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International Practices in Distributed Generation

T Hammons, L. L Lai, K P Wong

***Working Group on International Practices in Distributed Generation*[1]**

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Chairs: Tom Hammons, University of Glasgow, Scotland, UK
L. L Lai, City University London, UK
K P Wong, Hong Kong Polytechnic University, Hong Kong

Track: Understanding and Responding to System Events:

INTRODUCTION

Distributed generation (DG) is related with the use of small generating units installed at strategic points of the electric power system or locations close to load centers. DG can be used in an isolated way, supplying the consumer's local demand, or integrated into the grid supplying energy to the electrical power system. Distributed generation can run on renewable energy resources, fossil fuels or waste heat. Equipment ranges in size from less than a kilowatt (kW) to tens of megawatts (MW). Distributed generation can meet all or part of a customer's power needs. If connected to a distribution or transmission system, power can be sold to the utility or a third party.

DG and Renewable Energy Sources (RES) have attracted a lot of attention worldwide. Both are considered to be important in improving the security of energy supplies by decreasing the dependency on imported fossil fuels and in reducing the emissions of greenhouse gases (GHGs). The viability of DG and RES depends largely on regulations and stimulation measures that are a matter of political decisions.

2. Technical Impacts of Distributed Generation

Distributed generation technologies include engines, small wind turbines, small hydro, fuel cells and photovoltaic systems. Despite their small size, DG technologies are making stronger impacts in electricity markets. In some markets, DG is actually replacing the more costly grid electricity. However, there are technical issues that deserve attention. No single DG technology can accurately represent the full range of capabilities and applications or the scope of benefits and costs associated with DG. Some of these technologies have been used for many years, especially reciprocating engines and gas turbines. Others, such as fuel cells and micro turbines, are

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Document prepared and edited by T J Hammons[1] relatively new developments. Several DG technologies are now commercially available, and some will be introduced or substantially improved within the next few years.

2.1 Thermal Issues

When DG is connected to the distribution network, it alters the load pattern. The amount of feeder load demand will eventually result in the feeder becoming fully loaded. It is most likely that increased levels of DG will cause an increase in the overall current flowing in the network, bringing the components in the network closer to their thermal limits. If thermal limits of the circuit components were likely to be exceeded by the connection of DG, then the potentially affected circuits would need to be replaced with circuits of a higher thermal rating. This would usually take the form of replacement with conductors of a larger cross sectional area.

2.2 Voltage Profile Issues

Voltage profiles along a loaded distribution network feeder are typically such that the voltage level is at maximum close to the distribution network transformer bus bar, and the voltage drops along the length of the feeder as a result of the load connected to the feeder. Voltage drop is generally larger on rural networks, which are commonly radial networks with feeders covering long distances with relatively low current capacity conductors, especially at the remote ends of the feeders. The distribution transformer, feeding the distribution network, is fitted with a tap-changer, which controls the setting of the bus bar voltage. The tap changer will be set to ensure that, under maximum feeder loads, the voltage drop along a feeder does not result in voltage levels falling below the lower of the statutory voltage limits.

DG along a distribution feeder will usually have the effect of reducing the voltage drop along a feeder, and may lead to voltage rise at some points which could push the feeder voltage above the statutory voltage limit. Voltage rise is generally more of a problem on rural radial networks than on interconnected or ring networks, as excessive voltage rise can be initiated by relatively small amounts of DG due to the high impedance of the conductors and because these feeders are often operated close to the statutory upper voltage limit to counter the relatively large voltage drop over the length of such feeders.

2.3 Fault Level Contributions

A fault can occur in many ways on a network due to a downed overhead line or a damaged underground cable, etc. The current that flows into a fault can come from three sources on a distribution network, namely, in-feeds from the transmission system, in-feeds from distributed generators, or in-feeds from loads (with induction motors).

The connection of DG causes fault levels close to the point of connection to increase. This increase is caused by additional fault level from the generator, and can cause the overall fault level to exceed the designed fault level of the distribution equipment. Increased fault levels can be accommodated, or reduced, by either upgrading equipment or reconfiguring distribution networks.

Induction generators contribute very little to root mean square (RMS) break fault levels, as the fault current from the induction generator quickly collapses as the generator loses magnetic excitation due to the loss of grid supply. However, they contribute more to peak fault levels. Synchronous generators contribute less to the initial peak current when compared to induction generators but do have a larger steady state RMS fault contribution. For generators, which are connected to the distribution network via power electronics interfaces, it will be quickly disconnected under network fault conditions, when a current is 20% higher than the rated current. As a double-fed induction generator (DFIG) is only partially connected via power electronics, the RMS break fault current contribution is low. However, the peak current contribution can be up to six times the rated current.

2.4 Harmonics and Interactions with Loads

In ideal electricity networks the voltage would have a perfectly sinusoidal waveform oscillating, for example, at 50 or 60 cycles per second. However, any capacitive or inductive effects, due to switching of devices such as large cables, network reactors, rectified dc power supplies, variable speed motor drives and inverter-coupled generators, will introduce or amplify ‘harmonic’ components into the voltage sine wave, thereby distorting the voltage waveform. It is anticipated that small-scale micro wind and solar generation will be inverter connected. Inverter connections incorporate the use of a high proportion of switching components that have the potential to increase harmonic contributions.

2.5 Interactions between Generating Units

Increasing levels of intermittent renewable generation and fluctuating inputs from CHP units will ultimately make it more difficult to manage the balance between supply and demand of the power system. Unless the DG can offer the same control functions as the large generators on the system, the amount of generation reserve required when there is significant contribution to the system from DG will need to be increased.

2.6 Protection Issues

Distribution networks were designed to conduct current from high to low voltages and protection devices are designed to reflect this concept. Under conditions of current flow in the opposite direction, protection mal-operation or failure may occur with consequent increased risk of widespread failure of supply.

Due to reverse current flow, the reach of relay is shortened, leaving high impedance faults undetected. When a utility breaker opens, a portion of the utility system remains energized while isolated from the remainder of the utility system that may result in injuries to the public and utility personnel.

3. Economic Impact of Distributed Generation

Distributed generation has some economic advantages compared to power from the grid, particularly for on-site power production. The possibility of generating and using both heat and power generated in a CHP plant can create additional economic opportunities. Distributed generation may also be better positioned to use low-cost fuels such as landfill gas.

The relative prices of retail electricity and fuel costs are critical to the competitiveness of any DG option. This ratio varies greatly from country to country. In Japan, for example, where electricity and natural gas prices are high, DG is attractive only for oil-fired generation. In other countries, where gas is inexpensive compared to electricity, DG can become economically attractive. Many DG technologies can be very flexible in their operation. A DG plant can operate during periods of high electricity prices (peak periods) and then be switched off during low price periods.

The ease of installation of DG also allows system capacity to be expanded readily to take advantage of anticipated high prices. Some DG assets are portable. In addition to this technological flexibility, DG may add value to some power systems by delaying need to upgrade a congested transmission or distribution network, by reducing distribution losses, and by providing support or ancillary services to the local distribution network.

CHP is economically attractive for DG because of its higher fuel efficiency and low incremental capital costs for heat-recovery equipment. Domestic-level CHP, so-called 'micro-

CHP' is attracting much interest, particularly where it uses external combustion engines and in some cases fuel cells. However, despite the potential for short payback periods, high capital costs for the domestic consumer are a significant barrier to the penetration of these technologies.

The provision of reliable power represents the most important market for DG. Emergency diesel generating capacity in buildings, generally not built to export power to the grid, represents several percent of total peak demand for electricity. Growing consumer demand for higher quality electricity (e.g., 'five nines' or 99.999% reliability) requires on-site power production.

Many of these technologies can be more energy-efficient and cleaner than central-station power plants. Modularity is beneficial when load growth is slow or uncertain. Their smaller size can better match gradual increases in utility loads. Distributed generation also can reduce demand during peak hours, when power costs are highest and the grid is most congested. If located in constrained areas, distributed generation can reduce the need for distribution and transmission system upgrades. Customers can install DG to cap their electricity costs, sell power, participate in demand response programs, provide backup power for critical loads and supply premium power to sensitive loads.

The largest potential market for distributed generation is to supplement power supplied through the transmission and distribution grid. On-site power production reduces transmission and distribution costs for the delivery of electricity. These costs average about 30% of the total cost of electricity. This share, however, varies according to customer size. For very large customers taking power directly at the transmission voltage, the total cost and percentage are much smaller; for a small household consumer, network charges may constitute over 40% of the price.

Small-scale generation has a few direct cost disadvantages over central generation. First, there is a more limited selection of fuels and technologies to generate electricity – oil, natural gas, wind or photovoltaic systems, and, in certain cases, biomass or waste fuels. Second, the smaller generators used in DG cost more per kilowatt to build than larger plants used in central generation. Third, the costs of fuel delivery are normally higher. Finally, unless run in CHP mode, the smaller plants used in DG operate usually at lower fuel-conversion efficiencies than those of larger plants of the same type used in central generation. DG uses a more limited selection of fuels. For photovoltaic systems, operating costs are very low but high capital costs prevent it from being competitive with grid electricity.

4. Barriers of DG Development

Cooperation, property ownership, personal consumption and security will change attitude towards DG technologies and make people welcome them to their homes.

There is now evidence that there is strong interest from a small community willing to pay the premium to enjoy green energy.

There is significant regional variation in the use of DG systems. This is largely due to the fact that the potential benefits of DG are greater in some areas than others. In some areas, for example, relatively high electricity rates, reliability concerns and DG-friendly regulatory programs have encouraged comparatively fast DG development. But in many areas, even where DG could offer benefits, market and other barriers often block projects. The most commonly cited barrier to DG development is the process of interconnecting to distribution and transmission systems. Other barriers include high capital costs, non-uniform regulatory requirements, lack of experience with DG, and tariff structures.

The lack of experience with competitive markets often increases risk about the use of unconventional power sources. Customers can’t easily sell power from on-site generation to the utility through a competitive bidding process, to a marketer or to other customers directly. For customers, there is a risk of DG being uneconomical: capital investments under market uncertainty and price volatility for the DG system fuel. There is a concern about the reliability and risks that arise from using unconventional technologies/ applications with DG.

Utilities have a considerable economic disincentive to embrace distributed resources. Distribution company profits are directly linked to sales. Utilities' revenues are based on how much power they sell and move over their wires, and they lose sales when customers develop generation on site. Interconnecting with customer-owned DG is not in line with a utility’s profit motive. Other barriers to the deployment of DG exist on the customer side. A utility has no obligation to connect DG to its system unless the unit is a qualifying facility. If a utility does choose to interconnect, lengthy case-by-case impact studies and redundant safety equipment can easily spoil the economics of DG. If a customer wants the utility to supply only a portion of their load or provide backup power in case of unit failure, “standby” and “backup” rates can be cost prohibitive. Exit fees and competitive transition charges associated with switching providers or leaving the grid entirely can be burdensome. Market models with inclusion of distributed generation need to be considered. The panel is comprised of well-known experts who will present and lead the discussion on the latest information on distributed generation for the above areas.

The Panelists and Titles of their Presentations are:

1. Professor Wei-Jen LEE, University of Texas at Arlington and Dr David Yanshi WANG, Consolidated Edison Company of New York. Distributed Generation Policy at Consolidated Edison Company (Invited Panel Presentation Summary 08GM0318)
2. Mr P. K. LEE and Professor Loi Lei LAI. A Practical Approach to Wireless Power Quality, Energy and Facilities Monitoring System (Invited Panel Presentation Summary 08GM0831)
3. Seho Kim, Cheju National Univeristy, Korea, Young Hwan Kim, Korea Power Exchange, Korea and Kwang Y. LEE, Baylor University, USA. Impact of Wind Power Generation in the Korea-Jeju Power System (Invited Panel Presentation Summary 08GM1471)
4. Miss Xia Lin, Professor Yuping LU, and Miss Jiao Du. Southeast University, Nanjing, Jiangsu, China. The study of Fault Location System with the use DGs (Invited Panel Presentation Summary 08GM0497)
5. Dr Hui WAN, Professor Kit Po WONG and Dr. Chi Yung. CHUNG, Hong Kong Polytechnic University, Hong Kong. Multi-agent Application in Protection Coordination of Power Systems with Distributed Generation (Invited Panel Presentation Summary 08GM0590)
6. Associate Professor Tze-Fun CHAN, Hong Kong Polytechnic University, Hong Kong and Professor Loi Lei LAI, City University London, UK. Use of the Slip-Ring Induction Machine for Distributed Generation (Invited Panel Presentation Summary 08GM0883)
7. Professor Tianshu BI, Director, Si Fang Research Institute, China. Distributed Generation Protecting Microgrids (Invited Discusser)
8. Professor San Shing Choi, Prof. K J Tseng, Prof. DM Vilathgamuwa and Mr. T D Nguyen, School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore. Energy Storage Systems in Distributed Generation Schemes (Invited Panel Presentation Summary 08GM0434)
9. Invited Discussers

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

The Panel Session has been organized by Loi Lei Lai (Professor, City University London, UK; Kit Po Wong (Professor, Hong Kong Polytechnic University, Hong Kong) and Tom Hammons (Chair of International Practices for Energy Development and Power Generation IEEE, University of Glasgow, UK).

Loi Lei. Lai, Kit Po Wong and Tom Hammons will moderate the Panel Session.

PANELISTS

1. Wei-Jen LEE, Ph.D, FIEEE
Energy Systems Research Center
Electrical Engineering Dept
University of Texas at Arlington
UTA Box 19048
416 Yates Street
Nedderman Hall, Rm 517-518
Arlington, TX 76019
USA
E-mail: wlee@uta.edu
Tel: +1 817-272-5046

Dr.David Yanshi WANG
Considated Edison Company of New York
4 Irving Place
New York
NY 10003
USA
E-mail: wangd@coned.com

2. Ringo (P K) LEE
Director
"Your Network System Integrator"
Powerpeg NSI Limited
Unit D, 35/F., Morrison Plaza,
9 Morrison Hill Road, Wanchai, Hong Kong
E-mail: r_lee@hk.super.net
Tel : +1 (852) 2627-1347
Fax : +1 852) 2323-4983

Loi Lei LAI
Professor
Energy Systems Group
School of Engineering and Mathematical Sciences
City University
London, EC1V 0HB
UK
E-mail: l.l.lai@city.ac.uk
Tel: +44 20 7040 3889
Fax: +44 20 7040 8568

3. Seho Kim
Cheju National Univeristy
Jeju-Si
Jeju-Do
Korea 690-756
E-mail: hosk@cheju.ac.kr

Kwang Y. LEE
Professor and Chair of Electrical and Computer Engineering
Editor, IEEE Transactions on Energy Conversion
Baylor University
One Bear Place #97356
Waco
TX 76798-7356
USA
E-mail: Kwang_Y_Lee@baylor.edu
Tel: (254) 710-4188

Fax: (254) 710-3010

Young Hwan Kim
Korea Power Exchange
Jeju Branch
Jeju-Si
Jeju-Do
Korea 690-162
E-mail: yhwan@kpx.or.kr

4. Yuping LU Professor
Dept of Electrical Eng
Southeast University
Nanjing, Jiangsu
P.R.China (210096)
E-mail: luyuping@seu.edu.cn
Tel: +86 13809002279
Fax: +86 2583791817

Miss Jiao Du,
School of Electrical Engineering,
Southeast university
Nanjing,Jiangsu (210096)
P.R.China
Email: duzhuzhulx@163.com

Miss Xia Lin,
School of Electrical Engineering,
Southeast university
Nanjing,Jiangsu (210096)
P.R.China
Email: boulevard2@seu.edu.cn

Mr. Jinjie Ma
School of Electrical Engineering,
Southeast university
Nanjing,Jiangsu (210096)
P.R.China
Email: rainkai8@163.com

5. Dr Hui WAN
Assistant Research Professor
Lane Department of Computer Science and Electrical Engineering.
Advance Power& Electricity Research Center (APERC)
West Virginia University
P.O.Box 6109
Morgantown, WV 26506-6109
USA
E-mail: hui.wan@mail.wvu.edu
Tel: +1 304 293 0405 ext 2541
Fax: +1 304 293 8602

Professor Kit Po WONG
Chair Professor of Electrical Engineering
Department of Electrical Engineering
The Hong Kong Polytechnic University
Hung Hom
Kowloon
Hong Kong
E-mail: eekpwong@polyu.edu.hk
Tel: +852 2766-6168
Fax: +852 2330-1544

Associate Professor Chi Yung CHUNG
Department of Electrical Engineering
Hong Kong Polytechnic University
Hunghom
Hong Kong
Email: eecychun@inet.polyu.edu.hk
Tel: +852 2766 6165
Fax: +852 2330-1544

6. Associate Professor Tze-fun CHAN
Department of Electrical Engineering
Hong Kong Polytechnic University
Hong Kong
E-mail: eetfchan@inet.polyu.edu.hk
Tel: +852 27666183
Fax: +852 23301544

Professor Loi Lei LAI
Energy Systems Group
School of Engineering and Mathematical Sciences
City University
London, EC1V 0HB
UK
E-mail: l.l.lai@city.ac.uk
Tel: +44 20 7040 3889
Fax: +44 20 7040 8568

7. Tianshu BI, Ph.D
Professor
School of Electrical & Electronic Engineering Director
Si Fang Research Institute
Vice Director
Laboratory of Power System Protection & Dynamic Security
Monitoring and Control
Ministry of Education North China
Electric Power University at Beijing
Email: tsbi@ncepu.edu.cn
tsbi@graduate.hku.hk
Tel: +86-10-8079 8462
Fax: +86-10-5197 1480

8. Professor San Shing Choi
Prof. K J Tseng
Prof. DM Vilathgamuwa
Mr. T D Nguyen
Division of Power Engineering
School of Electrical and Electronic Engineering
Nanyang Technological University
Singapore
E-mail: esschoi@ntu.edu.sg
Tel: +65 67905406
Fax: +65 67912687

PANEL SESSION CHAIRS

Tom Hammons
Chair International Practices for Energy Development and Power Generation
Glasgow University
11C Winton Drive
Glasgow G12 0PZ
UK

E-mail: T.Hammons@ieee.org
Tel: +44 141 339 7770

Loi Lei LAI
Energy Systems Group
School of Engineering and Mathematical Sciences
City University
London, EC1V 0HB
UK
E-mail: l.l.lai@city.ac.uk
Tel: +44 20 7040 3889
Fax: +44 20 7040 8568

Kit Po WONG
Chair Professor of Electrical Engineering
Department of Electrical Engineering
The Hong Kong Polytechnic University
Hung Hom
Kowloon
Hong Kong
E-mail: eekpwong@polyu.edu.hk
Tel: +852 2766-6168
Fax: +852 2330-1544

BIOGRAPHIES

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

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

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

Loi Lei LAI (SM’92, F’2007) received the B.Sc. (First Class Honors) and the Ph.D. degrees from the University of Aston in Birmingham, UK. He also gained his D.Sc. from City University London. Currently he is Professor and Head of Energy Systems Group at City University, London, UK. He is a Visiting Professor at Southeast University, Nanjing, China and also a Guest Professor at Fudan University, Shanghai, China. He has authored/co-authored over 200 technical papers. In 1998, he also wrote a book entitled Intelligent System Applications in Power Engineering Evolutionary Programming and Neural Networks. Recently, he edited a book entitled Power System Restructuring and Deregulation Trading, Performance and Information Technology. In 1995, he received a high-quality paper prize from the International Association of Desalination, USA. Among his professional activities are his contributions to the organization of several international conferences in power engineering and evolutionary computing, and he was the Conference Chairman of the IEEE/IEE International Conference on Power Utility Deregulation, Restructuring and Power Technologies 2000. Dr. Lai is a Corporate Member of the IEE. He was awarded the IEEE Third Millennium Medal, 2000 IEEE Power Engineering Society UKRI Chapter Outstanding Engineer Award, and 2003 IEEE Power Engineering Society Outstanding Large Chapter Award.

Kit Po WONG (M'87-SM'90-F'02) obtained M.Sc and Ph.D. degrees from the University of Manchester, Institute of Science and Technology, UK in 1972 and 1974, respectively. Prof. Wong was awarded a higher doctorate DEng degree by UMIST in 2001. Prof. Wong is currently Chair Professor of the Department of Electrical Engineering, Hong Kong Polytechnic University. He was Guest Professor at Tsinghun University, Beijing, China and is Guest Professor at Southeast University, Nanjing, China. Prof. Wong was a Professor at the University of Western Australia. During this period he received three Sir John Madsen Medals (1981, 1982 and 1988) from the Institute of Engineers Australia, the 1999 Outstanding Engineer Award from the IEEE Power Chapter Western Australia and the 2000 IEEE Third Millennium Award. Professor Wong has published numerous research papers in power systems and on the applications of artificial intelligence and evolutionary computation to power system planning and operations. His current research interests include evolutionary optimization in power, power market analysis, power system planning and operation in the deregulated environment, and power quality. Professor Wong has served as Editor in Chief for IEE Proceedings Generation, Transmission and Distribution. He was the Conference Chair of IEEE/CSEE PowerCon2000. He is a Fellow of IEEE, IEE, HKIE and IEAust.

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1. Distributed Generation Policy at Consolidated Edison Company

Professor Wei-Jen LEE, University of Texas at Arlington
Dr David Yanshi WANG, Consolidated Edison Company of New York.

Abstract: Following the steps of the gas industry, the traditional paradigm of the vertically integrated electrical utility structure has begun to change. In the United States, the Federal Energy Regulatory Commission (FERC) has issued several rules and Notices of Proposed Rulemaking (NOPR) to set the road map for electric utility deregulation. The power crisis in California has drawn great attention and sparked intense discussion within the utility industry. One general conclusion is to rejuvenate integrated resource planning and promote the distributed generation via traditional fossil or renewable generation facilities for the deregulated utility systems. Consolidated Edison Company of New York, Inc. (Con Edison) permits any customer to operate generating equipment in parallel with the Con Edison's electric distribution system. Distributed Generation (DG) will play an increasingly important role in Con Edison's electric distribution system, and DG one day may become an integral part of Con Edison's electric system. This paper discusses the options and current development of DG at customer facilities on Con Edison's electric distribution system.

Keywords*:* Renewable Energy, Distributed Generation.

1. INTRODUCTION

The utility industry around the world is going through a fundamental change due to deregulation. The traditional vertically integrated utility environment will inevitably be changed. The power system operation will become more competitive, and many challenges will arise [1]. After experiencing the price hikes and rotating blackouts in California and the recent price increase in oil and gas supply, the disbursed or distributed generation (DG) via traditional fossil or renewable generation facilities becomes one of the most attractive alternatives for the future utility industry, due to its potentially high efficiency and low emissions. DG by itself is not a new concept. A small number of consumers have been installing their own generation on-site for decades. Recently, however, the creation of competitive retail electric markets and the development of new generation technologies, including fuel cells and micro turbines, have sparked new and broader interest in distributed generation. Properly planned and operated DG can provide a wide variety of benefits, including economic savings, improved environmental performance, and greater reliability. Many utilities have acted to bring the benefits of DG to their systems and are analyzing means to expand these benefits. Whether DG can provide grid support or other system benefits depends on local conditions and requires detailed analysis. In addition to the development of large-scale wind generators at remote sites, there are several promising distributed generation technologies for the urban residential and small commercial users.

With public policy continuing to promote DG (such as passing of the Energy Policy Act of 2005 and issuing of FERC Order 2006 DG guidelines); the significant improvements in DG technology (such as higher efficiency micro turbines, turbines and reciprocating engines, much cleaner diesel technology, and highly efficient solar PV technologies), the constrains placed on system upgrades (such as finding the sites for additional distribution substations); and Con Edison's policy of allowing any customer to operate generating equipment in parallel with Con Edison's electric distribution system, DG will play an increasingly important role in Con Edison's electric distribution system and DG one day may become an integral part of Con Edison's electric system. This paper discusses DG technology, Con Edison's distribution system, DG policy, and current DG installations within Con Edison. The issues and solutions of DG installations in Con Edison are discussed as well. [2]

2. DISTRIBUTED GENERATION TECHNOLOGIES [3, 4]

The global electricity industry reforms over the last 15 years have moved electricity supply from a central government-run generation and transmission system supported by local monopoly suppliers to an industry where there are multiple completing generators and retailers and a variety of interests in distribution and energy services. There is an open investment environment with minimal restrictions on those wanting to invest in distributed generation. Distributed generation, for the moment loosely defined as small-scale electricity generation, is a fairly new concept in the economics literature about electricity markets, but the idea is not new at all. When Thomas Edison started his electrical utility business at Pearl Street Station on September 4, 1882, it only served customers in a one-square-mile area and was an early example of DG. Later, technological evolutions allowed for electricity to be transported over longer distances, economies of scale in electricity generation lead to an increase in the power output of the generation units, and reliability concerns lead to the network development. Massive electricity systems were formed with huge transmission and distribution grids and large generation plants known as central plants. The benefit to this system was consolidating what were then high emission plants away from dense population. The cost was that heat had to be released to the environment, creating an overall efficiency that is only 33% to this day.

In the last decade, however, technological innovations and a changing economic and regulatory environment have resulted in a renewed interest for distributed generation to take advantage of the heat (i.e., raise efficiency) with equal or better than central plant. This renewed global focus on DG and, in particular, renewable along with improved generation and control technologies is quite appropriate for future development. The available DG technologies include internal combustion engines, combustion turbines, micro turbines, fuel cells, small steam turbines, photovoltaic cells, wind turbines, hydroelectric, and energy storage devices. Fig. 1 shows the conceptual diagram of a utility system with DGs.

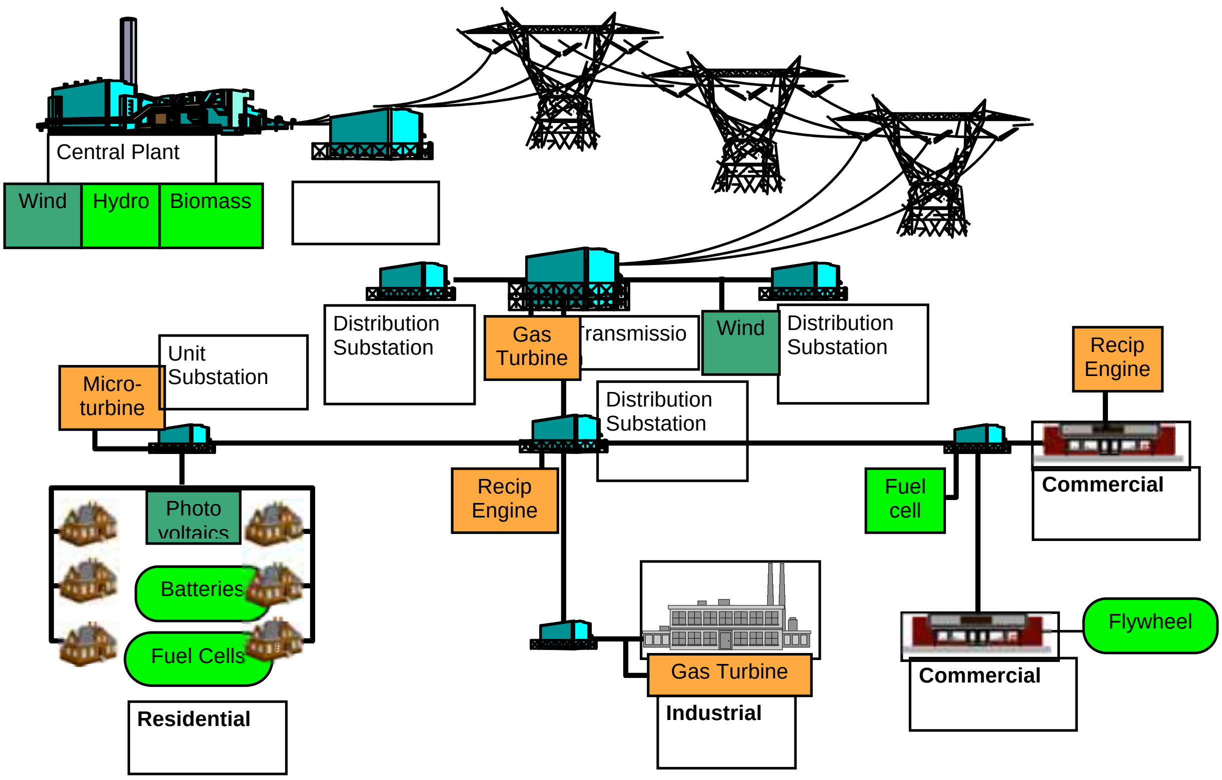

Fig. 1. DG may become an integral part of Con Edison's electric system

2.1 Internal Combustion Engines (ICE)

ICE is the most common and mature DG technology. ICE units have been used for power production for more than 80 years, but their use has traditionally been limited to emergency backup. ICE units rating range from a few kW to about 10 MW in most application. Efficiencies above 50 % for natural gas fueled units may be achievable in commercial products late this decade.

2.2 Combustion Turbines (CT)

CT is another popular DG technology. Its development dates back to the 1930's and starting in the 1970's, CT emerged as the leading type of generator for applications (>10MW). The efficiency for large-scale combined cycle plant may be up to 55-60%. The efficiencies of smaller simple cycle systems are on the order of 25-35%.

CT have fewer emissions, lower maintenance costs, better availability, more usable high-temp exhaust than ICE, but they are less efficient, have higher capital cost (at small sizes) than ICE. CT need higher pressure gas, and their performance is much more sensitive to altitude, air-temp, and partial load than that of ICE.

2.3 Fuel Cell

Fuel cells are one of the most promising technologies for vehicles, residential, and small commercial users because of their non-combustion conversion of H_2 or fossil fuels. President Bush announced a $1.2 billion Hydrogen Fuel Initiative in his 2003 State of the Union Address to reverse America's growing dependence on foreign oil by developing the technology needed for commercially viable hydrogen-powered fuel cell that produces no pollution and no greenhouse gases. The President's Hydrogen Fuel Initiative seeks to develop hydrogen, fuel cells, and infrastructure technologies needed to make it practical and cost-effective for large numbers of Americans to choose to use fuel cell vehicles by 2020. The initiative will dramatically improve America's energy security by significantly reducing the need for imported oil. At the same time, it is a key component of the President's clean air and climate change strategies. President Bush's budget ($159 million for FY2004 and $227 million for FY2005) has provided strong support for the hydrogen fuel initiative.

2.4 Hydroelectric Energy

Fast-flowing water spins turbines to produce electricity. Places with high rainfall and steep mountains are ideal for hydroelectricity. Several large-scale hydroelectric generation projects have been developed in Africa and China. Most large hydroelectric projects require the building of large dams on rivers, which can be very capital intensive and have severe impacts to the environment if not planned with a consensus from various disciplines. When large dams are built, the flow of the dammed river is changed radically and large areas of land are flooded, including wildlife habitats and farmland. If possible, run-of-the-river hydroelectric schemes are preferred as they cause less environmental damage. Run-of-the-river schemes divert only part of the river through the plant turbines by harnessing the natural gravity of the river flow to produce electricity. Since there are lots of rivers flowing in the Africa continent, this should be one of the most favorable technologies for the African community.

2.5 Biomass Energy

Biomass is plant and animal material that can be used for energy. This includes using wood from trees, waste from other plants (biogases from sugar cane or paddy husk from rice), and manure from livestock. Converting biomass energy into useable energy has many environmental benefits. An increasing number of sustainable energy projects using biomass have been developed. Most of these use waste products from agriculture, so they solve a waste disposal problem and, at the same time, create energy for use in homes, farms and factories.

Biogas can also be produced from livestock manure and human sewage. Farms where animals' graze and sewage plants are ideal places to produce energy from biogas. Waste peelings from food processing plants can also be used to produce biogas.

Converting the biomass to electrical energy can solve both energy and waste disposal problem at the same time.

2.6 Solar Energy

Solar energy is light and heat energy from the sun. Solar cells convert sunlight into electrical energy. There are two main ways of using solar energy to produce electricity. These are through the use of solar cells (photovoltaic) and solar thermal technology. Using solar technologies to generate electricity is, at present, more expensive than using coal-fired power stations, but it produces much less pollution, and costs are forecasted to drop over time.

2.7 Wind Energy

Large-scale and small-scale wind energy has gained an extensive interest and has become one of the most mature renewable energy alternatives to the conventional fuel-based power generation. The development of wind electricity generation has rapidly progressed over the last decade, largely driven by the public concern about global warming, limited fuel resources, as well as the provision of federal production tax credit. The record shows that wind power generation has expanded with annual rate of 25 percent since 1990 and has a great potential to be realized in many regions of the world.

3. CONSOLIDATED EDISON COMPANY OF NEW YORK, INC [3]

Con Edison, Inc. is one of the nation's largest investor-owned energy companies, with approximately $12 billion in annual revenues and $28 billion in assets. The company provides a wide range of energy-related products and services to its customers. Consolidated Edison Company of New York, Inc. (Con Edison), a regulated utility providing electric, gas, and steam service in New York City and Westchester County, New York; Orange and Rockland Utilities, Inc., a regulated utility serving customers in a 1,350 square mile area in southeastern New York state and adjacent sections of northern New Jersey and northeastern Pennsylvania. Con Edison operates one of the most complex electric power systems in the world. It is also the world's most reliable.

3.1 Con Edison's Distribution Systems

Con Edison's distribution systems supply power to more than 3 million customers in New York City and Westchester County from area substations at 4 kV, 13 kV, 27 kV, and 33 kV primary service voltage levels.

The two major types of systems in Con Edison are network systems and non-network (radial) systems. About 80% of the load in the Con Edison service territory is supplied by underground network systems. In New York City, there are currently 59 underground secondary networks, each of which has multiple primary feeders each supplying a number of underground network transformers that feed power into low voltage secondary grid and spot networks or local building buses. The majority of Con Edison customers in the urbanized boroughs of New York City receive Low Tension (low voltage) service directly from the secondary grid at voltage levels of 120/208, 120/240 or 265/460, while a small percentage of High Tension (high voltage) customers receive service at primary service voltage levels.

Primary feeders of underground network systems are connected only at the substation, and network transformers are dispersed throughout the grid. The average number of feeders in a network is 17, the peak loads of individual networks range from 60 MW to 400 MW, and the geographical areas server by individual networks range from several city blocks up to 30 square miles.

Con Edison's non-network systems have a single high voltage feeder delivering power from substation to a number of distribution transformers tapped along it, which step down voltage from primary voltage to low voltage service. Some of the suburban areas in Con Edison service territory, especially in the Westchester County, are served by non-network systems.

Network systems provide extremely high reliability to dense urban areas, such as Con Edison's service territory, and they are usually the most complex for DG to interconnect with. non-network systems are relatively easier to interconnect with. Since Con Edison's system was not designed with DG in mind, there are a wide range of issues associated with connecting customer DG facilities to Con Edison's distribution system, such as customer and worker safety, ground and ground-fault over voltages, over current protection and fault levels, islanding and restoration, power quality and reliability, voltage regulation and flicker, and real and reactive power flow.

4. CON EDISON'S DG POLICY [5]

Con Edison's DG policy is to permit any customer to operate on-site generators in parallel with Con Edison's electric system if the appropriate Con Edison requirements are met and the required protective devices (relays, circuit breakers, etc.) are installed.

A customer planning to connect DG facilities to Con Edison's electric system contacts the company to begin the application process. For DG of 2 MW and under, the application process is an 11-step process specified in New York State Standardized Interconnection Requirements (SIR). The SIR has specific technical requirements for DG that include the relays, grounding and certifications needed. Certain customers using solar, wind or biomass may be allowed to net meter under the SIR. For DG facilities larger than 2 MW and up to 20 MW, a detailed Coordinated Electric System Interconnection Review (CESIR) usually is required. The goal of a CESIR is to make sure DG facilities will have no adverse effect on Con Edison's other customers, equipment, personnel, or quality of service. Con Edison has agreed to follow the SIR timing for DG between 2 MW and 5MW.

In general, DG connected to the distribution system is limited to a maximum of 10 MW on a distribution feeder and 20 MW per network substation. Also, because customer DG connected to Con Edison's low voltage secondary grid could cause network protectors within the grid to trip open, no synchronous generators are permitted to connect to low voltage secondary grid. Small induction and inverter-based generator may be allowed on a case-by-case basis. Connection of generators on the spot networks are only permitted if the secondary bus is energized by more than 50% of the installed protectors as required by IEEE Std. 1547-2003.

DG ranging in size from 5 to 10 MW and installed on non-network systems should be connected to dedicated radial distribution feeders since the light load condition on the existing feeders may not meet the accepted norm to avoid islanding (i.e., one third of the feeder's all time light load be greater than the dispersed generation MW rating). The basic service classifications of DGs are discussed as follows:

4.1 Net Metering

A residential customer or operator of a farm within the Con Edison service area who are installing their own energy source based on solar, wind, or farm waste may qualify for net metering. With net metering, at the end of each billing period, customers' bills will reflect the net or overall amount of electricity used or supplied. Con Edison will credit their account for the following month if the total amount of electricity generated exceeds the total usage for the billing period. At the end of each year, customers may be eligible for a payment or credit.

4.2 Standby

Customers may install their own electric energy source for the purpose of supplying some, or all, of their own load. Con Edison will supply the remaining power requirements. In standby mode, the customer cannot sell power unless the DG is qualified for emergency export. When the utility source has been interrupted, customer cannot continue generating electricity for their own load unless they are using the stand-alone option for standby service.

4.3 Stand-alone

Customers may choose to install their own electric energy source for the purpose of supplying their entire load at all times, in isolation from the utility supply. Con Edison will not supply the remaining power requirements or provide any support in the event of the loss of customers' generation.

4.4 Standby with Stand-alone

Customer may install their own electric energy source for the purpose of supplying part or, all, of their own load. Con Edison will supply remaining power requirements of the customer. In standby mode, the customer cannot sell power unless the DG is qualified for emergency export. With the stand-alone option, customers can continue generating electricity for their own load even when the utility source has been interrupted.

4.5 Buy Back or Emergency Export

Customers can sell power directly to the utility, provided their DG is properly connected at high voltage and properly configured to respond to system conditions. For example, there must be a way for Con Edison to trip the generator via remote signal in the event that a system problem occurs. For purposes of reliability, and depending on the contractual arrangement with Con Edison, the DG may be designed for multiple contingencies.

4.6 Emergency Generation Only

There are two options for connecting an emergency generator at the customer site. Customer may choose a switch with "break before make" contacts, or a switch with "make before break" contacts that switches over within 15 cycles. This switch allows for continuous service during the transition from emergency mode to utility supply. Con Edison engineering specifications define the rules to transfer loads from Con Edison's supply to customer's emergency generators. It gives the requirements and characteristics of the transfer switch used with a customer owned low-voltage emergency generator. The operation of the transfer switch is done to prevent the accidental paralleling of the emergency generator with the Con Edison secondary system. Con Edison engineering specification also specifies the closed transition transfer from and to Con Edison's supply. It allows for brief "make before break" for emergency generators upon restoration from emergency to utility service.

5. CURRENT DG INSTALLATION WITHIN CON EDISON

Currently, there is approximately 245 MW of "small" DG connected to Con Edison's distribution system as shown below:

Table 1 Current DG installation within Con Edison Distribution Network

DG Technology	Total Output (MW)	Percent (%)
Internal Combustion Engine (ICE)	111.0	45
Combustion Engine (CT)	82.3	34
Steam Turbine	42.8	17
Hydroelectric	2.4	1
Fuel Cell	3.3	1
Micro turbine	1.5	1
Photovoltaic	1.4	1
Total	**244.7**	**100**

Of all the DG installed, 45 % is ICE, 34 % is CT, 17 % is steam turbine, and the rest 4 % is for the other DG technologies. Fig. 2 shows an example of DG installation within the Con Edison service territory. According to the New York Times, the photovoltaic panels that make up the canopy of the Coney Island Subway Terminal of New York City will generate 236,000 kilowatt hours of power a year, enough to cover about 15 percent of the energy used by the station.

Fig. 2. Coney Island Subway Terminal of New York City Transit Authority - 300 kW (2X150)

6. MAIN CONCERN ON DG INSTALLATION WITHIN CON EDISON

As mentioned earlier, Con Edison's network systems are the most complex systems to interconnect. A Con Edison network secondary network grid is fed by hundreds of network transformers that use dedicated network protectors to prevent back feed from the secondary grid onto primary feeders. DG connected to secondary grid may cause network protectors to open during light loading conditions.

Network protector relays are used to monitor and control the power flow of low voltage AC to secondary network systems. They are widely used in underground distribution networks with multiple power injection points that require high continuity of service in heavily loaded high population density urban areas. The purpose of the network protector is to prevent the system from back feeding and initiate automatic reclosing when the system returns to normal. Fig. 3 shows the operating characteristics of the network protector. [6]

Con Edison, in accordance with SIR requirements, conducts CESIR when applicable to avoid negative system impacts such as the tripping of network protector within the secondary grid. This section shows a case study of how load flow studies are done to make sure customer DG will not cause network protector tripping during light load conditions and contingencies.

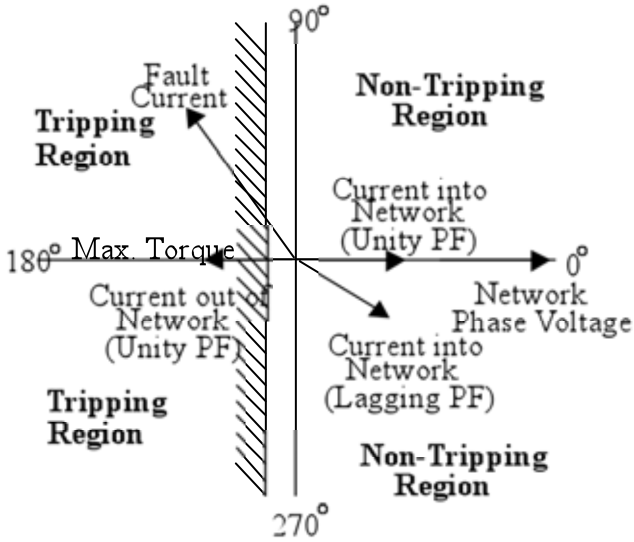

Fig. 3. Tripping Characteristic of Network Protector

6.1 Co-Op City 50 MW Co-generation

The RiverBay Corporation at Co-Op City's 50 MW co-generation CESIR was conducted using the one-line diagram shown in Fig. 4. TR-1, TR-2, TR-3 and TR-4 are customer 14,000 KVA (MAX), 27/13.5 KV transformers, each of which is limited to approximately 11 MW; the peak load at customer 13 kV bus is about 26,000 kVA; TR-5, TR-6, TR-7 and TR-8 are Con Edison 15,975 kVA, 138/29.1 kV transformers. Riverbay intends to sell back only surplus energy production.

There are nine spot networks connected to the four (4) 27 kV feeders and “Spot Network 1” is the only one shown in Fig. 4. The peak load of the nine spot networks is about 14,600 kVA. Some of the spot networks are 26.4/0.48 kV and the others are 26.4/0.216 kV. Each of the spot networks has three or four transformers (500 kVA, 1000 kVA or 2500 kVA). The total number of spot network transformers is 29.

BK-5, BK-6, BK-7, and BK-8 are customer 27 kV feeder breakers; BK-9, BK-10, BK-11, and BK-12 are Con Edison 27 kV feeder breakers. When a Con Edison feeder breaker opens, its associated customer feeder breaker on the same feeder will open as well. For example, when Con Edison feeder breaker BK-9 opens, customer feeder breaker BK-5 will open.

The existing system - without the new 50 MW DG - does not show any overloaded transformers or 27 kV feeder sections. In addition, all of the spot network transformers are in service and experience no back feeding conditions during various system contingencies.

The objective of the RiverBay Corporation’s cogeneration project CESIR is to determine the allowable customer generation during various contingencies, such as when one, two, or three of the customer breakers are open with one or more feeders out of service, none of the spot network transformers will be put out of service because of back feeding conditions, and none of the transformers or feeder sections will be overloaded.

When 50 MW DG is added, this CESIR shows that during the peak loading conditions, there will be spot network transformers out of service due to back feeding conditions, when one or more customer feeder breakers open. Table 2 shows the number of spot network transformers lost due to back feed conditions during various contingencies. During lighter system load conditions, there are many more back feeding spot network transformers, overloading the remaining spot network transformers and unwanted conditions where spot network customers could lose power with one transformer failure.

CESIR also shows that when the DG is added, feeders will not be the limiting factor in customer exporting power, given that each customer transformer is limited to 11 MW.

Following the CESIR studies, it is recommended that customer DG will be allowed to exporting power according to the numbers shown in Table 3, after determining that the network protector relay trip mode should be set to Insensitive, with insensitive trip current set to 75 % of the nameplate value.

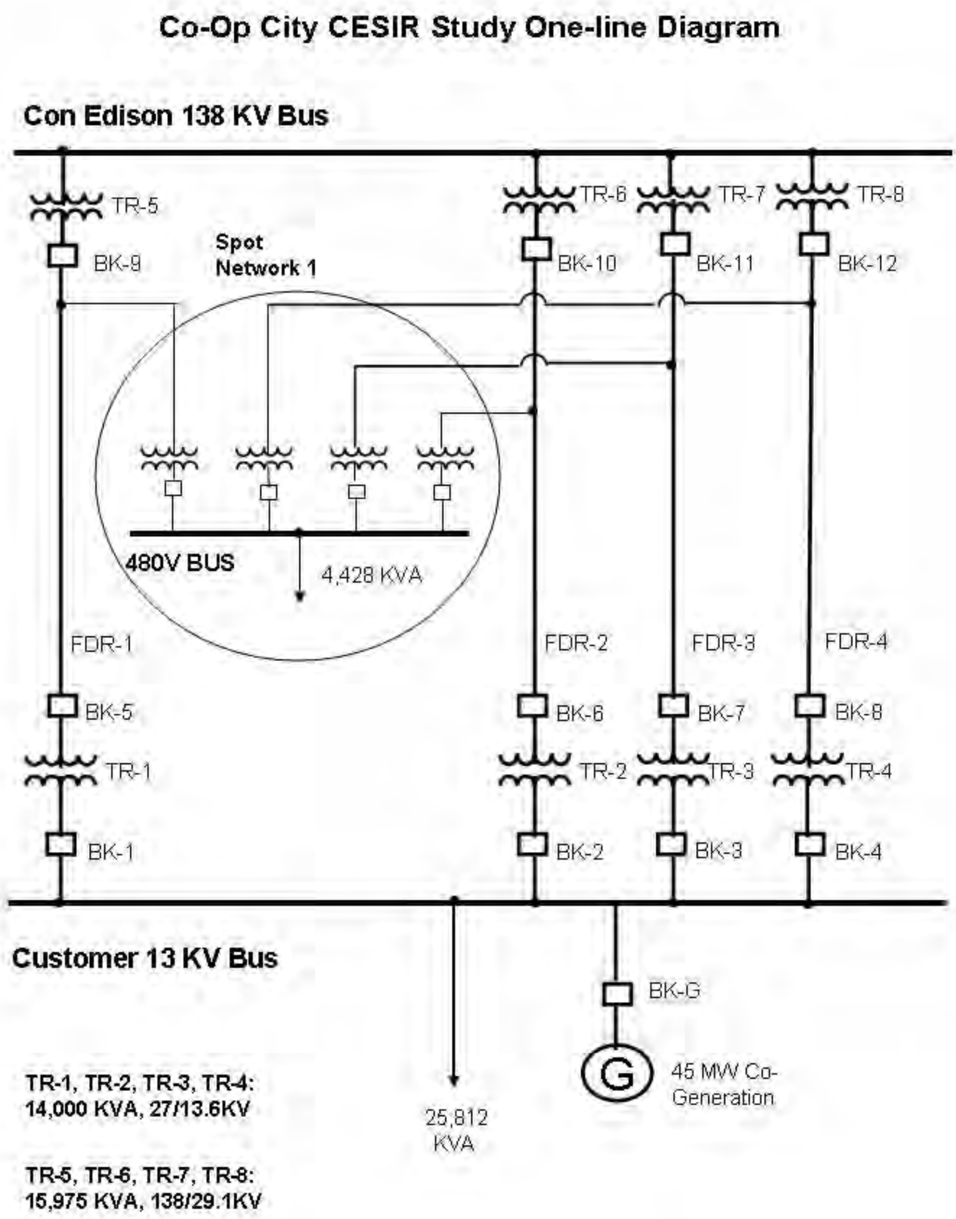

Fig. 4. Co-Op City CESIR study one-line diagram

Table 2 Number of spot network transformers lost due to back feed at the peak load condition

Customer Breaker Open	Number of spot network transformers lost due to back feed (causing network protector to open)
BK-5	6 (6 spot networks losing one out of 3 transformers each)
BK-6	4 (4 spot networks losing 1 out of 3 transformers each)
BK-7	5 (5 spot networks losing 1 out of 3 transformers each)
BK-8	3 (3 spot networks losing 1 out of 3 transformers each)
BK-6, BK-7	9 (3 spot networks losing 2 out of 3 transformers each)
BK-5, BK-6, BK-7	10 (3 spot networks losing 2 out of 3 transformers each, 1 spot network losing 3 out of 4 transformers, and two overloaded spot network transformers)

Table 3 allowable customer exports during various system conditions

Number of Feeders in Service	Feeder Breakers Open	MW Allowed for Exporting
4	None	33
4	One of the four customer breakers open	33
3	One of the four Con Edison feeder breakers and its associated customer breaker on the same feeder open	33
2	One of the four Con Edison feeder breakers and its associated customer breaker on the same feeder open	20
Any other numbers	Any other combinations	0

CESIR also shows that when the DG is added, feeders will not be the limiting factor in customer exporting power, given that each customer transformer is limited to 11 MW.

Following CESIR studies, it is recommended that customer DG will be allow exporting power according to the numbers shown in Table 3, after determining that the network protector relay trip mode should be set to Insensitive, with insensitive trip current set to 75 % of the nameplate value.

7. CONCLUSION

There will be more and more distributed generators connected to Con Edison's electric distribution system. Con Edison supports and expedites customers' efforts to establish DG facilities that will operate within Con Edison's electric service territory. To maintain reliability of service of Con Edison's distribution systems, DG operated in parallel with the Con Edison system is subject to equipment and operating requirements, so that the safety of Con Edison customers and workers will not be compromised, and desired interconnection performance can be achieved.

8. ACKNOWLEDGMENT

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10. BIOGRAPHIES

Wei-Jen Lee (S'85-M'85-SM'97-F'07) received his B.S. and M.S. degrees in Electrical Engineering from National Taiwan University, Taipei, Taiwan, in 1978 and 1980, respectively, and a Ph.D. degree in Electrical Engineering from the University of Texas at Arlington in 1985. Since then, he joined the University of Texas at Arlington and currently is the Director of the Energy Systems Research Center and a Professor of the Electrical Engineering Department. He has been involved in research on power flow, transient and dynamic stability, voltage stability, short circuit, relay coordination, power quality analysis, and deregulation of utility industries. He is also involved in research on the design of integrated microcomputer-based monitoring, measurement, control, and protection equipment for electric power systems. He is a Fellow of IEEE and a Registered Professional Engineer in the State of Texas

David Yanshi Wang (S'90-M'90-SM'07) received his B.S. degree in Electrical Engineering from Shanghai University of Engineering Science in1988, a M.S. degree in Electrical Engineering from New Jersey Institute of Technology in 1990, a M.S. degree in Computer Science from New York University in 1998, and a Ph.D. degree in Electrical Engineering from Polytechnic University in 2006. Mr. Wang is a Senior Engineer in the Distribution Engineering Department at Con Edison. He joined Con Edison's R&D Department in 1991 and currently he is the lead developer responsible for Con Edison's distribution system design and analysis software. He is also involved in Con Edison network systems reliability improvement projects. Mr. Wang is a senior member of IEEE.

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2. A Practical Approach to Wireless Power Quality, Energy and Facilities Monitoring System

P.K. Lee[2] and L.L. Lai FIEEE

***Abstract* -** In this paper, the authors discuss the way to adopt the cost effective Short Message Service (SMS) applications to Power Quality, Energy and Facilities Monitoring System. Also, the limited up to 160 characters will be considered during the design, which cannot be used on high data volume such as waveform pattern is not preferred. But for simple message such as voltage dip % is good enough.

1. INTRODUCTION

The Short Message Service (SMS) is a means of sending short messages to and from mobile phones. In some countries, the SMS is very cost effective transmission media in which real-time connection between point-to-point and point-to-multipoint are not required [1-2].

Nowadays, GPRS, 3G or 3.5G network are available, it is more convenient for higher speed data transmission services, consumer can enjoy advanced, feature-rich data services such as color Internet browsing, e-mail on the move, etc. However, SMS is still very popular since it can be used for pushing method without on-line connection and the cost is acceptable in some applications.

The application of SMS is introduced in this paper focused on the power quality/energy and facilities monitoring.

The adoption of SMS may be one of the simple, quick and cost-effective strategies when on-line connection is not needed for remote area and pushing method is preferable such as for energy profile collection and alarm reporting, etc.

In this paper, the authors discuss the way to adopt the cost effective SMS applications to Power Quality, Energy and Facilities Monitoring System. Also, the limited up to 160 characters will be considered during the design which cannot be used on high data volume such as waveform pattern is not preferred but for simple message such as voltage dip % is good enough [3-7].

Although there have been lots of theories and concepts on the SMS applications but the real applications and new concept applying to a large network, distributed power generation or building energy/power distribution monitoring are limited. The authors focus the application of the SMS to this area. A practical scheme is proposed and its use to real-life system will be introduced.

The paper starts with an overview on the practical implementation on the wireless Power Quality/Energy and Facilities Monitoring System.

2. SYSTEM DESIGN CONSIDERATION

1) **Operating Cost**: In many cases, the reason for the adoption of SMS is the cost. The SMS offer a very competitive price in many countries already. Some of them, the SMS are even free of charge if they are sent or received from the same mobile services provider.

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[2] P.K. Lee is with Powerpeg NSI Limited, Hong Kong.. E-mail: r_lee@hk.super.net
L.L. Lai is with the Energy Systems Group, City University, London, United Kingdom. E-mail: l.l.lai@city.ac.uk

With the support of price, system solution designers can implement many additional wireless functions from the new/existing system via SMS and they also have competitive advantages in the market.

2) **Connection/Connectionless:** SMS is a connectionless media. It pushes the SMS to single/multi users or receivers without any point-to-point or point-to-multipoint on-line connection. However, it has no feedback or acknowledge unless they are specially design. Some services providers may provide acknowledgement services without extra charge. However, it depends on the design.
3) **Data Volume:** It limits with typically 160 characters in one message max. However, it is really good enough in many cases such as voltage dip %/fault/trip alarm reporting in building services facilities. Energy or water flow date collections from properties management or voltage Dip level from fault recorder in Power Utilities, etc are some typical examples. However, high volume of data from waveform in power system is not recommended since it will be over the limit easily.
4) **Data Transmission:** During the data transmission, the character length per message is recommended to be adjustable since different countries may have some differences. Besides, the firmware of the modem should be able to divide the original transmitted message into few messages when they are over the preset limit. If the encryption is needed, the firmware from the received modem should be able to decrypt the message as well. In this case, further points should be considered such as handshaking, missing data, CRC and priority, etc.
5) **Encryption:** In many utilities, no matter they are SMS or GPRS or RF media, encryption is needed during the data transmission for security reason. Therefore, data encryption is considered indeed. Advanced Encryption Standard AES is one of the most popular encryption standards that are acceptable to many Power Utilities already. Designers may follow it to design your encryption programs to provide the data security such as AES 128 bits.
6) **Data compression:** It may or may not be necessary. In most of the cases, the main purpose for this feature is for cost saving. In order to make use of the 160 characters effectively, it may be applied in point-to-point or point-to-multipoint GSM modem applications. In this case, the Central SMS server is needed. If the SMS are sent to the mobile phones of maintenance staff/ end users directly. It should only be readable simple messages. The firmware from the remote modem should have options for sending message to server or maintenance staff's mobile directly [8]. Multiple COM ports or SMS gateway may be necessary when a large system is implemented such as 100 sites or more. In this case, database and its architecture should be carefully designed.
7) **System Scale:** The system designs for 10 remote sites are different from 100 or 500 remote sites. So, the design architecture should be scalable and flexile. A real example from figure 1 below is illustrated a simple one for reference.
8) **Intelligent firmware:** An intelligent firmware can be designed and downloaded into the GSM modem to collect and monitor the necessary data. In real application, a well-developed intelligent MODBUS Master firmware is able to map the register points inside the PLC or energy meters or any device with MODBUS RTU protocol via RS232 or RS485. Thus, set points can be defined to monitor those register points for monitoring and controls. Besides, data dump with interval setting can be defined to collect data from energy meters and push to the SMS Server Software periodically after encryption and compression. If the register points have problem, the modem can report to the mobile phone of maintenance staff directly with readable messages.
9) **SMS Server Software:** It may be designed in many ways but some points are highlighted for design consideration:

i. Graphical User Interface (GUI),

ii. Database structure,
iii. Communication structure,
iv. Data logging such as analogue log,
v. Graphical plot,
vi. Reporting format,
vii. Sequence of Event (SOE),
viii. Human Machine Interface (HMI),
ix. Diagnostic,
x. Protocol, and
xi. Hardware requirement.

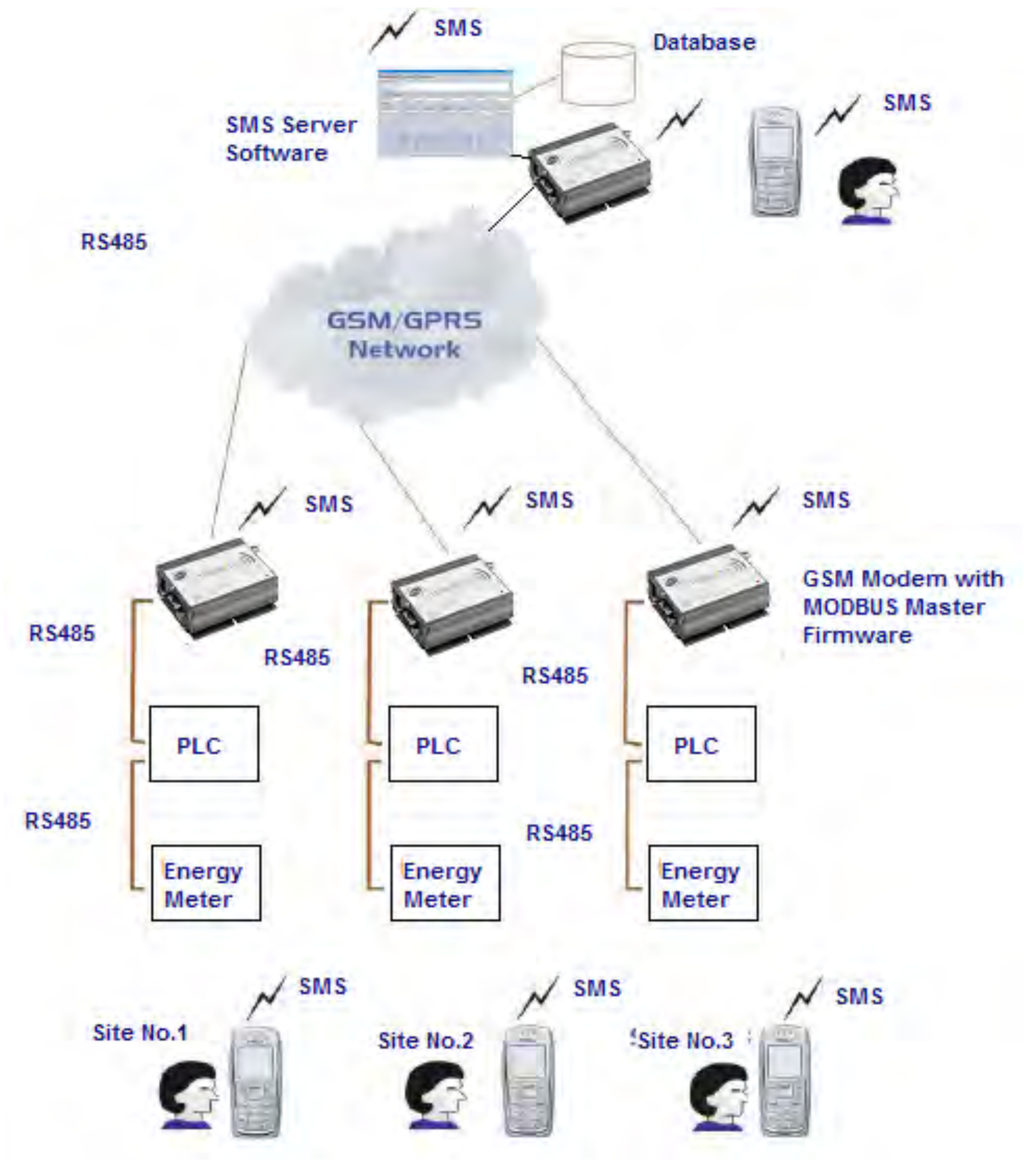

Figure 1: SMS based Power/Energy and Facilities Monitoring System Architecture

3. RESULTS

With the above implementation, AMR system and facilities monitoring can be implemented efficiently. The example is shown in figure 2 as below:

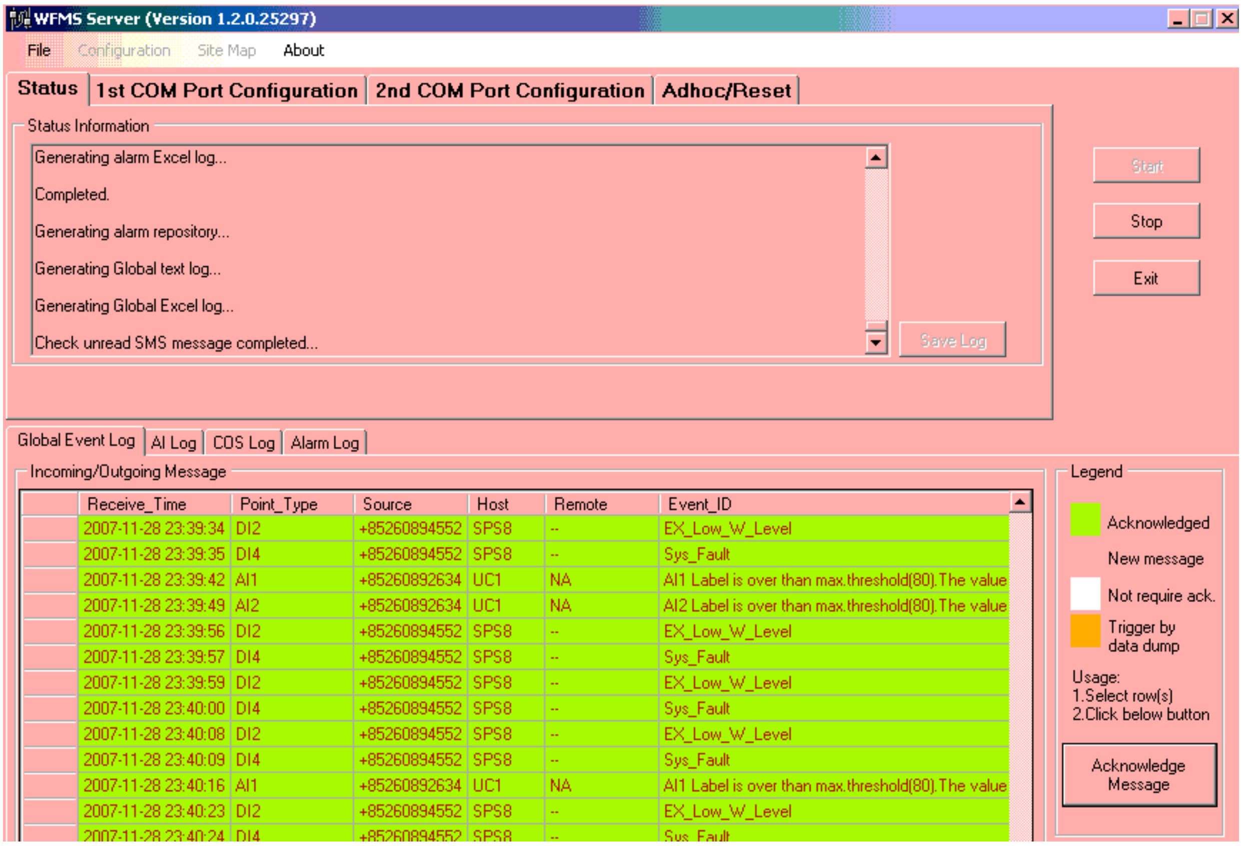

Figure 2: Implementation of SMS Sever Software for the Power Quality/Energy and Facilities Monitoring System

4. CONCLUSION

Based on the practical experience of the authors, the paper has elaborated the basic considerations for the system design of SMS based Power Quality/Energy and Facilities Monitoring System. The practical approach is simply introduced and some critical points have been mentioned for consideration during the implementation. However, the same techniques can be adapted widely to many other applications such as AMR and environmental monitoring systems, etc.

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BIOGRAPHIES

Lee. P.K. Ringo received the B.Eng (First Class Honors) from University of Sunderland (i.e. former Sunderland Polytechnic), UK, in 1991. Currently he is Director of Powerpeg NSI Limited in Hong Kong that has been a network system integrator for Intelligent Power Management/Monitoring System for both supply and demand sides in the HK.

L. L. Lai (SM’92, F’07) received his B.Sc. (First Class Honors) and Ph.D. degrees from the University of Aston in Birmingham, UK. He was awarded a higher doctorate, D.Sc. by City University London in 2005 and is its honorary graduate. Currently he is Head of Energy Systems Group and Chair Professor of Electrical Engineering at City University, London, UK. He is also a Visiting Professor at Southeast University, Nanjing, China and Guest Professor at Fudan University, Shanghai, China. He has authored/co-authored over 200 technical papers. In 1998, he also wrote a book entitled *Intelligent System Applications in Power Engineering - Evolutionary Programming and Neural Networks*. In 2001, he edited a book entitled *Power System Restructuring and Deregulation - Trading, Performance and Information Technology*. In 2007, he co-authored a book entitled *Distributed Generation - Induction and Permanent Magnet Generator*. In 1995, he received a high-quality paper prize from the International Association of Desalination, USA. Among his professional activities are his contributions to the organization of several international conferences in power engineering and evolutionary computing; he was the Conference Chairman of the IEEE/IEE International Conference on Power Utility Deregulation, Restructuring and Power Technologies 2000. Presently he is an Officer (Secretary) in the Board of Governors of the IEEE Systems, Man, and Cybernetics Society. Dr. Lai is a Fellow of the IET (UK). He was awarded the IEEE Third Millennium Medal, 2000 IEEE Power Engineering Society UKRI Chapter Outstanding Engineer Award and 2003 IEEE Power Engineering Society Outstanding Large Chapter Award. In June 2006, he was awarded a Prize Paper by IEEE Power Engineering Society Power Generation and Energy Development Committee.

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3. Impact of Wind Power Generation in the Korea-Jeju Power System

Seho Kim, Cheju National Univeristy, Korea,
Young Hwan Kim, Korea Power Exchange, Korea
Kwang Y. LEE, Baylor University, USA.

Abstract-- This paper investigates the impact that arises when integrating wind power in Korea-Jeju power system and discusses the interconnection consideration in future network. Penetration of wind power in the present power system of Jeju Island has a little influence on the operation and control of the grid to which the wind parks are connected. The interconnection of wind energy system to the system brings challenges of its own, especially the future network of Jeju island. These challenges include power quality, active and reactive power flow, network stability, service stabilization, etc.

Index Terms-- Renewable energy, impact of wind power, HVDC, capacity factor, wind speed.

1 INTRODUCTION

For the protection of environment and to meet the ever-increasing energy consumption, interest in renewable energy and distributed generation has been increasing worldwide. And due to concerns regarding air pollution and the environmental protection, there has been an international movement in the promotion of renewable technologies for electricity generation and the development of emissions limits [1]. Electric energy production from renewable sources is of great importance today for power system. These sources are expected to increase their participation in the future power production. Several types of renewable units are available such as wind power, photovoltaic, hydro/fuel cell, etc. Wind powers are available in a large range of power, with zero fuel cost and environmentally clean production, but with problems related to the inability to regulate frequency and voltage and the non-dispatch able characteristics of wind power. This lack of dispatch ability limits wind generation's ability to serve new system load [2].

Wind is the fastest growing energy source today, and there are widespread plans to significantly increase their penetration in power systems. Various planning and operating problems arise as wind power penetration increases in a power system [3].

This paper investigates the impact that arises when integrating wind power in Korea-Jeju power system and discusses the interconnection consideration in the future network.

Penetration of wind power in the present power system of Jeju Island has a little influence on the operation and control of the grid to which the wind parks are connected. The interconnection of wind energy system to the grid system brings challenges of its own, especially the future network of Jeju island. These challenges include power quality, active and reactive power flow, network stability, service stabilization, etc.

In Korea, air pollution of thermal power plants is likely to be a major impediment to generating electricity. Driven by air pollution and environmental concern, the government has

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K. Y. Lee is with Electrical and Computer Engineering, Baylor University, One Bear Place #97356, Waco, Texas 76798-7356, USA (e-mail: Kwang_Y_Lee@baylor.edu).

S. H. Kim is with the Department of Electrical Engineering, Cheju National University, Jeju-Si, Jeju-Do, Korea 690-756 (e-mail: hosk@cheju.ac.kr).

Y. H. Kim is with Korea Power Exchange (KPX), Jeju branch, Jeju-Si, Jeju-Do, Korea 690-162 (e-mail:yhwan@kpx.or.kr).

become interested in renewable energy and distributed sources. Concerning renewable energy, the government plans to replace 5% of the primary energy source by the year 2011.

2. RENEWABLE ENERGY IN KOREA

The Korea Electric Power Co. (KEPCO) has constructed generating plants with a capacity of about 65GW, 28,867km of transmission lines and 389,551km of distribution lines to supply the power demand. Power demand has increased at an average annual rate of over 10% until the year 2000 and 6% after the year 2000 (Table I).

TABLE I. STATISTICS OF THE ELECTRICITY INDUSTRY IN KOREA
UNIT: MW

year	Capacity		Peak power		Average power	
		Increase rate		Increase rate		Increase rate
1999	44,427	2.7	37,293	13.0	27,320	11.2
2000	47,876	7.8	41,007	10.0	30,328	11.0
2001	49,632	3.7	43,125	5.2	32,560	7.4
2002	52,799	6.4	45,773	6.1	34,986	7.5
2003	56,081	6.2	47,385	3.5	36,810	5.2
2004	59,129	5.4	51,264	8.2	39,058	6.1
2005	61,737	4.4	54,631	6.6	41,625	6.6
2006	64,778	4.9	58,994	8.0	43,665	4.9

Korea imports about 98% of primary energy from other countries. The generating plants have been diversified such as nuclear, coal, liquid natural gas (LNG), oil and hydro, etc. (Fig. 1). However, air pollution results from oil- and coal-fired thermal plants.

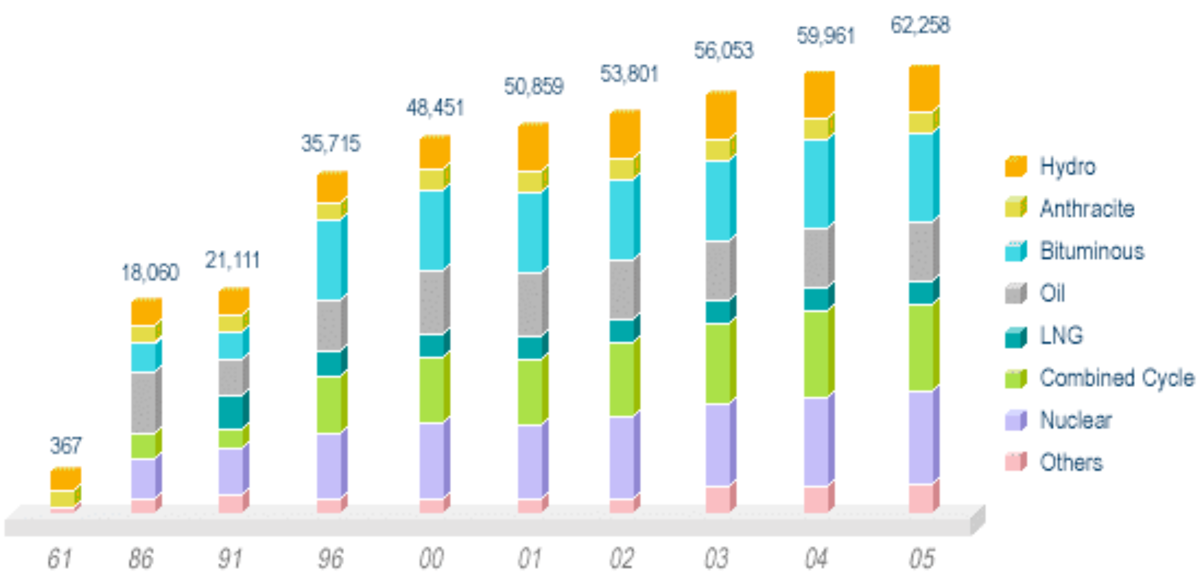

Fig. 1. Generating Facilities in Korea (Unit:MW).

In Korea, the category of renewable energy is as follows:
fuel cell, hydrogen, photovoltaic, bio, wind, hydro, ocean, waste matter, and geothermal. The government policy has emphasized mainly on the development of three major sources of renewable energy (hydrogen and fuel cell, photovoltaic, and wind power).
As concerns over environmental problem increase, this might be an important constraint in supplying power demand in the future. Therefore, air pollution of thermal power plants is likely to be a major impediment to generating electricity. Driven by these circumstances, the government has become interested in renewable energy and distributed sources. Renewable energy is gradually growing per year and the government plans to replace 5% of the primary energy source by the year 2011.

TABLE II. ACTUAL SUPPLY RESULT OF RENEWABLE ENERGY.
(UNIT:TOE, TONNAGE OF OIL EQUIVALENT)

category	2004		2005		2006	
	supply	%	supply	%	supply	%
Solar heat	36,143	0.8	34,729	0.7	33,018	0.6
photovoltaic	2,468	0.1	3,600	0.1	7,756	0.2
bio	134,966	2.9	181,275	3.7	274,482	5.3
Waste matter	3,313,273	72.3	3,705,547	75.9	3,975,272	76.1
hydro	1,082,341	23.6	918,504	18.8	867,058	16.6
wind	11,861	0.3	32,472	0.7	59,728	1.1
geothermal	1,355	0.0	2,558	0.1	6,208	0.1
Fuel cell	-		526	0.0	1,670	0.0
sum	4,582,407	100	4,879,211	100	5,225,192	100

Tables II and III show the actual result and goal of renewable energy in Korea [4].

TABLE III. SUPPLY GOAL OF RENEWABLE ENERGY.
[UNIT:THOUSAND TOE]

Category/year	2008	2009	2010	2011	2012
solar heat	169	208	258	318	385
Photovoltaic	65	103	192	341	448
wind	361	652	882	1,311	1,456
Small hydro	229	298	367	446	534
Hydrogen	0.1	0.1	1.3	1.3	1.3
IGCC	6.8	6.8	184	375	545
Waste matter	6,150	6,870	7,110	7,540	8,930
Bio	768	801	833	1,050	1,082
Fuel cell	3.6	15	77	147	226
Ocean	143	143	211	432	432
Geothermal	42	70	109	161	225
Large hydro	1,091	1,109	1,161	1,213	1,267
Sum	9,029	10,276	11,385	13,335	15,531
Supply rate(%)	3.60	3.99	4.32	5.00	5.60

IGCC : Integrated Gasification Combined Cycle

To increase the renewable energy and distributed generation as energy resources, the government provides the subsidies for generation margin (1$ = 1,000 won).

The generation margin is paid as follows:

- photovoltaic 714.40 won
- wind power 107.77 won
- small hydro power 73.69 won
- tidal power 62.81 won
- LFG (Landfill Gas) 65.20 won (below 20,000kW), 61.80 won (20,000 - 50,000kW)
-

The support period is given as follows:

- 15 years from operation time (photovoltaic, wind power)
- 5 years from operation time (small hydro power, tidal power, LFG), waste matter)

3. POWER SYSTEM IN JEJU ISLAND

Jeju is the largest tourist island in Korea, located approximately 100km south of the mainland, and had a peak load of about 550MW in 2007, with an average growth rate 8.6% over the last 5 years. The power system network in Jeju consists of 3 power plants and 360km of 154KV lines. Power plants are smaller and generation cost is higher in comparison with the Korea mainland. To meet the increasing demand and preserve the environment of Jeju, HVDC transmission system links with a 100km submarine cable from Haenam on the mainland to Jeju. The HVDC system provides Jeju with the high quality power of the mainland and avoids the difficulty of securing generation sites [5].

The general rating of HVDC link is:

- Voltage and capacity: DC 180kV, 150MW x 2 Pole, Bipole
- HVDC cable: 800 mm^2 Solid Cable 101km 2 line (sea bottom 96km, land 5km)
- Electrode line: ACSR/AW 410 mm^2 2 line (Jeju 12km, Haenam 16km)
- Normal operation: below 150MW, below 50 % of Jeju demand, frequency mode operation
- Basic control mode: constant current mode, constant frequency mode, constant power mode

The frequency mode operation of HVDC absorbs the load variation and maintains 60Hz frequency in Jeju.

Not only the supply energy, but also the quality of power is becoming an important issue to meet the expectation of international standard in building the infrastructures. Therefore, expansion of generation facilities is an essential requirement for securing power system stability and reliability in Jeju Island. Furthermore, since the island is located in a hurricane path and is known to have frequent lightening, there have been frequent contingencies because of the system heavily depending on overhead transmission and HVDC tie lines.

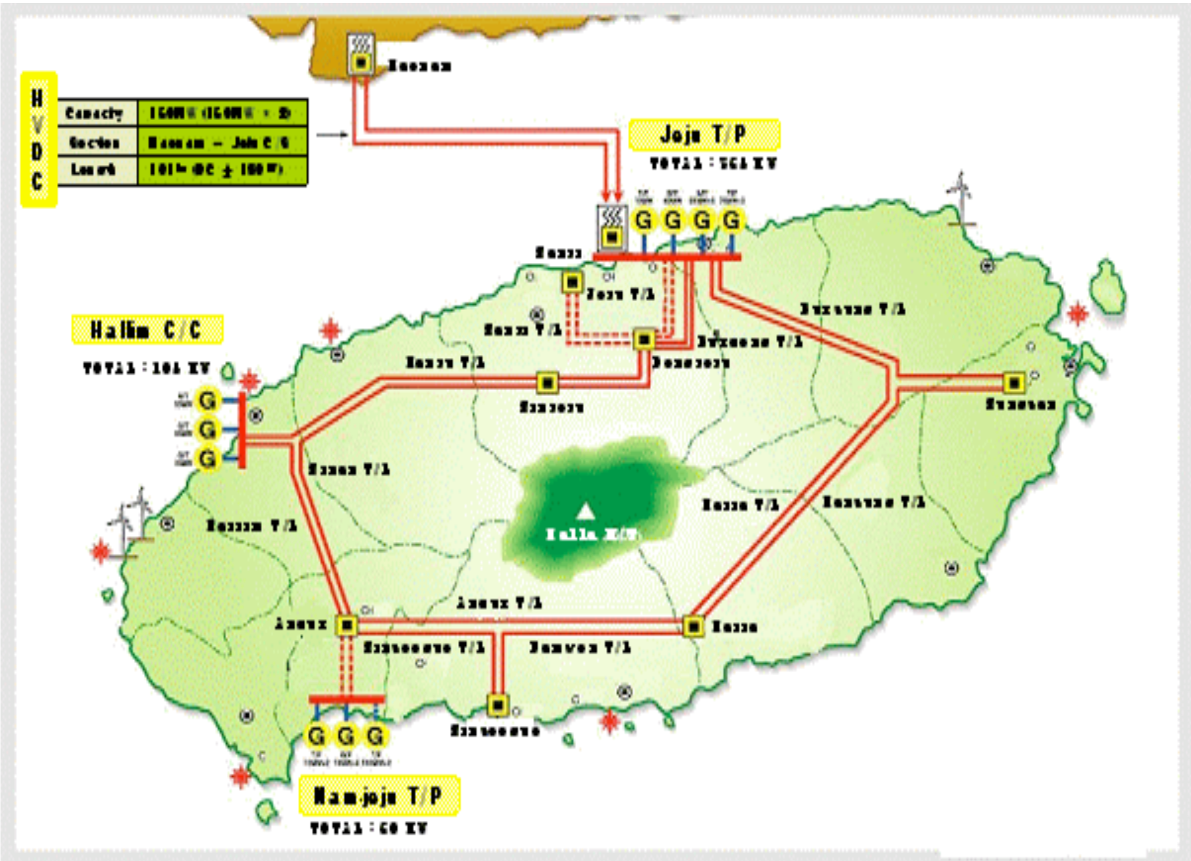

Fig. 2. Jeju power system.

The total installed capacity of Jeju Island is 878(MW), which includes 150(MW) transfer through the HVDC from the mainland. The power transfer through the HVDC is about 50(%) of the total demand in the island, and more than 40(%) in the average annually. Recently, relatively lager units are being planned and thus, the impact of failure of a unit is expected to be greater than before

TABLE IV. GENERATION CAPACITY IN JEJU.

Unit: MW

Section /year	HVDC	steam	Internal combus-tion	Com-pound	Gas turbine	WF1	LFG	WF2	WF3	WF4	sum
2007	150	360	80	105	165	9.8	1.0	6.0	1.7	0.0	878.5
2006	150.	280	80	105	165	9.8	1.0	6.0	1.7	1.5	800.0
2005	150	180	80	105	165	9.8	1.0	6.0			696.8
2004	150	180	40	105	165	9.8	2.0	6.0			657.8
2003	150	180	80	105	165	9.8	2.0				691.8
2002	150	180	80	105	165	7.8					687.8
2001	150	180	80	105	165	5.6					685.6
2000	150	105	80	105	165	4.3					609.3
1998	150	30	80	105	165	1.2					531.2
1997		30	80	105	165						380.0
1996		30	80	70	165						345.0
1995		40	80	35	165						320.0

WF1 : Hangwon Wind Farm, WF2 : Hankyung Wind Farm
WF3 : Sinchang Wind Farm, WF4 : Woljung Wind Farm

4. IMPACT OF WIND GENERATION IN JEJU POWER SYSTEM

Fig. 3 shows the wind distribution map of Jeju Island. Considering the map, wind mean speed in the east and west area is almost 6-7 (m/s), but north and south is 4-6 (m/s). This means that the east and west area has very good conditions for wind power generation site than north and south. Now a days, there are many wind farms under construction in the east and west areas and more will be constructed in future.

Hangwon wind farm has the 9.8MW capacity and is the first commercial wind farm in Korea. In 2004, Hankyung wind farm with 6MW capacity was constructed by KOSPO Generation Company.

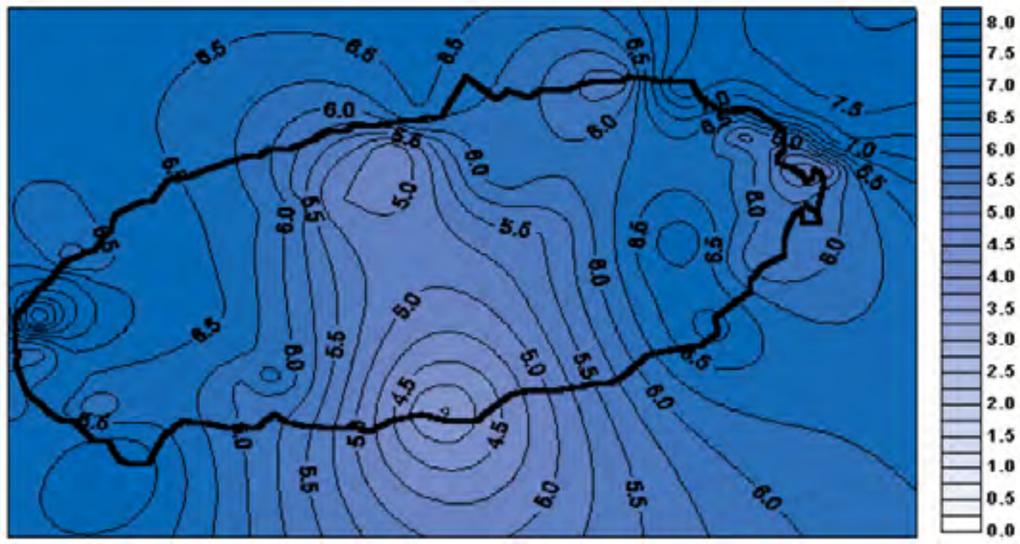

Fig. 3. Wind map of Jeju Island.

Fig. 4 shows the average wind speed of east and west sides during 2 years (January 2005 – December 2006) in Jeju. In Fig. 4, Sungsan is the measured place for wind data in east side and Hankyung is for the west side. From the average speed data, it is shown that the east and west areas have very good conditions for wind power generation.

By 2007, the total wind power capacity in Jeju is 20MW, and it is expected to increase to 207MW in the near future.

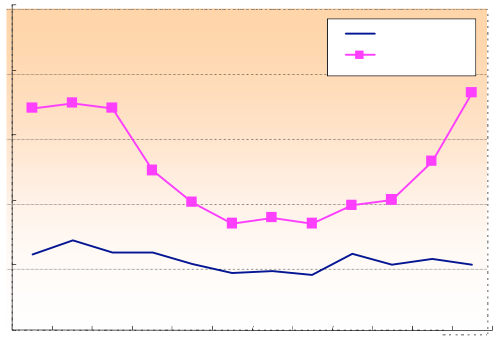

Fig. 4. Average wind speed of east (Sungsan) and west (Hankyung) sides.

This section presents the impact of wind generation for 2 wind farms (Hangwon-9.8MW in the east and Hankung-6MW in the west) during 2 years (2005. 1 – 2006. 12).

4.1 Power Production in Jeju Wind Farm

The total wind power production of Hangwon and Hankyung wind farms is 61GWh, which is 1.93% of the generation in Jeju during the last two years. The contribution of wind power to Jeju power demand is high in winter and low in summer. The average power productions are 2,075Mwh/year for Hankyung and 2,044Mwh/year for Hangwon.

TABLE V. AVERAGE POWER PRODUCTION IN JEJU WIND FARM
(2005.1 2006.12)

wind farm	Month (GWh)												Total
	1	2	3	4	5	6	7	8	9	10	11	12	
Hangwon	2.53	3.46	3.99	3.18	1.86	1.13	1.18	1.31	2.82	2.77	3.83	3.09	31.15
Hankyung	3.62	3.75	5.03	2.87	2.44	0.92	0.82	1.11	2.41	1.93	2.72	2.30	29.92
Total	6.15	7.21	9.02	6.05	4.30	2.05	2.00	2.42	5.23	4.70	6.55	5.39	61.07

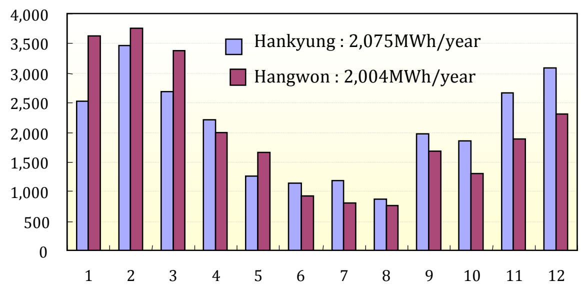

Fig. 5. Average power production in Jeju wind farm (2005.1 - 2006. 12).
(Unit : MWh)

1) *Capacity factor in Jeju wind farm.*

The average power, as the percentage of the nominal capacity (capacity factor, CF) of wind farm, in Jeju is 20.5% for Hangwon and 34.6% for Hankyung. These monthly capacity factors are high compared to other countries (England 27%, Denmark 20%, and Germany 15%).

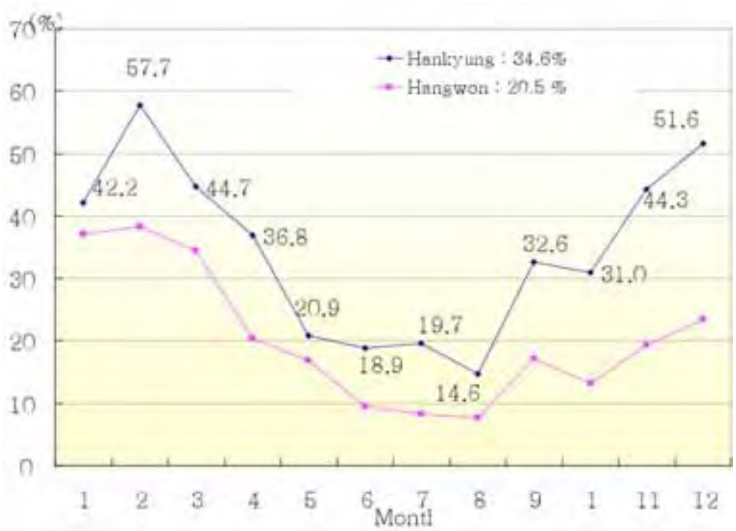

Fig. 6. Monthly capacity factor in Jeju wind farm.

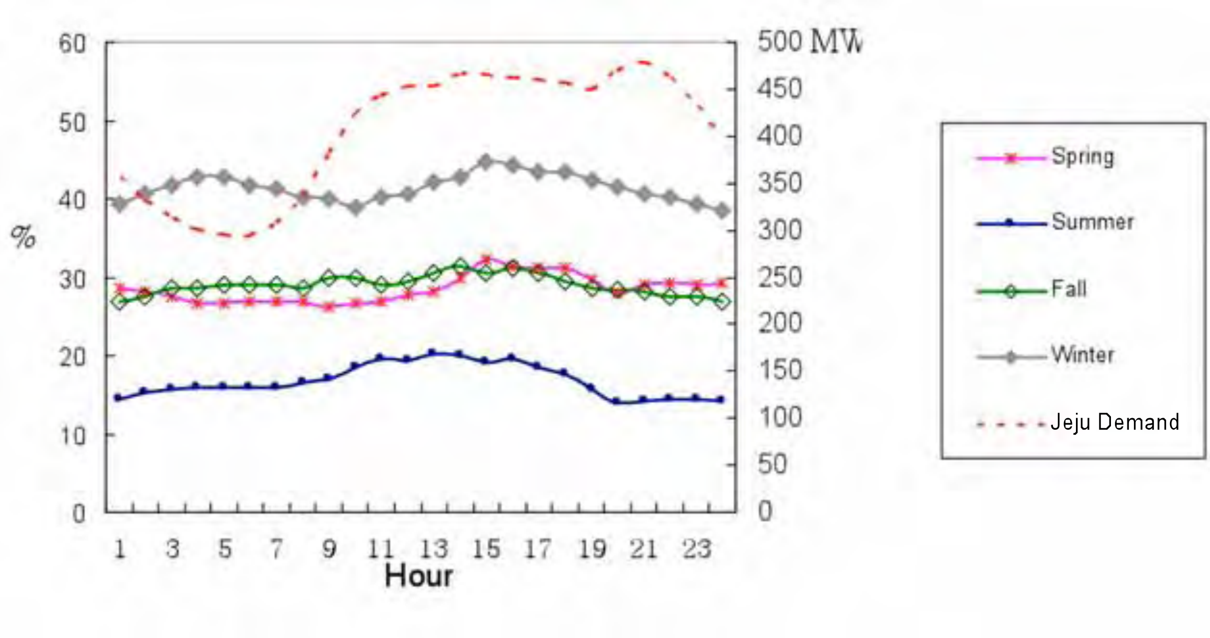

Fig. 7. Capacity factor classified by season.

2) *Occupation rate of power production.*

The occupation rate of wind power production to Jeju power generation is 1.22% in average and 1.99% for maximum. Until now, wind power has not affected Jeju power system operation owing to its small capacity compared to conventional generation capacity.

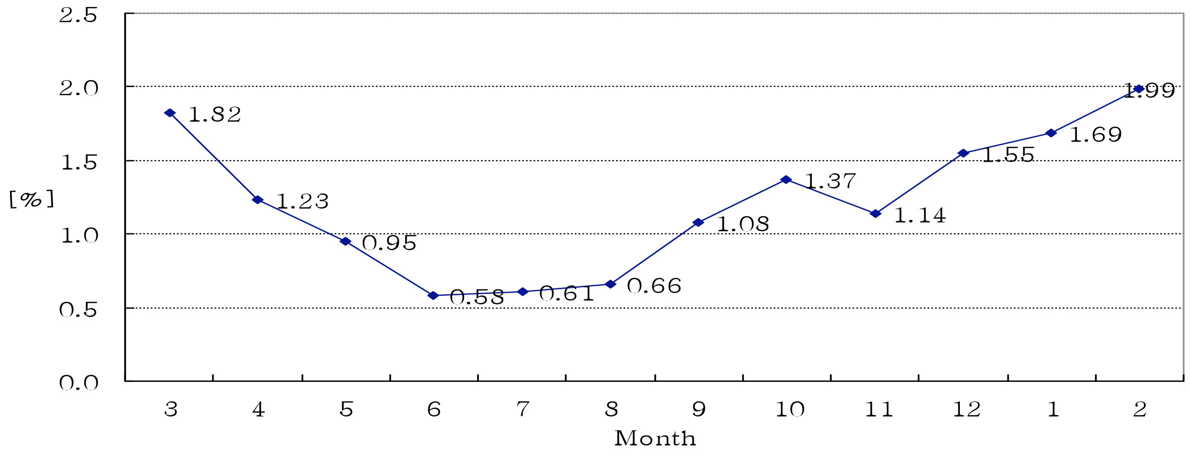

Fig. 8. Occupation rate of power production (2004.3 - 2006.2).

3) *Wind power production to capacity.*

In Fig. 9, the wind power production to wind capacity is shown. The wider the area below the curve is, the more the wind power produces and the utilization rate (power production to capacity) is high. In Fig, the case of Hankyung is broader than that of Hangwon. It is similar with the case of capacity factor.(CF of Hankyung is higher than that of Hangwon)

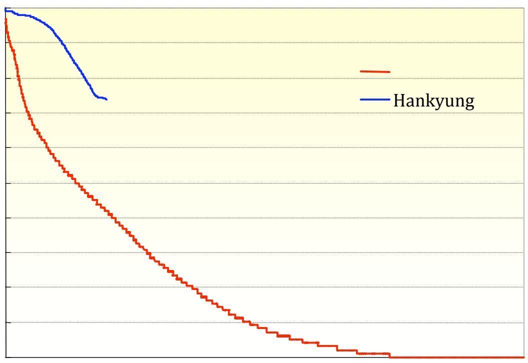

Fig. 9. Wind power production to capacity.

4) *Performance of wind power production.*

Fig. 10 shows the performance of wind power production. It includes the wind production energy, wind power output and frequency of wind speed. The performance curve can be used to estimate the output of wind farm with predicted wind speed.

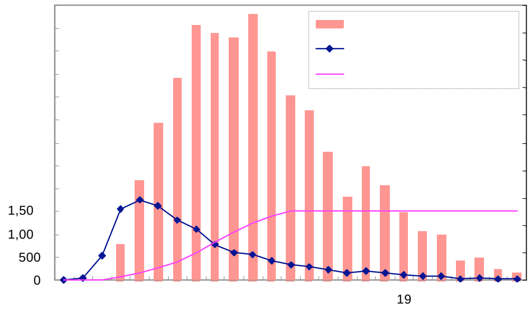

Fig. 10. Performance of wind power production.

5*) Impact to power system operation*.

Wind power can affect the frequency and voltage owing to variability of wind. In Fig. 11, are shown the network frequency and wind power output during HVDC overhaul (May, 12th, 2007). In the figure, the middle curve is the frequency and the bottom curve is the wind power output.

As shown, although the wind power output is variable, the frequency is maintained inside the desired range.

Fig. 11. Frequency and wind power output.

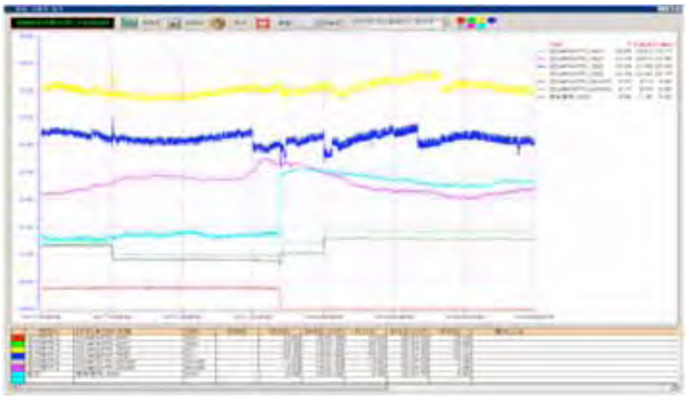

Fig. 12. Bus voltage (154kV) and wind power output.

In Fig. 12, there are shown the bus voltage (154kV) and wind power output. Two curves in upper part are voltage waveforms and the lowest curve is wind power output. The wind power output abruptly changed to zero because of the typhoon. Though the wind power output abruptly changes, the bus voltage is inside the prescribed range.

5. CONSIDERATION IN FUTURE POWER SYSTEM IN JEJU

By 2006, the wind power capacity was 20MW in Jeju. Wind power generation have a little influence on Jeju power system owing to small capacity compared to total generation capacity [6]. In the near future, 3 large wind farms are going to be constructed, with the total installed capacity of 207MW (79MW + 70MW + 58MW).

On April 1st, 2006, Jeju power system experienced the blackout of the entire island for 2 hours because of the HVDC fault. Jeju province requested to the government a means of stable power supply without blackout. As the result, government made decision to construct the addition of HVDC and an LNG generation station in Jeju. In 2011, two-pole HVDC systems will be constructed with one-pole capacity 200MW and in 2013; 300MW LNG station will be constructed.

Large wind power capacity, and addition of HVDC and LNG station are the major concerns in the stable operation of the small Jeju power system.

There are a number of issues to be resolved when implementing wind power generation. These include the followings:

- Economic assessment of the addition of HVDC and LNG generation station
- Stable network operation method including large wind generation system, and the addition of HVDC and LNG generation station
- Network operation during HVDC fault or overhaul
- Network operation in case of high wind penetration and low demand power
- Plan to maintain system reliability
- Reactive compensation method for HVDC and wind power generation
- Decision of a unit (generator) capacity for N-1 contingency
- Response characteristic analysis of HVDC and conventional generator according to wind variation and wind power generation
- Technical countermeasure in case of abrupt wind power reduction with typhoons.
- Quantification of reserve margin due to increasing wind power penetration
- Plan to construct wind farms with proper penetration (capacity) for stable network operation
- Plan to design wind farms considering natural view and the environment.

6. CONCLUSION

Presently, widespread integration of distributed generation and wind power in Korea is still in infancy. However, by the governmental and provincial policies, distributed generation will play an important role.

This paper investigated the impact that arises when integrating wind power in Korea-Jeju power system and discusses the interconnection consideration in future network. Penetration of wind power in the present power system of Jeju has a little influence on the operation and control of the grid. Wind generation system brings challenges of its own, especially in the future network of Jeju.

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8. BIOGRAPHIES

Kwang Y. Lee received his B.S. degree in Electrical Engineering from Seoul National University, Korea, in 1964, M.S. degree in Electrical Engineering from North Dakota State University, Fargo, in 1968, and Ph.D. degree in System Science from Michigan State University, East Lansing, in 1971. He has been with Michigan State, Oregon State, Univ. of Houston, the Pennsylvania State University, and Baylor University where he is now a Professor and Chair of Electrical and Computer Engineering. His interests include power system control, operation, planning, and intelligent system applications to power systems. Dr. Lee is a Fellow of IEEE, Associate Editor of IEEE Transactions on Neural Networks, and Editor of IEEE Transactions on Energy Conversion. He is also a registered Professional Engineer

Se Ho Kim was born in Seoul, Korea in 1961. He received his B.S., M.S. and Ph.D. degrees in electrical engineering from Yonsei University, in 1983, 1985 and 1992, respectively. Currently, he is a Full Professor in the Department of Electrical and Electronics Engineering, Cheju National University, Jeju, Korea. He is a Visiting Scholar at the Pennsylvania State University for February 2007 – February 2008. His current research interests include power system operation, renewable energy resources, wind power system, distributed system automation, and grounding systems. Dr. Kim is a member of IEEE and KIEE.

Young Hwan Kim was born in Jeju, Korea in 1966. He received his M.S. degree in electrical engineering from Cheju National University, in 2006. Currently, he works for Korea Power Exchange (KPX), Jeju Branch. The roles of KPX are the establishment of stable power supply, operation of the Korea-Jeju power system, and the power market. He is in charge of planning the Jeju power system operation. He has also investigated on the influence of power system operation by wind power.

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4. The Study of Fault Location System with the use DGs

Xia Lin, Yuping LU, and Jiao Du, Southeast University, Nanjing, Jiangsu, China

Abstract—For the DG system, it can use the fault current value of all the sources including DG to judge the fault location. This method will improve the system fault location accuracy compared to the traditional protection only based on the system main source current. However, each DG source has the different role in fault current contribution. In the paper, it is studied the fault sensitivity of every single source for the system certain fault point. It finds out that there is a sensitivity blind region and a sensitivity undulation region for DG system. And fault location efficiency will be improved by appropriate design DG power source location because it can reduce the sensitivity undulation and blind area. A DG source configuration model is proposed and an optimized configuration is expected to make sure there is the enough number of effective DGs to maintain the necessary accuracy for fault location.

Index Terms—fault location; source current sensitivity; high symmetry degree scattering mode; sensitivity undulation area; sensitivity blind area; multi-port circuit; branch coefficient.

1. INTRODUCTION

For the multi-DG system, with the DG connection into the system it changes the system faulty state and brings impact to the traditional protection [1, 2, 3]. The same time if all the sources including DGs take part into the fault point judgment, it also can improve the system sources judge ability for the fault location compared to the traditional protection system, where only the main source plays the role of fault judgment [4, 5]. It can judge the fault location according to the fault current value of every source. This method in essence is the distance protection principle. In the multi-DG system, for the different system topological structure and the system various DG connection location, each source of the system has the different fault current judgment ability for the same fault point.

In the paper it is with the introduction of the parameter of fault judgment sensitivity S_{DGi} to reflect the every source fault judgment ability. It is through the analysis in different DG connection cases of the parameter of $S_{DGi} = \frac{\partial I_{DGi*}}{\partial X_{1*}}$, the partial derivative of every source felt faulty current with respect to the fault point corresponded short-circuit impedance, reflecting the every source felt fault current sensitivity for the fault point. And based on this it is found that for every source there exist the sensitivity blind area $S_{DGi\ll}$, and the sensitivity undulation area $S_{DGi\gg}$. When a fault happens, as for the certain fault point sited range only the pre-defined corresponded effective source subjectivities fault judgment results are adopted for the fault point location. Shown in fig (1), where A and B are the fault judgment results of effective source subjectivities, and C is the result of ineffective ones. It can be seen the scheme can avoid the inaccuracy brought about by the ineffective source judge subjectivities, and can improve the fault point calculation accuracy. Also, it can give an instruction to the sources configuration to make sure for any fault point in the system can be located with enough effective subjectivity number to obtain the necessary accuracy.

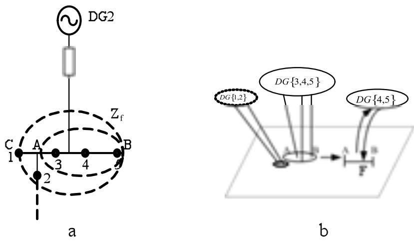


Fig.1 The effective fault judgment subjectivity set and its convergence fault area

2. THE SYSTEM POWER SOURCES FAULT JUDGMENT SENSITIVITY CHANGE RULE TO THE FAULT POINT

In order to analyze the each DG fault current contribution, here adopt the multi-port method.

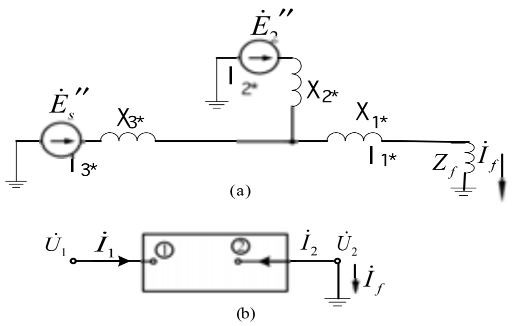


Fig.2. The DG injection to the single feeder expressed in multi-port way with the three phase fault happen

U1(0), U2(0) are the open circuit voltage of each node, which can be gotten from the load flow calculation, in the approximate calculation it takes as 1. With per unit on rating, the system branch felt current is:

$$I_{3*} = \frac{U Z_{12}}{X_{3*} Z_{22}} = \frac{U_{1(0)} U_{2(0)}}{X_{3*} Z_{22} X_{3*}} \cdot \frac{1}{\quad}$$

Ignore the load flow, and only consider the faulty current I_f, the gotten system source branch fault current is:

$$I_{3*} = \frac{Z_{12}}{Z_{22}X_{3*}} = \frac{1}{X_{3*} + X_{1*}\left(\frac{X_{3*}}{X_{2*}} + 1\right)} \qquad (1)$$

DG branch fault current is:

$$I_{2*} = \frac{1}{X_{2*} + X_{1*}\left(\frac{X_{2*}}{X_{3*}} + 1\right)} \qquad (2)$$

2.1 Introduction of power source fault current sensitivity parameter

Introduction of change sensitivity parameter $S = \frac{\partial I_*}{\partial X_*}$, it reflects the each power source fault current sensitivity to the fault point change. It is demanded that each power source has the certain sensitivity to the fault position change. But it cannot be too high which has the excessively intense response to the change of the fault point. And it cannot be too low which has the weak response to the change of the fault point. The sensitivity parameter for the system power source is:

$$S_{(x3)} = \frac{\partial I_{3*}}{\partial X_{1*}} = \frac{1+\frac{X_{3*}}{X_{2*}}}{\left(X_{3*}X_{1*} + \left(\frac{X_{3*}}{X_{2*}} + 1\right)\right)^{2}} \quad (3)$$

The sensitivity parameter for DG is:

$$S_{(x2)} = \frac{\partial I_{2*}}{\partial X_{1*}} = \frac{1+\frac{X_{2*}}{X_{3*}}}{\left(X_{2*}X_{1*} + \left(\frac{X_{2*}}{X_{3*}} + 1\right)\right)^{2}} \quad (4)$$

It can be seen from the above formula: as the fault point is far away the power source, each source is more insensitive to the fault point change; when the fault point approaches the source, the change sensitivity is increase in square times. Defines a binary array (χ, ϖ), (1) when there is $B \le \varpi_1, B \ge \chi_1$, it indicates the power source current change to the fault position change is extremely small, namely the power source current change sensitivity is too small; (2) when there is $B \ge \varpi_2, B \le \chi_2$, it indicates the fault point change to the fault position change is extremely big, namely the power source current change sensitivity is too large.

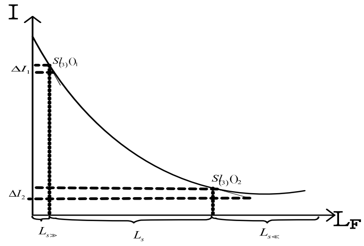


Fig.3. The fault point move along the feeder the corresponded power source fault current change curve

It can be seen from the fig3, the fault current flowing the source is monotonous decrease with the fault point moving away the source, give definition to the sensitivity blind region $L_{s\ll}$, there is $L_F \le L_{s\ll}$, satisfy (1). Give definition to the sensitivity undulation region $L_{s\gg}$, there is $L_F \ge L_{s\gg}$, satisfy (2). It can be seen each power source has the fault judgment sensitivity effective sector $L_{s\gg} \le L_s \le L_{s\ll}$.

2.2 *Different subjectivities judgment sensitivity change rule to fault point change*

Define symmetry parameter _ for the various power sources comparable fault judgment ability to the fault point: It is the short-circuit impedance ratio of one power source branch to the other power source branch in parallel. For the above example, there is: $\_ = \frac{X_{3*}}{X_{2*}}$, so can yield $\frac{S_{(x3)}}{S_{(x2)}} = \frac{X_{2*}}{X_{3*}} = \frac{1}{\_}$.

From the above formula it can be seen various power source judgment sensitivity ratio is in inverse proportion to the ratio of the power source branch short-circuit impedance. When the fault point is at the common part of the two parallel power sources branches, the source fault change sensitivity ratio is the short-circuit impedance ratio of its parallel power source branch to itself branch.

3. POWER SOURCE SUBJECTIVITY FAULT SENSITIVITY CHARACTERISTIC ANALYSIS

In this part, first discusses fault current distribution mechanism among every power source, and then discuss under different system structure and DG connection position, the various power sources fault sensitivities to fault point.

3.1 In single DG connection case power source judgment subjectivity fault sensitivity characteristic analysis

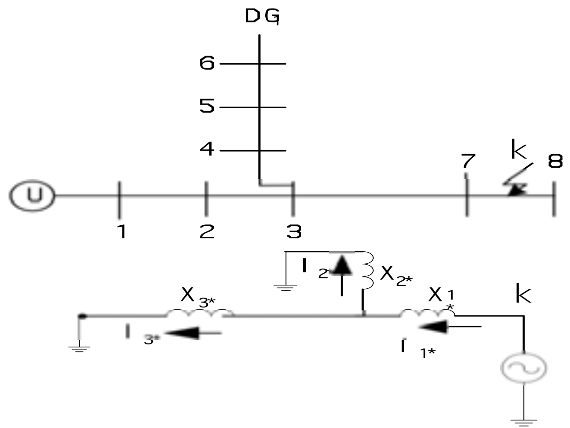


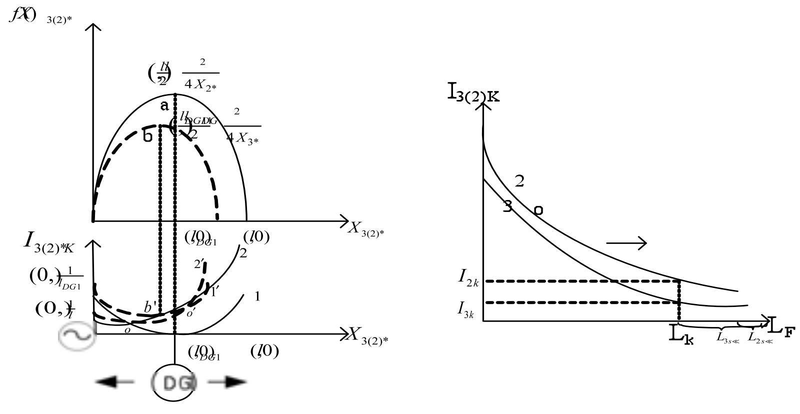
Fig.4 in the single DG connection case the equivalent circuit

First discusses the system power source and the DG1, the two different judgment subjectivities exited system. Assume one source is fixed, and the other source moves; study the source fault current change rule. Shown in fig 4, there are $X_{2*}=X_{1\sim4\sim6}$ X_{DGBUS} and $X_{3*}=X_{1\sim3}$ X_{SBUS} . When the one source branch moves, the other source branch short-circuit impedance correspondingly changes.

First consider the fault position is fixed, and when the relative position between two power sources changes, study the change rule of the source subjectivity sensitivity. Suppose the fault occurs at point K, study when the DG1 connection position changes the system source fault current is: there is DG1 with the fixed short-circuit capacity, namely X_{2*} to be the constant parameter of X_{2*0} , and $x_{1*}+x_{3*}=l$. then there is:

$$I_{3*K}=\frac{1}{l+\frac{X_{1*}X_{3*}}{X_{2*}}}=\frac{1}{l+\frac{-X_{3*}^2+lX_{3*}}{X_{2*}}} \qquad (5)$$

According to quadratic form nature there is: when $X_{3*}=\frac{l}{2}$, the formula $\frac{-X_{3*}^2+lX_{3*}}{X_{2*}}$ achieves the maximum value, the extreme point is $(\frac{l}{2},\frac{l^2}{4X_{2*0}})$, where I_{3*K} achieves the minimum. When DG1 connection position is at $\frac{l}{2}$, the system power source branch current reduces the most. And the DG1 fault current is $I_{2*K}=\frac{X_{3*}}{X_{2*}}I_{3*K}$ 。



(a) (b)

Fig.5 (a) in the single DG connection case when the other power source moves the other power source current change curve (b) the fault point moves, each power source current change curve

As shown in fig 5 (a), the system power source as the judgment subjectivity, whose current change curve is the curve 1, and the DG1 corresponded current change curve is the curve 2. When $\_ = 1$, the two power source fault currents are approximately equal. Two current curves intersect at the point “O”. And at the left side of point “O”, there is $\_ < 1$, the power system source fault current is bigger; with DG1 moving downstream, X_{3*} increases gradually, DG1 fault current then increases. At the right side of the point “O” there is $\_ > 1$, the DG fault current is bigger than the system power source current. At the same time, the intersect point “O” position is related with the DG1 branch short-circuit impedance. When the parameter x_{2*} increases, the intersection point “O” position migrates to the right side part of l.

If consider DG1 the judgment subjectivity, and moves the system power source branch position, can obtain the similar characteristic. Here suppose $x_{1*} x_{2*} l + = \quad '$, yield:

$$I_{2K*} = \frac{1}{l' + \frac{X_{1*} X_{2*}}{X_{3*}}} \qquad I_{3K*} I_{2K*} = = \frac{X_{2*}}{X_{3*}} \qquad \frac{1}{\_}$$

When the system power source branch moves downstream along DG1 branch, X_{3*} to be constant, X_{2*} increases gradually, and the system power source current gradually increases. DG1 fault current change curve is curve 1$'$, and the system power source fault current change curve is 2$'$.

When $\_ \gg 1$ or $\_ \ll 1$, that the two power sources short-circuit impedance X_{3*} and X_{2*} difference is become big, then two extreme points $(l, \frac{l^2}{X_{2*}})$ and $(l', \frac{l'^2}{X_{3*}})$ value difference become big, and the gap between two curves increases. If the one fault subjectivity judgment sensitivity for a fault point is at the sensitivity blind region, the other judgment subjectivity is still at the effective sensitivity region for the fault point.

With the fault point change in the system, the source position is farther away the fault point, the source fault judgment sensitivity reduces because of the short-circuit impedance increase, and at last the fault point enters the source judgment blind region. And for that power source near the fault point, its sensitivity is higher. So appropriate choice of the source subjectivities for different fault location can avoid the big error brought by the judgment subjectivity with too high or too low sensitivity, to improve the fault location accuracy. As shown in fig 5(b), when $X_{3*} \gg X_{2*}$, there are $l \gg l'$ and $\frac{l^2}{X_{2*} X_{3*}} \gg \frac{l'^2}{}$, the curve 2 approaches the upper-right side. For the system power source the sensitivity seriously declining region is still the region with much higher sensitivity for DG1. For example when the fault happens at point K, for the system power source it is the judgment sensitivity blind region $L_{3s\ll}$, namely the K point falls in the system power source subjectivity sensitivity blind region. And for the DG1 there is the fault current I_{2K*}, K is still in its sensitivity effective region, fell in left side of $L_{2s\ll}$.

3.2 Multi- DG connection power sources judgment sensitivity characteristic analysis

From the above analysis, it can be seen for the single-DG injection system, the symmetry parameter $\_$ of the DG branch and the system power source branch is the important index for measuring the source subjectivities comparable fault judgment ability. When for the multi-DG condition it can deduce the similar conclusion

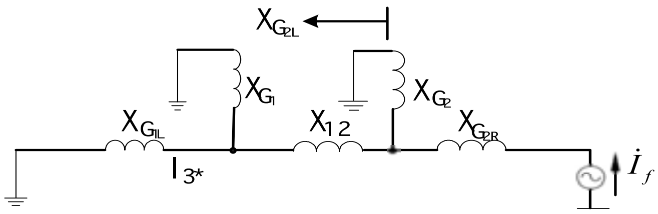


Fig.6 in the two DG injection to the single feeder case the equivalent circuit

As shown in fig 6, DG1 is close to the system power source side, DG2 is close to the load side. X_{G2L} and $X_{G_{1L}}$ are the system side resultant impedance before DG1, DG2 connection position respectively; X_{12} is the short-circuit impedance between DG1 and DG2. After DG1 is connected to the system, the newly system resultant impedance is: $l_1 = X_{G1} // X_{G1L}$, and there is $X_{G2L} = X_{sDG1} + X_{12}$. If regards DG1 and the system power source as a judgment subjectivity combination X_{sDG1}, and compares with DG2 the judgment subjectivity, which can be deduced to the single DG connection case, there is:

$$I_{(sDGK1)*} = \frac{1}{l_1 + \frac{X_{G2L*}}{X_{G2*}}} \qquad (6)$$

DG2 is as the judgment subjectivity there are: $I_{2KG*} = \_ \frac{1}{l_1 + \frac{X_{G2L*}}{X_{G2*}}}$ (7)

where $\_{}_{G2} = \frac{X_{G2L*}}{X_{G2*}}$.

When the two DG separately are connected to the system, the latter one will bring impact to the system power source current and the early connected DG current, so it changes the each source judgment sensitivity effective region size. When the fault is at point ③ as shown in fig 6, after the DG2 branch is connected to the system, its shunting action cause the system power source and the DG1 judgment subjectivity combination sensitivity effective area to be reduced. But DG2 itself as the subjectivity may use its fault judgment effective sensitivity to make up the subjectivity combination sensitivity effective area reduction. When DG1 is connected to the system, it brings reduction to the parameter X_{G2L} and $\_{}_{G2}$. When it approaches the DG2 load side, it can effectively suppress the DG2 sensitivity undulation region. At the same time, with the DG2 connection the system all power sources including DG1 and DG2 the sum fault judgment effective region is expanded. Certainly as a result of the DG1 shunting action, the system power source itself sensitivity effective region may be reduced, but with the DG2 connection it can make up the lost effective region with the DG2 judgment subjectivity.

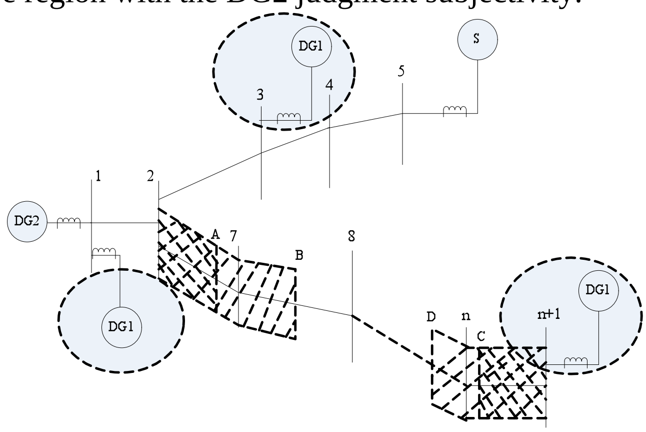


Fig7. The sensitivity blind region and undulation region distribution pattern

As shown in fig 7, when DG1 is connected to the power source branch with the bigger short-circuit impedance, here is to the bus 3, and causes DG2 subjectivity sensitivity undulation region for the fault happen at the sources common part to be reduced from 2-B region to the 2-A region, in this way to improve the DG2 fault judgment ability. But for the system power source, its original sensitivity blind area the D- (n+1), after the DG1 connection, is reduced to C- (n+1) as for the DG1 and the system power source subjectivities combination. Similarly, if DG1 is connected to the short-circuit impedance relative smaller DG2 branch, here is to the bus 1, for the sources common part fault, the system power source judgment effective region reduces, its sensitivity blind region of n- (n+1) is expanded. But as a result of the DG1 shunting action, it causes the DG2 sensitivity undulation region to be reduced, and expands the DG2 sensitivity effective region. If DG1 is connected to the system power source blind region at bus (n+1), it can effectively reduce the system power source sensitivity blind region, but creates the sensitive undulation region around bus (n+1) for DG2.

4. THE MULTI POWER SOURCES JUDGMENT SUBJECTIVITIES FAULT LOCATION PLAN

According to 2.2nd part of the two DG short-circuit current distribution formula between the sources it can deduce the multi-DG system fault current distribution formula among the sources:

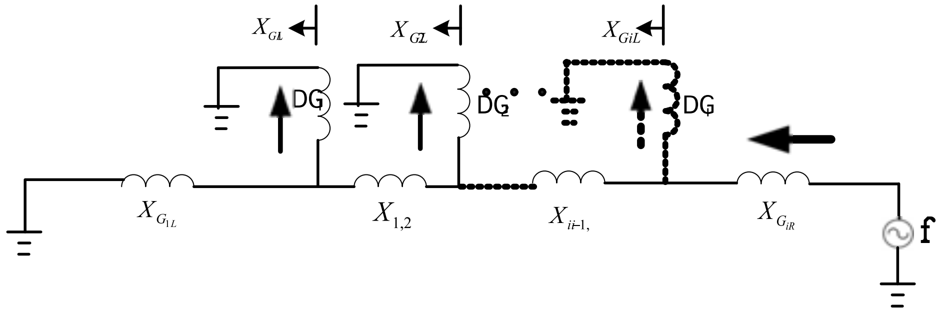


Fig.8 in the multi- DG injection to the single feeder case the equivalent circuit

Shown in fig 8, the closest to the fault point is the DG_i branch, whose fault current is:

$$I_{GiK*} = \frac{X_{GiL*}}{X_{Gi*}} \frac{1}{l_{i+1} + \frac{X_{GiL*}X_{GiR}}{X_{Gi*}}} \qquad (8)$$

The fault current of the system side combined branch in parallel with DG_i is:

$$I_{(1)*K} = \frac{1}{l_{i+1} + \frac{X_{GiL*}X_{GiR}}{X_{Gi*}}}; \qquad (9)$$

Move towards the system source side to pass a node to get the DG_{i+1} branch fault current：

$$I_{G(1)K*} = C_{G(1)*} I_{(1)*K}; \qquad (10)$$

The fault current of the system side branch in parallel with DG_{i+1} is:

$$I_{(2)*K} = C_{G(\bar{1})*} I_{(1)*K} \qquad (11)$$

Where $C_{G(1)*}$ and $C_{G(\bar{1})*}$ are the DG_{i+1} branch and its system side parallel branch coefficient respectively:

$$C_{G(1)*} = \frac{X_{G(\bar{1})*}}{X_{G(1)*} + X_{G(\bar{1})*}}, \quad C_{G(\bar{1})*} = \frac{X_{G(1)*}}{X_{G(1)*} + X_{G(\bar{1})*}}$$

DG_i and its parallel branch symmetry parameter is:

$$-_{Gi} = \frac{X_{Gi*}}{X_{GiL*}} \quad -_{GiL} = \frac{X_{GiL*}}{X_{Gi*}}$$

For the system with the certain network structure, the different power source has the different sensitivity as:

$$S_{(X_{Gi})} = \frac{\oplus I_{GiKGi}}{\oplus X_{GiR*}} \frac{1}{(lX_{1GiGiR} + \_)^2} \chi_i \qquad (12)$$

$$S_{(X_{GiL*})} = \frac{1 + \_{GiL}}{(lX_{1GiLGiR} + \_)^2} \chi_{GiL} \qquad (13)$$

Because the only variable is the sources common part short-circuit impedance X_{GiR*}, namely the short-circuit impedance from DG_i to the fault point. Every source sited at DG_i upstream, the fault judgment sensitivity just take the same branch coefficient with its branch current. It is deployed in terms of DG, first to obtain $S_{(X_{GiL*})}$, and then it is multiplied by the corresponding branch coefficient to obtain the each source subjectivity fault judgment sensitivity. When there is $DG_{work}DG_j = \{ \quad , \chi\chi\chi(\ll\gg) \}$, the set contains the effective fault judgment subjectivities for the certain fault point. When a fault happens, every source judges the fault distance according to its own fault current value, that is the fault point possible existed bus sector. Then according to beforehand decided effective judgment subjectivity match table it eliminates the bus sector corresponded ineffective subjectivities. In this way it removes the ineffective judgment subjectivities with big error, and obtains the mean value $\overline{X}_{GiR*}$ is:

$$\overline{X}_{GiR*} = \frac{\underset{DGi \in DG_{work}, i=1}{\overset{n}{\leftrightarrow}} X_{GiR*}}{n} \qquad (14)$$

5. SIMULATION & VERIFICATION

PSS/E software is used in simulation to verify the method proposed above. The test network used here is the IEEE34 node system with DG, as shown in Figure 4, where DG1, DG2, DG3 and DG4 are connected to bus 11, 18, 28 and 30 respectively. The base voltage of the network was Vb=24.9 kV and the reference voltage in the root node were 1.05p.u. = 26.145kV. The base apparent power was Sb = 10 MVA. The parameters of the electrical sources, loads and network are seen in [6, 7].

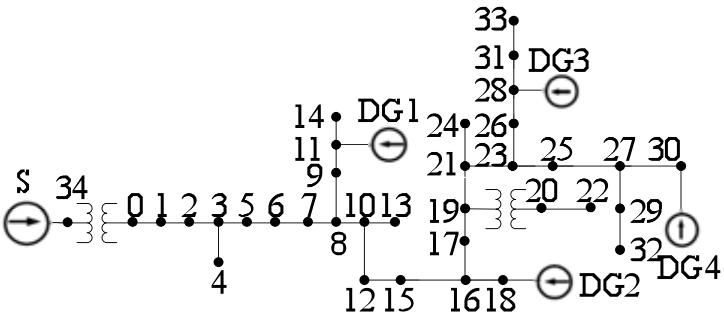


Fig.9 the IEEE34 node system with DG

As shown in fig 9, with the each power source fault judgment sensitivity value for the fault point at every bus to obtain the effective judgment subjectivity match table.

TABLE 1:
JUDGMENT SUBJECTIVITY MATCH TABLE

source / sensitivity / bus sector	S	DG1	DG2	DG3	DG4
L_{12}	≫	✓	≪	≪	✓
L_{23}, L_{34}	✓	✓	≪	≪	✓
L_{35}	✓	✓	✓	≪	✓
$L_{56}\sim L_{10,12}$,	≪	✓	✓	✓	✓
$L_{10,13}$	✓	✓	✓	✓	✓
$L_{10,14}\sim L_{21,24}$	≪	✓	✓	✓	✓
$L_{23,26}\sim L_{31,33}$	≪	✓	≫	✓	✓
$L_{25,27}\sim L_{29,32}$	≪	✓	✓	≫	✓

When the fault is between bus sector of 1and 2, it is the sensitivity undulation region for the system power source subjectivity S, and the sensitivity blind region for the farthest power sources DG2, DG3.When the fault point moves to the bus sector of 10 to 13, it has the largest number of effective judgment subjectivities. And it can be seen from fig 9, the power sources are in symmetry distribution with respect to bus sector of 10 to 13. Also it can be seen that when the fault point moves to the bus sector of 5 to 12, for the small fault sensitivity value the system power source is to become the ineffective judgment subjectivity. But as fault point moves to bus sector of from 10 to 13, the system power source restores its fault judgment validity. This is because the bus sectors of from 10 to 13, DG1 andDG4 branches are in parallel with the system power source branch results to the increase of the system power source current, so increase with the fault judgment sensitivity.

Below tables follows the source subjectivity order of S, DG1, DG2, DG3, and DG4 in column. "The current change" refers to when the fault point moves 5% either side around the 50% of the certain bus sector, the each power source short-circuit current change quantity. "The relative sensitivity" refers to when take the smallest current change quantity as reference value, and the ratio of other current value to the reference value, which reflects each judgment subjectivity sensitivity comparable value for the certain fault position.

TABLE 2-1
: 50% OF BUS SECTOR 02~03 SHORT-CIRCUIT

Current (pu)	Current change pu)		relative sensitivity	
50%	-5%	+5%	-5%	+5%
5.6368	0.4777	-0.4085	530.7778	-408.5000
0.5131	-0.0074	0.0076	-8.2222	7.6000
0.1185	-0.0017	0.0018	-1.8889	1.8000
0.0643	-0.0009	0.0010	-1.0000	1.0000
0.3632	-0.0052	0.0054	-5.7778	5.4000

TABLE 2-1

: 50% OF BUS SECTOR 07~08 SHORT-CIRCUIT

Current (pu)	Current change (pu)		Relative sensitivity	
50%	-5%	+5%	-5%	+5%
1.1058	0.0002	-1E-04	1.0000	-1.0000
2.219	-0.0013	0.0014	-6.5000	14.0000
0.5127	-0.0004	0.0003	-2.0000	3.0000
0.2782	-0.0002	1E-04	-1.0000	1.0000
1.571	-0.0010	0.0009	-5.0000	9.0000

TABLE 2-3

: 50% OF BUS SECTOR OF 19~21 SHORT-CIRCUIT

Current (pu)	Current change (pu)		Relative sensitivity	
50%	-5%	+5%	-5%	+5%
0.1813	0.0008	-0.0008	1.0000	-1.0000
0.3666	0.0015	-0.0016	1.8750	-2.0000
6.9428	-0.1514	0.1583	-189.2500	197.8750
3.7671	-0.0821	0.0859	-102.6250	107.3750
1.4313	0.006	-0.0059	7.5000	-7.3750

For example when the fault point is at the 50% of bus sector 02~03, and the fault point moves 5% right side, the each power source fault current change value shown in table 2-1. The system power source closest to the fault point is of the biggest current change value, and DG3 the farthest to the fault point is of the smallest current change value, so it is of the biggest relative sensitivity of 408.5 for system power source. Compared to the other power sources judgment subjectivities, the system power source judgment sensitivity is too high, and DG3 judgment sensitivity is too low, resulting to the two source to become the ineffective subjectivities for the bus sector 02~03 fault.

6. CONCLUSION

In this paper it is studied the various power sources fault judgment sensitivity to the certain fault point under the different DG connection pattern, and based on this it gives the DG configuration to be more beneficial for the fault point judgment. And fault location efficiency will be improved by appropriate design DG power source location because it can reduce the sensitivity undulation and blind area. Then it is proposed the method: when the fault happens, the beforehand locked effective judgment subjectivities are adopted to take part into the fault location, in this way it removes the ineffective judgment subjectivities caused oversize error and effectively improves the fault location accuracy.

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8. BIOGRAPHIES

Xia Lin was born in Fuzhou, China, on Oct 22, 1975. She graduated from Shandong University of technology in June 1997 and Shandong University in June 2002, received B.E and M.E respectively. Now she is pursuing her PhD in Southeast University. Her current interesting area is protection and control of distribution system with DGs

Yuping Lu was born in Danyang, China, in Oct 1962. He was received the Ph.D. degree in electrical engineering from the City University, UK in 2003. He is working as a professor in Southeast University of china. His research interests are power system protection, especially digital relaying of generator-transformer unit, and protection and control technique in distribution system with DGs.

Jiao Du was born in Xuzhou, China, in May 1985. She received the Bachelor's degree in electrical engineering from Southeast University in June 2007. Now she is pursuing her M.E. in Southeast University. Her current research areas are protection and control of distribution system with DG.

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5. Multi-Agent Application in Protection Coordination of Power Systems with Distributed Generation

Dr Hui WAN, Professor Kit Po WONG and Dr. Chi Yung. CHUNG, Hong Kong Polytechnic University, Hong Kong.

Abstract-This paper presents new explorations into the use of agent technology applied to substations protection coordination of power system. The impact of distributed generation on protection is firstly discussed. Then a coordination multi-agent system is proposed with the functions of the agents described. In the proposed system, communication will play an important role to provide more information for the relay coordination besides the relay settings. Relay coordination strategy is also discussed and communication simulation between different substations has been carried out on Java Agent Development Framework (JADE) platform. The simulation results show that proper protection coordination can be achieved by the proposed coordination strategy and information communication.
Index Term- protection coordination, distributed generation, multi-agent technology, Substations

1. INTRODUCTION

THE coordination of protection devices aims to maintain the selectivity among the devices involved in several fault possibilities, in order to assure the safe operation and reliability of the electric system. In an efficient and coordination protection system, faults are eliminated in the smallest possible time, isolating the smallest part of the system containing the cause of the fault. Deregulation of the utility industry is creating a situation in which utilities must automate and acquire more information to remain competitive. The process of substation automation can be defined as deployment of substation and feeder operating functions ranging from supervisory control, data acquisition (SCADA) and alarm processing to integrated volt/var control in order to optimize the management of capital assets and enhance operation and maintenance efficiencies with minimal human intervention [1]. This process is closely related to the substation integration – which by integration of monitoring, protection and control functions into a minimal number of platforms, aims at reduction of operating costs, redundant equipment and databases. Modern Intelligent Electronic Devices (IEDs) not only perform various control and protection functions but also monitor and record valuable information, both operational and non-operational. Consequently, the new architecture of the substation protection systems is being based on integration of the IEDs, instead of the previously used RTUs (Remote Terminal Units).

When the penetration of Distributed Generation (DG) increases, the owner of the DG unit and the owner of the connecting network both have to consider a number of critical issues in addition to the traditional protection issues for distribution systems, generators and transformers. One of the most influential issues is the coordination of protective devices. The presence of DG tends to affect the protection coordination. Evidently, the short circuit current would be altered due to the contribution of DG, especially the aggregate contributions of several DG sources. The unacceptable operation of protective device may occur. Since the protection coordination will be lost if the fault current flowing through any protective device is changed. Finally, this might lead to the large damage in system and the decrease in system reliability [1].

Traditionally, the coordination can be achieved by topology [2], optimization [3] and intelligent methods [4]. These protection relay coordination relies on standalone units that use local measurements and settings as the basis for most decision-making. Communication plays a very limited role in these legacy systems. In this paper, a new protection coordination architecture based on agent technology is proposed after discussing the impact of distributed generation on power system protection coordination. New protection coordination strategy is also presented. In this work, communication will play an important role to provide more information for the relay coordination besides the relay setting. Communication simulation has been developed that would facilitate information exchange for communication not only between agents such as relay agents and substation management agent, within same agent container, but also within different agent containers

2. DG IMPACT ON DISTRIBUTION NETWORK PROTECTION AND COORDINATION

2.1 Fault Level

In today's distribution networks, distributed generator (DG) from both synchronous and asynchronous machines provides an additional contribution to the fault level. Circuit breaker capability and configuration of protective relays that were previously designed for the system without DGs may not safely manage faults. There may be some operating and planning conditions that are imposed by the fault current interrupting capability of the existing circuit breakers and the protective relay configurations. These situations can result in the safety degradation of the electric power system.

The fault contribution from a single small DG unit is not large, however, the aggregated contributions from many small units, or a few large units, can significantly later the short circuit levels and cause fuse-relay or fuse-fuse miss-coordination. This could affect the reliability and safety of the distribution system [5].

The severity of increasing fault current in the system depends on many factors such as penetration level, impedance of DG, the location of DG and etc. The consequences of increased fault current from proliferation of distributed generator are mainly the change in coordination of protective devices, nuisance trip and recloser settings

2,2 Reverse Power Flow

Radial distribution networks are usually designed for unidirectional power flow, form the infeed downstream to the loads. This assumption is reflected in standard protection schemes with directional over current relays. With a generation on the distribution feeder, the load flow situation may change. If the local production exceeds the local consumption, the power flow will change the direction. Reverse power flow is problematic if it is not considered in the protection system design.

2.3 Islanding

Another new technical issue created by distributed generation (DG) interconnection is inadvertent islanding. Islanding occurs when a portion of the distribution system becomes electrically isolated from the remainder the power system, yet continues to be energized by DG connected to the isolated subsystem. Distribution networks with DG are presently not designed to operate in island mode. If unplanned islanding occurs it presents a number of hazards and thus need to be avoided. The loss-of-mains protection in DG units can be said to serve as anti-islanding protection by tripping the unit when islanding is detected [6].

Although loss of mains protection systems will detect islanding in most cases, there is no system that can guarantee to detect it in all cases. Problems can arise when the islanded part of the network included loads that closely match the output of the distributed generator. It is extremely difficult for loss of mains protection system to detect islanding in this situation. The only way to guarantee loss of mains protection is to provide inter-tripping with Distribution Network Operator's (DNO's) circuit breaker at the primary sub-station. This arrangement means that the generator is automatically disconnected from the DNO's network if the local network becomes disconnected from the grid. Whilst inter-tripping of the generator and its interlocking to prevent reconnection prior to the network

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H. Wan is with the lane department of computer science and electrical engineering of West Virginia University, Morgantown, WV, USA (hui.wan@mail.wvu.edu)

K.P.Wong is with the department of electrical engineering of the The Hong Kong Polytechnic University, Kowloon, Hong Kong (eekpwong@polyu.edu.hk)

C.Y.Chung is with the department of electrical engineering of the Hong Kong Polytechnic University, Kowloon, Hong Kong (C.Y.Chung@inet.polyu.edu.hk)

connection being restored is readily achievable where the generator is close to the DNO primary substation this may not be the case for a remote generator.

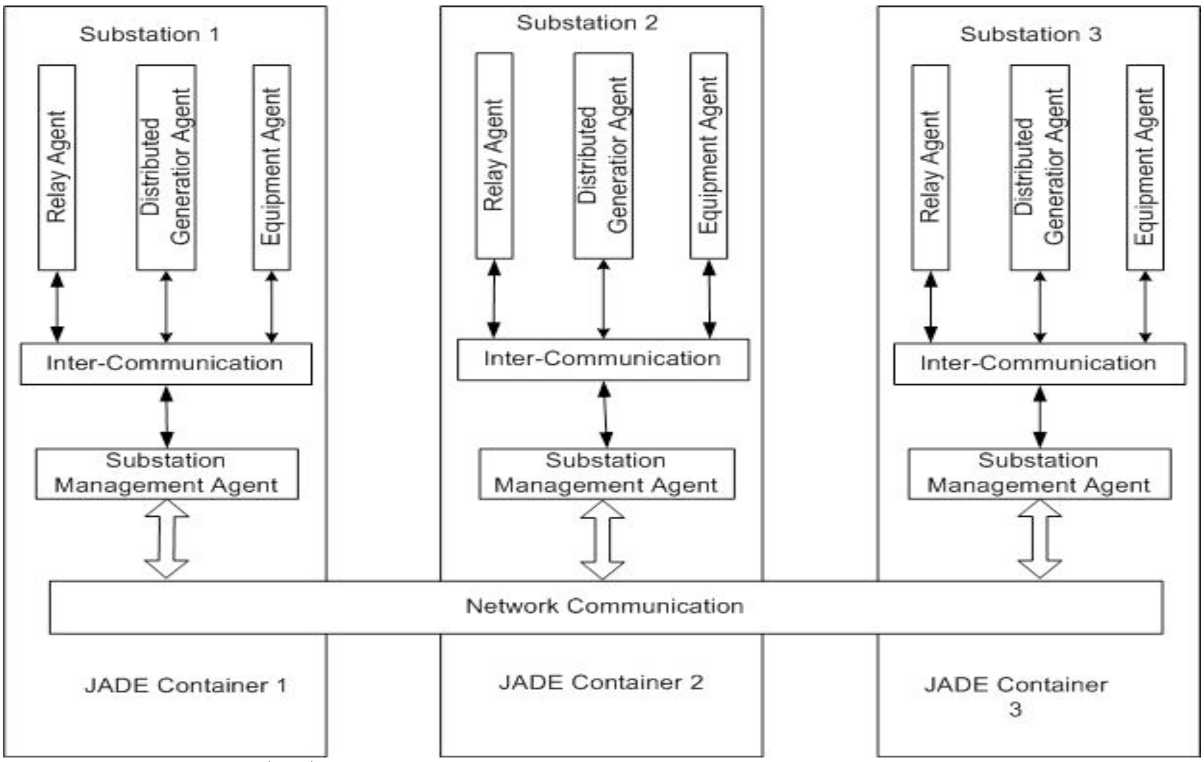
3. MULTI-AGENT PROTECTION COORDINATION ARCHTECURE

In this section, the multi-agent architecture for power system protection coordination is introduced. One substation can be regarded as one Jade (Java Agent Development Framework) agent container. Each container can have a number of agents inside. The Substation Management Agent (SMAG) can achieve the communications between the substations.

3.1 Agent Technology

An agent is a computer system that is capable of autonomous action in this environment in order to meet its design objectives. Autonomy means that the components in an environment function solely under their own control. Agents operate and exist in some environment, which typically is both computational and physical. The environment provides a computation infrastructure for such interactions to take place. The infrastructure includes communication protocol and interaction protocols.

Communication protocol enables agents to exchange and understand messages. A communication protocol might specify that messages for a particular course of action to be exchanged between two agents. The behavior of a multi-agent depends not just on its component agents, but also on how they interact. In a multi-agent system of sufficient complexity, each agent would not only need to be able to do the tasks that arise locally, but would also need to interact effectively with other agents. The communication protocols can be regarded as the specification of these interactions. Protocols are a nice way of enforcing modularity in the design of a multi-agent system. They help in separating the interface between agents from their internal design.



◂▸ : Inter-Communication, ⟺ Network Communication

Fig.3.1. Multi-agent architecture for Distribution Network Protection Coordination

3.2 Agent Architecture for Distribution Network Protection Coordination

The proposed multi-agent protection coordination system, as shown in Fig.3.1, consists of substation management agent, relay agents, distributed generator agents and equipment agents. The agents can communicate with each other not only within the same agent society, but also within different agent societies.

The proposed architecture uses geographically distributed agents located in a number of Intelligent Electronic Devices (IEDs). An IED is a hardware environment that has the necessary computational, communication, and other I/O capabilities needed to support a software agent. The agent takes sensory input, which might include local measurements of the current, voltage, and breaker status, from system, and produces as output actions such as breaker trip signals, adjusting transformer tap settings, and switching signals in capacitor banks.

3.3 Substation Management Agent

Each substation has one substation management agent. Substation management agent plays as the interface between the inside and outside of the substation. Within the substation, the substation management agent collects information, such as DG connection status, breaker status, and etc, which are sent by other agents. And substation management agent will send this information to other substation management agent when needed. Also substation management agent can receive information from other substation management agent. Substation management agent achieves communications between different substations.

3.4 Relay Agent

Each relay installed in the system will be regarded as one relay agent. The relay agent structure is illustrated in Fig.3.2. The relay agent searches for relevant information by communicating with other agents. Its purpose is to detect relay misoperations, breaker failures and DG connection status and perform backup protection with much better performance than can be expected from traditional methods. Coordination strategy will be different under different circumstances. It should also be emphasized that, since the communication is available, relay strategy is the main methodology for the relay function and coordination.

A group of agents that achieve the same relay function can form a small society, such as the over current relay agent society and the differential relay agent society. Each group defines its own relay roles and roles define the relay logic associated with them. When an agent joins a society, it takes up one or more relay roles and acquires the relay logic of that role.

3.5 Distributed Generator Agent

Distributed generator agent takes every single distributed generator as one agent. In protection coordination, distributed generator agent mainly communicates with relay agent in the distribution system to provide connection status of its own for the relay agent to coordinate.

3.6 Equipment Agent

The equipment agent includes CT agent, breaker agent, etc. These distributed equipment collects local power system information, operates the local power system equipment, and communicate information with relay agent to provide protection and coordination function.

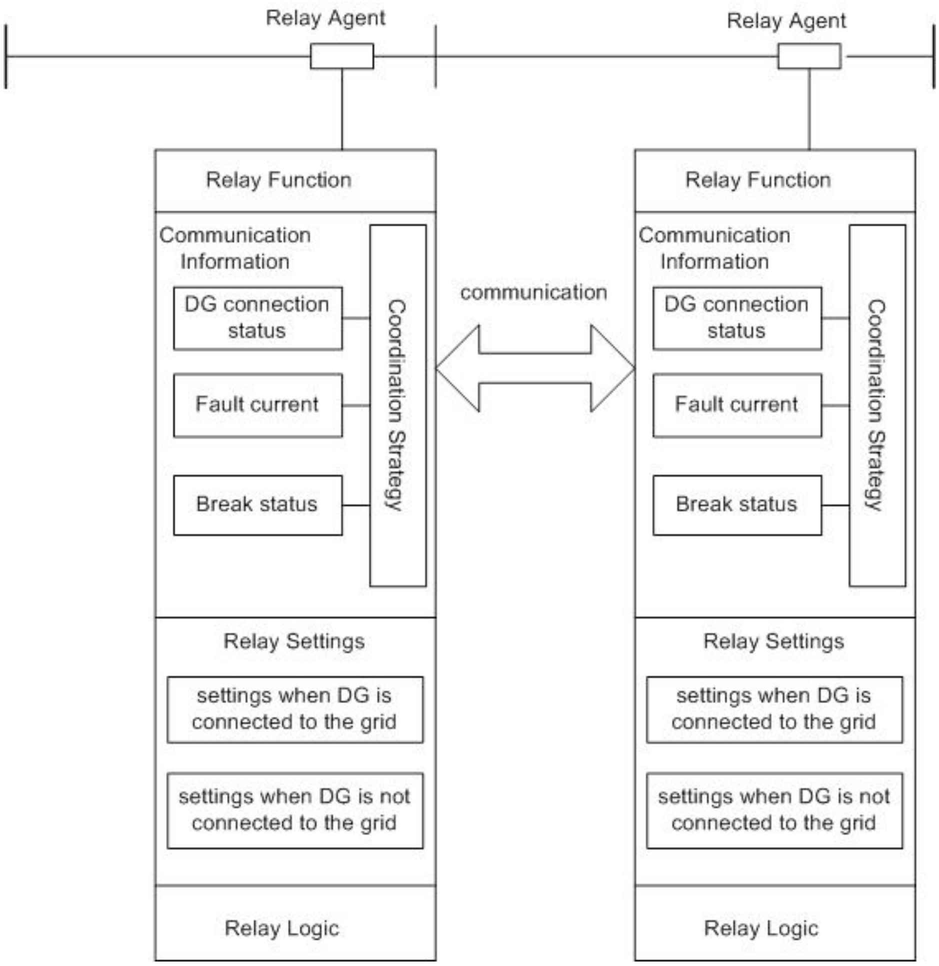


Fig 3.2 Relay Agent Model

4. COMMUNICATION SIMULATION

In order to test the proposed system protection coordination model, stimulation was carried out based on the Java agent Development Framework (JADE) platform[14]. The main purpose of communication stimulation is to make sure the information, which is one of the tripping determination parameters, are exchanged correctly between different agents not only within one JADE container, but also within different JADE containers. The JADE toolkit provides a FIPA-compliant agent platform and a package to development. It is an open source project distributed by TILab (Telecom Italia Labs).

4.1 System Description

Substation 1 and Substation 2 are interconnected at 33KV and are located some 12 miles apart, with each substation having a single 45 MVA 132/33 KV transformer. The incoming 132 KV feeders are both long overhead lines, each approximately 50 miles in length. Historically, the substation 1 was installed to supply the main load center, whilst the substation 2 was installed to provide export capacity for the large hydro power station.

The hydro generator (S2_DG4) was installed before electricity privatization and so has inherited rights to operate unconstrained (system normal). However, the three wind farms were constructed with support from the non-fossil fuel obligation at various times during the 1990's. The 6MW wind farm (S2_DG2) was connected first and was able to operate unconstrained within the available network firm capacity. However, the next generator (S1_DG1) to connect was the 12 MW wind farm. This caused power flows to exceed the firm capacity of the 132KV network and so the first part of the Scheme A inter-trip was introduced. The 3MW wind farm (S2_DG3) was the next to connect and so the Scheme A inter-trip was extended to include this wind farm. More recently, the original 6 MW wind (S2_DG2) increased its capacity to 9MW. This increase caused the power flow in the 33KV interconnecting network to exceed its rating. Thus, the Scheme B inter-trip scheme was introduced and is applied only to the extra 3 MW of generation capacity (S2_DG1).

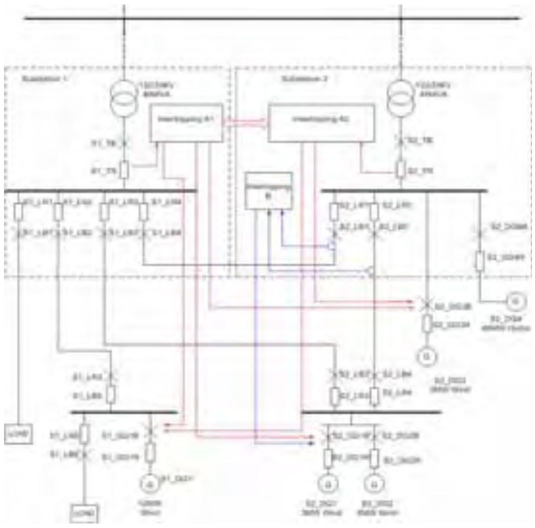


Fig.4.1 Relay Coordination Strategy

4.2 Relay Coordination Strategies

Protection system planning is an indispensable part of an electric power system design. Analysis of fault level, pre-fault condition, and post fault condition are required for selection of interruption devices, protective relays and their coordination.

It can be seen that the local network contains two functional inter-tripping schemes, described here as Scheme A, Scheme B. These two schemes are described in more detail below:

The scheme A inter-trip consists of two independent halves (A1 & A2), triggered by which are monitoring each of the two substation transformers. When substation transformer tripped, S1_DG1, S2_DG1, and S2_DG3 should all be disconnected from the substation to prevent unplanned islanding. The distributed generator intertripping was achieved by the substation management agent of substation to which it connected. The two inter-trip halves are communicated by the two substation management agents.

As an added complication, the power flows through the 33 KV network between generation, which is predominately connected to Substation 2, and the load, which is predominately connected to Substation 1, can cause excessive power flows within the 33 KV network. Hence, the need for the additional inter-trip scheme (Scheme B), monitoring the substation interconnecting circuits.

4.3 Simulation Results

JADE platform is made up of a number of containers that operate on individual machines. Each container can have a number of agents. A JADE system is made by one or more Agent Container; each one located in a separate Java Virtual Machine and communicating using Java RMI (Remote Monitoring Interface)

On the JADE platform, a remote monitoring agent (RMA) provide control of a platform life cycle and all registered agents within platform, acquire information about the platform and execute the GUI (Graphic User Interface). Through the RMA, a sniffer agent, which is a useful debugging tool, can help monitoring and checking the messages exchanged among agents. When the user decides to sniff an agent or a group of agents, every message directed to/from that agent/agent group is tracked and displayed in the Sniffer Agent's GUI. The use can view every message and save it to disk. The user can also save all the tracked messages and reload it from a single file for lager analysis.

TABLE.1.Communication Content

System Statue	Message Sender	Message Receiver	Message Content
Pre Fault	S1_DG1	S1_SMAG	DG connection status, location, etc
	S2_DG1 S2_DG3	S2_SMAG	
Fault Occurred	S2_SMAG	S2_DG1B S2_DG3B	Intertripping Scheme A2
	S2_SMAG	S1_SMAG	Propose to execute intertripping A1
	S1_SMAG	S1_DG1B	Intertripping A1
Post-Fault	S2_DG1B S2_DG3B	S2_SMAG	Breaker status
	S1_DG1B	S1_SMAG	Breaker status
	S1_SMAG	S2_SMAG	Scheme A1 executed

The communication simulation shows both the communications within the substation and between the substations when intertripping scheme A was trigged by transformer relay in substation 2. The communication information has been listed in the table 1. Fig 4.2 shows all the agents that involves in the communication. It can be clearly seen that agents within each substation are all in each container. Fig. 4.3 (a) shows the information track within substation 2 container when intertrip A scheme is applied. The information needed to be communicated in this condition is mainly between the substation management agent (S2_SMAG) and distributed generation agent (S2_DG1 and S2_DG3). Under this situation, the intertripping A2 communication is achieved. One of the messages content can also been seen from this figure. Fig.4.3 (b) shows the information track between two substation containers when intertripping A is applied. The information needed to be communicated in this condition is mainly between two substation management agents (S1_SMAG and S2_SMAG). Under this situation, intertripping A1 communication is achieved. One of the messages content can also been seen from this figure.

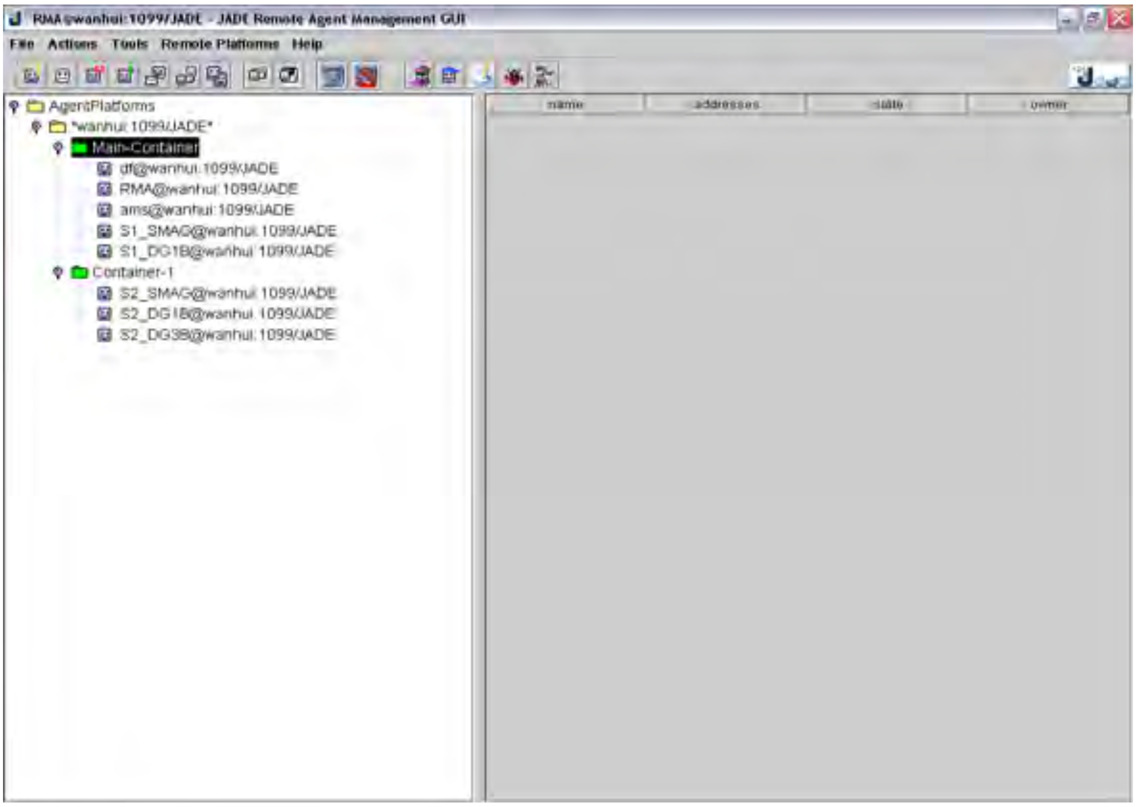


Fig.4.2. Agent list in different containers

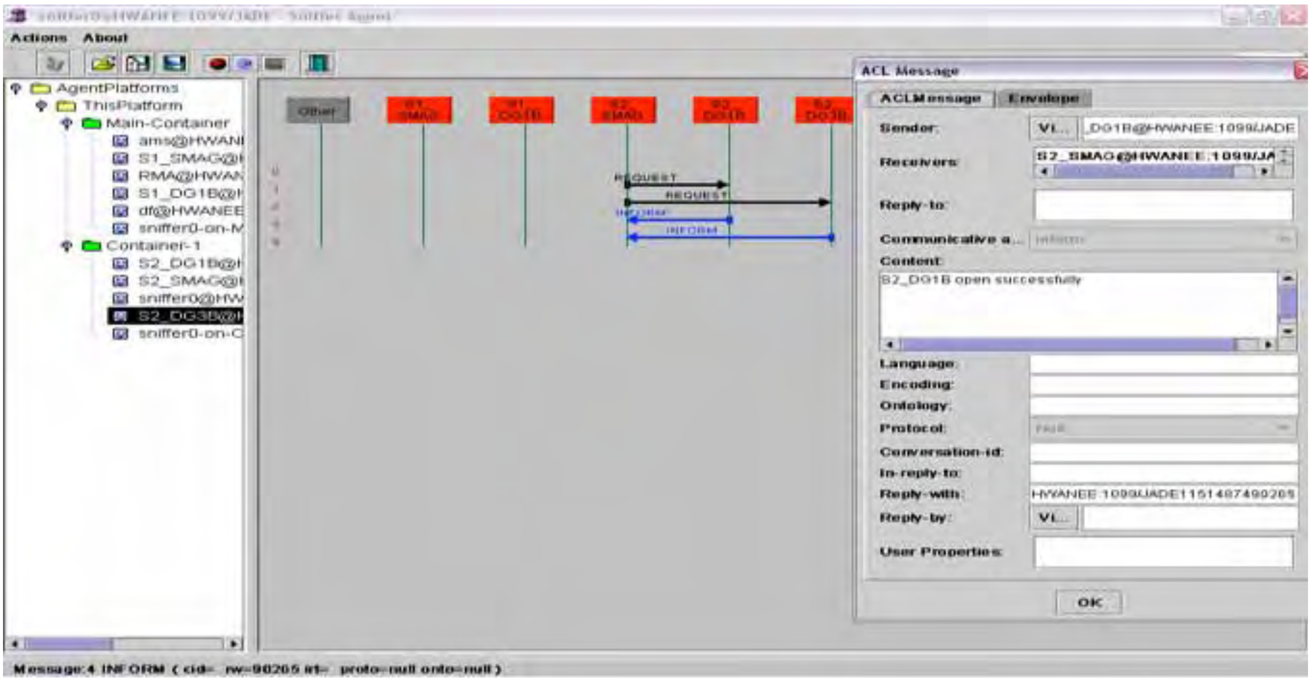


Fig 4.3 (a) Communication information monitoring through sniffer agent within one container

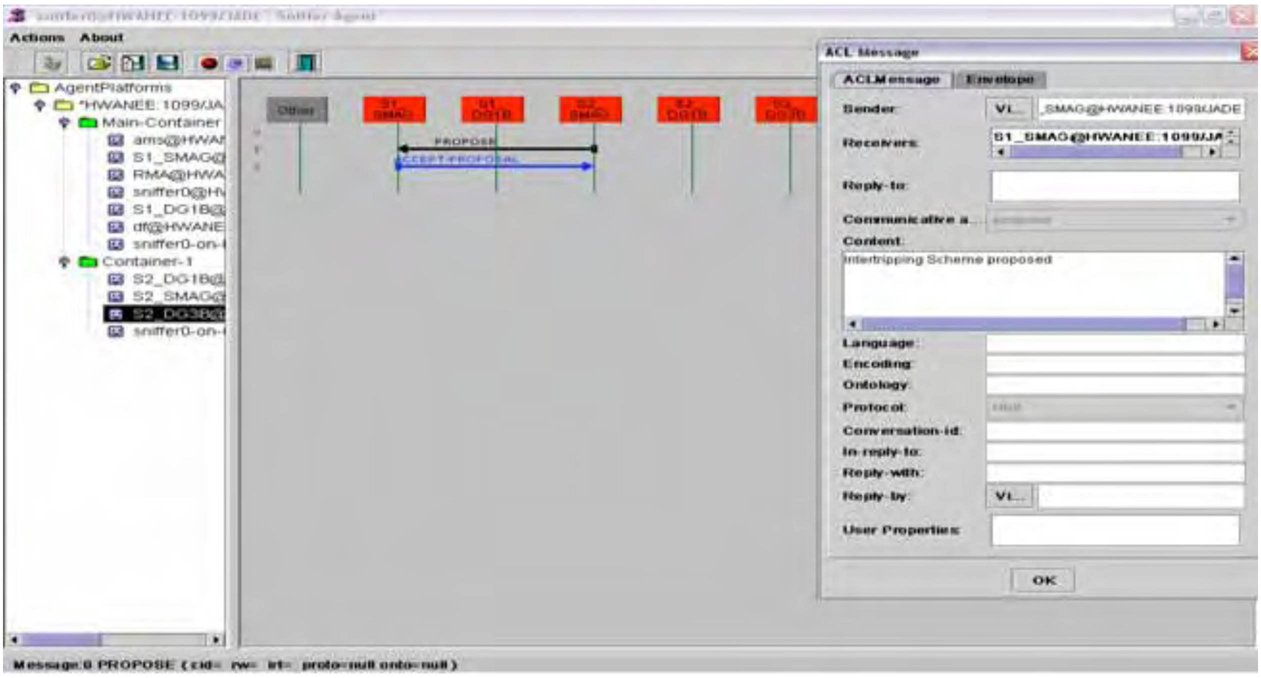


Fig 4.3 (b) Communication information monitoring through sniffer agent between different containers

5. CONCLUSION

In this paper, a multi-agent approach to power system protection coordination has been proposed. The proposed multi-agent system takes the substation as one Jade Agent Container that consists of a substation management agent and a number of relay agents, DG agents and equipment agents. Coordination strategy is embedded both in substation management agent and relay agent to facilitate the relay agents to be coordinated in which pre-fault constraints, fault constraints and post-fault constraints are also taken into account. In the coordination strategy, relay settings and time will not be the only parameters that will decide the relay coordination. Relay agents communicate themselves in the relay society and also with substation management agent, DG agents and equipment agents in order to obtain for a successful coordination. The different substation management agents can also communicate with each other between different

JADE containers. The validity and effectiveness of the proposed multi-agent system have been demonstrated by applying it to an agent-based platform-"JADE". The communication simulation shows that the successful information communication has been achieved not only between agents within one JADE container but also between different JADE containers, indicating that the proposed multi-agent system is a feasible approach in protection coordination.

The agent based relay coordination has the ability to self-check, self-correct, and rapidly acts while achieving highly selective fault regions backup function when either primary protection or circuit breakers fails. The subsequence work to be continued will be to improve the multi-agent system's performance in order for it to cope with protection coordination in a more complex system. Based on the work in this paper, the future work will be directed to expand this approach to handle the relay coordination within different agent platforms.

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7. BIOGRAPHIES

H.Wan (M'07) received the B.S and M.S in electrical engineering from the Southeast University, Nanjing, China in 1999 and 2002 respectively. She got her PhD degree in electrical engineering from the Hong Kong Polytechnic University, Hung Hom, Hong Kong in 2007.

From 2002-2003, she worked in the electrical engineering department as lecturer at University of Shanghai for Science and Technology, China. From 2006-2007, she worked as Research Associate in the electrical engineering department at The Hong Kong Polytechnic University. Currently, she worked as research assistant professor in the lane department of computer science and electrical engineering at West Virginia University, Morgantown, USA. Her research interests include power system protection and control, distributed generation, artificial intelligence application in power system.

K.P. Wong (M'87-SM'90-F'02) obtained M.Sc and Ph.D. degrees from the University of Manchester, Institute of Science and Technology, UK in 1972 and 1974, respectively. Prof. Wong was awarded a higher doctorate DEng degree by UMIST in 2001. Prof. Wong is currently Chair Professor of the Department of Electrical Engineering, Hong Kong Polytechnic University. He was Guest Professor at Tsinghun University, Beijing, China and is Guest Professor at Southeast University, Nanjing, China. Prof. Wong was a Professor at the University of Western Australia. During this period he received three Sir John Madsen Medals (1981, 1982 and 1988) from the Institute of Engineers Australia, the 1999 Outstanding Engineer Award from the IEEE Power Chapter Western Australia and the 2000 IEEE Third Millennium Award. Professor Wong has published numerous research papers in power systems and on the applications of artificial intelligence and evolutionary computation to power system planning and operations. His current research interests include evolutionary optimization in power, power market analysis, power system planning and operation in the deregulated environment, and power quality. Professor Wong has served as Editor in Chief for IEE Proceedings Generation, Transmission and Distribution. He was the Conference Chair of IEEE/CSEE PowerCon 2000. He is a Fellow of IEEE, IEE, HKIE and IEAust.

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6. Use of the Slip-Ring Induction Machine for Distributed Generation

Associate Professor Tze-Fun CHAN, Hong Kong Polytechnic University, Hong Kong
Professor Loi Lei LAI, City University London, UK.

Abstract**—** The use of slip-ring induction machines for isolated distributed generation is investigated. By varying the effective rotor resistance of a self-excited slip-ring induction generator (SESRIG), the magnitude and frequency of the output voltage can be controlled under variable-speed operation. Analysis of a SESRIG supplying isolated single-phase loads is presented. Practical implementation using a chopper-controlled rotor resistance is discussed. Operation of the slip-ring induction machine as a series-connected synchronous generator (SCSG) is briefly described.

Index Terms**—**Slip-ring induction machine, induction generators, distributed generation.

1. INTRODUCTION

Over the past few decades, there has been an increasing use of squirrel-cage-type self-excited induction generators (SEIGs) for distributed generation, particularly in wind energy systems and micro-hydro power systems. Due to the distributed nature of the energy resources, these power systems are usually small scale in terms of rating. They may not be as efficient as bulk power systems, but this disadvantage is offset by the reduction or even elimination of the transmission losses over long distances. Unlike induction generators connected to the power utility grid, both the frequency and the terminal voltage of the SEIG vary with load even when the rotor speed is maintained constant. An increase in the rotor speed will result in a proportionate increase in frequency, often accompanied by severe over voltage and excessive current. Recently, there has been rigorous research on the voltage and frequency control of squirrel-cage type SEIGs [4]-[8], but relatively little research efforts have been devoted to the use of the slip-ring induction machine for generator applications. Although the slip-ring machine is more expensive and requires more maintenance, it permits rotor slip-power control when driven by a variable-speed turbine. When a grid connection is permissible, the slip-ring machine may be operated as a double-output induction generator (DOIG) using the slip-energy recovery technique [9]. In the case of a self-excited slip-ring induction generator (SESRIG), the system cost can be further reduced by the use of a simple rotor resistance controller [10], [11]. Since only a capacitor bank need to be connected to the stator terminals, the SESRIG provides a good quality a.c. source with little harmonic distortion to the stator load. Another advantageous feature of the SESRIG is that independent control of the voltage and frequency can be achieved easily. Even with a wide variation in speed, the generator frequency can be maintained reasonably constant by rotor resistance control, while varying the excitation capacitance can control the voltage. The rating of the rotor resistance controller is small compared with the generator rating, hence the cost saving is quite significant.

This paper discusses the use of the slip-ring induction machines for distributed generation. Attention is focused on the standalone mode of operation. Since the machine is operated in the self-excited mode, it will be referred to as self-excited slip-ring induction generator (SESRIG) in this paper. Both three-phase and single-phase loads are considered.

2. SESRIG SUPPLYING THREE-PHASE LOADS

Fig. 1 shows the circuit arrangement of a three-phase SESRIG [12]. The excitation capacitance C is required for initiating voltage build-up and maintaining the output voltage. It is noticed that the electrical output power is dissipated in both the stator impedance Z_L as well as the external rotor resistance R_x; hence the machine may also be regarded as a DOIG if the power in R_x is effectively utilized. By varying R_x with the rotor speed, both voltage and frequency control of the SESRIG may be achieved.

Fig. 2 shows the per-phase equivalent circuit of the SESRIG, where the rotor resistance R_2 is the sum of the rotor winding resistance and the external rotor resistance, both referred to the stator side. The circuit has been normalized to the base (rated) frequency through the introduction of the per-unit frequency a and the per-unit speed b [13].

For convenience, the conductance $G_e = G_t + G_m$ is introduced, where G_t and G_m are the conductanc of branches Y_t and Y_m in Fig. 2. For a specified value of a, G_e is a constant when the excitation capacitanc and load resistance are both constant.

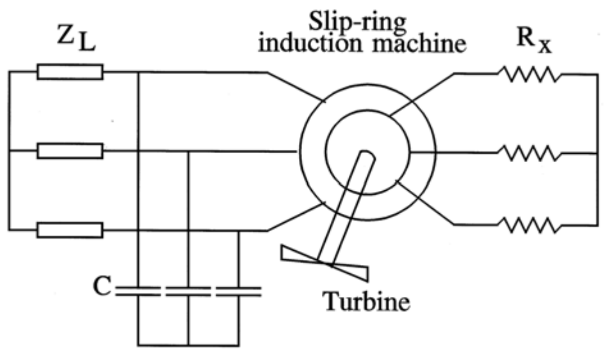

Fig. 1. Self-excited slip-ring induction generator.

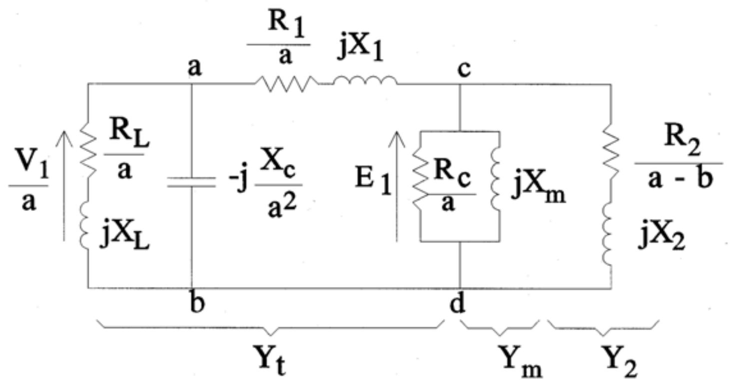

Fig. 2. Equivalent circuit of SESRIG.

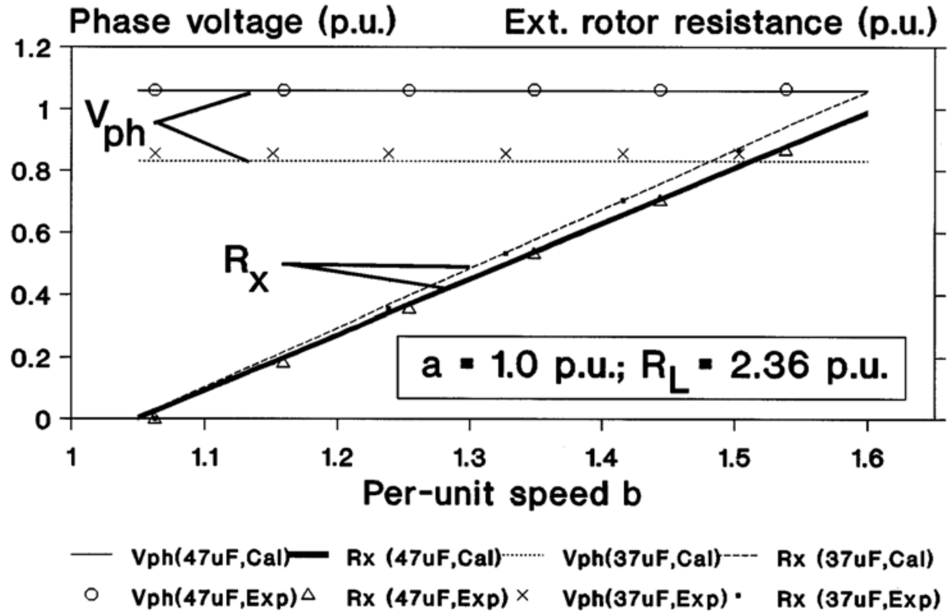

Fig. 3. External rotor resistance R_x for the SESRIG to operate at rated frequency and the corresponding variation of stator phase voltage.

It can be shown that

$$\frac{R_2}{a-b} = \frac{-1-\sqrt{1-4G_e^2X_2^2}}{2G_e}\ . \qquad (1$$

and

$$\frac{1}{X_m} = B_t - \frac{2G_e^2X_2}{1+\sqrt{1-4G_e^2X_2^2}}\ . \qquad (2$$

Eqn. (1) shows that the total rotor circuit resistance should be varied linearly with the per-unit speed b in order to control the frequency at a given value, while (2) implies that, for a given per-unit frequency a, excitation capacitance and load resistance, the magnetizing reactance X_m of the SESRIG, and hence the air gap voltage, is independent of the rotor speed. It follows therefore that both the stator current and terminal voltage are constant.

To achieve higher system efficiency, it is important that the power dissipated in R_x be fully utilized. If R takes the form of resistive heater elements, the slip power could conveniently be used for storage heatin which is a common load in an autonomous power system. The total power output of the SESRIG is then th sum of the stator load power and the power consumed by R_x.

When the stator load is variable, the capacitance also needs to be controlled in order to maintain both constant frequency and constant voltage [12].

3. SESRIG SUPPLYING SINGLE-PHASE LOADS

Single-phase loads can be supplied from a three-phase SEIG. A typical phase-balancing scheme is based on the Steinmetz connection in which two capacitors are employed both for sustaining self-excitation as well as achieving perfect phase balance in a cage-type SEIG [14]-[16]. In these studies, emphasis has been on generator operation at constant rotor speed with minimum phase imbalance. As shown in Fig. 4(a), the main excitation capacitance C_2 is connected across phase B (the lagging phase), while the auxiliary excitation capacitance C_1 and the load resistance R_{L1} are connected across phase A (the reference phase). Each phase of the rotor winding is assumed to be connected to an external resistance R_x, as shown in Fig. 4(b). It can be shown that if $C_2 = 2C_1$, perfect phase balance could be achieved in the SESRIG for some value of load resistance [16].

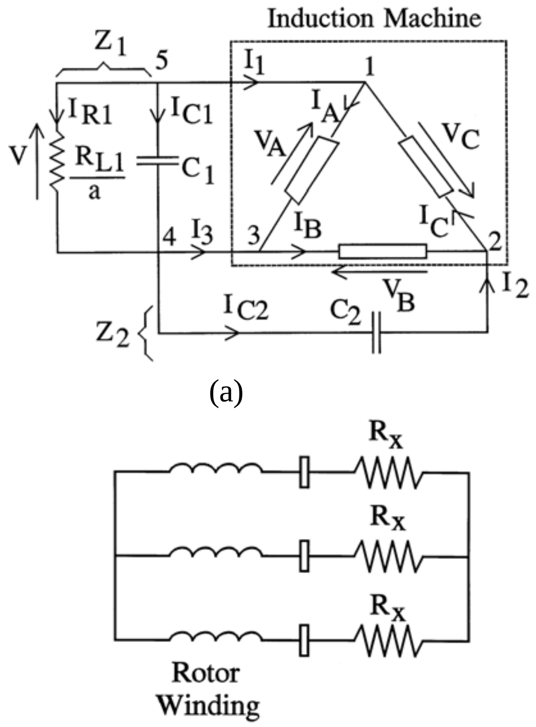

Fig. 4. Single-phase operation of a three-phase SESRIG: (a) stator winding connection; (b) rotor connection with external resistance.

For the purpose of analysis, all the circuit parameters in Fig. 4(a) have been referred to the base (rated) frequency f_{base} by introducing the per-unit frequency *a* and the per-unit speed *b* [13]. Thus, each voltage shown in Fig. 4(a) has to be multiplied by *a* in order to give the actual value and the per-unit slip is equal to $(a - b)/a$. Besides, the motor convention has been adopted for the direction of phase and line currents.

3.1 . Steady-State Analysis

A general analysis of the single-phase SESRIG can be carried out using the method of symmetrical components. All the equivalent circuit parameters are assumed to be constant except the magnetizing reactance that is a function of the positive-sequence air gap voltage. With reference to Fig. 4, the following 'inspection equations' [16] may be written:

$$V = V_A \tag{3}$$

$$V_A + V_B + V_C = 0 \tag{4}$$

$$I_1 = I_A - I_C = -\frac{V}{Z_1} = -VY_1 \tag{5}$$

$$I_2 = \frac{V_B}{Z_2} = V_B Y_2 \tag{6}$$

where

$$Y_1 = \frac{1}{Z_1} = G_1 + jB_1 = \frac{a}{R_{L1}} + ja^2.2\pi f_{base}.C_1 \quad (7)$$

and

$$Y_2 = ja^2.2\pi f_{base}.C_2 \ . \quad (8)$$

Equation (4) implies that zero-sequence voltages and currents are absent in the single-phase SESRIG. By solving (3) to (6) in terms of the delta system of symmetrical components, the positive-sequence voltage V_p and negative-sequence voltage V_n can be determined:

$$V_p = \sqrt{3}V \ . \frac{Y_n + \frac{e^{j\pi/6}}{\sqrt{3}} Y_2}{Y_2 + Y_p + Y_n} \quad (9)$$

$$V_n = \sqrt{3}V \ . \frac{Y_p + \frac{e^{-j\pi/6}}{\sqrt{3}} Y_2}{Y_2 + Y_p + Y_n} \quad (10)$$

where Y_p and Y_n are the positive-sequence and negative-sequence admittances of the SESRIG.

A measure of the phase imbalance is given by the voltage unbalance factor (VUF), which is defined as the scalar ratio of V_n to V_p. The VUF can readily be computed from (9) and (10).

The input impedance Z_{in} of the SESRIG when viewed across stator terminals 1 and 3 (Fig. 4(a)) is given by

$$Z_{in} = R_{in} + jX_m = \frac{Y_2 + Y_p + Y_n}{3Y_pY_n + Y_pY_2 + Y_nY_2} \ . \quad (11)$$

Applying Kirchhoff's voltage law to loop 1345 in Fig. 1,

$$I_1 \, (Z_1 + Z_{in}) = 0 \, . \quad (12)$$

For successful voltage build-up, $I_1 \neq 0$; hence

$$Z_1 + Z_{in} = 0 \, . \quad (13)$$

For a given per-unit speed b and a given set of excitation capacitances, Z_{in} is a highly nonlinear function of a and X_m, implying that (13) is a complex equation in these two variables. To avoid lengthy mathematical manipulations, the solution of (13) is formulated as the following optimization problem:

Minimize $Z\,(a\,,X_m) = \left| Z_1 + Z_{in} \right|,$ (14)

subject to the constraints:

$$0 < a < b \, ,$$

and $0 < X_m < X_{mu}$

where X_{mu} is the unsaturated value of the magnetizing reactance.

Equation (13) is satisfied when the scalar impedance function $Z(a, X_m)$ given by (14) assumes a minimum value of zero. For function minimization, a classical search algorithm such as the Hooke and Jeeves method [17].

After a and X_m have been determined, the positive-sequence air gap voltage, and hence V_p, is found from the magnetization curve. The generator performance can then be computed using (3) to (10).

3.2 Variable-Speed Operation of Single-Phase SESRIG

In this paper, the computed and experimental results refer to a 3-phase, 4-pole, 50-Hz, 380-V, 4.5-A, 1.8-kW, delta/star connected slip-ring induction machine whose per-unit equivalent circuit constants are given in the Appendix. It was found that, with the slip ring short-circuited, perfect phase balance in the SESRIG was obtained at approximately rated speed with C_1 = 60 μF, C_2 = 120 μF and a load resistance of 0.67 p.u. These values were kept constant in the subsequent performance evaluation.

Fig. 5 and Fig. 6, show, respectively, the stator load voltage and per-unit frequency variations with the per-unit rotor speed b for various values of R_x. It is noticed that increasing R_x causes the voltage and frequency characteristics to be displaced to the right along the speed axis. This implies that the SESRIG can be operated at higher speeds without over voltage and excess frequency if a higher value of R_x is inserted into the rotor circuit.

Fig. 7 shows the variation of phase and line currents of the single-phase SESRIG with slip rings short-circuited. Despite the variation in rotor speed, the phase imbalance is very small. The results indicate that once the proper values of phase-balancing capacitances and load resistance have been selected, the phase imbalance is not sensitive to the variation in rotor speed. This is confirmed by the VUF characteristics shown in Fig. 8. For a given value of R_x, the variation of VUF with speed is a V-shaped curve, the minimum value occurring when the SESRIG is balanced. Over a wide speed range, the VUF is less than 0.05. Increasing R_x also results in a rightward shift of the VUF characteristic, i.e. perfect phase balance will occur at higher speeds.

Very good agreement between the computed and experimental results is observed in Fig. 5 to Fig. 8, confirming the validity of the method of analysis.

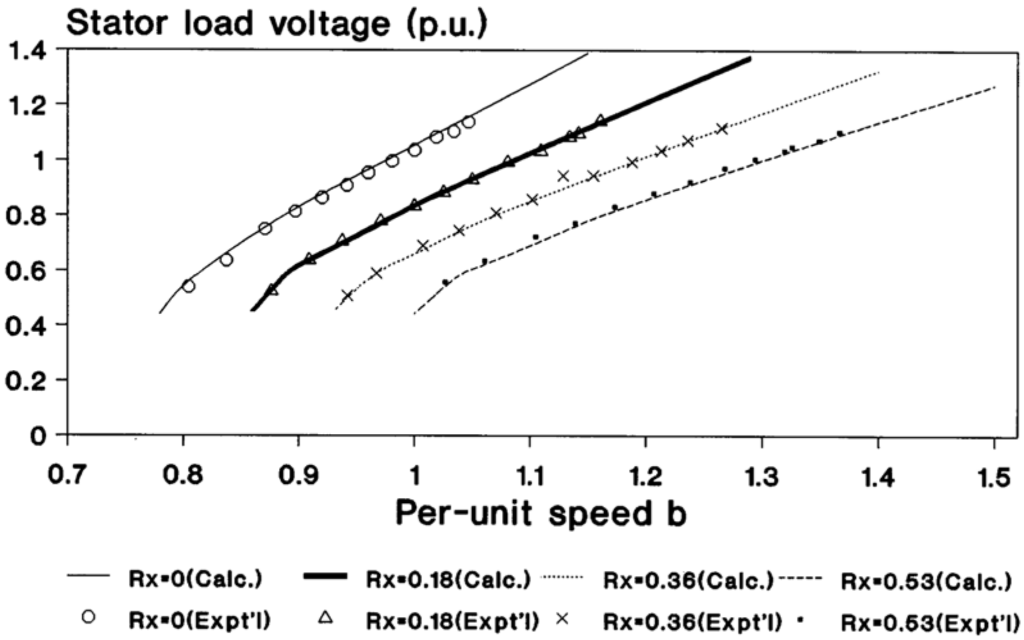

Fig. 5. Variation of stator terminal voltage with speed.

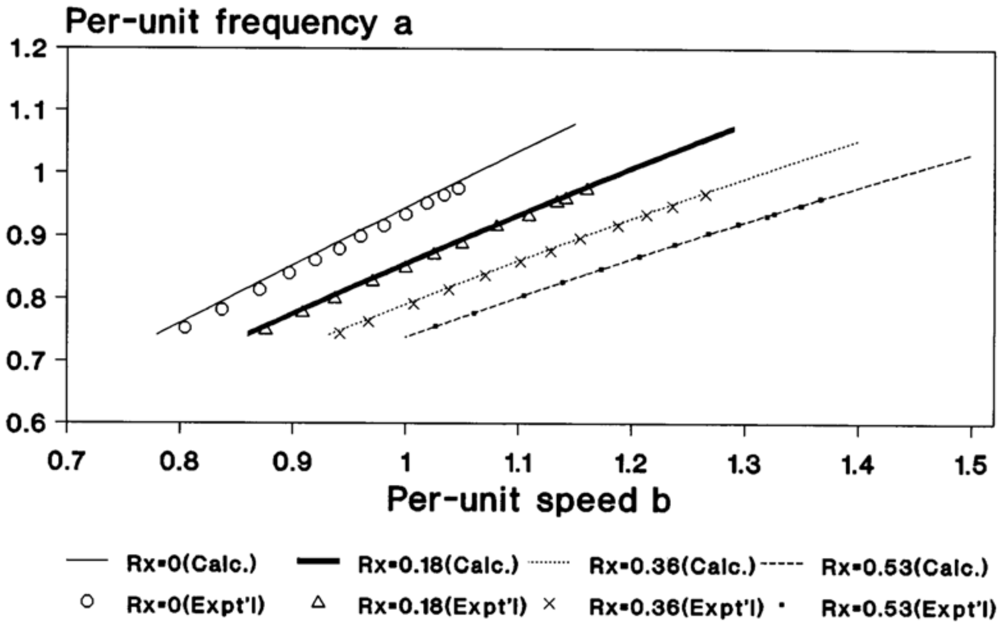

Fig. 6. Variation of per-unit frequency with speed.

3.3 Voltage and Frequency Control

The results obtained in Section III*B* suggest the possibility of controlling the voltage and frequency of the SESRIG under variable-speed operation by varying the rotor resistance R_x. From the circuit viewpoint, the positive-sequence impedance Z_p of the SESRIG is

$$Z_p = Z_s + Z_m // Z_{rf} \tag{15}$$

where Z_s = stator leakage impedance, Z_m = magnetizing impedance, and Z_{rf} is the positive-sequence rotor circuit impedance.

$$Z_{rf} = \frac{R_{rf}}{a-b} + jX_r \tag{16}$$

In (16), R_{rf} is the sum of the rotor winding resistance R_r and the external rotor resistance R_x.

If the rotor circuit resistance R_{rf} is varied as the per-unit speed *b* changes so that Rrf /(*a*–*b*) is constant, Zrf, and hence Z_p, will remain invariant. Solution of (13) will therefore yield approximately the same values of *a* and X_m. This implies that both the output voltage and frequency will be approximately constant. Rotor resistance control thus provides an economical method for regulating the voltage and frequency.

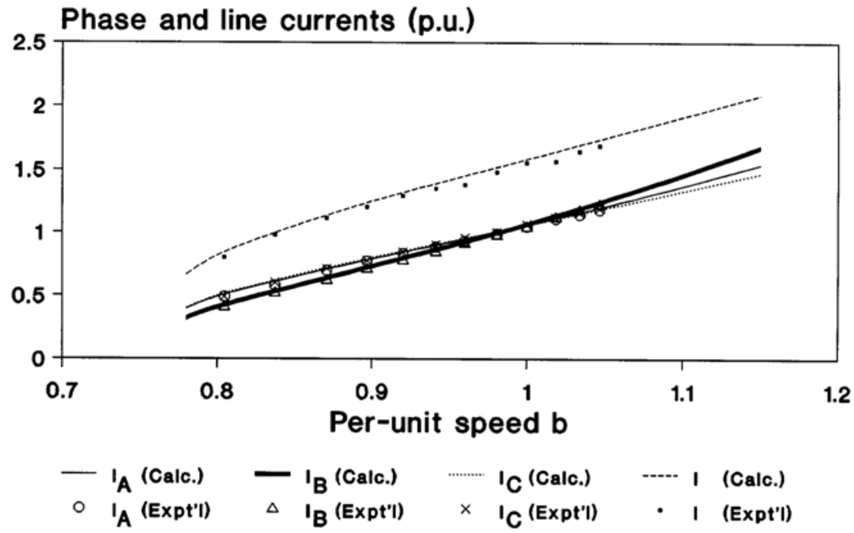

Fig. 7. Variation of phase and line currents with speed, $R_x = 0$.

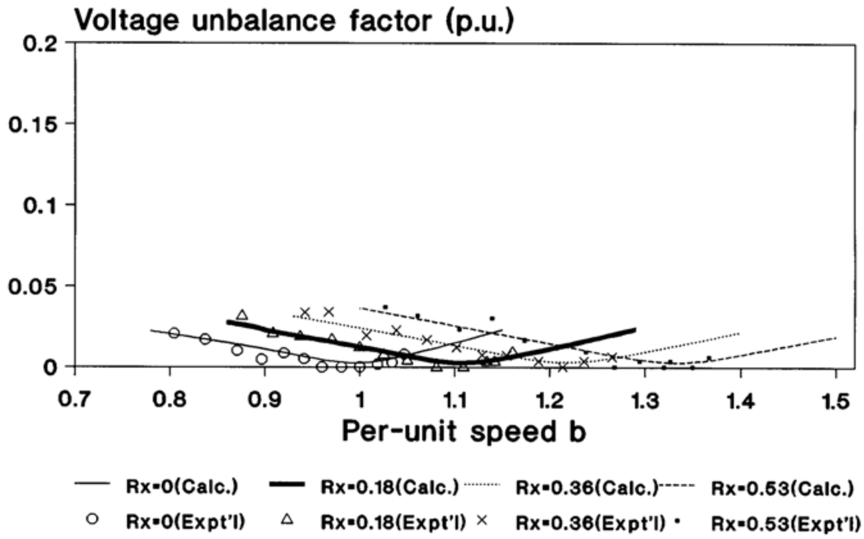

Fig. 8. Variation of voltage unbalance factor (VUF) with speed.

Furthermore, the power dissipated in R_x may be considered as part of the power output if it is properly utilized, for example, in storage heating or battery charging applications. The total power that the single-phase SESRIG can supply therefore increases with speed, resulting in better winding utilization and higher overall generator efficiency.

Fig. 9 shows the computed variation of R_x to give a constant output frequency and voltage at different speeds. It is noticed that an approximately linear variation of R_x with b results in the single-phase SESRIG operating at a constant voltage and frequency. For an output voltage of 0.8 p.u., the frequency may be maintained constant at 0.82 p.u. for $b > 0.89$ p.u. Higher operating voltage will demand progressively higher rotor speeds and the output frequency will be maintained constant at higher values. It should be noted that the maximum operating speed is limited only by mechanical considerations and/or the voltage rating of the rotor winding.

Fig. 10 shows the efficiency characteristics of the single-phase SESRIG with different values of R_x. Fig. 11 shows the variation of stator-to-rotor power ratios with speed. At larger values of R_x, the proportion of power dissipated in R_x increases and can be a significant portion of the total input mechanical power.

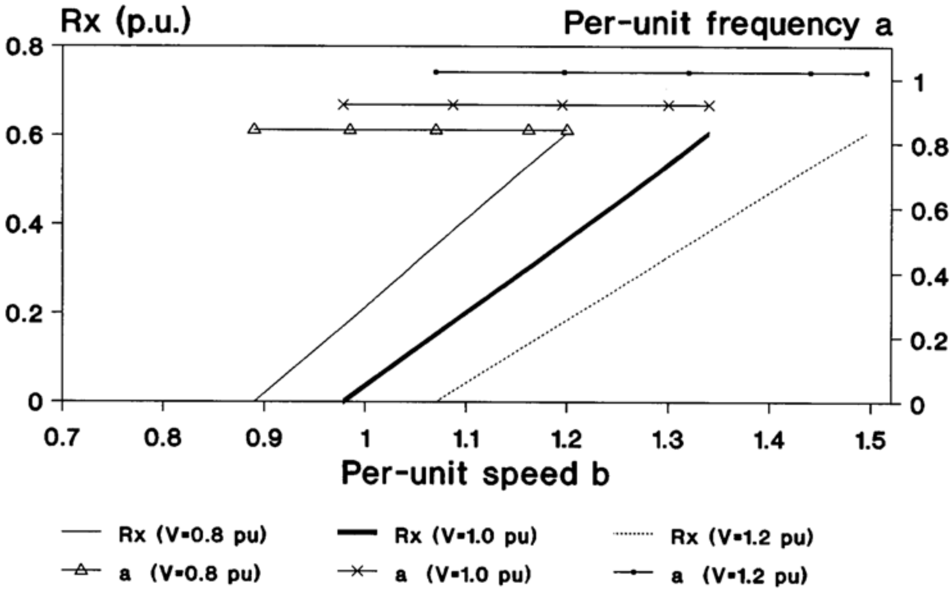

Fig. 9. Variation of R_x with speed to give constant output voltage and the corresponding stator frequency characteristic.

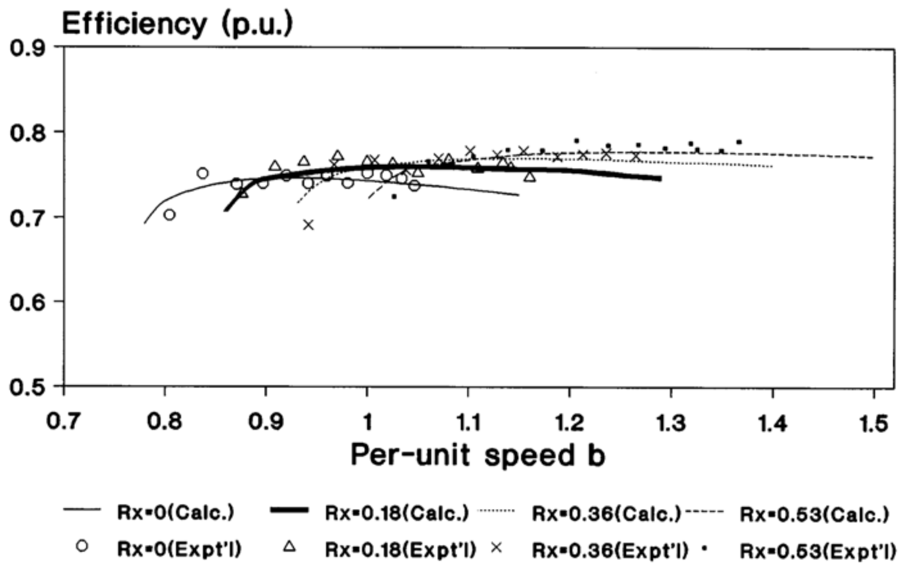

Fig. 10 Efficiency of SESRIG with different values of R_x.

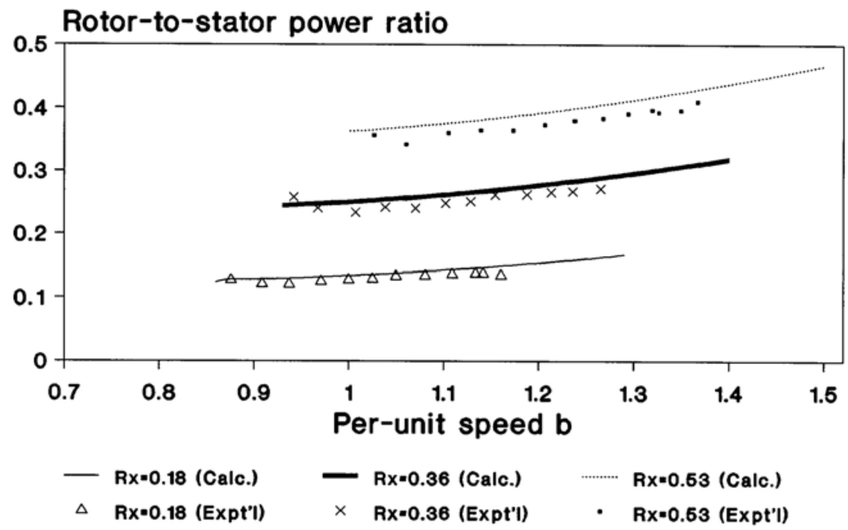

Fig. 11. Ratio of stator and rotor power outputs of SESRIG.

4. Practical Implementation

It is desirable to have automatic control of the voltage and frequency when either the stator load impedance or the rotor speed changes. Instead of a variable three-phase rotor resistance, a chopper-controlled external resistance may be employed, as illustrated in Fig. 12 for a SESRIG supplying three-phase loads. Assuming that the diodes in the rotor bridge rectifier are ideal and the choke is loss less, the effective external resistance per phase R_x in the rotor circuit, referred to the stator winding, is given by [18]:

$$R_x = 0.5a_t^2(1-\alpha)R_{dc}. \tag{17}$$

where

R_{dc} d.c. resistance across the chopper;
α duty cycle of the chopper;
a_t stator / rotor turns ratio.

A reduction in the duty cycle α of the chopper results in an increase in the effective rotor resistance of the SESRIG. A variable external resistance is thus presented to the rotor circuit. A simple feedback circuit can be implemented to realize closed control of the voltage and frequency. Studies on a prototype controller have shown that the voltage can be maintained constant, while the frequency change after load or speed changes is less than 0.1 Hz with a nominal frequency of 50 Hz [12].

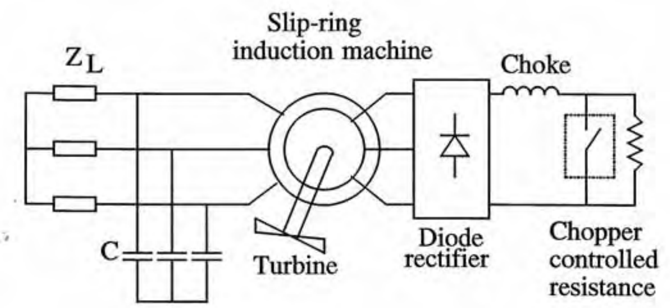

Fig. 12. SESRIG with chopper-controlled rotor external resistance.

5. Series-Connected Synchronous Generator

Besides being operated as an SEIG, a slip-ring induction machine can also be configured to operate in the synchronous mode, i.e. the frequency of the output voltage is directly proportional to the rotor speed. A machine configuration that is suitable for operation at very high speeds is the series-connected self-excited synchronous generator (SCSG) [19] reported by Mohamadein *et al.* In this machine, the rotor phase windings of a slip-ring induction machine is connected in series with the stator phase windings but with the sequence of two phases reversed. When a sufficiently large capacitance is connected across the stator terminals the machine will self-excite at a frequency that is one-half the angular frequency of the synchronous speed. The generator has high power density for a given frame size since both the stator and rotor are involved in energy conversion. Except for constancy of frequency, the electrical performance of the SCSG is quite similar to the SEIG. When driven at a given speed, the output voltage decreases with load current and there is a maximum load current that the generator can deliver. Steady state and transient analysis of the SCSG was investigated by Mohamadein *et al.* [19], [20].

6. CONCLUSION

This paper has shown that the slip-ring induction machine is suitable for distributed generation, particularly in supplying isolated loads. The performance of the SESRIG when supplying three-phase and single-phase loads is studied. Rotor resistance control enables the voltage and frequency to be controlled despite large variations in the rotor speed. Compared with slip-power recovery schemes using inverters, chopper-controlled rotor resistance has the advantage of lower cost and simpler circuit design. The series-connected synchronous generator (SCSG) that employs a slip-ring induction machine has a high power density, suitable for operation at high speeds.

7. APPENDIX

The experimental SESRIG has the following equivalent-circuit data:

Stator resistance R_s = 0.0597 p.u.
Stator leakage reactance X_s = 0.118 p.u.
Rotor resistance R_r = 0.0982 p.u.
Rotor leakage reactance X_r = 0.118 p.u.
Core loss resistance R_c = 31p.u.

The magnetization curve (plot of E_1 versus X_m) is represented by the following describing equations:

$$E_1 = \begin{cases} 1.4613 - 0.3327X_m, & X_m < 1.7728 \\ 1.5294 - 0.3711X_m, & 1.7728 \le X_m < 2.045 \\ 3.0455 - 1.1125X_m, & 2.045 \le X_m < 2.213 \\ 185.1 - 83.37X_m, & 2.213 \le X_m < 2.22 \\ 0, & 2.22 \le X_m \end{cases} \cdot \tag{18}$$

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BIOGRAPHIES

T. F. Chan (M '95) received the B.Sc. (Eng.) and M.Phil. Degrees in electrical engineering from the University of Hong Kong, Hong Kong, China, in 1974 and 1980, respectively. He received the PhD degree in electrical engineering from City University, London, UK, in 2005. Currently, Dr. Chan is an Associate Professor at the Department of Electrical Engineering, the Hong Kong Polytechnic University, Hong Kong, China, where he has been since 1978. His research interests are self-excited a.c. generators, brush less a.c. generators, and permanent-magnet machines. In June 2006, he was awarded a Prize Paper by IEEE Power Engineering Society Power Generation and Energy Development Committee.

L. L. Lai (SM'92, F'07) received the B.Sc. (First Class Honors) and the Ph.D. degrees from the University of Aston in Birmingham, UK, in 1980 and 1984, respectively. In 2005, he was also awarded a D.Sc. degree by City University, London, UK.

Currently he is the Head of Energy Systems Group at City University, London, UK. He is a Visiting Professor at Southeast University, Nanjing, China and also a Guest Professor, Fudan University, Shanghai, China. He has authored/co-authored over 200 technical papers. He is the author of the book *Intelligent System Applications in Power Engineering—Evolutionary Programming and Neural Networks* and the editor of *Power System Restructuring and Deregulation—Trading, Performance and Information Technology*. His professional activities include his contributions to several international conferences in power engineering and evolutionary computing,

Dr. Lai was awarded the IEEE Third Millennium Medal, 2000 IEEE Power Engineering Society UKRI Chapter Outstanding Engineer Award and 2003 IEEE Power Engineering Society Outstanding Large Chapter Award. In June 2006, he was awarded a Prize Paper by IEEE Power Engineering Society Power Generation and Energy Development Committee. He was the Conference Chair of the IEEE/IEE International Conference on Power Utility Deregulation, Restructuring and Power Technologies 2000. In 1995, he received a high-quality paper prize from the International Association of Desalination, USA.

Paper Invited Discusser

7. Distributed Generation Protecting Micro-grids (Invited Discusser)

Professor Tianshu BI, Director, Si Fang Research Institute, China

Discussion pending.

Received 1 February 2008
Paper 08GM0434

8. Energy Storage Systems in Distributed Generation Schemes

SS Choi, *Member, IEEE*, KJ Tseng, *Senior Member, IEEE*, DM Vilathgamuwa, *Senior Member, IEEE*, and TD Nguyen

Abstract- An overview is given of the various energy storage technologies that can be used in distributed generation (DG) schemes. Description of the recent photovoltaic DG initiative in Singapore is included, in which several of the storage systems can find ready applications. Schemes pertaining to the use of solid oxide fuel cell for power quality enhancement and battery energy storage system used in conjunction with wind power generation are also described.

Index Terms- Distributed Generation, Energy Storage System.

1. INTRODUCTION

Due to the concern for the environment and on energy supply security, electricity productions based on green/clean fuel sources have become increasingly important. If possible, it will be attractive to site generation electrically closer to demands, in the form of distributed generation (DG). Amongst the DG, wind turbines and photovoltaic power plants of several megawatts apiece have also seen commercial operations in many parts of the world in recent years. Moderate and small-scale power generation are even more numerous.

Renewable DG systems are often grid-connected. Unfortunately the intermittence and unpredictable nature of the wind or solar power make the successful integration of the DG schemes a challenging task. Technical concern centered on the impacts of DG on network system security and reliability. In this connection, the use of energy storage systems (ESS) has been identified as an effective method to mitigate the negative impacts of DG [1, 2, 7]. Based on the variety of applications, ESS can be classified for Power Quality, Bridging Power or Energy Management purposes.

In this paper, firstly a brief review of the various ESS technologies will be given in Section II. Examples of the design of energy storage schemes to serve one of the three applications will then be described in Sections III - V. These include the recent photo-voltaic DG initiative in Singapore where ESS can be expected to provide effective energy management; the case of fuel cell to help increase voltage disturbance ride-through capability of sensitive loads; and the use of battery in wind farm for load tracking purpose.

The authors are with the Center for Smart Energy Systems, School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore. (Emails: esschoi@ntu.edu.sg,; ekjtseng@ntu.edu.sg,;emahinda@ntu.edu.sg; T.D.Nguyen@pmail.ntu.edu.sg.)

2. SOME SELECTED ENERGY STORAGE SYSTEMS

2.1 Battery Energy Storage System (BESS)

A battery stores potential energy through the chemical reactions of its electrochemical components. Charging a battery causes reactions in the compounds that then store the energy in a chemical form. Upon demand, reverse chemical reactions cause electricity to flow out of the battery and back to the grid. Quick response is one of the battery technology's strong points: some batteries can respond to load changes in about 20 milliseconds. The efficiency of battery modules is in the 60 - 80% range, depending on how often they are cycled and the types of electrochemical used [2, 3]. Most battery technologies are optimized for either power or energy, but not both. Furthermore, batteries designed for high power often cannot provide the repeated charge/discharge cycles that are required in many energy storage applications.

Examples of possible applications of BESS in conjunction with DG will be described in Sections III and V.

2.2 Compressed Air Energy Storage (CAES)

This scheme makes use of a compressor that uses off-peak energy to compress air and store the compressed air at high pressure (typically around 75 bar) in an air reservoir (i.e., an aquifer, natural caverns, or mechanically formed caverns, etc.). During discharges at peak loads, the compressed air is released to a combustor where the compressed air is mixed with oil or gas driving a gas turbine to create electrical energy. Typical ratings for a CAES system are in the range of 50 -300 MW, with efficiency of about 85% (when properly accounting for thermal and electrical input energies). The world's first commercial 290-MW, 4-hour CAES located in Huntorf in Germany was commissioned in 1978. It has been running for 30 years, showing strong performance: 90% availability and 99% starting reliability. Recent research in CAES is devoted to the maximum efficiency point-tracking control or integrated technologies for power-supply applications [4, 5].

2.3 Pumped Hydro Storage

Pumped hydro was first used in Italy and Switzerland in the 1890's. Since 1930’s it has been used as the most widespread ESS on power networks with over 90 GW of pumped storage in operation worldwide. Pumped-hydro plants use off-peak power to pump water uphill to an elevated reservoir. When required, the water flow is reversed to generate electricity by the release of its potential energy [2, 6]. Open sea can also be used as the lower reservoir. Generally pumped hydro is available at almost any scale, with discharge times ranging from several hours to a few days. Its efficiency is 70 - 85% depending on plant size, penstock diameter, hydro turbines used, and the height between the upper and lower reservoir. Pumped hydro plant’s main applications are for energy management, frequency control and provision of reserve.

2.4 Super conducting Magnetic Energy Storage

A Super conducting Magnetic Energy Storage (SMES) system stores energy in the magnetic field created by the flow of direct current in a coil of super conducting material. To maintain the coil in its super conducting state, the coil is immersed in liquid helium that is contained in a vacuum-insulated cryostat. The energy output of a SMES system is much less dependent on the discharge rate than batteries. SMES systems also have high cycle life and as a result, are suitable for applications that require constant, full cycling and continuous mode of operation. Although research is being conducted on larger SMES systems in the range of 10 - 100 MW, recent focus has been on the smaller micro-SMES devices in the range of 1 - 10 MW for system stability applications. Micro-SMES devices are available commercially for power quality applications. High temperature SMES cooled by liquid nitrogen is still in the developmental stage and may become a viable commercial ESS in the future [8].

2.5 Flywheel Energy Storage

Flywheel energy storage system consists of a massive rotating cylinder (comprised of a rim attached to a shaft), substantially supported on a stator by magnetically levitated bearings that eliminate bearing wear and increase system life. This cylinder spins at a very high speed while the integrated electrical apparatus operates either as a motor to turn the cylinder and stores energy, or as a generator to produce electrical power on demand using the energy stored in the cylinder. The efficiency of flywheel modules is in the 80 - 85% range, depending on bearing losses, winding losses, and how often they are cycled. Research is now focusing on increasing in torque, energy and power density with novel designs [9-11], lowering eddy current losses and/or improving cooling systems that remove heat from the wheel inside a vacuum enclosure.

2.6 Ultra-capacitor Energy Storage

Ultra-capacitors store electrical energy in the two series capacitors of the electric double layer, formed between each of the electrodes and the electrolyte. The distance over which the charge separation occurs is just a few angstroms. The capacitance and energy density of these devices are thousands of times larger than electrolytic capacitors. Compared to lead-acid batteries, ultra-capacitors have lower energy density but they can be cycled tens of thousands of times and have much faster charge and discharge capabilities than batteries. They have considerable promise as replacements for batteries, or use together with batteries in a wide variety of applications. New trends focus on using ultra-capacitors in power quality applications, covering temporary high peak-power demands, integration with other energy-storage technologies, and development for high-voltage applications [12, 13].

2.7 Hydrogen-based Energy Storage Systems

Hydrogen-based energy storage systems are receiving increasing attention recently. Essential elements comprise an electrolyser unit that converts electrical energy input into hydrogen, the hydrogen storage system itself and a hydrogen energy conversion system that converts the stored chemical energy in the hydrogen back to electrical energy. Its major applications are for electric vehicles and electricity production via fuel cells. Depending on the operating pressure and efficiency of an electrolyzer-fuel cell combination or the operating pressure and efficiency of the reversible fuel cell device, efficiency is expected to be in the 60 - 85% range. As hydrogen-based storage is generally somewhat at a cost disadvantage, recent R&D is focused on new materials or technologies for hydrogen storage. Applications to identify and investigate advanced concepts for material storage that have the potential to achieve the target of 2kWh/kg and 1.5kWh/L by 2010.

An application example of fuel cell DG will be given in Section IV.

2.8 *Comparison of Technologies*

Performance parameters of storage devices are often expressed in a wide variety of terms and units. A comparison of the key features of different storage technologies has been given in e.g. [2]. Each technology has some inherent advantages and limitations /disadvantages that make it practical or economical for only a limited range of applications.

For large-scale stationary electrical power storage, the applications can be divided into three major functional categories:

- Power Quality: in these applications, stored energy is only applied for seconds or less, to ensure continuity of quality power.
- Bridging Power: stored energy is used for seconds to minutes to ensure continuity of service when switching from one source of generation to another.
- Energy Management: storage media is used to decouple the timing of generation and consumption of electric energy. A typical application is load leveling, which involves the charging of storage when energy cost is low and discharging the energy when it is needed. This would also enable consumers to be grid-independent for many hours.

Although some storage technologies can function in all the three application ranges, most options would not be economical to be applied in all. Simultaneous combination of technological and economical considerations, such as ratings, volume, weight, capital cost, efficiency and cycle life, and per-cycle cost are essential in the selections of storage mediums [2, 3].

3. PHOTOVOLTAIC DG – SINGAPORE PRACTICE

In Singapore, photovoltaic DG has received a significant boost recently. Under new regulations, PV systems may now be connected to the electrical installation within any residential or non-residential premises in Singapore, to generate electricity for self-use. Any excess power may also be sold into the wholesale electricity market through the power grid owned by SP PowerAssets. The Energy Market Authority of Singapore (EMA) lays down the regulations.

A typical PV system in Singapore is not expected to exceed 1 MW in generation capacity. For a generation capacity of 1 MW or above, the licensing requirement is as follows:

- For 1 MW or above but less than 10 MW and connected to the grid, a Wholesaler (Generation) License is required. License fee payable to EMA is currently S$1,000 per annum.
- For 10 MW or above, a Generation License is required.

If the PV-generated electricity is of less than 1MW generation capacity, the PV owner is not required to hold a Generation License. Instead, it is optional for the owner to register with the wholesale electricity market, called the NEMS (National Electricity Market of Singapore). The need to register with the NEMS as a Market Participant and the PV system as a Generation Settlement Facility applies only if the owner wishes to sell and get paid for the electricity injected into the power grid.

For electrical safety reasons, a residential electricity consumer is required to have his PV system installed and connected to his electrical installation by a Licensed Electrical Worker. However, the residential consumer is not required to hold an Electrical Installation License to use or operate his electrical installation with the PV system connected.

If the residential consumer will export electricity into the power grid and wishes to be compensated for the electricity exported, the residential consumer will have to apply to SP Services (“SPS”). SPS will make arrangements for the compensation by way of a credit adjustment in the monthly electricity bill to the consumer. The credit adjustment will effectively compensate the residential consumer for the amount of electricity the PV-owner exports into the power grid during that month, based on the prevailing low-tension electricity tariff rate less the grid charge. However this scheme to compensate the residential consumers is not applicable to those consumers whose electricity consumption is metered under the master-sub metering scheme.

By selling electricity to the wholesale electricity market, the owner is paid the prevailing spot electricity price for the electricity injected into the power grid. The spot electricity price varies every half-hour, depending on the demand-supply situation in the wholesale electricity market.

Clearly the new regulations on photovoltaic DG system provide owners the opportunity to minimize their energy cost. By installing BESS to work in conjunction with the PV for example, the owners will have additional operational flexibility in power flow control. The potential for cost saving will be significant through judicious energy management practices.

4. SOLID OXIDE FUEL CELL DG FOR POWER QUALITY ENHANCEMENT

Power quality has become an important issue as increasingly amount of sensitive loads, such as computer-controlled equipment and power-converter drives, is being used. These loads require high-quality supply. However, there are also other kinds of loads which do not require high quality supply; rather, the demand would be more price-sensitive. Hence, it is highly desirable if utility can provide supply quality of different levels, to match the quality with varied customers' requirements. In this application example, solid oxide fuel cell (SOFC) DG is considered and the intention is to examine how such unbundled power quality service can be realized through its application. Indeed, the investigation leads to the concept of Power Quality Control Center (PQCC). The Center is located between the high voltage distribution lines and the customers. It consists of power electronic devices for controlling power flows, DG for efficient use of energy and as backup sources, among other functions. So far, several types of PQCC and the corresponding operational schemes have been suggested. See e.g. [14-16].

4.1 UPS-Type PQCC

A particular type of PQCC, known as the UPS-type, has been described in the literature [14-16]. A generic schematic diagram of the PQCC is shown in Fig. 1. The UPS-type PQCC uses the basic idea of Uninterruptible Power Supply (UPS) system and consists of two PWM controlled inverters (Inv.1 and Inv.2) and a DC bus. Unlike conventional UPS system, however, the PQCC is equipped with a DG in the DC side.

According to [14-15], unbundled power quality service could be realized with such an arrangement: there are three levels of power quality in the AC supply, named Ordinary Quality (OQ), High Quality (HQ), and Super Premium Quality (SP), plus one quality level in DC. As the names imply, the SP load enjoys the highest quality level amongst the AC loads, followed by the HQ load. The OQ load would have the lowest level of quality and reliability, as will be elaborated on later. In [16], the design of the PQCC takes into consideration the impacts of the most severe voltage disturbances on the loads. These are short-duration voltage sags or dips, commonly associated with the occurrences of system faults and their clearances.

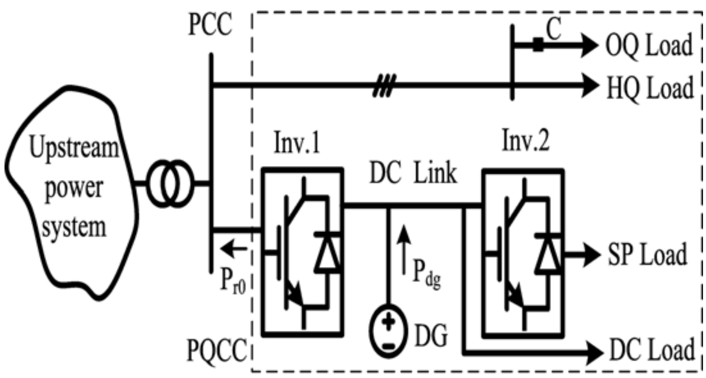


Fig. 1. Interior structure of the UPS-type PQCC proposed in [14-15]

4.2 Role of SOFC DG in the PQCC Scheme

As the DG plays a central role in the PQCC operations, the functional characteristic of the DG has been examined closely in [16]. The choice of SOFC over other types of DG is due to the impressive service record of a number of demonstration units of SOFC currently in operation. The analysis in [16] shows that the operation of the SOFC must be within its so-called feasible operating area (FOA). Essentially the constraints governing the FOA are pertaining to limits placed on the SOFC output power P_{dg} and its hydrogen fuel utilization factor u. Operation outside of FOA will reduce the cell life and is considered unacceptable. Due to the above considerations, it is also shown in [16] that the maximum allowable instantaneous active power change imposed on the SOFC is limited. This limit, denoted as $\Delta P_{dg,max}$, depends on the steady-state initial SOFC output power $P_{dg,0}$ and the allowable range of the fuel utilization factor. Typically, $\Delta P_{dg,max}$ is of the order of 12% of $P_{dg,0}$. A power demand change smaller than $\Delta P_{dg,max}$, can certainly be satisfied instantaneously by the SOFC. However for a power demand change larger than $\Delta P_{dg,max}$, the internal dynamics of the SOFC is such that it would require several tens of seconds before the fuel cell can meet fully the new load demand.

As shown in [16], the voltage sag ride-through capability of the PQCC system is seen to be relatively low. Typically for voltage sags of less than 80%, the PQCC has to be disconnected from the upstream system. The reason is that the PQCC system is operated as a shunt compensator, which gives little help in protecting the sensitive loads during upstream voltage sags. After the PQCC is disconnected from the upstream system, there is also a severe constraint on the size of the HQ load that can be supported by the PQCC under the islanding mode.

The two new PQCC-SC systems to be described in the next section are intended to alleviate these shortcomings. They attempt to lessen the need of the disconnection of the PQCC from the upstream system during a voltage-sag and at the same time, can still realize unbundled power quality supply. The Schemes require the use of series compensator (SC).

4.3 PQCC-SC Scheme 1

The configuration of the PQCC-SC Scheme 1 is shown in Fig. 2. It is seen that the complex upstream system is represented simply by the Thevenin equivalent voltage source $\vec{V}_s$ and a source inductor L. In this way, an upstream voltage disturbance due to a fault or load-switching event could therefore be approximated as the corresponding change in the magnitude and phase angle of $\vec{V}_s$.

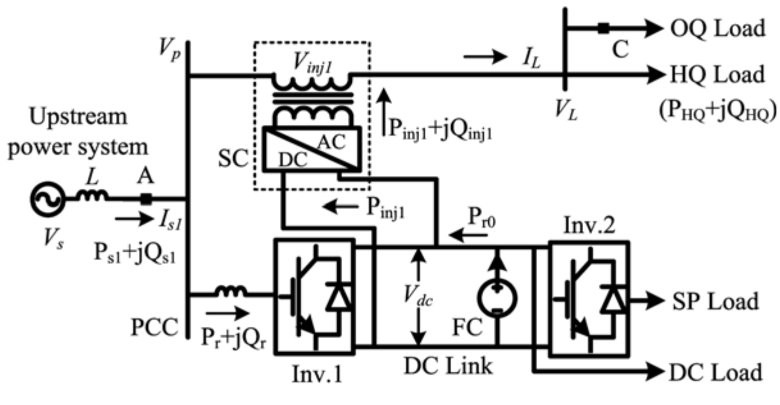


Fig. 2. PQCC-SC Scheme 1: single-line representation

In addition to the PQCC shown in Fig. 1, a series compensator (SC) is included in the proposed scheme. See Fig. 2. In the proposed scheme, the compensator is installed just upstream of the HQ/OQ load. The function of the SC is to introduce a voltage component ($\vec{V}_{inj1}$) in series with the HQ/OQ load terminal voltage $\vec{V}_L$ only during an upstream voltage disturbance. The compensator attempts to assist in restoring the HQ load voltage $\vec{V}_L$ to a pre-specified minimum level V_{min} during the upstream sag. In order to differentiate the power quality levels that would be offered to the HQ and SP loads, the SC would be designed only to compensate for up to a specified level of severity of the upstream sags.

Under normal operating conditions, the SC will play no role and its converter will be in off state. The SOFC DG supplies all the DC and SP loads, and also injects a surplus power P_{r0} to the PCC. Power factor at point 'A' is maintained at unity: the upstream system supplies only active power to the PCC.

When sag occurs, magnitude of the source voltage $\vec{V}_s$ reduces while its phase angle may also undergo a sudden change. The OQ load would be disconnected if the PCC voltage consequently decreases below V_{min}. If the load voltage remains below V_{min} after the shedding of the OQ load, the SC will attempt to maintain supply to the HQ load by helping to restore its voltage to V_{min}. The DC and SP loads would still be supplied by the SOFC and would not be affected by the sag as long as V_{dc} is in a reasonable range and Inv.2 can maintain the SP load terminal voltage. During the sag, Inv.1 is also controlled to maintain unity power factor at point 'A'.

The SC has to inject a certain amount of active power (P_{inj1}) over the above voltage restoration stage. Due to the complexity and intricacy of the SOFC power plant, it is desired that the SOFC DG remains undisturbed at the pre-sag power level of P_{r0} during the sag. Therefore active power injected by the SC is given by

$$P_{inj1} = P_{r0} + P_r \qquad (1)$$

where P_r is the active power absorbed by Inv.1 from the PCC. Therefore, during severe sags where $P_{inj1} > P_{ro}$, active power will be absorbed from the PCC through Inv.1. However, for shallow sags where $P_{inj1} < P_{ro}$, surplus active power will be supplied to the PCC through Inv.1. The changes to the power flow through Inv.1 can be easily achieved by using Inv.1 switch control signals.

Although several strategies in achieving voltage restoration through series compensation have been described in e.g. [17], a modified version has been proposed in [18] for the PQCC-SC. In [17], a technique calls for the injection of $\vec{V}_{inj1}$ which is the phasor difference between the pre-sag and sag voltages. In this way, the restored voltage will be identical to the pre-sag voltage. However, the present scheme only requires the magnitude of the load voltage to be restored to V_{min} instead of the pre-sag magnitude. This will maximize the ride-through potential for the PQCC-SC scheme. Details of the injection technique are given in [18].

4.4 PQCC-SC Scheme 2

Fig. 3 shows an alternative PQCC-SC scheme. The configuration and operations of Scheme 2 are very similar to that of Scheme 1. The only difference is the location of the voltage injection of the SC. In Scheme 2, the compensator is installed immediately upstream of the PCC. The compensator injects a voltage in series with $\vec{V}_A$ so as to restore $\vec{V}_p$ to V_{min}. Details of the scheme are again given in [18].

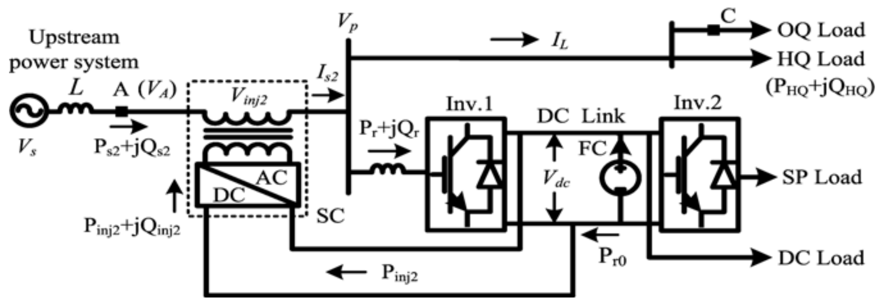


Fig. 3. PQCC-SC Scheme 2: single-line representation

4.5 Some Numerical Examples

Comparison of the two schemes has been carried out in [18]. Typical results are shown in Fig. 5 and 6. In this example, using typical values of V_{min} = 0.9 pu and P_{r0} = 0.1 pu, the relationships between the respective maximum load ride-through levels for PQCC-SC Scheme 1 and Scheme 2, denoted as $V_{sag1,max}$ and $V_{sag2,max}$, and *Vs* phase angle jump have been plotted in Fig. 4 and 5 under varied HQ load power factor and *k*. *k* is defined by the ratio (SC rated MVA)/(HQ load MVA).

Fig. 4 shows the variation of the ride-through capabilities of the two schemes under varied phase angle jump α and HQ load power factor (cosθ). The figure shows that the ride-through capability of both schemes would decrease when the absolute value of the phase shift α increases. Unlike Scheme 2, Scheme 1 ride-through capability is not affected by the HQ load power factor. The proof of this is given in [18]. When the HQ load power factor (cosθ) increases, Scheme 2 ride-through capability decreases. The figure shows that in this numerical example, for the given power ratings of the HQ load and the SC, if the HQ load power factor is above 0.8, Scheme 1 would be preferable over Scheme 2.

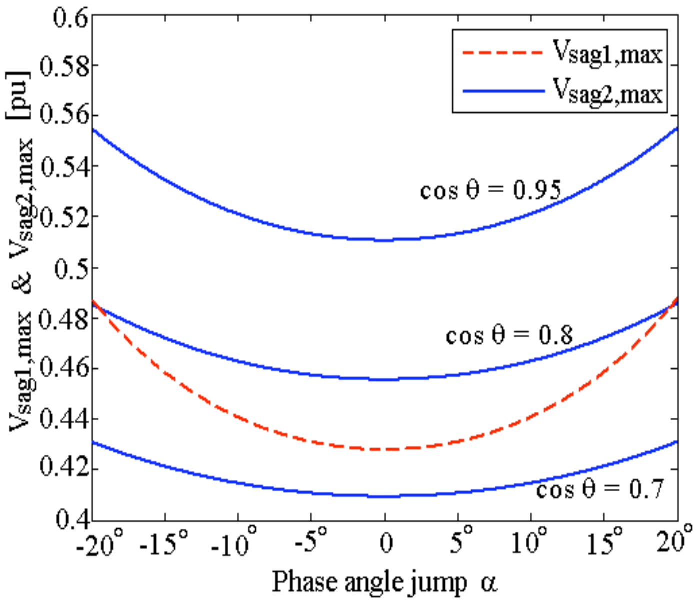


Fig. 4. Variations of $V_{sag1,max}$ and $V_{sag2,max}$ with phase jump α and HQ load power factor cosθ for k = 0.52, S_{HQ} = 0.38 pu, L=0

Fig. 5 shows the relationship of $V_{sag1,max}$ and $V_{sag2,max}$ under varied SC rating. S_{HQ} and cosθ are fixed when evaluating these curves and hence *k* is varied. It is not surprising to see from the figure that when *k* increases, i.e. when the power rating of the SC increases, the ride-through capabilities of both schemes would also increase. In Fig. 5, it also shows that for the given load power factor when *k* is relatively small (≤ 0.35), the ride-through capability of Scheme 2 is superior compared to that of Scheme 1. However when *k* becomes larger, the ride-through capability of Scheme 1 could exceed that of Scheme 2, e.g. when *k* = 0.7. In summary, the preference of one scheme over the other depends on the HQ load power factor and the power rating of the SC relative to that of the HQ load.

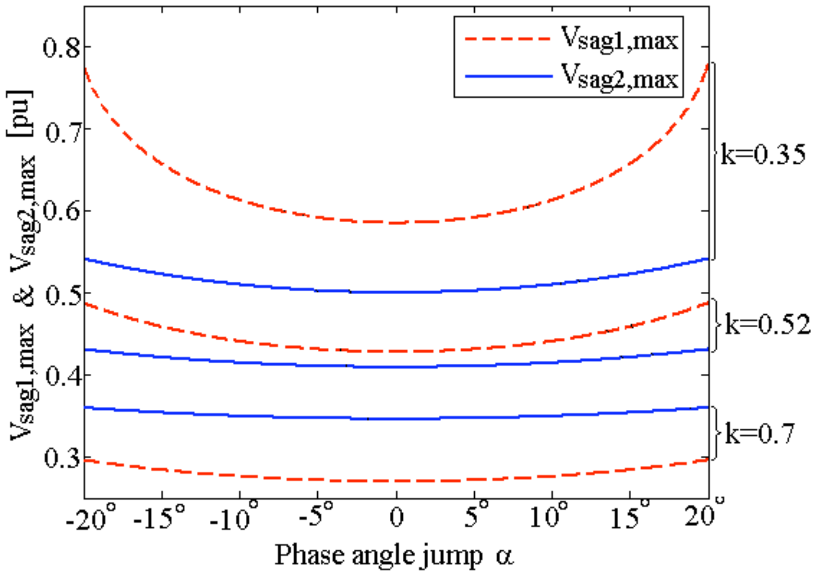


Fig. 5. Variations of $V_{sag1,max}$ and $V_{sag2,max}$ with α and k for HQ load power factor of 0.7 (lag), S_{HQ} = 0.38 pu, L=0

The study on the PQCC schemes has shown that the SOFC DG has played a crucial role in the voltage sag compensation schemes. By incorporating a series compensator into the PQCC and by the judicious control of the SOFC DG, the schemes appear to be able to provide significant load ride-through capability during voltage sags. It allows for the realization of unbundled power quality supply.

5. ENERGY BUFFER FOR WIND POWER DG

Power generated from wind turbines tends to be unsteady as wind speed is influenced by natural and meteorological conditions. As the wind power fluctuates, it can result in network frequency and voltage deviations especially if the wind turbines are located electrically close to loads. To attenuate the negative impacts of the variability of the wind power, the use of a power buffer that includes a BESS will be described in this Section. Specifically, a methodology to determine the required BESS capacity for the purpose of daily load tracking or load leveling is described. The method is based on known wind power profile and the optimization of an objective function, through which the optimal dispatched power level from the wind farm will be obtained. The corresponding BESS power and energy capacities will be determined while the accompanying converter DC voltage will be controlled to within specified limits. This latter requirement is needed in order to ensure proper operation of the converters.

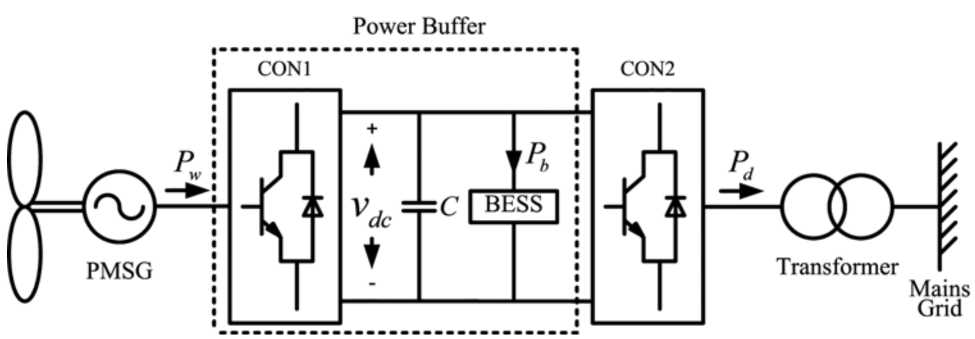


Fig. 6. Variable speed wind turbine with inter-connection to the mains grid through power buffer system.

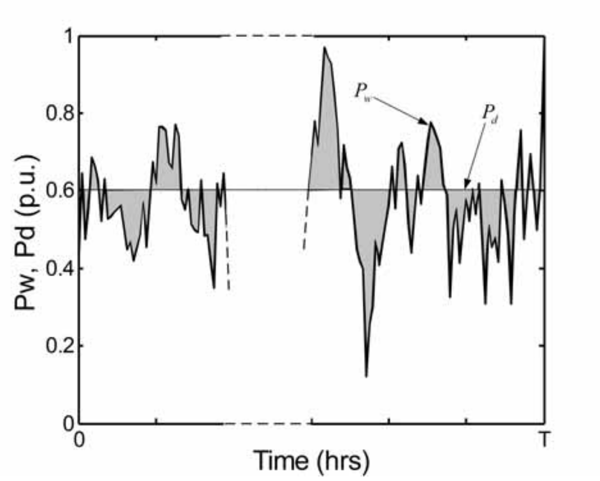


Fig. 7. A typical wind power profile based on data taken from [19]: constant P_d is shown

The particular wind-turbine grid-connected system is as shown in Fig. 6. It shows that the wind energy captured by the turbine blades is converted through a permanent magnet synchronous generator (PMSG) into electrical power, denoted as P_w. From previous discussion, it is clear that P_w tends to be highly stochastic. As part of wind farm planning, site selection and design process, wind data is often collected at site. Since the main focus herewith is on the design of the BESS, it is now assumed that sufficient wind data is available and the profile of P_w is known over a period of T hours. Fig. 7 shows a typical profile of P_w, derived from the wind speed data taken from a site described in [19]. In the figure, P_w has been normalized and hence is within the range [0, 1] p.u. The profile has been obtained by averaging the wind speed data over 10-minutes interval.

To cater for grid integration, the back-to-back converters (CON1 and CON2 in Fig. 6) are utilized to inter-connect the generator and grid transformer through a DC-link. One can assume that the power loss in the two converters is negligible. The DC-link capacitor C functions as a harmonics filter and in some designs, it can also take the role of the energy-storage system [20]. However, typical energy storage capacity of capacitor tends to be small compared to the BESS considered in the study. Hence, in terms of initial power flow analysis, the capacitor power may be neglected. It is further assumed that the dispatched power P_d from CON2 to the mains grid is to be kept constant over the interval T. Although this assumption tends to facilitate analysis, it also has a desirable effect from a practical viewpoint: it prevents the fluctuating P_w from impacting negatively on the grid. To realize the constant power feature, the mismatch power between P_w and P_d has to be compensated for by the BESS, which has the output P_b (t) shown in Fig. 6.

The front-end boost converter (CON1) and the BESS constitute the power buffer system. The power buffer smoothes the fluctuations in P_w in the following way: to achieve a given P_d, CON1 is controlled to adjust the DC-link voltage v_{dc} through controlling its modulation index so that the net power supplied from CON1 and BESS is exactly P_d. CON2 converts the DC power into ac form at grid frequency and also controls the reactive power flow.

To ensure the success of the above scheme, the determination of the P_d level and BESS capacity specification have to be addressed. This is elaborated in the next Section.

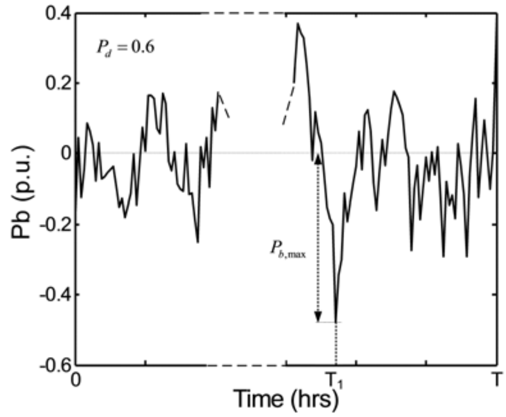
5.1 Determination of BESS Power and Energy Capacities

Battery capacity is normally specified in terms of power- and energy-capacity. The capital cost of the battery can also be determined, based on the power and energy capacities. Consequently, the design problem in hand is to determine the BESS capacity based on a cost-benefit consideration, as follows.

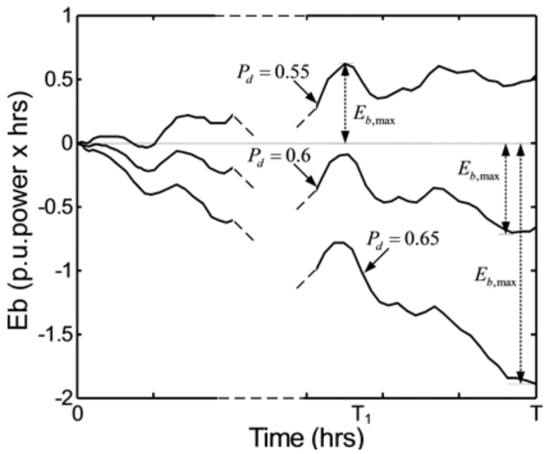
In the buffer system, the BESS power P_b (t) can be written in terms of P_w and P_d as,

$$P_w = P_b(t) + P_d \qquad (2)$$

From (2), for a given constant P_d, $P_b(t)$ will vary in the same manner as P_w. By setting P_d to another constant value will only result in the P_b (t) curve being shifted up or down, but P_b (t) will remain the same shape as P_w. For example, for the P_w profile given in Fig. 7, the P_b (t) profile given in Fig. 8(a) corresponds to P_d = 0.6 p.u. From Fig. 8(a) one finds that the maximum battery power, $P_{b,\max}$, occurs at T_1 when $P_{b,\max}$ = -0.5 p.u. over the interval T. The negative sign indicates that at this precise moment, the BESS is discharging. It is quite conceivable for a different value of P_d, the corresponding $P_{b,\max}$ may be positive. It then indicates that the BESS is being charged at the maximum value at that instance.



(a)



(b)

Fig. 8. Profiles of (a) battery power for Pd = 0.6 pu, and (b) battery energy corresponding to Pd = 0.55, 0.6 and 0.65 pu for the typical wind power profile given in Fig. 8.

Integration of $P_b(t)$ with respect to time yields the net energy (E_b) injected into or discharged from the BESS, up to time t. Correspond to changes in $P_b(t)$, the $E_b(t)$ profile will also vary for different P_d. For instance, $E_b(t)$ profiles corresponding to P_d = 0.55, 0.6 and 0.65 p.u. respectively have been given in Fig. 8(b). Positive values in Fig. 8(b) show net gain in stored energy in the BESS, as compared to the battery initial stored energy level.

For specific value of P_d, the corresponding value of $P_{b,\max}$ determines the BESS power capacity. To achieve the goal of dispatching the constant P_d over the designed period T, the BESS capacity has to be specified to be at least as large as the corresponding $P_{b,\max}$. Take the profile shown in Fig. 8(a) for example; once the BESS capacity is designed to be at least as large as $P_{b,\max}$, the BESS could absorb/supply the surplus/shortfall in power for the corresponding constant dispatched level P_d.

Besides power capacity, battery energy capacity should also be considered. For the study undertaken in this paper, the BESS energy capacity is specified in similar manner as in the case of BESS power capacity: the energy capacity of the BESS has to be as large as that it could absorb/supply the maximum amount of the charged/discharged energy. Hence, the BESS energy capacity should be at least as large as $E_{b,\max}$ for the corresponding P_d value.

5.2 Determination of P_d

From the last sub-section, it is noted that with different P_d, $P_{b,\max}$ and $E_{b,\max}$ will change accordingly. Since the focus of this work is on the design of the BESS, one can assume the capital cost of the wind turbine and power converters are constant. Therefore, the benefit (per hour) for dispatching P_d into the grid over period T could be calculated from

$$B = \alpha P_d - \beta P_{b,\max} - \gamma E_{b,\max} \qquad (3)$$

where α is the unit price of the wind energy (\$/kWh) sold to the grid. β (\$/kW) and γ (\$/kWh) are the amortized BESS capital costs per hour over T. Note that in the p.u. system, α, β and γ could also be considered as three coefficients or weights pertaining to P_d, $P_{b,\max}$ and $E_{b,\max}$ respectively. Therefore, the net benefit (B) obtained by the wind farm by incorporating such a BESS could be calculated.

With the design problem so formulated, the objective is therefore to design the BESS to maximize B. From the discussion in the last sub-section, one notes that BESS ratings are intrinsically determined by the dispatch-able level P_d. Therefore, with known α, β and γ, one can search for the optimal P_d to maximize B in an iterative manner: first set $P_d = 0$ and the increase P_d progressively until the optimal P_d, denoted as P_d^*, which maximizes B is obtained. The optimal P_d^* therefore provides the power- and energy-capacities of the BESS, $P_{b,\max}$ and $E_{b,\max}$.

Having the BESS capacity determined by following the procedure described earlier, another design consideration is to ascertain whether the DC-link voltage v_{dc} is within pre-set limit [$v_{dc,\text{lower}}$, $v_{dc,\text{upper}}$], i.e., one has to verify the BESS capacity is sufficiently large that v_{dc} will remain within the pre-set limit as P_w varies. In order to carry out the analysis and calculate v_{dc}, a numerical method described in [21] can be used. The method is based on a circuit model of BESS suitable for the load leveling study.

6. CONCLUSIONS

Energy Storage Systems can be used to provide energy management, power quality or bridging power supports. Under the context of these application areas, examples illustrating the roles of the ESS in distributed generation schemes have been described. In particular, applications involving batteries and fuel cells for enhancing load ride-through and load leveling are illustrated. The examples demonstrate that significant benefits can be obtained by incorporating the ESS in the DG systems.

7. ACKNOWLEDGEMENT

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9. BIOGRAPHIES

S.S Choi (M' 76) received his B.Eng. and PhD degrees from the University of Canterbury, Christchurch, New Zealand in 1973 and 1976 respectively. He is now a Professor in the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore.

KJ Tseng obtained his B.Eng. and M.Eng from National University of Singapore in 1988 and 1990 respectively, and the PhD from Cambridge University in 1993. He is currently an Associate Professor in the School of Electrical and Electronic Engineering, and the Director of Center for Smart Energy Systems, Nanyang Technological University, Singapore.

D. Mahinda Vilathgamuwa obtained his B.Sc. and Ph.D. degrees in Electric Engineering from the University of Moratuwa, Sri Lanka, and Cambridge University, UK, in 1985 and 1993 respectively. Dr. Vilathgamuwa is an Associate Professor in the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore.

TD Nguyen received his B.Eng. and M.Eng. Degrees from Hochiminh City University of Technology, Vietnam, in 2004 and 2006, respectively. He is currently a Ph.D. student in the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore.