] Park, D.W., Hwang, C., Na, K.Y., Kim, I.S., "The Status Quo and Prospects of Korea Power System," *Proceedings of the International Conference on Eastern Energy Policy of Russia and Problems of Integration into the Energy Space of the Asia-Pacific Region*, September 22-26, 1998, Irkutsk, Russia, pp. 71-74.
[5] Robert R. Booth, *Warring Tribes: The Story of Power Development in Australia*, The Bardak Group, Perth, Australia, 2000. ISBN 0-645-38909-1

Fig. 3. Proposed Trans-Asia Interconnection Extended through to Japan

7. Biography

Dennis Woodford (M'71) was born in Melbourne, Australia and graduated from the University of Melbourne (BE) and the University of Manitoba (MSc). He was Special Studies Engineer in Transmission Planning of Manitoba Hydro, Executive Director of the Manitoba HVDC Research Centre, and now President of Electranix Corporation. He is a registered Professional Engineer with the Province of Manitoba and an Adjunct Professor at the University of Manitoba.

PANELISTS

1. Takeichi Sakurai
Advisor
Tokyo Electric Power Company (TEPCO)
Engineering Research Center
4-1, Egasaki-cho, Tsurumi-ku, Yokohama,
230-8510
Japan.
E-mail: sakurai.takeichi@tepco.co.jp
Tel: +81-45-613-2135
Fax: +81-45-613-3052

2a. Sang-Seung Lee
EESRI, 130-dong
Seoul National University
San 56-1 ShinLim 9 Dong
KwanakGu
Seoul, 151-742
Korea
Telephone: 82-2-880-5516
Fax numbers: 82-2-883-0827
E-mail: sslee@er.snu.ac.kr
Tel: +82-2-880-5516
Fax: +82-2-883-0827

2b. Jong-Keun Park
School of Electrical Engineering
301-dong
Seoul National University
San 56-1 ShinLim 9 Dong
KwanakGu
Seoul 151-742
Korea
Korea
E-mail: parkjk@snu.ac.kr
Tel: +82-2-880-7247
Fax: +82-2-883-0827

2c Seung Il Moon
School of Electrical Engineering
301-dong
Seoul National University
San 56-1 ShinLim 9 Dong
KwanakGu
Seoul, 151-742
Korea
E-mail: moonsi@plaza.snu.ac.kr
Tel: +82-2-880-1821
Fax: + 82-2-883-0827

3a. Dong-Wook Park
Vice President of R&D and Testing
Korea Electro technology Research Institute
28-1, Sungju-Dong
Changwon-City
Kyungnam
Korea, 641-120
E-mail: c/o hykim@keri.re.kr
Tel: 055 280 1012
Fax: 055 280 1390

3b Jae-Young Yoon.
Head of Power System Research Group
Korea Electro technology Research Institute
28-1, Sungju-Dong
Changwon-City
Kyungnam
Korea, 641-120
E-mail: jyyoon@keri.re.kr
E-mail: c/o hykim@keri.re.kr
Tel: 055 280 1012
Fax: 055 280 1390

4. Subrata Mukhopadhyay
Central Electricity Authority
D11-62 Pandara Road
New Delhi—110 003
India
E-mail: pesdelhi@ieee.org
Tel: +91 11 2338 7501
+91 11 2338 1502 (H)
Fax: +91 11 2617 0541

5. Nikolai Voropai
Director
Energy Systems Institute (ESI)
Russian Academy of Sciences
130 Lermontov St
Irkutsk 664033
Russia
E-mail: voropai@isem.sei.irk.ru
Tel: +7 3952 461 700
+7 3952 464 803
+7 3952 467 558 (pr)
Fax: +7 3952 462 797

6. Dennis Woodford
Electranix Corporation
107-865 Waverley Street
Winnipeg, Manitoba

Canada, R3T 5P4
E-mail: daw@electranix.com
Tel: +1-204-953-1832
Fax: +1-204-953-1839
www.electranix.com

END