THE NEW FRONTIERS OF ELECTRICAL ENGINEERING

The Hong Kong Institution of Engineers - Electrical Division

The 23rd Annual Symposium 2005

20th October 2005

THE HONG KONG INSTITUTION OF ENGINEERS ELECTRICAL DIVISION

The 23rd Annual Symposium

Thursday

20th October 2005

THE NEW FRONTIERS OF ELECTRICAL ENGINEERING

at

Ballroom

Sheraton Hotel

Nathan Road

Kowloon

Hong Kong

SYMPOSIUM PROGRAMME

08.30 Registration and Coffee

09.00 Welcome Address

- Ir T.H. Tai
  Chairman, Electrical Division, The HKIE

09.05 Opening Address

- Ir Dr Greg C.Y. Wong
  President, The HKIE

09.10 Keynote Speech

- Mr Joseph Y.W. Pang
  Executive Director & Deputy Chief Executive
  The Bank of East Asia, Limited, Hong Kong

1. Forefront Development in Power Generation

09.40 First Grid-connected Wind Turbine for Power Generation in Hong Kong

- Ir Dr C.W. Tso, Head of Department
- Ir L.M. Chan, Mechanical Engineer
  Mechanical Department, Projects Division
  The Hongkong Electric Co. Ltd.

10.00 Future of LNG as a Fuel for Hong Kong Power Generation

- Mr Richard Lancaster
  Commercial Director
  CLP Power Hong Kong Limited

10.20 Discussion

10.40 Coffee Break

2. *New Projects*

11.10 Beijing Metro Line 4 – A New Railway Business Model in China

– Ir Lawrence K.L. Chung
Manager – China Technical Support
MTR Corporation Ltd., Hong Kong

11.30 Beijing Green Plaza – A Leading Edge Ecological Mixed Development in the City of Beijing

– Ir Simon F.W. Chung, Director
– Mr Eddie C.M. Choy, Senior Engineer
Ove Arup & Partners Hong Kong Ltd.

11.50 Meeting the Challenges Arising from the Installation of 132kV Circuits from Pui O to Cheung Chau

– Ir S.P. Tang, Acting Project Manager
– Ir Sandun N. Wimalasena, Senior Project Engineer
Engineering Projects Department
CLP Power Hong Kong Ltd.

12.10 Discussion

12.30 Lunch

3. *Energy Efficiency & Sustainability*

14.15 Life Cycle Energy Analysis of Building Construction

– Ir Welman W.M. Leung
Senior Building Services Engineer
Energy Efficiency Office
Electrical & Mechanical Services Department
The Government of the HKSAR

14.35 Enhancing Energy Efficiency in Electrical Infrastructure in Government Buildings

– Ir K.C. Mak
Senior Project Manager
Architectural Services Department
The Government of the HKSAR

14.55 Discussion

15.15 Coffee Break

4. State-of-the-art Technologies

15.45 Development of Power Electronics and Its Impact on Industry

– Prof. Eric K.W. Cheng
Professor
Department of Electrical Engineering
The Hong Kong Polytechnic University

16.05 High Temperature Superconducting Fault Current Limiter for Application in the Electric Power Net

– Dr Heinz-Werner Neumüller
Head, Department of Power Components and Superconductivity
Corporate Technology, Siemens, Germany

16.25 Discussion

16.45 Summing Up

– Ir P.N. Ip
Symposium Chairman
Electrical Division, The HKIE

Closing Address

– Prof. C.F. Lee
Pro-Vice-chancellor
University of Hong Kong

Acknowledgement

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Speakers / Authors

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Ir Lawrence K.L. Chung
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Mr Eddie C.M. Choy
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Paper No. 1

FIRST GRID-CONNECTED WIND TURBINE FOR POWER GENERATION IN HONG KONG

Speakers : Ir Dr C.W. Tso, Head of Department
Ir L.M. Chan, Mechanical Engineer
Mechanical Department, Projects Division
The Hongkong Electric Co. Ltd.

FIRST GRID-CONNECTED WIND TURBINE FOR POWER GENERATION IN HONG KONG

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Paper No. 1

ABSTRACT

Provision of adequate and reliable electricity is vital to sustained economic development of Hong Kong. The Hongkong Electric Company, Limited (HEC) is committed to provide quality power supply to its customers with due care for the environment. Recognizing the importance of sustainable development, HEC has undertaken a feasibility study of utilizing wind energy for power generation as an on-going effort to explore the use of renewable energy resources in Hong Kong

Lamma Island was selected for the feasibility study of wind power project and collection of wind data over a period of one year was completed in 2002. A wind atlas has been built for assessing wind potential and identifying suitable site on Lamma Island. Results of study have concluded that it is technically feasible and environmentally acceptable to install one 800kW wind turbine as a demonstration project to utilize wind energy for power generation at Tai Ling on Lamma Island. The wind turbine system with built-in safety and protection devices for high reliability and good power quality is now at the construction stage, and will be connected to HEC's existing power grid in early 2006 to supply one million kWh of "green" electricity per year adequate for 200 families in Hong Kong.

1. INTRODUCTION

The Hongkong Electric Company Limited (HEC) was founded in 1889 and is one of the world's longest established power companies. For more than one hundred years, HEC has been a leader in the power business in Hong Kong with a strong commitment to environmental protection while providing a safe and reliable electricity supply to the community. Recognizing the importance of sustainable development, the pressing need to combat global climate change and improve air quality in Hong Kong, HEC took an initiative in 2000 to explore the feasibility of utilizing renewable energy to supplement fossil fuel for power generation in Hong Kong.

Using wind energy for power generation has been expanding very fast over the past 10 years as it offers a clean power source which completely avoids the emission of carbon dioxide and other gaseous pollutants. Historic meteorological data indicate some areas in Hong Kong have fair good wind potential. However, there was limited information on the wind profile analysis and utilizing wind energy in commercial scale in Hong Kong. As such, HEC commissioned Friends of the Earth Hong Kong in 1999 to undertake wind monitoring on Lamma Island and Po Toi Island. The objectives of HEC's initiative were:

(a) to identify site(s) technically feasible and environmentally acceptable for building a pilot scheme wind turbine,

(b) to gain local knowledge and experience on planning, design, construction, operation and maintenance of wind turbine for power generation for wider application in Hong Kong, and

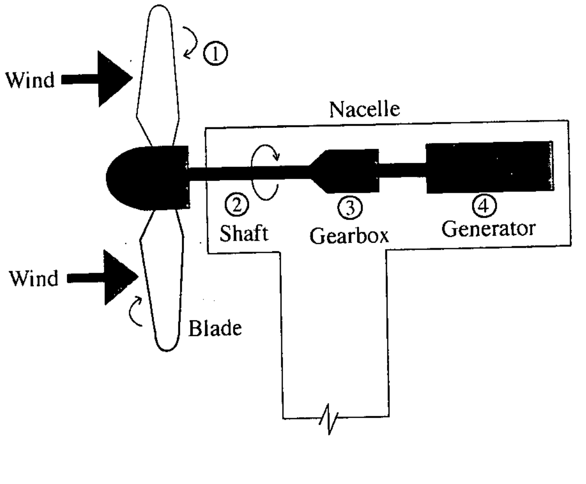
(c) to promote public awareness of the benefits as well as the limitations of wind as source of renewable energy for power generation in the context of Hong Kong's unique situations

2. DESCRIPTION OF POWER WIND TURBINE

The most common configuration of an in-service wind turbine for power generation consists of three rotor blades rotating, a nacelle and a tubular tower as illustrated in Fig.1 The nacelle houses the rotor blade shaft, gearbox, generator, and electrical, instrument and control components. Wind turbine uses its wing profile to transform the lift forces generated by the wind into a rotating motion of the rotor blades. The rotor blade shaft drives the generator via a gearbox to produce electricity.

The capacity of wind turbine ranges from few kilowatts to several megawatts. The crucial parameter is the diameter of the blade – the longer the blade, the large the area swept by the rotor and the greater the energy output. At present the average size of commercial wind turbine unit being installed is well over 1,000kW, and the trend is towards even larger unit size of up to 5MW for off-shore wind farm. Theoretically a wind turbine is able to extract more than 60% of the energy inherent in the flow of air. In practice, however, the extraction of energy is less than 50% due to conversion losses.

Figure 1 Principle of Power Wind Turbine

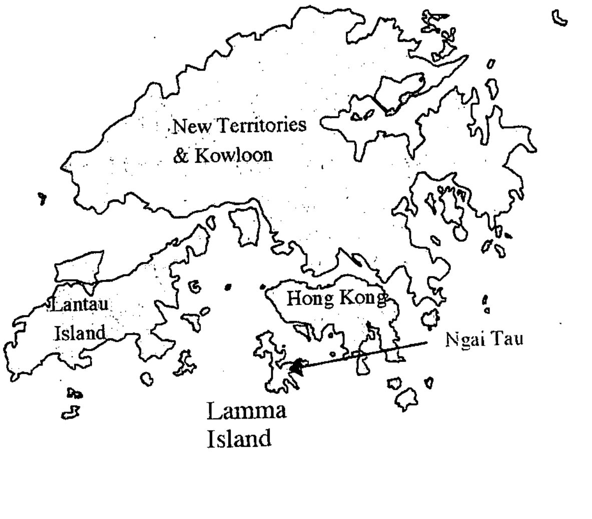


The power available from the wind is a function of the cube of the wind speed. This means that if wind blows at twice the speed, its energy content will increase eight-fold, and hence an accurate prediction of wind resource is necessary. The estimation of wind resource requires the input of wind data obtained by on-site measurement for computer simulation. The duration of wind monitoring depends on a number of factors such as availability of topography information and surrounding meteorological data. Typically at least one year monitoring at wind turbine hub height is desirable.

3. WIND POWER MONITORING

Based on the results of desktop study on the technical constraints and initial environmental considerations, the site survey conducted in end 1999 identified Ngai Tau, a densely populated ridge located about 1000m east of Mo Tat village on Lamma Island, as the preferred location for setting up a wind monitoring station (Fig. 2). The site was granted by the Government under a short-term tenancy in September 2001.

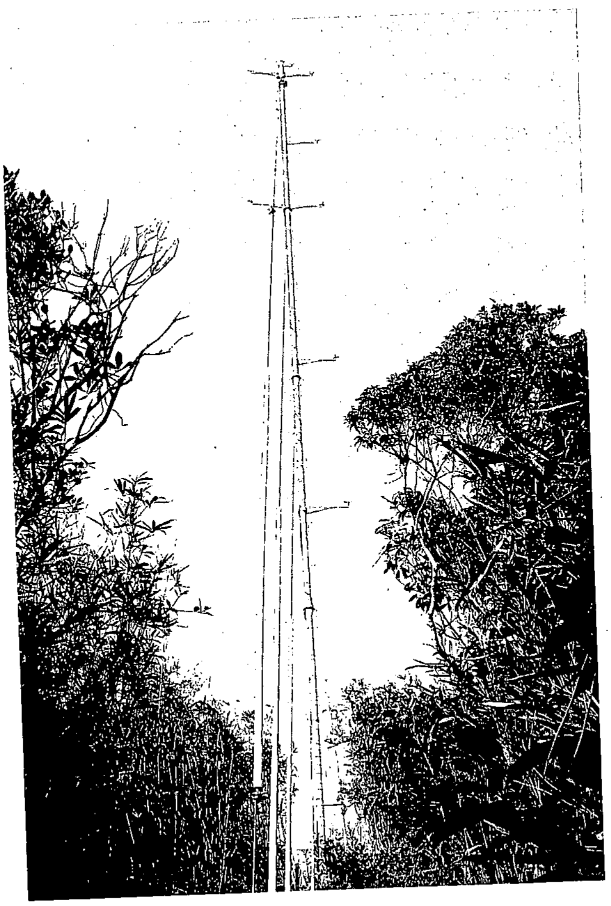
Figure 2 Location of Wind Monitoring Station



3.1 MONITORING STATION

The Lamma Wind Monitoring Station at Ngai Tau was commissioned in November 2001. The station comprised primarily of a tower, wind sensors and a data logger. The tower was held in position by wires anchored at 4 corners, and with sensors for wind speed (anemometers) and direction (wind vanes) mounted at 10m intervals up the tower as shown in Fig. 3. Wind data was logged in every second by the wind sensors. Cables from the sensors ran down the tower to a data logger which was housed in a locking box attached to the tower for easy access of download data. The data logger was downloaded manually approximately once per month.

Figure 3 Wind Monitoring Station

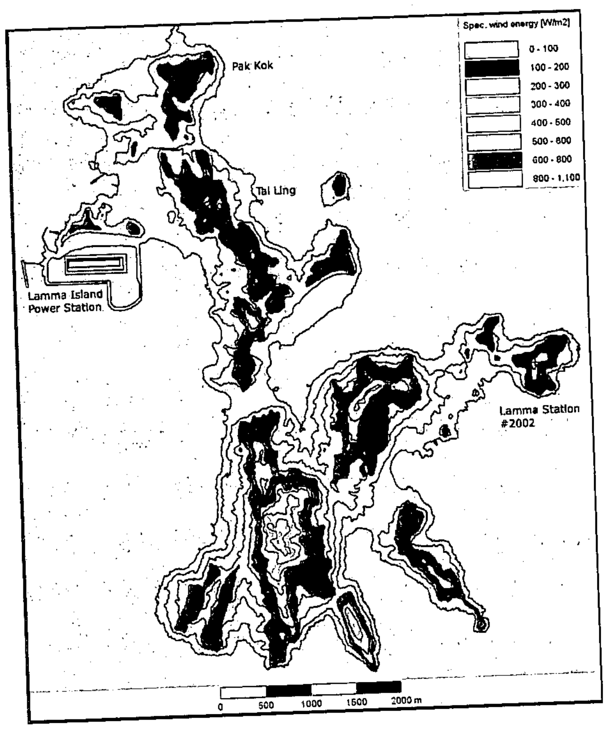


3.2 WIND RESOURCE MAP

The data of wind speed and wind direction collected over a 12-month period from November 2001 to November 2002 together with topographical information in digitized map were fed into standardized software, WAsP and WindPro, to build up a wind atlas for evaluating the wind potential of Lamma Island. The wind rose and wind atlas were built up in end 2002, and the resultant wind atlas of Lamma Island **[1]** is presented in Fig. 4.

Analysis of data revealed that over 50% of land area on Lamma had specific wind energy above 100W/m^2. The southern part of the island had in general better wind potential than the north. The relatively high wind potential areas were found in the mountain ridges and hilltops.

Figure 4 Wind Resource Map of Lamma Island



To eliminate the effect of annual variation on wind profile, the collected data were compared and normalised with the meteorological data of Hong Kong Observatory Waglan Station. Wind speeds of Lamma were normalised by using the ratio of the parallel Waglan wind speed of the 13-year normal months for the same time period. The scaled annual average wind speed was adjusted from 5.5m/s to 6.11m/s. The wind potential of Lamma was hence considered adequate for wind turbine installation.

4. SITE SELECTION & PLANNED CAPACITY

4.1 SITE SELECTION CRITERIA

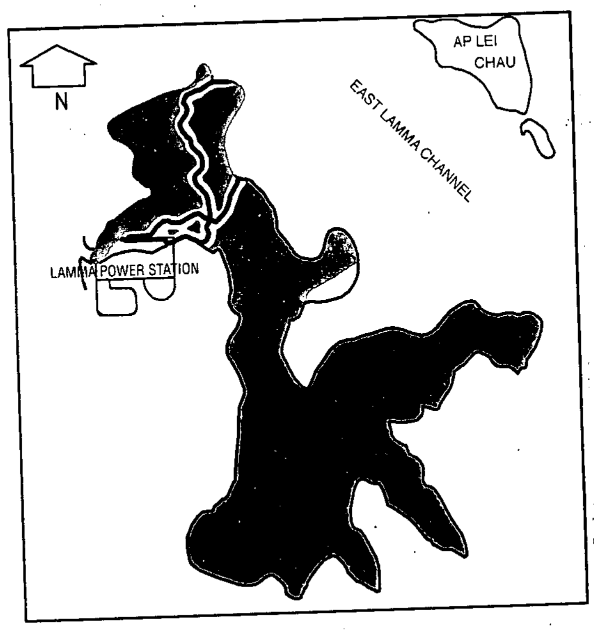
Desktop screening and site surveys were conducted to identify potential sites for a wind turbine of suitable size on Lamma Island based on criteria recommended in the guidelines for wind energy development issued by reputable national establishments. The wind turbine site was then examined against engineering requirements and environmental considerations and further refined using the following screening criteria:

Wind Potential – Areas of wind power density over 150W/m^2 are considered adequate for wind energy utilization. Wind resource map of Lamma Island (Fig. 4) indicates that the areas of favourable potential are general found on hilltops and areas of high elevation, especially in the southern part of the island.

Land Use – Southern part of Lamma Island consists of site of special scientific interest (SSSI), conservation area and potential Country Parks. Northern part of Lamma Island has been zoned mainly as agricultural and green belt area, and is well away from areas of ecological importance such as habit sites of Romer's Tree Frog and green turtle. Further consideration is given to the current and future options for land use with reference to the latest Lamma Island Outline Zoning Plan.

Site Access – Proper paved vehicular access road is required for heavy-duty wheel-loader and crane are required for transporting, installation and maintenance of wind turbine equipment. As construction of a new access road will not only substantially increase the project cost but cause significant disruption to existing landscape, especially for a demonstration project, it is desirable to make best use the existing 275kV cable route which is the only vehicular roads on the island as shown in Fig.5. Hence, the practical approach is to look for potential sites along the cable routes.

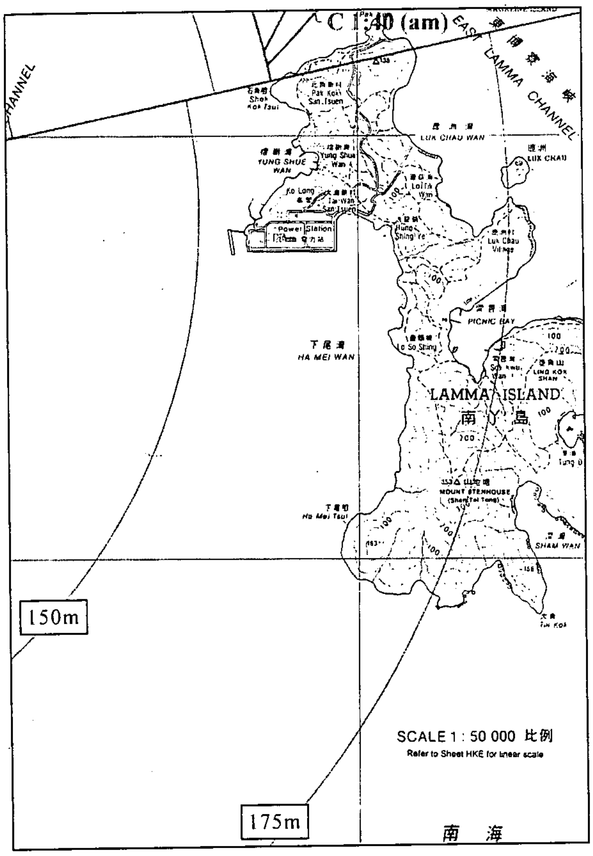
Figure 5 Areas with Vehicular Access Road



Distance from Main Power Grid – The benefit of grid-connection design is to allow full utilization of wind energy produced by the wind turbine. It is desirable to have the wind turbine located close to the gird to reduce cabling cost and transmission loss especially for a demonstration project. The northern part of Lamma Island has a network of 11kV can facilitate such grid connection arrangement.

Height Restriction – Under the provisions of Hong Kong Airport Control of Obstruction Ordinance, height restrictions are imposed on permanent structures on Lamma Island. Most areas in the northern part of Lamma Island along the cable routes fall between the limiting heights of 160m to 165m above the principal datum as shown in Fig.6. As commercial scale wind turbines available in market have minimum capacity of 600kW with a tip height of 68m, ground level of the wind turbine site is limited to 92 to 97m depending on its exact location. As a result most of the areas having favourable wind potential are considered unsuitable for wind turbine installation due to the inherent height limitations.

Figure 6 Aviation Height Restriction on Lamma Island



4.2 POTENTIAL SITES

Taking into account the above criteria, following six potential sites as shown in Fig. 7 were identified with the application of constraint mapping techniques

Site 1 – Lamma Power Station Extension

Site 2 – Tai Ling

Site 3 – Yung Shue Long

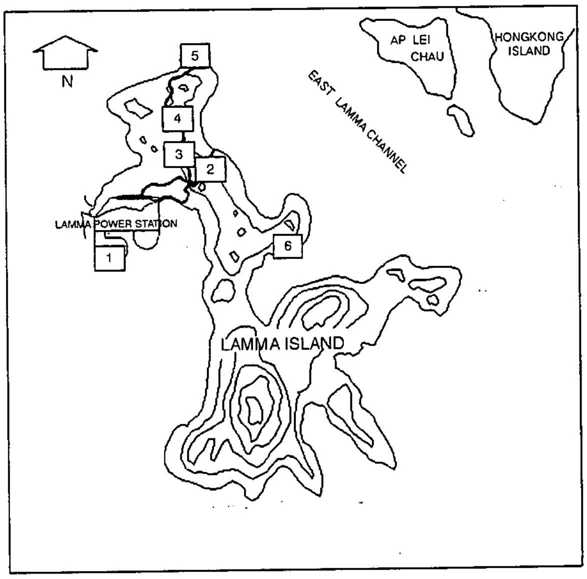
Site 4 – Tai Peng

Site 5 – Pak Kok Tsui

Site 6 – Lamma Quarry

These potential sites not only avoided ecologically sensitive areas, SSSI and the potential Country Parks at South Lamma, but are situated along the existing 275kV Cable Route which is the only vehicular access road on Lamma Island, and close to the local grid.

Figure 7 Potential Wind Turbine Sites



4.3 PREFERRED SITE

Having identified sites that met the broad environmental and engineering criteria, a site specific appraisal was conducted to establish a short-list of feasible sites for further detailed investigation.

Qualitative approach was adopted to identify potential conflicts with the development of the wind turbine. Each potential site was scrutinized more closely with engineering criteria on wind potential, geological considerations and electrical connection; and environmental criteria concerning visual, noise and ecological impacts. Of the 6 potential sites within the areas of least constraints, four sites were excluded due to principal conflicts identified, leaving two sites for final comparative assessment:

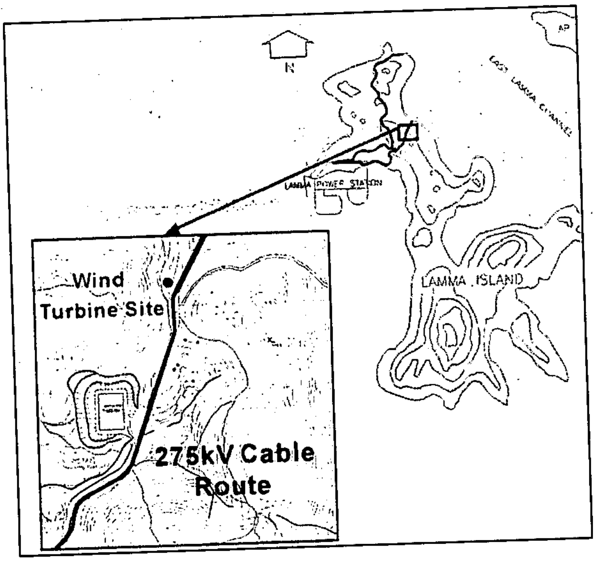
Site 2 – Tai Ling

Site 4 – Tai Peng

The two short-listed sites were evaluated and compared according to the potential impacts likely to arise due to construction and operation of the wind turbine. Site 2 – Tai Ling was identified as the overall preferred site due to its distinct merits in site access, ground conditions, noise and visual impact compared with Site 4 – Tai Peng. The site at Tai Ling was also considered the more remote of the two in terms of proximity to village houses.

The preferred site at Tai Ling (Fig. 8) is a relatively level platform to the west of the joint bay of HEC's existing cable route. Taking advantage of the joint bay area as part of the works area for erection of the wind turbine, the land take requirement can be optimized.

Figure 8 Preferred Site (Tai Ling) for Wind Turbine



4.4 WIND TURBINE CAPACITY

The planned capacity of the wind turbine at Tai Ling was ranging from 600 to 850kW depending on the model sizes available from respective suppliers. This wind turbine capacity was selected based on the following considerations:

- It should be a proven design with a large number of installations worldwide.
- It should still be on the production line and available from the majority of the suppliers due to worldwide trend for large capacity machine.
- It would be the maximum size of wind turbine complying with the aviation height restriction imposed at Tai Ling Site

5. EIA STUDY

Citing that the electricity generated from wind turbine would be connected to HEC's grid, the Environmental Protection Department (EPD) was of the view that the project should be classified as Public Utility Electricity Power Plant under D.1 of Part 1 of Schedule 2 of the Environmental Impact Assessment Ordinance Chapter 499. Notwithstanding that the wind turbine was recognized as a pilot project for demonstration and education purpose, a full EIA was required to ascertain that the Wind Turbine Project on Lamma Island would not cause unacceptable impacts on the environment.

Following the submission of a Project Profile [2] to the authority in March 2004, an EIA study Brief No. ESB-112/2004 was issued by EPD in May 2004. The Study Brief specified detailed assessment of the potential environmental impacts associated with the Project in relation to the issues including noise, ecological, landscape and visual, air quality and water quality.

The EIA conducted had critically assessed the overall acceptability of any environmental impacts likely to arise as a result of the construction and operation of the wind turbine on Lamma Island. The EIA Report also specified the conditions and requirements for the detailed design, construction and operation of the Project in order to mitigate the identified environmental impacts to acceptable levels.

The EIA Report [3] submitted to the authority in August 2004 predicted the Project would comply with all environmental standards and legislation after the mitigation measures are implemented, and concluded that there would be no adverse long term or cumulative effects/ impacts on the environment. Following public inspection of the EIA Report and presentation to the EIA sub-committee in September 2004, approval of EIA Report was given in October 2004. An Environmental Permit under the EIAO for construction and operation of the wind turbine on Lamma Island was subsequently issued to HEC in November 2004, i.e. 8 months from submission of Project Profile

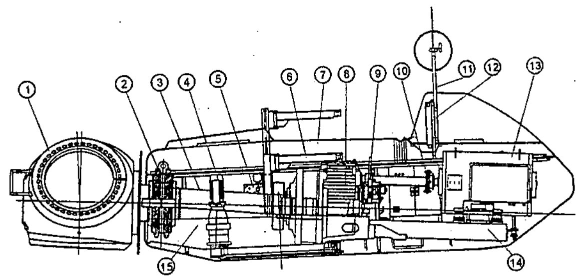
6. WIND TURBINE SYSTEM

6.1 TECHNICAL SPECIFICATION

The wind turbine system is designed and supplied by Nordex Energy GmbH of Germany. It is Nordex's standard N50/800kW machine [4] with a rotor diameter of 50m and a rated power of 800kW. The wind turbine is of stall-regulated, "horizontal axis" design and is mounted up-wind. The major components of the nacelle are shown in Fig. 9.

The rotor blades are made of fibre-reinforced plastic (FRP). The blade tips are pivotable and can be swiveled 85 degrees relative to the main blade to act as aerodynamic brakes. The generator is a double-winding, 4/6 pole water-cooled squirrel-cage asynchronous type. The wind direction and wind speed are constantly monitored by two mutually independent wind sensor systems above the nacelle. When the wind direction is different from the direction of the wind turbine, the wind turbine is yawed actively.

Figure 9 Nacelle of Nordex's N50 Wind Turbine



Technical particulars of the N50/800kW wind turbine are as follows:

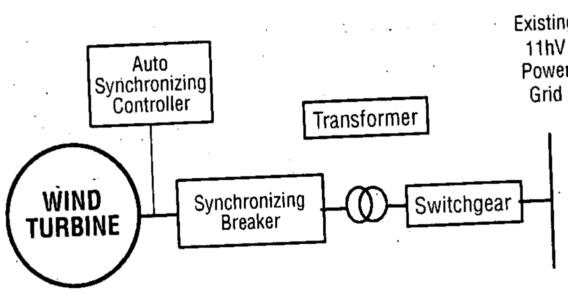
Number of Rotor Blades	3
Rotor Blade Diameter	50 m
Tower Hub Height	46 m
Blade Swept Area	1,964 m^2
Blade Rotational Speed	15.3 / 23.75 rpm
Turbine Cut-in Speed	3 m/s
Turbine Cut-out Speed	25 m/s
Generator Output Voltage / Frequency	690 V / 50 Hz

Paper No. 1

6.2 SYSTEM DESIGN

The grid connected 800kW wind turbine system is designed for automatic operation and will generate electricity when wind speeds are in the range of 3 to 25 m/s. As illustrated in Fig. 10, the output of the wind turbine is transmitted to the existing 11kV power grid via a transformer, switchgear and power conditioning devices housed inside a high voltage distribution pillar (HVDP) next to the wind turbine. Power cables are buried underground for connecting the wind turbine, HVDP and nearby 11kV power grid on the 275kV cable route.

Figure 10 Schematic Diagram of Wind Turbine System



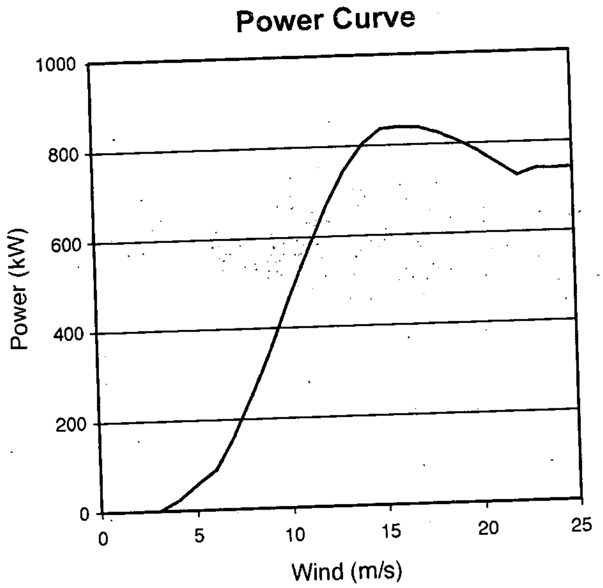
The operation of the wind turbine is monitored and controlled through a central monitoring system located in a control room of Lamma Power Station. The wind turbine site is unmanned and requires attendance of operational personnel only during emergency or routine maintenance.

6.3 POWER OUTPUT

According to the power curve (Fig. 11), the output from the 800kW wind turbine with an average wind potential of 150W/m^2 and wind speed of 5.5m/s will generate about 1 million kWh electricity. When completed in early

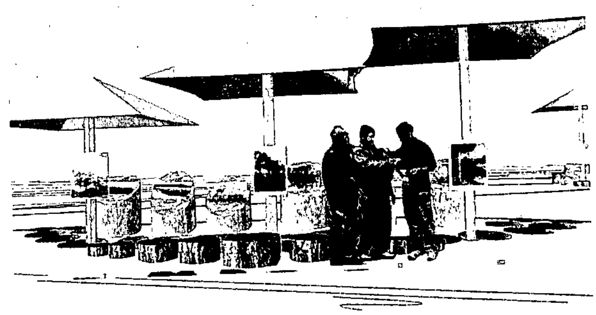
2006, the Lamma Wind Turbine is expected to produce electricity adequate for the consumption of 200 families in Hong Kong. This will help to avoid the use of around 350T of coal and offset the emission of 2,800kg of SO_2, 1,400kg of NO_X, 140 kg of particulates and 850 tonne of CO_2.

Figure 11 Power Curve for N50



Educational exhibits (Fig. 13) will be installed at the wind turbine site to promote public awareness and understanding of the benefits as well as the limitations of wind as source of renewable energy. The project will also enable HEC to gain local knowledge and experience in the design, construction, operation and maintenance of wind turbine for wider application of renewable energy in Hong Kong.

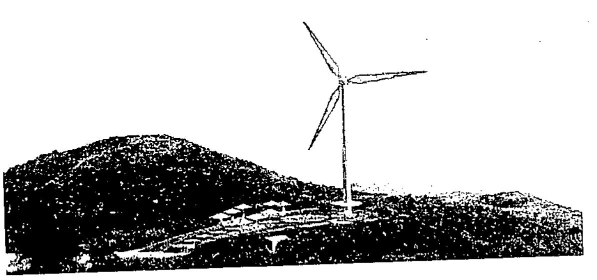
Figure 13 Educational Exhibits at Wind Turbine Site



7. CONCLUDING REMARKS

The construction of the 800kW Wind Turbine Project at Tai Ling on Lamma Island is a pilot scheme to demonstrate HEC's effort to explore the use of wind energy for power generation in Hong Kong. The wind turbine project is now at the construction stage and is scheduled for completion in early 2006. Fig.12 shows an artistic view of the Lamma wind turbine in operation.

Figure 12 Artistic View of Lamma Wind Turbine Project



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[1] *Wind Energy Study Final Report for Hongkong Electric Co. Ltd.* 2003, Friends of the Earth (Charity) Ltd.

[2] *Project Profile – Renewable Energy by a Wind Turbine System on Lamma Island,* 2004, The Hongkong Electric Co. Ltd.

[3] *Final Environment Impact Assessment – Renewable Energy by a Wind Turbine System on Lamma Island,* 2004, ERM Hong Kong Ltd.

[4] *Technical Description of NORDEX N50,* 2003, NORDEX Energy GmbH, Germany

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The Authors wish to thank the management of The Hongkong Electric Co Ltd for the permission to publish this paper.

Paper No. 2

FUTURE OF LNG AS A FUEL FOR HONG KONG POWER GENERATION

Speaker : Mr Richard Lancaster
Commercial Director
CLP Power Hong Kong Limited

FUTURE OF LNG AS A FUEL FOR HONG KONG POWER GENERATION

Mr Richard Lancaster
Commercial Director
CLP Power Hong Kong Limited

Paper No. 2

ABSTRACT

Since 1996 with the start-up of the Black Point Power Station, natural gas has been an important component of the CLP's fuel supply. Natural gas has delivered environmental benefits as well as added diversity to the mix of fuels used for electricity generation, thereby enhancing the security of electricity production. Natural gas can be delivered to markets either by pipelines connected to gas reserves or in the form of Liquefied Natural Gas (LNG). This paper will provide a background to LNG as a fuel for power generation, a description of the LNG supply chain and the benefits of locating a LNG terminal in Hong Kong.

1. INTRODUCTION

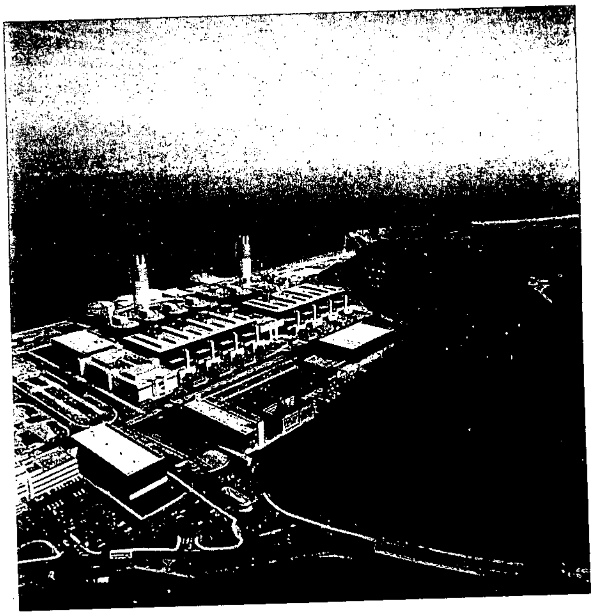
Natural gas can be delivered to markets either by pipelines connected to gas reserves or in the form of LNG. As most of the world's gas resources are not in close proximity to Hong Kong, LNG becomes the necessary source for long-term gas supplies since it is the means to access global reserves. This paper will provide a background to LNG as a fuel for power generation, a description of the LNG supply chain and the benefits of locating a LNG terminal in Hong Kong.

2. INTRODUCTION TO LNG

Liquefied Natural Gas (LNG) is the liquid form of natural gas, the main component of which is methane.

In the liquefied form, at atmospheric pressure, LNG occupies only 1/600th of its volume at gaseous state under normal temperature and atmospheric pressure and, is therefore more economical to store and transport over long distances.

Figure 1 Natural Gas is used for Electricity Generation in Black Point Power Station



LNG is produced by cooling natural gas to –162°C (–260°F) through a liquefaction process. Prior to cooling and condensing the natural gas into LNG, impurities such as carbon dioxide, water and sulphur are removed. The end result of this process is an odourless, colourless product consisting mostly of methane with small amounts of ethane, propane, butane and pentane.

LNG is one of the cleaner and more efficient for transportation forms of energy available. There are a number of environmental and safety benefits to using LNG:

- Regasified LNG is clean burning, producing virtually no particulates and less NO_X and CO_2 than other fossil fuels. Since sulphur is almost entirely removed in the

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liquefaction process, combustion of regasified LNG emits negligible amounts of sulphur dioxide;

- By warming LNG it vaporizes to become lighter than air and therefore rises when released;
- LNG, when released to the atmosphere, will evaporate at normal temperatures and disperse quickly, leaving no residue behind and therefore requiring no environmental cleanup;

Figure 2 Evaporation of LNG

- LNG is stored at near atmospheric pressure, reducing the storage hazard compared with pressurized fuels (e.g. Liquefied Petroleum Gas - LPG). In the unlikely event of an unconfined release of LNG vapour to the atmosphere, the vapour is not explosive in nature;
- LNG is non-corrosive and non-toxic; and
- LNG cannot ignite without first being vaporised, mixed with the right amount of air to result in a mixture of 5 to 15% methane in air, and provided with an ignition source.

3. THE LNG SUPPLY CHAIN AND DEVELOPMENT LEAD TIME

LNG is an industry that requires long lead-time from initial planning to completion of the supply chain infrastructure. It requires significant resources and investment commitment from both suppliers and buyers of LNG. Each element of the chain has to be carefully planned and coordinated with other elements. The LNG supply chain comprises four main elements:

1. Exploration and gas production
2. Liquefaction
3. Shipping
4. Regasification and storage

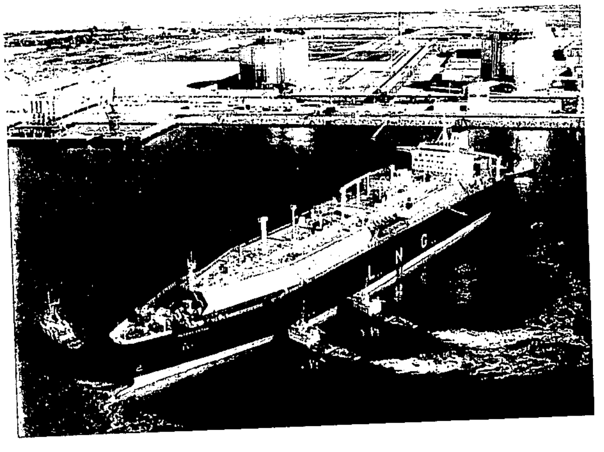
The LNG supply chain starts with the exploration and development of gas reserves. The gas that is extracted and produced from below ground or seabed is processed to remove impurities and contaminants. It then acts as feed gas to the liquefaction plant.

The second element of the LNG chain involves liquefaction of the gas to become LNG, and it is the most capital-intensive part of the LNG chain. In terms of development timing, it usually takes about 3 years for the necessary approvals and design plus another 4 years to engineer and construct the liquefaction facilities once the final investment decision is made.

The third element of the LNG chain involves the transportation of gas from liquefaction facilities to markets where the gas demand is located. LNG is loaded onto specialized carriers, which can contain and maintain the LNG at its low temperature, for long distance transportation. In terms of timing, it usually takes about 3 years to design and construct a LNG carrier, subject to the availability of slots in the 10 or so shipyards around the world engaged in this work. These slots are typically reserved for some years in advance. Shipping costs depend on the distance between the liquefaction and regasification terminals.

The final element involves the LNG receiving and regasification process. LNG carriers arrive at the receiving terminal and unload the LNG in the storage tanks of the receiving terminal. As and when gas demand is needed, LNG is transferred from the storage tanks to the regasification facilities to convert the gas back to its gaseous state. It usually takes one or more years for internal planning followed by about 3 years for the necessary approvals and design plus another 3 years to engineer and construct the receiving terminal and regasification facilities.

Figure 3 A Typical LNG Receiving Ship and Terminal



4. LNG TERMINAL TO SERVE HONG KONG

A LNG terminal consists of marine facilities (berth, jetty, unloading arms, etc.), LNG storage tanks, facilities to regasify the LNG, pumping systems, and utilities. It is analogous to coal or oil unloading terminals except that it is designed to handle an extremely cold liquid which also requires regasification. The terminal in Hong Kong would occupy a site area of approximately 30 ha and is expected to provide storage of LNG in two to three cryogenic tanks, each with a capacity of approximately 160,000m^3 to 180,000m^3. A deep water channel with a minimum draft of approximately 15m is required for LNG ship passage to the terminal. A turning basin would also be required to allow the LNG carrier to berth at the unloading jetty.

Feasible sites for a LNG terminal in Hong Kong have been identified. The two lead sites are Black Point and South Soko Island, which have been extensively studied with Government through an Environmental Study Management Group. A project profile was submitted to the Environmental Protection Department in May 2005 and an extensive Environmental Impact Assessment process is being conducted for both sites.

There are a number of reasons for the need to locate a LNG receiving terminal to serve CLP in Hong Kong. Black Point, as one of biggest gas-fired generation plants in the world, is a very large user of natural gas.

Paper No. 2

A LNG terminal located in Hong Kong would provide the following benefits:

4.1 FUEL SECURITY AND RELIABLE SUPPLY OF ELECTRICITY

Dependable fuel sources are critical to maintain world-class power supply to our customers. Having a LNG receiving terminal in Hong Kong allows CLP to secure sufficient and dependable supplies of this clean fuel to meet future needs. The terminal, once commissioned, would be operated and maintained to world-class standards, with seamless delivery of gas from the terminal to the power plants.

4.2 ENVIRONMENTAL BENEFITS

A receiving terminal in Hong Kong offers CLP the flexibility of sourcing LNG from gas fields around the world. With sufficient natural gas supplies, CLP will be able to significantly increase its use of this clean fuel. As LNG emits virtually no particulates and negligible SO_2, as well as less NO_X and CO_2 than other fossil fuels, it will contribute to further improvements in the air quality in Hong Kong.

4.3 PROJECT DEVELOPMENT AND TERMINAL OPERATIONS SYNERGIES

A LNG terminal located within Hong Kong enables smoother and faster project development under one single jurisdiction with clear policy and regulations applicable to infrastructure built in Hong Kong. This means that the environmental benefits can be brought about earlier.

SIEMENS

4.4 ECONOMIC BENEFITS AND JOB CREATION

Constructing a LNG terminal in Hong Kong would comprise a major investment in Hong Kong and would, additionally, provide a significant number of construction and engineering jobs for Hong Kong.

5. SUMMARY

LNG has been used as a fuel for power generation for many years around the world. There are environmental and safety benefits for using LNG as a fuel for power generation. The timely development of the LNG terminal in Hong Kong will allow the continuation of the highly reliable supply of electricity for Hong Kong. Furthermore, with sufficient natural gas supplies, CLP would be able to increase the use of this clean fuel and contribute to further improvements in the air quality of Hong Kong.

Paper No. 3

BEIJING METRO LINE 4
A NEW RAILWAY BUSINESS MODEL IN CHINA

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Manager – China Technical Support
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BEIJING METRO LINE 4
A NEW RAILWAY BUSINESS MODEL IN CHINA

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Paper No. 3

ABSTRACT

In February 2005, MTR Corporation (MTRCL) and its Public-Private Partnership (PPP) partners initiated a Concession Agreement with the Beijing Municipal Government to build and operate the Beijing Metro Line 4 for a term of 30 years from date of opening.

The 29 km Beijing Metro Line 4 is an underground metro line running from Ma Jia Lou Station on the South Fourth Ring Road to the north west Hai Dian District and terminates at Long Bei Cun Station. There are 24 stations (23 underground) along the line including major stops at Beijing South Station, Xuan Wu Men, Xidan, Xi Zhi Men, Xue Yuan Nan Lu, Zhong Guan Cun, Yuan Ming Yuan, and Yi He Yuan. Threading through Feng Tai, Xuan Wu, Xi Cheng and Hai Dian Districts, Beijing Metro Line 4 will be the main north-south traffic artery of Beijing. The total journey time is approximately 48 minutes.

The Concession Agreement signed in September 2005 and the Project is expected to open to the public in 2009.

The paper describes the project and in particular the PPP model for the investment, construction and operation of the Beijing Metro Line 4.

1. INTRODUCTION

Beijing, the capital city of the People's Republic of China, is the political and cultural center of the country. It is also one of the biggest cities in the world with a population of over 13 million. There are over two million vehicles in Beijing and the car ownership rate is increasing at more than 10% per annum. The result is that road traffic congestion becomes a growing problem and the Beijing Municipal Government has to work out a long term solution.

The Beijing Municipal Government had carried out a comprehensive study on the planning and development of the city and issued the "Beijing City Master Development Plan 1991 - 2010" which gave the overall direction of the development of the city. Following the plan, metro expansion proposals were developed to create a grid line network metro system to cover the whole of Beijing City areas. It aims to use the metro networks as the backbone of the public transport which will improve the public transport and resolve the traffic congestion problem.

The latest proposal is to expand the existing metro system in stages from the original 2 lines of 54km to the targeted 22 lines of total 693km in 50 years. The Beijing Metro Line 4 is one of the lines planned to be built in the early stage.

2. PROJECT DESCRIPTION

The 29 km Beijing Metro Line 4 will be a main north-south traffic artery in the western part of the city, running from Majialou Station（马家楼）on the South Fourth Ring Road and terminating at Longbeicun Station（龙背村）on the north of the Fifth Ring Road. There are altogether 24 stations, with the only at grade station at Longbeicun. Cutting through four major districts of Beijing: Fengtai（丰台）, Xuanwu（宣武）, Xicheng（西城）and Haidian（海淀）, major stops includes Yuanmingyuan（圆明园）, Yiheyuan (or the "Summer Palace")（颐和园）, Xuanwumen（宣武门）, Xidan（西单）, Xizhimen

SIEMENS

（西直门）, Zhongguancun（中关村）and Beijing South Station（北京南站）. The total journey time is approximately 48 minutes.

Approval of the Beijing Line 4 Project and its feasibility study report was granted by the State Council on August 12, 2004. The route map and some key data of the project are shown in Figure 1 and 2.

Interchange with existing lines is made possible by adits enabling passengers to interchange within the paid area of the concourses. Provisions for future extensions for Line 9 at Baishiqiao Station and Line 4 Extension at Majialou Station are also included, where passengers can interchange seamlessly across the same platform.

Figure 1 Beijing Line 4 Route Map

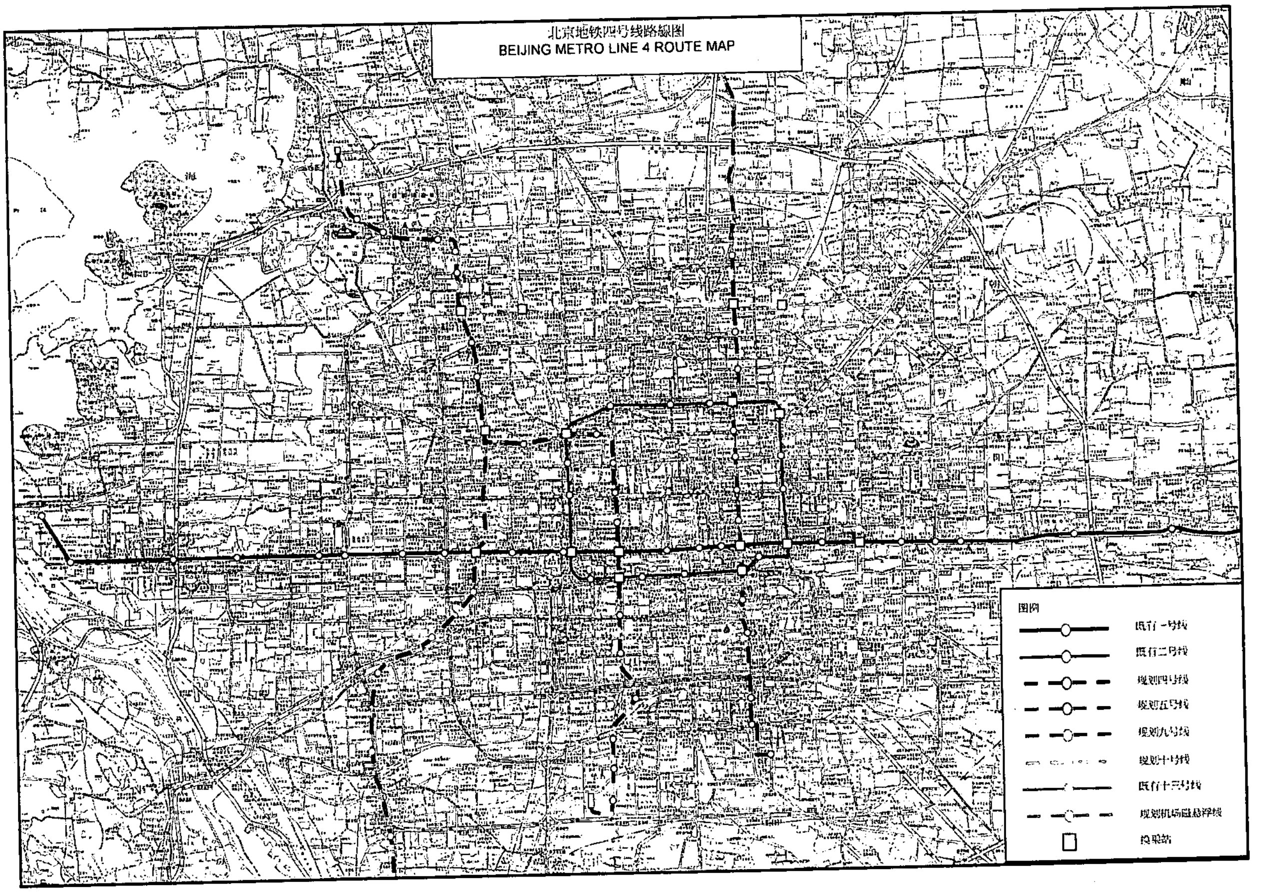


Figure 2 Key Project Data

Route Length	28.65 km
No. of Stations	24 (23 underground)
Depots	2
Interchange Stations	4 (initial) 14 (ultimate)
Journey Time	48 minutes
Capital Cost (RMB)	15.3 billion
Daily patronage	600,000 (2010)
Planned Opening Date	30th September 2009
Operating Concession	30 years from the date of opening

Automatic Fare Collection (AFC) system will be used in Beijing Line 4 to replace the tradition of manual ticket arrangement. Station upgrade and implementation of AFC system for existing Line 1 and Line 2 are being carried out. It is expected that by 2008 a common electronic ticketing system will be employed for all metro lines in Beijing.

Further down to the south of Majilou Station is the Majiabao Depot which is equipped with daily running maintenance facilities as well as overhaul equipment; whereas the Longbeicun Stabling Yard is located at the northern end of the line.

There is a dedicated Operation Control Centre (OCC) for BJL4 at Xiaoying (小营). The OCCs of other new metro lines such as Line 5 and Line 10 and the Traffic Control Centre (TCC) will also be located at the same building at Xiao Ying, which will monitor and coordinate the operation of all metro lines under certain emergency circumstance.

As most of the areas along the corridor have already been developed, patronage is not a concern for the Municipal Government. However, advanced works such as resettlement, utilities and traffic diversions had created many problems to the civil contractors as well as the Municipal Government.

3. PUBLIC PRIVATE PARTNERSHIP

In China, infrastructure and services are traditionally provided by Government. In the recent years, the policies have been changed and the use of private capital to fund public works has been increasing. A series of privatizations and Public Private Partnership (PPP) schemes have been applied to the power supply, telecommunications and transport sectors.

In Beijing, the planned metro networks system is so extensive that the Beijing Municipal Government has to find a new and effective way to create and manage the metro assets. The introduction of PPP model to the Beijing Line 4 Project will inject more market discipline, innovation, value for money in provision of services. It will also reduce the public spending of the Beijing Municipal Government.

For a normal railway PPP project, the client will not be responsible for the design and construction of the works. The client will specify his requirement for the provision of train services, the technical requirements, standards, and other mandatory elements of the design. The PPP company is responsible for the delivery of the service including the design, construction and operation the railway.

When the Beijing Municipal Government decided that the Beijing Line 4 Project should go for the PPP model, the project had already been progressed in an advance stage. The civil and structural design works had more or less completed and some of the civil construction works had already commenced.

When the Corporation started to be involved in the project, there was not much scope for the Corporation to influence the design of the project including the alignment and station layout. The effort was focused on the design of the train, signaling system, power supply and other E&M works of which the design had just commenced and we had to ensure the future operation could be maintained to a satisfactory standard.

There are many benefits that the Corporation can bring to Beijing through this PPP project. The Corporation can leverage their expertise and innovation in project management, customer focus, facility management, access to the latest technology, maximizing development potential and exploitation of alternatives uses.

The late involvement in the Beijing Line 4 project had limited the Corporation's ability to fully utilize all the above benefits to this PPP project. However, the Corporation had managed to bring the following changes to the project.

1. The Corporation had reviewed the station layout and altered the design to suit the MTR operation requirement without changing the civil and structural work. The alterations are based on the Corporation's experience in customer services, management of passenger flow and emergency evacuation. One example is that the ticket gates of some stations have been relocated to allow a smoother passenger flow.

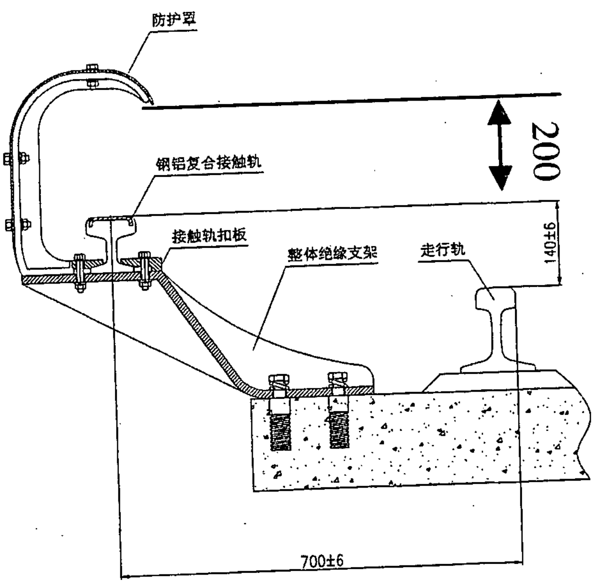
2. As the PPP company is responsible for the provision of E&M works, the Corporation will bring in the expertise and innovation in project management to deliver a cost-effective and quality product in order to minimize the capital and recurring costs. The Corporation will introduce modern system assurance concept to ensure that the railway will meet the highest safety and reliability requirements. As this concept is new to the metro industry in Beijing, the Corporation is developing a SA management system that can suit the local situation while meeting the Corporation's requirements. As the local manufacturers of systems, including Rolling Stock manufacturers, do not possess such experience, the Corporation will work with them as partners to bring up their standards to meet the Corporation's requirements.

3. Safety is a key objective for the Corporation in the design, construction and operation of a railway. The Corporation will ensure that the safety standard will be maintained throughout the concession period. The typical example is the use of third rail for traction power supply to the trains.

Unlike MTR's overhead line power supply system in Hong Kong, a third rail is used for providing traction power to the trains. A Hazard and Operability Study (HAZOP) had been carried out to identify any high level hazard arising from the Preliminary Design.

As per the current design (Figure 3), it is a 750 DC top-contact running third rail. Since there is no safety walkway along the tracks, passengers will be exposed to direct contact with the third rail in case of detrainment. In the absence of any sophisticated interlocking electrical isolation system to cut off the power to the third rail when detrainment occurs, the driver is required to call the OCC to cut off the power instead. In order to avoid the chance of human fault and mitigate this operating risk, we had proposed to install a trip wire along the running lines and adopt a stinger system at the maintenance track area at the depot.

Figure 3 Third Rail Details



说明：
1. 本图为整体道床区段接触轨安装示意图·
2. 图中尺寸以毫米计·

Although it is not an ideal situation, the Corporation has managed to convince the client to accept most of the comments and changes by working closely with the client. The client understands that the changes are mainly for the safety and effective operation which would benefit the future operation and will also improve the services to passengers.

4. CONCESSION AGREEMENT

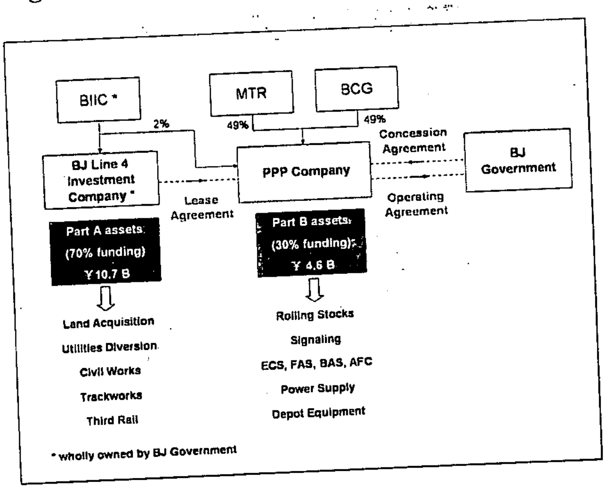
In formulating the concession agreement, the most important issue is the assessment and allocation of risks. There are financial and operation risks.

On the financial side, the fare revenue is the main concern and the key factors are the fare level and the patronage estimate.

If the PPP company cannot determine the fare structure of the metro line, it becomes a major risk which cannot be easily assessed. We have to accept the fact that the Beijing Municipal Government has to control the fare level of all public transport systems and will not allow the operator to adjust the fare according to the market discipline. The Government also understands that the principle that who controls the fare level should also be responsible for taking the risk. In the agreement, a fare table and a fare adjustment mechanism were agreed. The PPP company will get compensation, should the fares be not set at the agreed level.

During the negotiation period, a patronage study for the Beijing Line 4 was carried out by a consultant jointly appointed by the Beijing Municipal Government and the Corporation. The Corporation has deeply involved in the study and has full visibility of the consultant's works. The study provides enough information for the Corporation to assess the business risk on the patronage estimate and to make a business judgment on the business case.

Figure 4 Project Financing Arrangement



After over one year of negotiation, MTR Corporation signed an agreement to form a PPP Company with Beijing Infrastructure Investment Co. Ltd (BIIC) and Beijing Capital Group (BCG) for the investment, construction and operation of the Beijing Metro Line 4 in December 2004. The total investment for the Beijing Metro Line 4 project is about RMB¥15.3 billion, 70% of which (approximately RMB¥10.7 billion) will be funded by the Beijing Municipal Government for the provision of the civil and finishes works (Part A assets). An agreement will be signed to lease the Part A assets for the PPP Company to operate the railway during the concession period. Both MTR Corporation and BCG will each own 49% of the PPP joint venture company whilst BIIC will own 2% of the PPP Company. The PPP Company will be responsible for the provision of trains and related electrical and mechanical systems (Part B assets) which cost about RMB¥ 4.6 billion as shown in Figure 4. The Part B assets will be transferred to the Beijing Municipal Government at no cost after the concession period.

Paper No. 3

5. CONCLUSIONS

The Beijing Line 4 is the first PPP metro project in Beijing. It is essential to build up this project as a successful demonstration project to convince the Government that this is the way to go.

MTR Corporation has considerable expertise and experience in design, project management, operations and customer services which can benefit the PPP projects in development of the metro network system in Beijing. For the next PPP metro project in Beijing, the Corporation will work together with the Beijing Municipal Government from the early stage of the project in order to utilize the full benefit.

6. ACKNOWLEDGEMENTS

Design and construction of the Beijing Line 4 Project is being undertaken by the Beijing MTR Construction Administration Corporation and the E&M works are project managed by the MTR Corporation project staff. All PPP Company partners have played their part in getting the project to the current stage. The author acknowledges the significant contribution of all who have contributed to the project in the pursuit of a new metro line for Beijing.

The author is grateful to the MTR Corporation for permission to publish this paper.

Paper No. 4

BEIJING GREEN PLAZA – A LEADING EDGE ECOLOGICAL MIXED DEVELOPMENT IN THE CITY OF BEIJING

Speakers : Ir Simon F.W. Chung, Director
Mr Eddie C.M. Choy, Senior Engineer
Ove Arup & Partners Hong Kong Ltd.

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Paper No. 4

ABSTRACT

Beijing Green Plaza is a mixed development with a total construction floor area of 200,000sqm located in Chaoyang District of Beijing city. It comprises four tower blocks on top of one level of podium with three basement levels. The entire development is encased in a glazed enclosure creating an ecological environment within the enclosure, thereby protecting it from Beijing's severe weather, i.e. very cold winter and very hot summer.

The new frontiers for the involvement of electrical engineering in this project include the application of the state-of-the-art energy savings and efficient measures in the design of the electrical supply and distribution systems and the provisions of the latest information and communications technology services. More important are the consolidated efforts among the designers, i.e. architects, mechanical and electrical engineers, in making use of all possible passive and active means in the design and construction of the project. Such efforts have accomplished an adaptive and intelligent control system to control key devices on the envelope of the environmental shelter achieving an internal ecological environment for all seasons. The various devices being under control are the natural ventilation louvres and glazed elements that will regulate the internal airflow, temperature and day lighting factors under a sophisticated control system.

This paper will provide an overview on the electrical, information and communications technology design for this project. In addition, the paper will also evaluate different communication protocols on how to integrate the various control systems of different devices such that a holistic control strategy can be adopted for the entire development.

1. INTRODUCTION

Figure 1 Prespective View

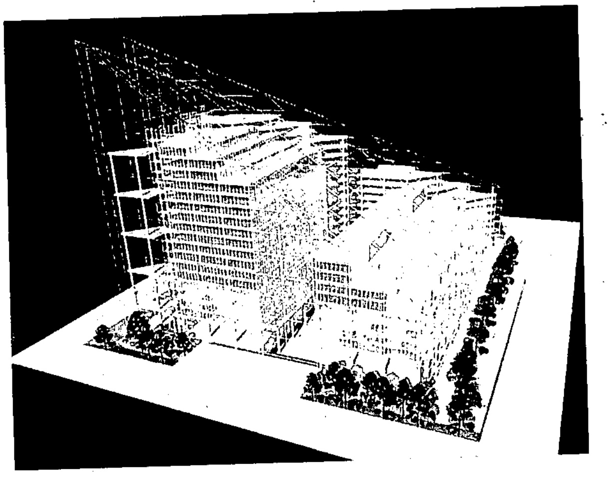
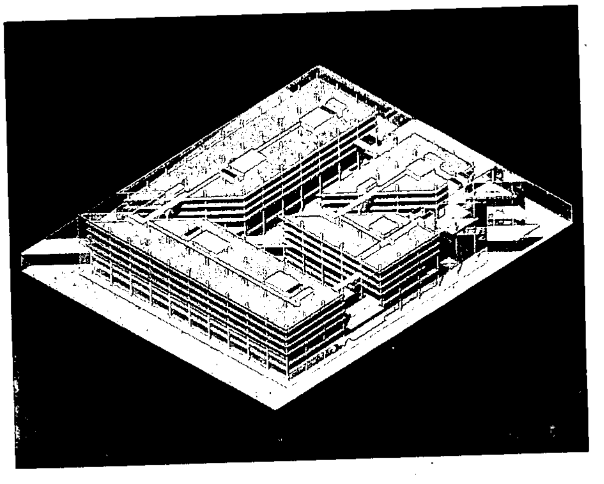


Figure 2 Horizontal Sectional View



The Beijing Green Plaza is composed of four towers and three storeys of common basement floors. There are four storeys of retail and restaurant floors, seven to eleven storeys of office floors, five storeys of guest rooms and a main lobby. The built form and building arrangement are located to maximize daylight access to every office floor whilst minimizing the daylight blockage to the surrounding buildings.

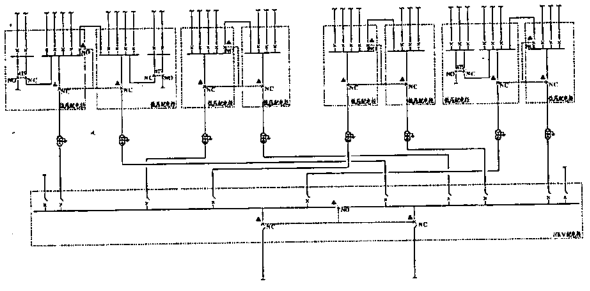
The environmental shield is the major feature of green building technology that promotes a better natural ventilation environment for the office floors during moderate climate periods. Fully automatic control is provided to control the ventilation logic of motorized ventilation dampers such that the natural air flow path can be controlled through the integrated control strategy.

2. POWER SUPPLY SYSTEM

The power supply to the Green Plaza is a dual 10kV power supply from the nearby local Power Supply Bureau's zone substation. In case of failure or maintenance of any one of supply feeders, the other feeder could take over the total load of the Green Plaza. The estimated load demand of the entire development is 16.4MVA and the installed transformer capacity is 20.4MVA.

Two standby diesel generators provide the emergency power system for the Green Plaza. Each generator is rated at 2MVA. One generator is to back-up the fire services equipment and installations and the essential portion of the chilled water plant. The other generator provides the back-up power to the office tenants and all critical loads such as security, IT and communication facilities. An uninterruptible power supply system is proposed to provide a high quality and secure power supply to the most critical equipment.

Figure 3 - Main Power Supply Schematic



For load demand distribution amongst the transformers, power supply risers at the lower office block are to be split into two risers on each floor. While power supply risers at the higher office block are to be split into high zone and low zone.

To provide a reliable and efficient emergency back-up power supply to the office tenants, an additional fully automatic start standby diesel generator will be provided. This will supply essential power to the office tenants in case of normal power failure. Tenants' essential supply is mainly provided for tenants' computers and tenants' computer room air conditioning units. The rating of the generator for office tenants is based on a provision of 20W/m^2 of office usable area. To avoid disruption to the tenants' computer operations during mains to generator power switchover, the tenants will install their own UPS system.

In view of the south-east side of the environmental enclosure is the highest end, which has an advantage to adopt the design of a Building Integrated Photovoltaic (BIPV) to provide a clean power system to the Green Plaza. The BIPV system consists of integrating Photovoltaic into the environmental enclosure vertical façade, simultaneously serving as environmental enclosure material and power generator. BIPV system provides savings in materials and electricity costs. The power from the BIPV provides the power supply to the façade/landscape lighting. Since the solar power is not always available at all times, the installation is also connected to the city electricity grid.

3. INFORMATION AND COMMUNICATIONS TECHNOLOGY

The platform used for information sharing and different communications technology between the four blocks and connecting to outside of this development is a generic cabling system. The designed generic cabling system seeks to be future-proof such that it will be able to support increasing speeds for future networking technologies over a period of years.

The basis of generic cabling system is the use of common cabling, terminations and outlets to support different services like telephony, data, video, audio, analogue/digital applications, Local Area Network (LAN), broadband internet access, etc. on a common platform. This typically involves the use of twisted pair cabling, terminated in RJ-45 outlets. Therefore, any outlet can be re-configured for voice, data or video services via simple patching and offers maximum flexibility for moves, changes and different in layouts.

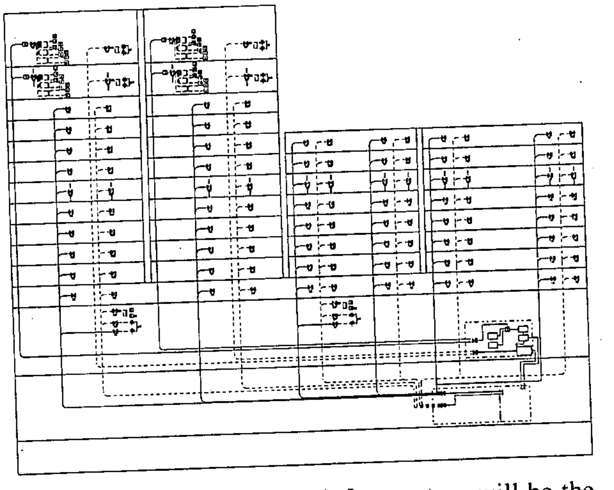
To connect a voice service, an outlet is patched to a PABX port, for data it is patched to a switch port. For video transmission, this can be achieved through the use of simple baluns at either end of the cable. For the backbone cabling between IT equipment rooms and between buildings, a combination of fibre optic and copper multi-pair cabling is used.

The backbone cabling system will make use of a combination of copper and optical fibre cables to provide the required connectivity for the IT, communication and building systems in order to ensure that the cabling systems are future proof. Current standards recognize the optical fibre 50/125 micron multi-mode optical fibre cable will be used as the backbone for data communication while multi-pair Category 6 copper cables will be used as the backbone for voice communication. They will be used to connect the telecom rooms to the communications closets in each floor in the office towers. Multi-mode optical fibre cable is traditionally used for short distances e.g. backbones within buildings. Multi-mode optical fibre cable has the advantage of being able to use inexpensive switching equipment based on LEDs, with single mode requiring more costly laser technology.

Some copper cabling will also be required in the backbone, primarily for voice services.

The horizontal cabling system will make use of the latest copper UTP cables to provide connectivity from the patch panels in the communications closet to the outlets. In general the recent generation of copper cabling system conforms to Category 6.

Figure 4 Generic Cabling System Schematic



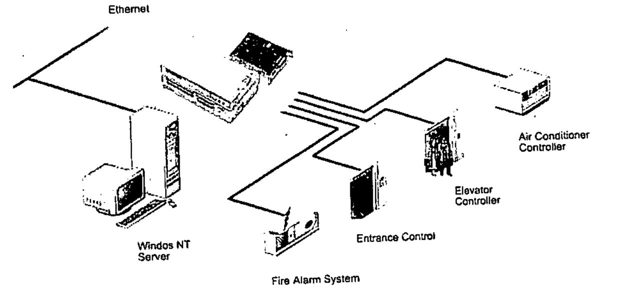
The generic cabling infrastructure will be the media used for the transmission and reception of the communication signals for the following systems:

i) Network infrastructure
ii) Telecommunications infrastructure
iii) Service infrastructure
iv) Wireless communications infrastructure
v) Video system infrastructure

All other systems will communicate via their own dedicated cabling scheme including:-

i) Security and safety system
ii) Lighting control system
iii) HVAC control
iv) Lift control
v) Access control
vi) CCTV system
vii) Fire Alarm System

Figure 5 Integrated Building Services System Schematic



4. MODE OF ECOLOGICAL ENVIRONMENT WITHIN THE ENCLOSURE

The integrated building design is linked with

Paper No. 4

the built form, materials of building envelope as well as the local climatic conditions. The environmental enclosure is able to separate the outdoor environment from the indoor microclimate. The design objective of the building envelope is to reduce the solar heat gain in the summer, trap warm air inside the enclosure in the winter and to minimise sand storm impact during moderate climate periods.

In the spring season the outdoor temperature and humidity fall and provide comfortable conditions which are able to satisfy the thermal comfort requirements of the building occupants. The vent openings on the environmental enclosure and the four buildings can be opened such that natural ventilation, by means of transferring outdoor air at building low level to the enclosure top vent via the office interior, is feasible. The air-conditioning and ventilation modes are described in the table below.

Zone	Operation mode in moderate climate period
Office	Natural vent (if temperature, humidity and outdoor air quality are acceptable)
Hotel	Air-conditioning
Retail	Air-conditioning
Atrium	Natural ventilation
Skygarden	Natural ventilation

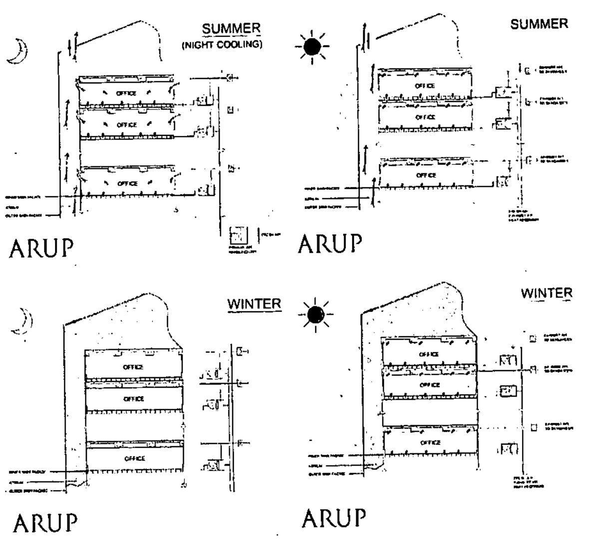
In the summer season, the outdoor temperature can reach 35°C such that natural ventilation in the office and commercial areas are is feasible. Meanwhile, in order to further reduce the building cooling energy consumption, excessive heat shall be released from the environmental enclosure to the outdoors. The top vent of the environmental enclosure will be opened automatically such that hot air inside the environmental enclosure will be released to the outdoors. The performance of air cavity between the environmental enclosure and the four building facades is similar to that of a ventilated window.

Zone	Operation mode in summer
Office	Space cooling
Hotel	Space cooling
Retail	Space cooling
Atrium	Natural ventilation + general exhaust air reused for cooling
Skygarden	Natural ventilation + general exhaust air reused for cooling

In the winter season, the environmental shield is designed to minimise heat loss from the building interior to the outdoors via the building fabric and the environmental enclosure. In this period, the top vent of the environmental enclosure is closed such that warm air stratified from the atrium level to the top of the enclosure is trapped and the enclosure will then fill-up gradually. Hence, the warm air cavity between the environmental enclosure and the buildings is acting as a thermal buffer and to reduce heat loss from the building.

Zone	Operation mode in winter
Office	Space heating
Hotel	Space heating
Retail	Space heating
Atrium	Natural ventilation + general exhaust air reused for heating
Skygarden	Natural ventilation + general exhaust air reused for heating

Figure 6 Hybrid Ventilation Mode



The automatic control of vent openings on the environmental enclosure relies on various electrical power and control facilities. The facilities consist of temperature sensors, humidity sensors, control network cabling, network interfacing units, direct digital controllers (DDC), relays, volt-free contacts, motorised devices and operator workstations.

The DDC reads the outdoor temperature via the sensor and the mode schedule to determine the vent openings ON/OFF under different climatic conditions. Upon receiving analogue input signals from the sensors, the DDC will analyse the condition inside the environmental enclosure and then output the digital ON/OFF signals to the motorised devices to control the vent openings ON/OFF.

5. CONTROL STRATEGIES

Intelligent monitoring and management of the buildings design have been considered.

The integration of monitoring, communication and control of different building automation systems from various manufacturers would be built on an open-system architecture and standards. An Integrated Building Management System (IBMS) will be considered for integrating and interfacing various building services systems between the four blocks of the entire development for information sharing, data transmission, system management or other higher layer interface. The IBMS will also provide the interface communication services between building users and management offices as well as dynamic, flexible control and automation of various services with inputs from the environment and human. The networking systems will adopt open-architecture to form a high speed, high-performance and flexible network.

In the industrial world, the integration of control and field components from various manufacturers has, in the past, often proved to be a difficult task. Application, such as operator control and monitoring or process data management, requires a driver for every automation component whose data needs to be read out. Moreover, automation systems can only be operated with applications for which special drivers have been developed.

Therefore, we proposed to use the well-developed open protocol of LonWorks and BACnet as the driver for the control system. These open protocols will be the drivers for every automation component because they are the two most commonly used open protocols used in the PRC. In addition, it is easy to find the automation component, which applies these standards in the market of PRC.

6. CONCLUSIONS

The application of electrical engineering skills in the design of electrical power distribution in this development includes the integration of energy saving systems. The project has adopted the latest information and communications technologies in the control and monitoring of a wide variety of building systems. More important are the consolidated efforts among the designers, i.e. architects, mechanical and electrical engineers, in making use of all possible passive and active means in the design and construction of the project. Such efforts have accomplished an adaptive and intelligent control system to control key devices on the envelope of the environmental shelter achieving an internal ecological environment for all seasons. The consolidated control strategies have enabled a complicated environmental shelter to be designed and implemented, and the follow-up control and monitoring of the internal environment become easy tasks. The design concept for an environmental shelter for this project is an excellence idea, but it could only be achieved with the contribution the electrical engineers applying the latest leading edge knowledge in electrical engineering. This is considered to be a case demonstrating a new frontier of electrical engineering.

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Paper No. 5

MEETING THE CHALLENGES ARISING FROM THE INSTALLATION OF 132KV CIRCUITS FROM PUI O TO CHEUNG CHAU

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Ir Sandun N. Wimalasena, Senior Project Engineer
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ABSTRACT

To enhance the reliability and efficiency of the electricity transmission network which supplies 45,000 customers in South Lantau and Cheung Chau, all the existing 33kV equipment and overhead lines are being decommissioned and replaced with 132kV cable circuits. A scheme to install three 132kV cable circuits from Pui O Substation to Cheung Chau is an integral part of this essential project. The overall cable circuit consists of not only cables laid in trench but also cables laid through tunnel and underneath the seabed. During the route selection stage CLP Power Hong Kong Ltd (CLP Power) carried out comprehensive option studies, a full environmental impact assessment and extensive public consultation to arrive at an optimal solution. During the construction phase there have been many technical innovations: by way of example trenching was constructed through a fully operational campsite; horizontal directional drilling technology was used to cross a river estuary, tunnelling technology was used to excavate through the Chi Ma Wan peninsula and submarine cables had to traverse through a section of a seawall at Cheung Chau. To strengthen the excellent relationship that CLP Power has built up with the community many initiatives have been undertaken throughout the project lifecycle. In particular on maintaining open communication with government and responsibly managing the impact of construction activities is demonstrated by overcoming of objections where both the local community and environmental groups have commended CLP Power on their approach. The final solution has met the expectations of the local residents, reduced environmental impact whilst at the same time overcoming many engineering difficulties. The paper explains the solutions to the many challenges faced including those encountered during route selection, those initiatives taken to strengthen the relationship with the community and innovative technologies adopted during the implementation stage.

1. INTRODUCTION

CLP Power Hong Kong Limited (CLP Power) supplies electricity to 2 million customers in Kowloon and the New Territories of Hong Kong Special Administrative Region (HKSAR) with a service area covering about 1,000 square kilometers. With a focus on project management and as a responsible corporate citizen CLP Power is continuously seeking innovative solutions to deliver projects in an effective and transparent manner. Due to the constraints, challenges and risks associated with the 132kV circuits from Pui O to Cheung Chau, CLP Power carried out comprehensive option studies, an environmental impact study and public consultation to arrive at an optimal solution. This solution respected community concerns, took care of environmental issues and overcame many engineering difficulties. The following paragraphs outline some of the challenges faced and how they were overcome.

2. ELECTRICITY SUPPLY IN CHEUNG CHAU

In the 1950's there were many small scale leather, incense, paper making, ice, ship-building and plastic factories operating on Cheung Chau island. Most of the inhabitants worked on the island and electricity was supplied by the Cheung Chau Electricity Company. Kerosene was the fuel for electricity generation. The price of electricity to the residents was high. In 1984 CLP Power acquired the Company. The tariff, which was then unified with that of CLP Power's customers in Kowloon and the New Territories, significantly helped the population on Cheung Chau economically. This improvement has brought about prosperity to Cheung Chau. Many locals and foreigners have moved to Cheung Chau to enjoy the atmosphere of the fishing port and island living.

With the increase in population the electricity demand in Cheung Chau has continued to grow. CLP Power's existing 33kV network is composed of overhead lines and submarine cables supplied from the main grid on Lantau Island. The overhead transmission system is however vulnerable to inclement weather, with lightning and typhoons resulting in more than 200 faults over the past 10 years. To enhance the supply reliability and electricity transmission efficiency to over 45,000 customers on South Lantau and Cheung Chau all of the existing 33kV equipment and overhead lines on Lantau Island are being decommissioned and replaced with 132kV cable circuits. The installation of three 132kV cable circuits from Pui O Substation to Cheung Chau is an integral part of this upgrading program.

3. ROUTE SELECTION

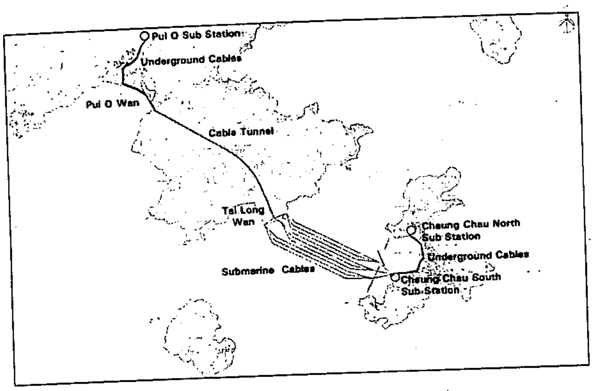
Feasibility studies for the scheme started in 1999. Altogether thirteen different route options were considered. By late 1999, four of these options were shortlisted for further development in a Route Options Study. The options were evaluated with due consideration of landscape & ecological impact, visual impact, statutory requirements, land requirements, traffic impact, marine impact, construction cost, ease of maintenance and construction impact. Based on the evaluation criteria, the preferred scheme involved trenching along the South Lantau and Chi Ma Wan roads, followed by a cable tunnel transversing the Chi Man Wan Peninsula to Tai Long Wan with submarine cables then running to Cheung Chau. An Environmental Impact Assessment (EIA) was conducted and approval was granted by the Environmental Protection Department in early 2002. The endorsement from multiple stakeholders including Island District Office, South Lantau Rural Committee, Village Heads, Fisherman Associations, the Green Lantau Association and various Government Departments was obtained through consultation.

3.1 KEY CONCERNS RAISED BY THE COMMUNITY AND GREEN GROUPS

Very soon after contract award and in spite of the previous consultations undertaken with stakeholders, some 2,400 objections were raised by the community. Further public consultation was arranged by CLP Power to understand in more detail the nature of the community's concerns. During a 5-month period some 43 activities were undertaken by CLP Power to solicit comments from residents, environmental groups, the media, government departments and other interested parties. The key concerns of the public were grouped into four broad categories: issues related to the development of the original scheme; health and safety issues; environment issues and issues related to construction nuisance.

In consulting the views of the public, CLP Power came to better understand their needs and specific concerns. With this in mind, modifications were made to the existing scheme to reduce the disturbance to the environment and the local community, whilst optimising cost, time and construction risks. These modifications included: re-routing the cable circuit away from the Chi Ma Wan Road to reduce the traffic impacts and thereby inconvenience to local residents; eliminating at Pui O the construction of temporary structures on the beach and permanent structures on the hillside, thereby improving upon the environmental and visual impacts of the scheme; using materials and components delivered from Tai Long Wan to reduce insitu works at Pui O. Details of the specific modifications made to the original scheme were outlined in a Public Consultation Report which was given to all the objectors as a document forming the basis of CLP Power's commitment as to the way forward. As a consequence the vast majority of objectors withdrew their objections and construction commenced some 9 months after the first objection was raised.

Figure 1 132kV Circuits Routing from Pui O to Cheung Chau



4. TECHNICAL INNOVATIONS

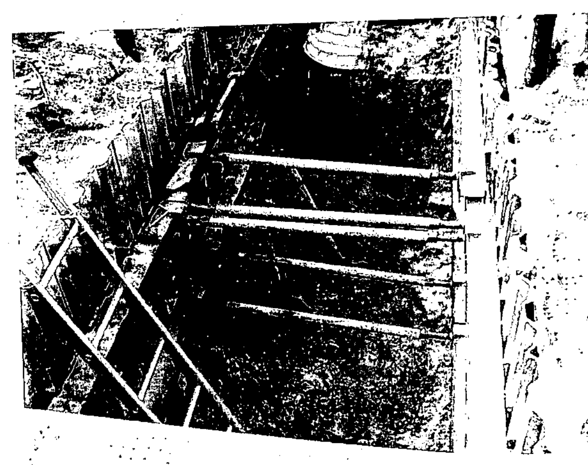
4.1 TRENCHING

Before entering the cable tunnel, the 132kV cable has to transverse through the Pui O camp site, a popular destination for holiday makers. In order to minimize the disturbance to the general public due to trenching operations, special attention had been drawn on safety, environmental protection and site tidiness matters. Prior to commencement of trench excavation, hoarding at the work area inside the camp site was erected to segregate the trenching area. Excavation was carried out predominantly with a small excavator to avoid the movement of large vehicles. Trenches and duct blocks were constructed and reinstated in sequence as agreed with the Leisure and Cultural Services Department (LCSD) and the local shop proprietors so that major access to all facilities could be maintained. Decking was provided along the trench inside the campsite to ensure safety. Soil and waste was carted away to an approved dump site twice a day.

Figure 2 Trenching Works behind the Hoarding inside the Campsite

The section of trenching near the Pui O School and playground has been modified with the inclusion of reinforced concrete layers. All trenching works along the campsite was performed in the shortest possible duration and confined to 5 days/week and from 9:00 a.m. to 5:00 p.m. as far as practicable. The trench was also constructed in the verge area and footpath as agreed with LCSD and did not affect the beach or the beach users.

Figure 3 Trenching Works Excavation



4.2 HORIZONTAL DIRECTIONAL DRILLING

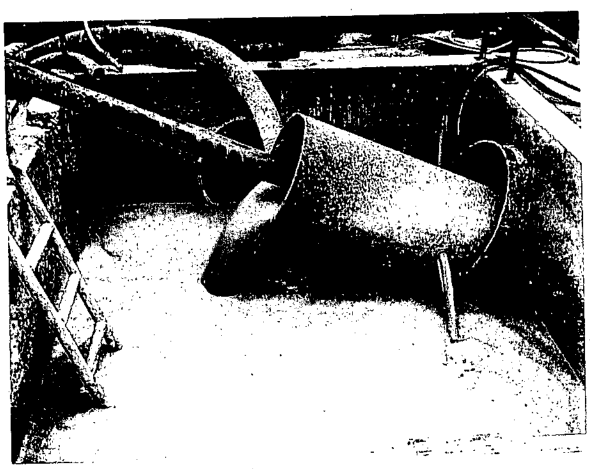
Horizontal Directional Drilling (HDD) technology was used to construct two river crossings under the estuary at Pui O from the Pui O campsite. A surface launched drilling rig was used to drill a pilot hole which was then

Paper No. 5

progressively enlarged. Ducts and then cables were installed in the holes.

Due to the close proximity of campers and local residents, significant attempts were made to better noise levels stipulated in construction noise permits issued by the Environmental Protection Department. By way of example fixed plant such as compressors and generators were super silenced. An acoustic barrier was provided around the worksite. The site was paved with the drainage system leading directly to a sedimentation tank and water treatment plant. Separate bunding was also provided around the bentonite handling area. The worksite was also designed to absolute minimum dimensions.

Figure 4 Drilling in Operation with Bunding around the Bentonite Handling Area

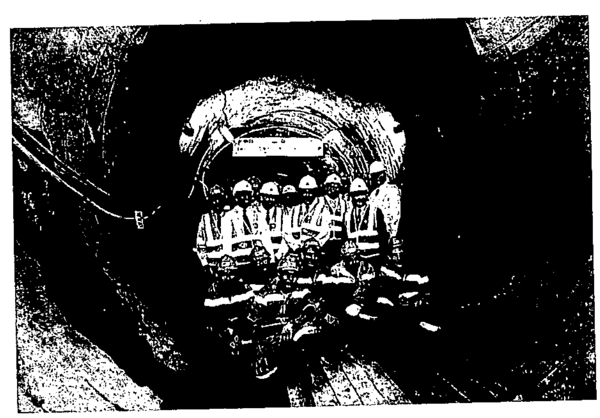


4.3 CABLE TUNNEL

Figure 5 TBM Naming Ceremony

The concerns of the local residents were of particular importance when reviewing the design of the scheme, as the work is being undertaken in a rural village location. After extensive stakeholder engagement a number of amendments were made. The amendments included the lowering of the tunnel entrance in the hillside to minimize the visual impact of the permanent portal. Traffic movements along the Chi Ma Wan road were largely curtailed through the use of materials delivered from Tai Long Wan by sea traffic. A temporary footpath diversion was formed and a noise screen erected to facilitate construction of a receiving chamber for the tunnel boring machine (TBM). After site investigation had identified a structurally stable tunnel exit point at the footpath level of the hill side, the tunnel alignment was lowered from the originally designed mid level. As a result, the construction of a temporary platform on the beach to receive the tunnel boring machine from an otherwise elevated tunnel exit level was no longer required.. By re-designing the ventilation system, the fan house on the hillside facing the Pui O beach was also eliminated in the revised scheme. The access to the tunnel was recessed into the hillside. An artificial rock face masked the opening in the permanent condition. Also included was a change in the direction of tunnelling. Some 49,000m^3 of excavated material was taken out by barge from Tai Long Wan and not by road through Pui O. This change also removed the requirement for a temporary reclamation and the disruption of having a large number of plant and vehicles movements going through the village.

Figure 6 TBM Breakthrough Ceremony



4.4 SUBMARINE CABLES

Three circuits of 132kV, 80MVA, 3-core XLPE submarine power cables with three optical fiber communication cables were laid to provide the link up from Tai Long Wan to Cheung Chau Island. The length of each cable was approximately 2.7km long with an installed depth of 5.0m below the seabed. The cables had to traverse through a section of a seawall and breakwater at Cheung Chau. Therefore the shore end preparation works at Cheung Chau had to be completed prior to the cable landing operation. Works included the construction of six HDPE ducts under the toe of the seawall and breakwater for installation of the cables and excavation of a 60m trench on the seabed across the Cheung Chau typhoon shelter connecting the ducts from the seawall to the breakwater. Instead of using traditional buoys, marine lifting bags that can hold up to 1815 kg on floating water were used to keep the cable end raised and prevent it from being buried in the seabed during the cable pulling operation.

After the cable landing operation was completed, the cables were laid from the laying barge into the seabed through the burial machine. At the Tai Long Wan end, the cables were routed into the pre-cast concrete duct blocks by use of a hauling winch located at the shore end.

Figure 7 Cable Duct Installation in Cheung Chau Seawall for Submarine Cable

Figure 8 Submarine Cable Laying Barge and Burial Machine

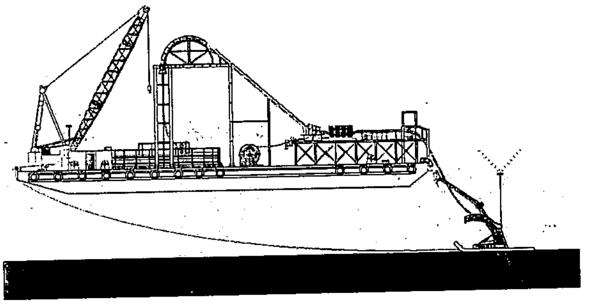


Figure 9 Tai Long Wan Cable Landing Trough

Various environmental protection measures were employed during the submarine cable laying operation. These measures included: continuously collecting sub-bottom soil samples on the dredged area for analysis of the chemical composition; establishing monitoring points for monitoring the water quality during the cable installation and fencing of the marine dredging by use of a specially-built 'silt curtain' to prevent the spread of contaminated water.

5. ENVIRONMENTAL INITIATIVES

Environmental Monitoring was carried out in accordance with the approved Environmental Permit and Environmental Monitoring & Audit (EM & A) Manual for the works. An Independent Environmental Team totally separate from the Project Team undertook the monitoring. The work of this team was verified

Paper No. 5

by an Independent Environmental Checker. The type and frequency of monitoring were explicitly specified in the EM & A Manual. In addition, the Resident Site Staff under the control of CLP Power checked and monitored on the contractor's performance. In line with the revision in the routing of the cable circuits, the EM&A Manual was updated to include the new alignment and the associated works. The role of the Environmental Team, Independent Environmental Checker and the Resident Site Staff was expanded to cover for these additional works.

All excavated spoil was only disposed of at approved Government dumping sites. The contractors were required to submit detailed method statements for the works, which needed to include the proposed disposal areas. During the works a Trip Ticket System was employed to track and control the movement and disposal of the spoil. Further checking by the Supervising Officer was undertaken on a weekly basis and unannounced spot checks made to ensure that the spoil was dumped at the location as indicated and agreed on the contractor's method statements.

Figure 10 Noise Enclosure at Pui O Tunnel Portal

6 COMMUNITY INITIATIVES

A number of other initiatives have been put in place to encourage a good working relationship with the community. For example local villagers have been employed as far as practicable. Clean up of some local areas were organized jointly with community groups. Good relationships have been established with local environmental groups. A hoarding painting competition was developed to encourage interaction and environmental learning with local schoolchildren. Care was also taken to minimize the visual impact of site hoardings and images of real trees were pasted onto the site hoardings to sensitively blend in the structures with the surroundings.

Figure 11 Minimization of Visual Impact of HDD Site Hoardings

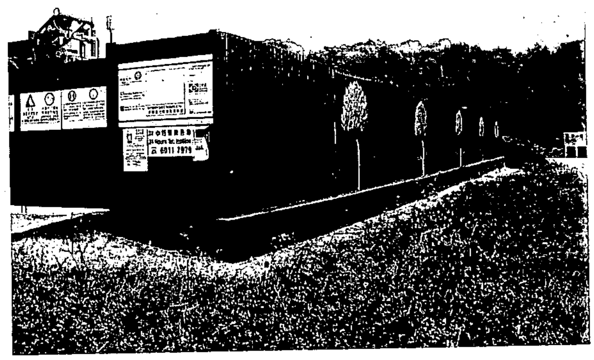


Figure 12 Community Cleanup at Chi Ma Wan Road

Figure 13 Extract from Hoarding Painting Competition

To ensure that the construction works caused minimum disturbance and disruption to the communities near the project sites, relationship management was stipulated as a priority in the contract documentation. All site workers were briefed through initial induction training and thereafter through regular 'toolbox talks' to encourage a culture of good relations with the public. The works themselves have been designed to minimize the impacts on the community by limiting noise, dust, vibration and vehicle movements. Liaison with the local communities has been ongoing to ensure regular feedback of any concerns that the residents may have in order to allow the Project Team to mitigate them appropriately. Local residents are able to contact the Project Team via a 24-hour bilingual telephone hotline. The number of the telephone hotline was displayed on the hoardings of all of the work sites. Comments raised by callers to the hotline were logged in through a community feedback register and were acted upon promptly. Community Feedback Forum Meetings were also held on a regular basis to allow the residents to meet up with the Project Team and to discuss any aspect of the project with them.

Figure 14 Community Feedback Forum Meeting

7. RESULTS ACHIEVED

Figure 15 Typical Visit to Site by Schoolchildren

CLP Power's commitment to maintaining open communication with government and regulatory bodies and minimising possible environmental impacts from construction activities helped to win over a previously sceptical community. It is also most encouraging to note that appreciation letters have been received from environmental groups and local schools.

Paper No. 5

8. CONCLUSION

It is clearly important to involve key stakeholders in planning of major infrastructure projects. It is also clear that the application of modern technology, innovations and initiatives can address the concerns thereby yielding optimal solutions.

ACKNOWLEDGEMENT

The authors wish to thank the Management of CLP Power Hong Kong Ltd for their support and encouragement given to publish this paper.

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Paper No. 6

LIFE CYCLE ENERGY ANALYSIS OF BUILDING CONSTRUCTION

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LIFE CYCLE ENERGY ANALYSIS OF BUILIDNG CONSTRUCTION

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ABSTRACT

The Electrical and Mechanical Services Department commenced a study on Life Cycle Energy Analysis of Building Construction in April 2003. The purpose of the study is to develop a computer software tool and compile localized data that appraises life cycle environmental impacts, costs and energy performance of building construction. The software tool so developed aims to facilitate professionals to conduct assessments over building designs, for arriving at optimum solutions on the life cycle economic and environmental performance of building materials, components and engineering systems. This paper describes the key tasks carried out in the development of the Software Tool.

1. INTRODUCTION

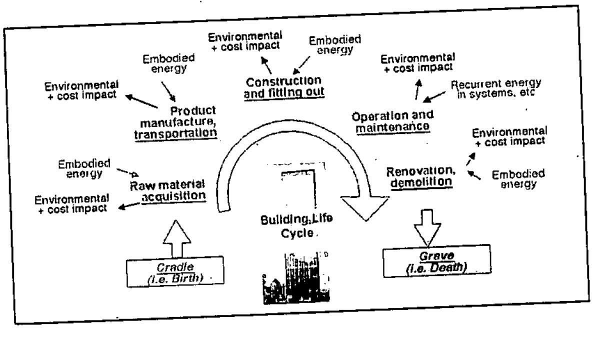
Buildings are climate modifiers that provide indoor environments suitable for habitation and various economic and social functions. However, the cost of having buildings to fulfil our needs involves enormous amount of resources consumption during construction, operation, maintenance and demolition of the buildings, from which large quantities of wastes and pollutants are also generated.

In Hong Kong, buildings are responsible for a major portion of the city's overall energy use. Demolition of buildings generates huge amount of solid waste, which is becoming a major load on our landfills. Enhancing sustainability of building development is paramount important to the sustainability of Hong Kong. To achieve this goal, developing a reliable tool for quantifying environmental impacts of buildings is necessary.

Life Cycle Assessment (LCA) is an objective method to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials uses and releases to the environment, and to evaluate and implement opportunities to influence environmental improvements. The method assesses the entire life cycle of the product, process or activities, encompassing extracting and processing materials; manufacturing, transporting and distribution; use, reuse and maintenance; recycling and final disposal. And more recently the LCA concept is applied to building development by many European and North America countries.

Paper No. 6

Figure 1 Life Cycle Analysis of Building Development



2. DEVELOPMENT OF LOCAL DATABASE AND THE LCA/ LCC TOOL

The major tasks associated with the development of the Life Cycle Assessment (LCA)/ Life Cycle Cost (LCC) tool and database are discussed in the following paragraphs.

SIEMENS

At the Research Stage, a comprehensive review of worldwide LCA development and applications was conducted; various available LCA methods, development tools and sources of data evaluated; and further data needs are identified.

Well-know LCA programs for buildings currently available are:

- ATHENA (Canada)
- BEES (US)
- EcoQuantum (The Netherlands)
- ENVEST (UK)

This reviews informed the selection of LCA method, development tools and data sources for use in the Study to develop the LCA/LCC program and the databases, which are parts of the major deliverables of the Study. The need for surveys to source for information about local construction practices has been identified. The target functions and features to be incorporated into the LCA/LCC program are also set in for accomplishment in the program development work.

Additionally, surveys of the types and quantities of materials that are used in building construction in Hong Kong were conducted. This part of the work was intended to identify the range of materials and systems that dominate the total environmental impacts of commercial buildings in Hong Kong such that the Localisation work can concentrate on the dominant materials and system.

Survey and analysis of the types and quantities of materials used in 28 recently completed commercial building projects in Hong Kong, including quantification of the environmental impacts associated with the material used and prioritization of the materials according to the incurred impacts.

The data about the types and quantities of materials used in the 28 building projects in the sample were extracted from the detailed bills of quantities. The top 20 most influential building materials found from the survey are as listed in Fig. 2. These 20 materials already accounted for over 99.5% of the total impacts incurred by all materials identified. The survey also identified the top 40 most influential services systems and components that contributed over 99.9% of the total impacts incurred by all services systems and components identified.

Figure 2 Life Cycle Inventory of Building Material and Services System

Top 20 dominant building materials in respect of LCI in the database:	List top 40 building services systems & components with greatest LCI in the database:
1. Concrete	1. Power cables
2. Reinforcing Bar	2. Busbar trunking or busducts
3. Plaster, Render and Screed	3. Chillers
4. Galvanised Steel	4. Air conditioning duct work & fitting and insulation
5. Tiles	5. Chilled water systems including pipework excluding chiller
6. Stones	6. Mcb and mccb distribution boards
7. Aluminium	7. Sprinkler systems including pipework
8. Structural Steel	8. AHU/PAUs
9. Access Floor Panel	9. Submain conduits and trunkings
10. Stainless Steel	10. Luminaries
11. Plasterboard	11. Escalators
12. Glass	12. FCU
13. Bricks and Blocks	13. Lift
14. Plywood	14. Fresh water systems
15. Formwork	15. Ventilation fans
16. Structural Pre-cast items (Floor Planks, Beams,Staircase)	16. Fire hydrant and hose reels systems
17. Acoustic Tiles	17. Condensate drain systems
18. Plastic, Rubber, Polymer	18. Diesel Generators
19. Plastic Laminate	19. Plumbing and drainage systems
20. Thermal Insulation	20. LV switchboards
	21. ....etc

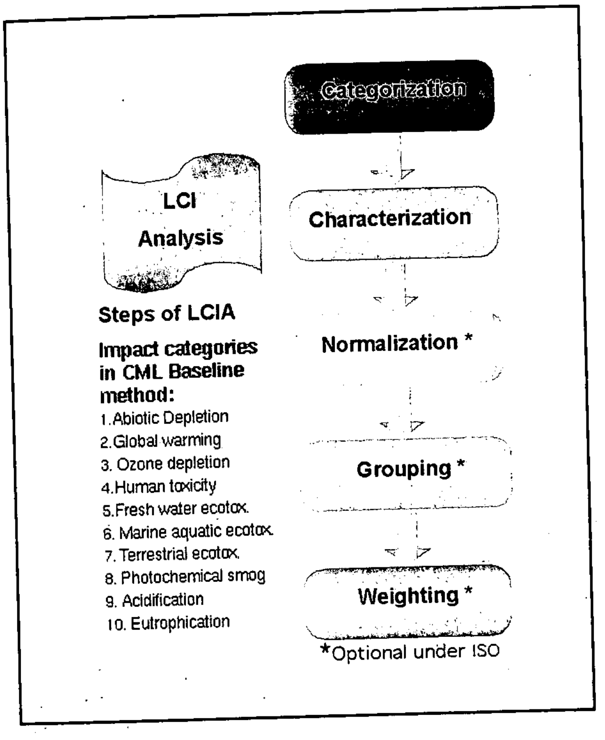
At the Development Stage, the approach and the required methods for the establishment of appropriate data that can reflect the environmental impacts and costs associated with consumption of materials and energy throughout of the life cycle of commercial buildings in Hong Kong, and to produce a set of data to embrace the most significant materials were established.

Furthermore, methods were developed to solicit subjective judgments on the relative importance among various impact categories and between life cycle impact and life cycle cost; and on that basis establishment of an appropriate set of weighting factors for aggregating life cycle impact assessment (LCIA) result as into a single impact indicator, and combing the LCA and LCC results into an overall assessment result, to facilitate designers to make decisions.

An accurate and computationally efficient building energy simulation model was developed for prediction of the operating energy use in commercial building to allow this important contributing factor to be included in the LCA and LCC calculations.

The technical aspects on the development of LCA/LCC model and database is summarized by the following flowchart:

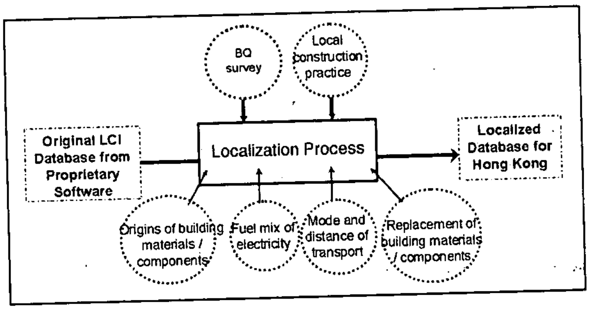
Figure 3 Life Cycle Analysis Processes



The LCIA method selected, the CML2 Baseline 2000 Method, is based on the mid-point approach, which yields an impact indicator for each of the 10 impact categories embraced by the Method. This makes interpretation of the assessment result difficult to non-LCA-experts. An extra step called weighting can be taken which, according to ISO14000 series of Standards, is an optional LCA step to aggregate the LCIA results into a single score to ease interpretation. This, however, requires the establishment of a set of weighting factors for the set of impact indicators.

The Localisation process is to obtain life cycle inventory (LCI) data for various processes involved in producing building materials from established LCI databases that were developed for application in European countries. Adjustments to the data are made in the localisation process to account for the different energy mixes used for electricity generation and for production of the materials in various countries of origin of the materials that are imported into Hong Kong, for transportation of the materials to Hong Kong, and for the materials and energy used during the construction processes that take place in Hong Kong.

Figure 4 Localisaton of Material Database

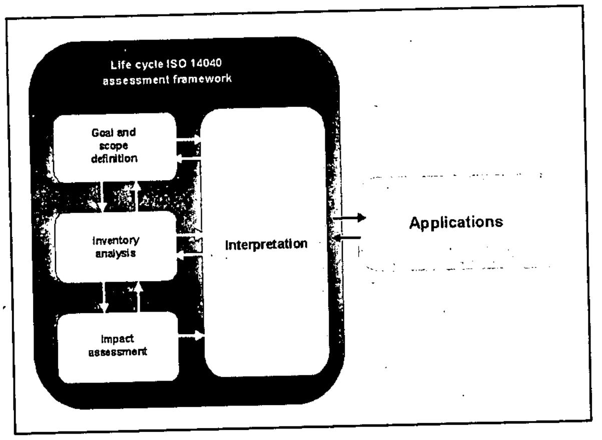


The localisaton process is needed to produce data that can reflect the impacts incurred by the consumption of construction materials in Hong Kong, to provide a meaningful basis for LCA of local commercial building. The LCIA profiles can then be lodged into a database for use with the LCA /LCC program. Compared to using localized LCI data, using LCIA profiles has the advantage that the volume of data to be incorporated into the database can be drastically reduced, and no proprietary data sourced from the LCI databases will be divulged.

3. KEY FEATURES OF THE LCA/ LCC TOOL

To ensure the credibility of the LCA/LCC program, it is developed under the established framework of ISO 14040. The 14040 series of ISO Standards provides and internationally accepted framework for LCA. The Framework is shown in Fig. 5

Figure 5 Framework of Life Cycle Assessment Under ISO 14040

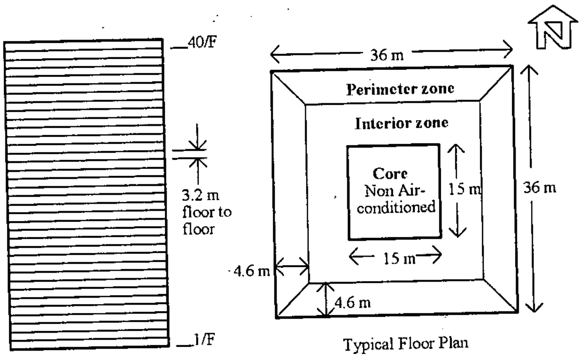


The LCA/LCC tool developed is a computer program that can facilitate building designers to input the required data to model the building designed; perform calculations of the environmental impacts and life cycle cost of the building; and to compare the impacts and costs of alternative designs. The program can output calculated results for different stages in the life cycle of a building, including up to the as-built stage, the operating stage and the end-of life stage. Separate results can also be retrieved for different parts of a building, such as the impacts of the foundation, the building fabric and the services. Facilities are provided to allow the user to compare results down to individual element level. In addition to data outputs, graphical outputs that show a comparison between alternative designs and a breakdown of the total impacts to by individual impact categories can be provided.

4. A WORKED EXAMPLE

The following illustrates the key features of the software tool with a sample office building of 40-storey:

Figure 6 Characteristics of a 40-storey Office Building



Item	Unit	Value
No. of storey	No.	40
Floor-to-floor height	m	3.2
Width of typical floor	m	36
Depth of typical floor	m	36
Construction floor area per floor (CFA)	m^2	1296
Total CFA in building	m^2	51840
Width of building core	m	15
Depth of building core	m	15
Core area	m^2	225
Air-conditioned area		
Depth of perimeter zone	m	4.6
North perimeter zone	m^2	144.44
East perimeter zone	m^2	144.44
South perimeter zone	m^2	144.44
West perimeter zone	m^2	144.44
Interior zone	m^2	493.24
Total air-conditioned area	m^2	1071

To accurately access the environmental and cost performance of the building, it is necessary to input the quantities of the major components and elements used in the building. Fig. 8 shows the main data input screen for the three major portions of the building under Foundation, Floor and Services. While Fig. 9 is the main input screen for energy calculation.

Figure 8 Form to Add, Edit or Delete Components and Element of Foundations, Floors and Services Portions.

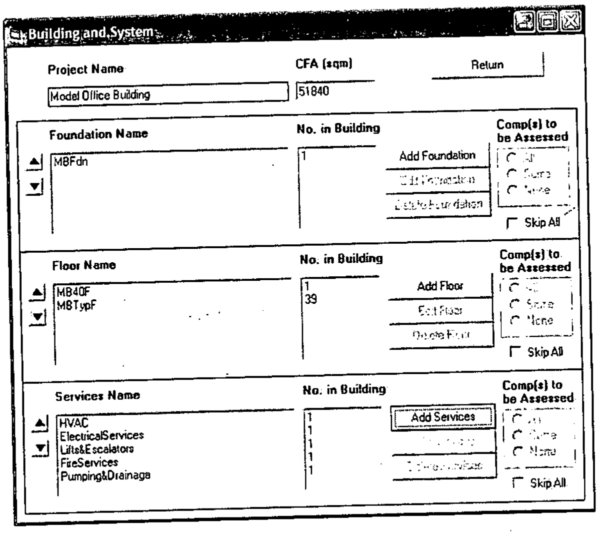
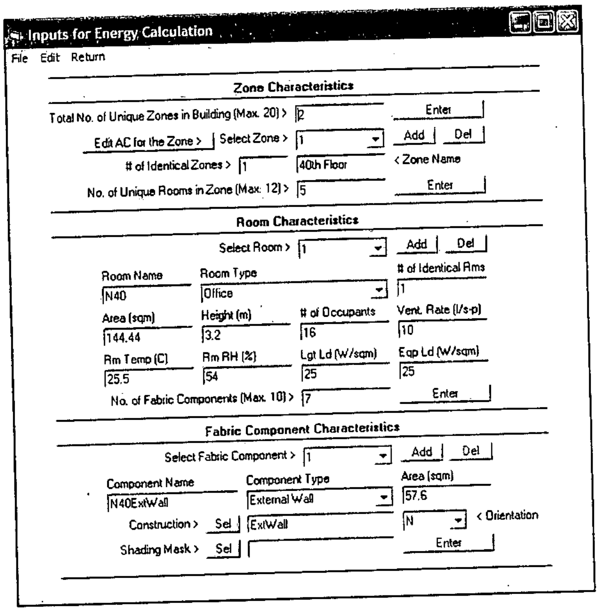
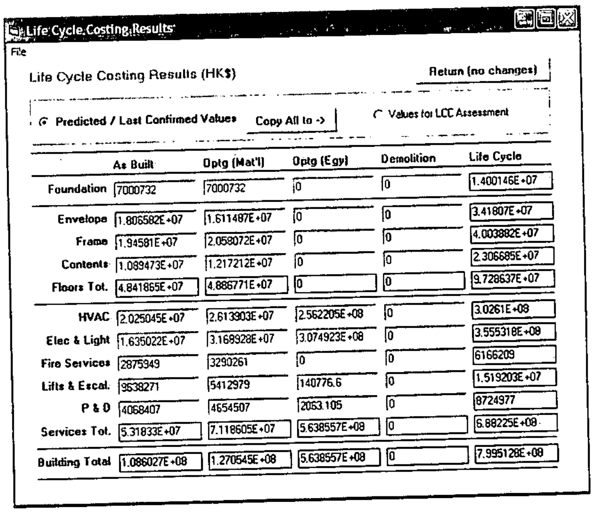


Figure 9 Form for input the Characteristics of Zones, Rooms and Fabric Components for Energy Calculation



Upon all quantities of the building components and elements are entered into the program and LCA, LCC and energy calculations carried out various outputs were provided.

Figure 10 Summary of Life Cycle Costing Results Sub-divided in Stages of As Built, Operation (Material), Operation (Energy), Demolition, Sub-Total and Total

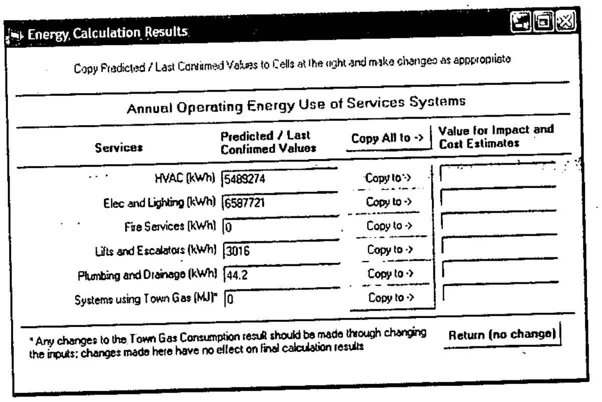


Life Cycle Costing Results (HK$)

Predicted / Last Confirmed Values — Copy All to -> — Values for LCC Assessment — Return (no changes)

	As Built	Optg (Mat'l)	Optg (Egy)	Demolition	Life Cycle
Foundation	7000732	7000732	0	0	1.400146E+07
Envelope	1.806582E+07	1.611487E+07	0	0	3.41807E+07
Frame	1.94581E+07	2.058072E+07	0	0	4.003882E+07
Contents	1.089473E+07	1.217212E+07	0	0	2.306685E+07
Floors Tot.	4.841865E+07	4.886771E+07	0	0	9.728637E+07
HVAC	2.025045E+07	2.613903E+07	2.562205E+08	0	3.0261E+08
Elec & Light	1.635022E+07	3.168928E+07	3.074923E+08	0	3.555318E+08
Fire Services	2875949	3290261	0	0	6166209
Lifts & Escal.	9538271	5412979	140776.6	0	1.519203E+07
P & D	4068407	4654507	2063.105	0	8724977
Services Tot.	5.31833E+07	7.118605E+07	5.638557E+08	0	6.88225E+08
Building Total	1.086027E+08	1.270545E+08	5.638557E+08	0	7.995128E+08

Figure 11 Summary of Annual Energy Use of each Service System



Energy Calculation Results

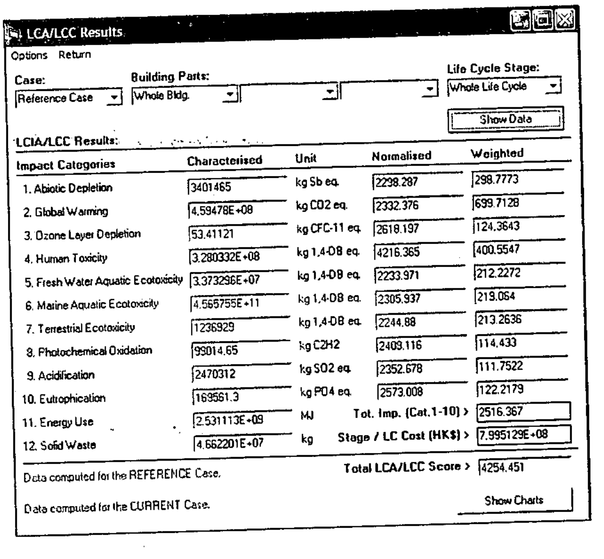
Copy Predicted / Last Confirmed Values to Cells at the right and make changes as appropriate

Annual Operating Energy Use of Services Systems

Services	Predicted / Last Confirmed Values	Copy All to ->	Value for Impact and Cost Estimates
HVAC (kWh)	5489274	Copy to ->	
Elec and Lighting (kWh)	6587721	Copy to ->	
Fire Services (kWh)	0	Copy to ->	
Lifts and Escalators (kWh)	3016	Copy to ->	
Plumbing and Drainage (kWh)	44.2	Copy to ->	
Systems using Town Gas (MJ)*	0	Copy to ->	

* Any changes to the Town Gas Consumption result should be made through changing the inputs; changes made here have no effect on final calculation results — Return (no change)

Figure 12 Overall Results of LCA/LCC Assessment



LCA/LCC Results

Options Return

Case: Reference Case — Building Parts: Whole Bldg. — Life Cycle Stage: Whole Life Cycle — Show Data

LCIA/LCC Results:

Impact Categories	Characterised	Unit	Normalised	Weighted
1. Abiotic Depletion	3401465	kg Sb eq.	2298.287	298.7773
2. Global Warming	4.59478E+08	kg CO2 eq.	2332.376	699.7128
3. Ozone Layer Depletion	53.41121	kg CFC-11 eq.	2618.197	124.3643
4. Human Toxicity	3.280332E+08	kg 1,4-DB eq.	4216.365	400.5547
5. Fresh Water Aquatic Ecotoxicity	3.373296E+07	kg 1,4-DB eq.	2233.971	212.2272
6. Marine Aquatic Ecotoxicity	4.565755E+11	kg 1,4-DB eq.	2305.937	219.064
7. Terrestrial Ecotoxicity	1236929	kg 1,4-DB eq.	2244.88	213.2636
8. Photochemical Oxidation	99014.65	kg C2H2	2409.116	114.433
9. Acidification	2470312	kg SO2 eq.	2352.678	111.7522
10. Eutrophication	169561.3	kg PO4 eq.	2573.008	122.2179
11. Energy Use	2.531113E+09	MJ	Tot. Imp. (Cat.1-10) >	2516.367
12. Solid Waste	4.662201E+07	kg	Stage / LC Cost (HK$) >	7.995129E+08

Total LCA/LCC Score > 4254.451

Data computed for the REFERENCE Case.

Data computed for the CURRENT Case.

Show Charts

Paper No. 6

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The tool will also allow user to compare the current design to a reference design and an alternative design. By changing the design or the building materials, it is possible to make comparisons for any one or all these measures in different life cycle stages. With the comparison function, the user is able to optimize the building system designs at the design stage and find out the most suitable and sustainable way.

5. CONCLUSIONS

Given that conducting LCA and LCC of building is a complicated process, equipping designers with an appropriate tool is a key step in promoting sustainable building development. There are at present a few tools that have been developed specifically for assessing buildings. These tools, however, vary in scopes and methods of assessment and are embedded with data specific to construction practices in either the West Europe or North America. Therefore they can neither be used directly for buildings in Hong Kong nor can the embedded data be amended.

The LCA and LCC of buildings must be based on data that reflect the impacts incurred by consuming the resources in the local context, including local practices of construction and operation and maintenance of building. Such data are, until now, unavailable in Kong Kong.

The study includes development of a LCA and LCC tool suitable for application to commercial building development in Hong Kong. The work involved the establishment of an impact and cost database for the dominant range of building services system and components, and materials that can be found in commercial buildings in Kong Kong.

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Paper No. 7

ENHANCING ENERGY EFFICIENCY IN ELECTRICAL INFRASTRUCTURE IN GOVERNMENT BUILDINGS

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ENHANCING ENERGY EFFICIENCY IN ELECTRICAL INFRASTRUCTURE IN GOVERNMENT BUILDINGS

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Senior Project Manager
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ABSTRACT

Proactive approach with application of various state-of-the-art equipment and design techniques in the implementation of electrical distribution system and lighting installation, which form the basis of electrical infrastructure in building, is one of the fundamental criteria for uplifting the energy efficiency performance of building. Power quality control together with integrated daylight and artificial lighting control are essential design elements for enhancing energy efficiency in electrical infrastructures for buildings. Technical advancement in power electronics technologies significantly improves the effectiveness and performance of harmonic reduction device and power factor correction equipment. Maximization of the use of daylight and proper application of various types of controls in artificial lighting installation are areas that designer must pay attention to in order to achieve energy saving targets. Types of artificial lighting controls include occupancy-based, time-scheduled, daylight-linked and fully integrated control techniques enabling possible energy saving effectiveness in lighting installation.

1. INTRODUCTION

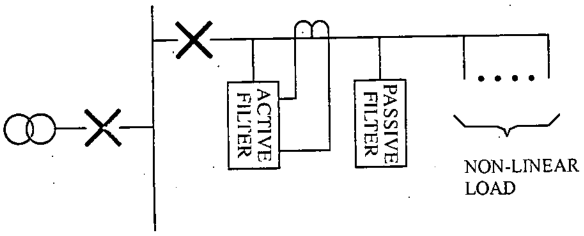
Presence of excessive harmonic distortion in an electrical distribution system not only causes energy wastage in terms of copper loss along the power distribution cables, it will also boost up the electrical equipment failure rate and decrease the power quality and supply system reliability. Removal of harmonic pollutants from the electrical infrastructure will effect a reduction in line currents as well as the neutral current, and followed by alleviation of the maximum electricity supply demand in term of KVA. Optimization of energy efficiency by means of power quality control should be accompanied by due consideration of reactive power compensation. Instantaneous responding power factor correction device working in pace with the dynamic load profile is another promising technology in enhancing energy efficiency for an electrical distribution system.

On the other hand, application of various types of lighting control techniques such as time-scheduled, occupancy-based, daylight-linked on/off or dimming and fully integrated lighting control with various technologies enable a lighting installation to perform in an efficient manner in meeting occupants' needs. These lighting control schemes will be exploited in the area of energy saving potential.

2. IMPROVED ENERGY EFFICIENCY THROUGH POWER QUALITY CONTROL

In this connection, hybrid filters consist of passive filter(s) and active filter(s) have recently been installed in the electrical distribution installation of a government office building. In a typical hybrid filter installation (Fig. 1), a shunt connected active filter is featured to work in conjunction with a passive filter for optimization of the filtering performance. The passive filter provides a harmonic sink for diverting triplen harmonic currents (3^{rd}, 9^{th}...etc.) away from the transformer source while the balance of the remaining harmonic contents are handled by the active filter installed upstream of the passive filter. The hybrid filter offers an attractive balance between the capital cost and performance achievements for the electrical infrastructure.

Figure 1 Hybrid Filter in Shunt Connection for Office Supplies



In order to ascertain the effectiveness of the hybrid filter, an installation (comprising a 430A passive filter and a 120A active filter) in which the connected feeder circuit is for office supply loads with a rated current of 800A rising main has been studied. Examinations of the filter performance in following various test scenarios are carried out :-

Test Scenario 1
Triplen harmonics conditioning performance with operation of the passive filter alone

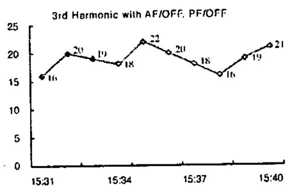
Test Scenario 2
Harmonics conditioning performance with operation of the active filter alone

Test Scenario 3
Harmonics conditioning performance with combined operation of the passive filter and the active filter (i.e. filtering of triplen orders to be taken care by both active and passive filter simultaneously)

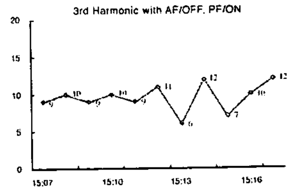
Through the installed power quality monitoring devices, the harmonic conditioning performance of the above electric circuit is recorded by the system computer terminal at a sampling rate of 1 minute, which is considered appropriate for a typical steady office load pattern. Under each of the testing scenarios, switching of the respective filters is effected for 10-minute operation in order to collect 10 sampled data of resultant harmonic contents. The quality of the power supply of the above circuit is recorded immediately before each of the filter testing. The recorded data of the Total Harmonic Distortion (THD) in current are then averaged out to arrive at the Average THD for analysis and comparison. The operating current of the circuit is measured at about 140A during the tests. The results of THD in current are tabulated and detailed in Fig 2, 3 & 4 respectively.

Figure 2 Test Results of Scenario 1

Scenario 1		
Filter switching state	Average THD in current for Triplen Harmonics	Snapshot of harmonic profile
Before switching of passive filter	25.34%	1-1
After switching of passive filter	15.66%	1-2



Snapshot of harmonic profile 1-1

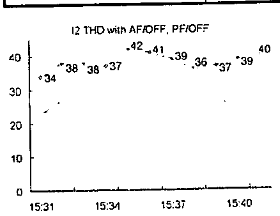


Snapshot of harmonic profile 1-2

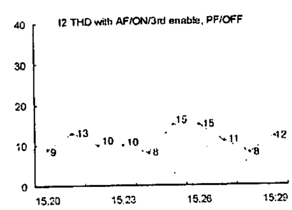
Referring to the operating performance results under the test scenario 1 (Fig. 2), in general the passive filter alone can reduce the triplen harmonics by about 9.68% in its operation. The snapshots of the harmonic profiles in Fig. 2 show the 3rd order harmonic content, which is the dominant order amongst the triplen harmonic spectrum, before and after the switching of the passive filter. A decline in the neutral current from the original 83A to 60A is observed at the upstream circuit breaker with the passive filter put in operation. The test gives evidence on the effective blocking of the excessive neutral current back to the transformer.

Figure 3 Test Results of Scenario 2

Scenario 2		
Filter switching state	Average THD in current	Snapshot of harmonic profile
Before switching of active filter	38.27%	2-1
After switching of active filter	11.10%	2-2



Snapshot of harmonic profile 2-1



Snapshot of harmonic profile 2-2

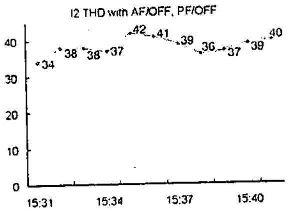
Under the test scenario 2 (Fig. 3) where the active filter is put into operation alone, the resultant average THD in current is reduced considerably from 38.27% to 11.10%.

When both filters are switched on for operation as designed under the test scenario 3, the ultimate harmonic conditioning performance of the hybrid filter is demonstrated in Fig. 4.

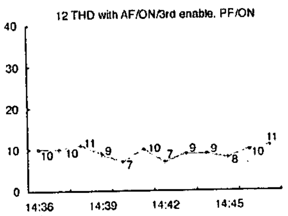
The results show that the average THD in current is reduced considerably from 38.27% to 9.25%. While a significant reduction of the neutral current from 83A to 42A at the upstream circuit breaker is recorded, a slight reduction of about 5% in the line current is also observed during the operation of the hybrid filter. As a result, it yields a total saving of 18% from the energy loss on the 800A rising main. With the given operating characteristics in the above cited example where the THD in current is 38.27% bearing with the THD for triplen harmonics of about 25.34%, the proportion of energy saving rendered by passive filter's operation is estimated at about 20% of the total saving accomplished by the whole hybrid filter. The potential of energy saving arising from the use of harmonic filter in an electrical infrastructure will become more attractive when harmonic currents exist at high level.

Figure 4 Test Results of Scenario 3

Scenario 3		
Filter switching state	Average THD	Snapshot of harmonic profile
Before switching of passive & active filters	38.27%	3-1
After switching of passive & active filters	9.25%	3-2



Snapshot of harmonic profile 3-1



Snapshot of harmonic profile 3-2

3. POWER FACTOR CORRECTION EQUIPMENT

Apart from the harmonic control facilities, power factor correction (PFC) by reactive power compensation is another essential element for enhancing electrical system efficiency. To optimize energy saving, fast respond PFC capacitor bank is recommended to be installed close to the concerned loads as far as practicable.

The reduction of active power loss and the energy saved in an electrical system when the power factor is improved can be calculated by:-

$$\% \text{ power loss reduction} = 100\% \times [\,1 - (pf_{(1)}/pf_{(2)})^2\,]$$

$$\text{Energy saving (kWh)} = \% \text{ power loss reduction} \times \text{Total circuit power loss} \times \text{No. of operating hours} \times T_{fr}$$

where:

$pf_{(1)}$ = power factor before improvement
$pf_{(2)}$ = power factor after improvement
T_{fr} = Response Time Factor

With the employment of the fast respond PFC capacitor bank of which the typical acquisition time for full compensation of reactive power is commonly accomplished within a cycle, an additional energy saving (kWh) of about 5% would have been gained as compared to that from its counterpart of traditional contactor switching PFC capacitor bank. In a recently completed government office building where the total active running power is recorded at about 12MW with an average power factor of 0.8 before improvement, the total active power loss in the distribution network is estimated to be about 300kW, representing 2.5% of the total electric loads. With the employment of fast respond PFC equipment for power factor improvement from 0.8 to 0.9, the power loss would be reduced by about 20% to 240kW. The overall energy saving accomplished would be roughly 0.53% of the total annual energy consumption.

Paper No. 7

4. IMPROVED ENERGY EFFICIENCY THROUGH LIGHTING CONTROL

Lighting installation typically contributes to almost 15% of the total energy consumption in a non-domestic building and is one of the major energy consuming sectors. As energy efficient lamps have been widely used in government projects, the room for further saving in energy consumption by lighting system is adoption of appropriate lighting management system to best fit for the building occupants' demands. The most effective lighting system requires thorough integration of various lighting design elements and control solutions to suit the specific functional requirements of the spaces.

The automatic lighting control methodologies, including occupancy based, time scheduled, daylight linked and integrated lighting control, are fully integrated into a computerized lighting management system for one of the Government buildings. Details of the installed lighting management system are summarized below:-

No. of lighting points managed by the system	Over 40,000
No. of local lighting controller installed	Over 1,700
No. of lighting zone installed	Over 13,000

4.1 OCCUPANCY BASED CONTROL

Occupancy based lighting control installed forms part of the lighting management system. It relies the occupancy sensors for detection of motion activities by passive infrared and/or ultrasonic technologies and reacts with switching actions of the corresponding lighting to meet the principle of supply-on-demand. The office lighting is arranged in such a manner that lighting off will be effected when the sensor detects no movement for a preset period of time of 20 minutes. Consideration on optimum setting of the sensor delay off timing has been given to avoid unpleasant effect on frequent switching of lighting and reduction of energy saving.

In order to suit the local ad-hoc needs and allow certain degree of flexibility with the local users, occupancy based control has been arranged to override the master time scheduled control which is performed by the central computerized lighting management system.

4.2 TIME SCHEDULED CONTROL

Time scheduled control function is installed in the lighting management system to supplement the occupancy based control. It has been arranged to perform master switching off of the lighting after normal working hours.

In order to achieve an effective lighting management, the time scheduled control and local switching facility is arranged in a non master-slave configuration so that the occupant who works late after office hours can turn on the light locally at his/her own discretion. However, in order to eliminate possible energy wastage in case the lights are left on after the last occupant has left, the system itself would turn off the lights at regular interval after the normal office hours. The sweeping interval of such master switching would have been increased over the 24-hour period on weekend or public holiday.

4.3 DAYLIGHT-LINKED CONTROL

In addition to the above lighting control mechanisms for saving energy in those areas that are frequently unoccupied, daylight-linked control has been employed for continuous ambient lighting compensation. Photoelectric sensor is employed and positioned at building perimeter zone where the daylight availability normally exceeds the required room lighting level during the daytime. As daylight will vary and the light level will fluctuate considerably, the daylight-linked dimming arrangement is considered more desirable.

4.4 INTEGRATED LIGHTING CONTROL

To maximize saving in lighting energy, total integration of the time scheduled control, occupancy based control, daylight-linked control plus the fundamental manual control has been adopted and fully coordinated by the central lighting management system in the recent government office buildings.

In addition, financial benefit in reducing the building maximum KVA demand from the fully integrated lighting control techniques can be as large as the benefit in energy reduction. With the appropriate settings of dimming / switching of the lighting system, the peak KVA demand can be adjusted to achieve the most optimum result.

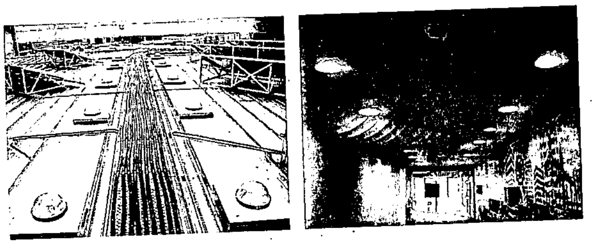
5. DAYLIGHT AS RENEWABLE ENERGY SOURCE

Harvesting daylight for interior illumination is one of the potential use of renewable energy resources. Effective channeling of natural light to the building interior not only enhances the quality of the interior environment, but also reduces the energy used in artificial illumination.

A small scale sunlight-guiding system is installed in a government building in which a space of approximately 3.4m x 10m is illuminated by 10 numbers of 250mm diameter vertical light pipes. The area is supplemented with electric illumination. The sunlight-guiding system is externally equipped with dome shaped sunlight collector on roof and channel the daylight over a straight run of light pipe with diffuser at the corridor ceiling (Fig. 5). The pipe is straight and about 3m long. On-site measurement indicates that in an overcast sky condition with average outdoor illumination of about 17.8 klux, the average internal illuminance was recorded at about 300 lux, with an effective daylight factor of 1.7%.

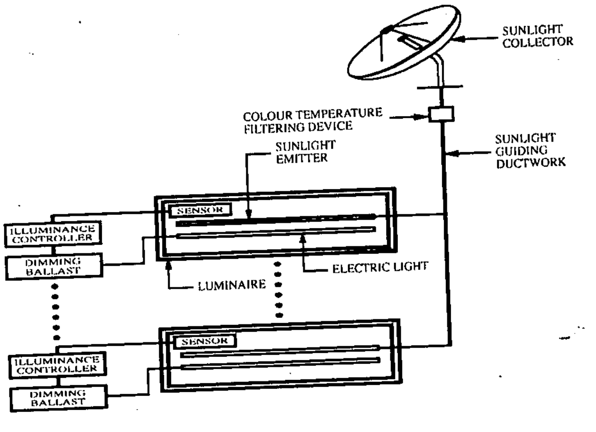
The performance of the sunlight-guiding system would be inevitably affected in applications where the light pipes have to run long lengths with bends, causing a loss in light transmission. A study indicated that typical light pipe with moderate aspect ratio (upto 6) will produce an illuminance level of 450 lux. In this case, since silver film with reflectance value of over 99% has been used in the light pipe, a reasonable lighting performance can be achieved with aspect ratio of about 12.

Figure 5 Sunlight-guiding System Installed in a Government Building (External and Internal Views)



In a not too distant future, hybrid solar lighting system can be a promising advancement in daylighting technology and is now under active research in the world class leading laboratories with concept as shown in Fig. 6.

Figure 6 Block Diagram for Hybrid Solar Lighting System



6. ENERGY SAVING POTENTIALS

It is tabulated below the estimated energy savings accomplished in our project experiences:-

Item	Energy efficiency Measures	% Saving in Energy Consumption
1.	Hybrid filter	0.15%
2.	Fast respond PFC capacitor bank	0.53%
3.	Occupancy based lighting control	0.58%
4.	Time scheduled lighting control	1.21%
5.	Daylight linked lighting control	0.29%
	Total savings (1+...+5)	2.76%

Given annual energy consumption by the government building projects being equipped with the aforesaid energy efficiency measures in the electrical infrastructure, the savings would be in the order of million dollars.

Paper No. 7

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Paper No. 8

DEVELOPMENT OF POWER ELECTRONICS AND ITS IMPACT ON INDUSTRY

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Professor
Department of Electrical Engineering
The Hong Kong Polytechnic University

DEVELOPMENT OF POWER ELECTRONICS AND ITS IMPACT ON INDUSTRY

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ABSTRACT

The advanced development of power electronics has great impact to many branches of engineering. Coupled with the recent development in control techniques, magnetics and circuit topology, power electronic devices have found numerous practical applications in industry. Moreover, the shortage of the power supply, environmental awareness and oil crisis has increased the need to apply power electronics devices and systems to new areas. The power electronics devices can significantly improve the efficiency and performance in power conversion, both static and dynamic. The international regulations in safety, performance, power quality and electromagnetic interference are also now a challenge in power electronics development. This paper will discuss the development and applications of power electronics with respect to the above issues and its impact to industry, products and systems.

1. INTRODUCTION

Power electronics is a rapid developing industry and has received attention by the public recently. Power electronics is enabling technology. It pays a supporting role to many different aspects of systems and applications. Today, our daily life is full of electronic devices or systems. For examples, all the audio or video entertainment devices have a switched-mode power supply that converts mains voltage to low voltage DC for the electronic circuits. The personal computers require a power supply or an adaptor which is a power electronic converter. The electronic ballasts for fluorescent lamps are also composed of a power factor correction and an inverter. Air-conditioning and ventilation system is driven by inverters using variable speed drive. All the mass transportation systems including train, cable-car and peak tram are driven by power electronic inverters. Elevators and escalators in the buildings are driven by inverters. All the battery chargers are also switched-mode circuits. Power distribution and transmission are using power electronics for protection, and certain degree of power processing. Therefore power electronics is part of our life.

2. BASIC PRINCIPLE IN POWER ELECTRONICS

Power electronics is based on the switched-mode concept and high frequency operation. Switched-mode refers to switching devices switched on and switched-off totally with no intermediate linear stage. Therefore theoretically the power loss is zero. This is the main reason today's power electronics system is of high efficiency. High efficiency also reduces the requirement of thermal subsystem and the system size can be reduced. High frequency can reduce the size of the passive components including inductors, capacitors and transformers. The operational frequency, or the switching frequency of the power electronic system is about inversely proportional to the size of the reactive components. Today the switching frequency is usually increased to kHz for MW system and MHz for tens of watt system.

The above two features lead to a number of issues. One is the electromagnetic interference. The waveforms of switched mode system are usually square wave which is full of harmonics. During the switching transient, the switching devices are turned on

Paper No. 8

SIEMENS

and off and there are additional switching loss and switching surge current. The switching waveforms will induce harmonics of much higher frequency than the fundamental switching frequency of the converter and there is a need to reduce the interference. Besides harmonics, the power electronic system also affects the power factor, voltage dip and many other power quality issues.

High frequency induces higher switching loss. Although there is virtually no loss during on-state or off-state of the switching devices, but during the switching instant, the voltage or the current has to change from high level to low level or vice versa and this will increase the switching loss. The switching loss increases with the switching frequency and therefore imposes certain limitation to the switching frequency for a given power rating.

3. POWER ELECTRONICS AND ENERGY SAVING

Recently there is an urgent need for energy saving because of the public awareness of the environmental issues, shortage of power supplies in the south China and the inconsistent oil supply and price. There are many energy saving proposals and methods in the market and it is confusing and many of them may or may not be feasible. Some of the methods can be classical as summarized as follows:

3.1 VARIABLE SPEED DRIVES (VSD)

In the past or some simple machine system, the motor is connected directly to the AC mains and there is no proper method to regulate the motor speed or torque. Variable speed drive [1] is emerged since mid-80s to control the machines under variable speed scheme. Methods including direct torques [2] and vector control [3] have been developed and found in market. Some of the drives can also provide sensorless control [4] such that the motor speed is not needed to be measured and it is estimated by using the measurement from the voltage and current of the motor. VSD can enable the motor to drive at low frequency slip and high efficiency region and therefore increases the efficiency of the motor. It also produces a better dynamic performance of the motor.

Most of the inverters are driven by pulse width modulation (PWM) that allows the inverter to output variable voltage and frequency according to the modulation strategy. Other modulation scheme such as space vector [5] is now also popular especially when it is used together with vector control and direct torque control.

3.2 VOLTAGE CONTROL DRIVES

Classically, the voltage mode control is using the thyristor firing angle to control the voltage to the motor. This is similar to the dimming light switch. This method is simple and very successful in controlling the voltage and has been used in many domestic dimming or speed controls. However, for higher power application, an improved phase-angle control [6] is needed that can control desired phase angle with the measurement of the stator voltage and current.

3.3 ELECTRONIC BALLAST

Electronic ballast is a common method to replace the magnetic ballast for the fluorescent lamps [7]. The average energy saving is round 25%. The saving is due to the higher efficiency of the electronics and the phosphor coating under the high frequency excitation by the electronic ballast. Many of the quality electronic ballast have a power factor correction rectifier and hence it can provide near unity power factor whereas the conventional magnetic ballast has a power factor of 0.6. Electronic ballast has also been developed to drive the high intensity discharge (HID) lamp [8]. Dimming control is also easily be achieved by the electronic ballast whereas the conventional magnetic ballast is difficult.

For HID electronic ballast, the warm re-strike for startup requires tens of kV and this can be easily achieved by electronic ballast. In the past, HID lamp cannot be switched on again within 5 minutes because the high striking voltage requirement cannot be achieved by magnetic ballast. Today, the warm startup ballast for HID lamps has been found in market. The HID head lamp is now also available for automotive market.

3.4 POWER FACTOR AND HARMONIC COMPENSATION

Power electronics system produces switching harmonics and the power factor is therefore affected even though the voltage and the current of the system are in phase. The power factor is reduced by the present of the harmonics.

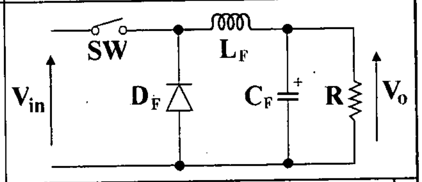
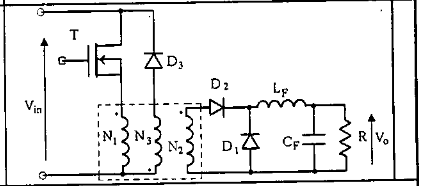
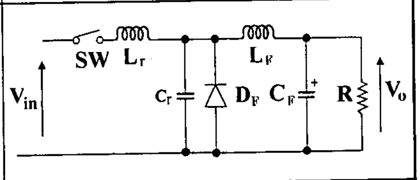
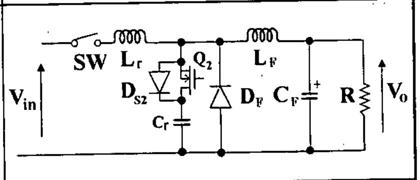
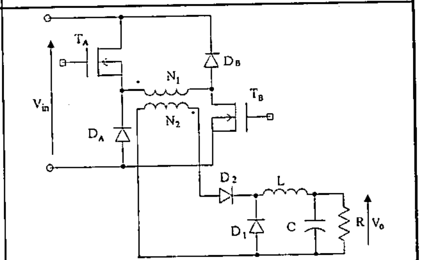
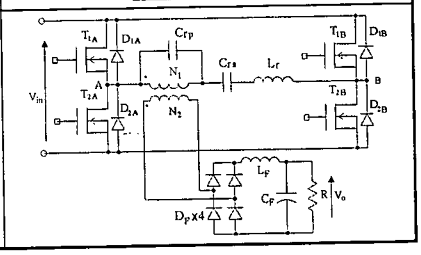
For the electric machine without inverter, the power factor is usually below 0.87 and reduced to less than 0.4 for light load. Therefore in the main switching rooms of factories, there are capacitor banks for the compensation of the power factor to near unity. In the market, there are suggestions to add capacitors next to the machines to do local compensation such that the current can be reduced and the associated conduction loss in the cable between the machines and switching room can be reduced.

4. POWER CONVERTERS

4.1. DC-DC POWER CONVERTER

Power electronics has been applied in DC/DC Power conversion and today most of the converters are operated by the switched-mode. In general the power converter can be divided into the non-isolated and isolated versions. The isolated version uses a high frequency transformer to separate the input and output. Table 1 shows a series of the buck derived power converters. There are other converter series that are based on other topologies such as Boost, Buck-Boost Cuk, Zeta and Sepic [9].

Table 1 Buck derived DC-DC Power Converters

	Basic circuit
Buck	
Forward	
Quasi-resonant	
Extended-period quasi-resonant	
Two-transistor Forward	
H-bridge Resonant	

4.2 AC-DC POWER CONVERTER

DC/DC power converter plays an important role in all types of the power conversions. The switched mode enables very high efficiency of power processing. The circuit can be easily used in AC-DC converter which is called power factor corrected (PFC) rectifier [10]. Basically, a bridge rectifier can be added in the front of the converter and a current mode control is added to become a PFC rectifier or AC-DC converter. PFC reduces the size of the

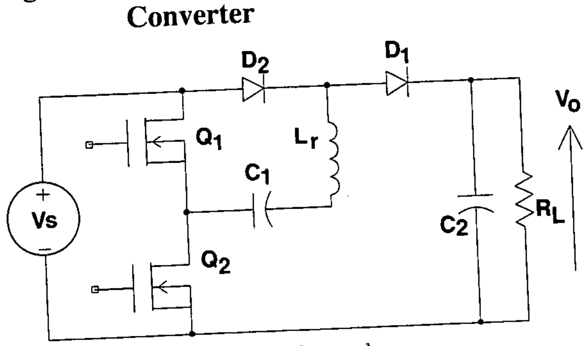
Paper No. 8

bulk inductor and also provides an active or higher performance AC-DC conversion. Because of the need of international standard for EMC, the AC-DC power converters have usually included an AC-DC PFC unit. The power factor can be corrected to near unity and the total harmonic distortion can be reduced to less than 10%.

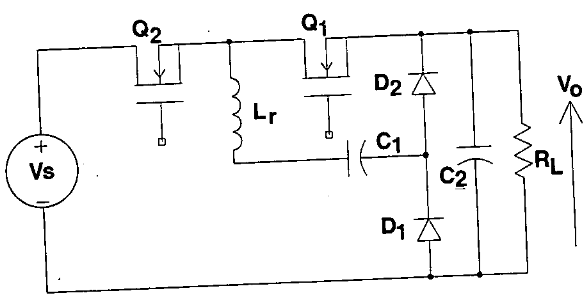
4.3 SWITCHED-CAPACITOR CONVERTER

The above power converter is using both inductor and capacitor as the passive components. One typical drawback is that the size of inductor is usually large and has difficulty to be procured and designed for high power. Recently switched-capacitor power converter has emerged to give alternative solution for the DC-DC power conversion [11]. The resonant version of the circuit has also been developed as listed in Fig. 1 which only shows the basic version. They have the advantages of small inductor, soft switching and simple design [12]. The size of the resonant inductor is usually very small and less than 1μH for 100kHz operation. Fig 2 shows an industrial power unit for 200W with 2W/cm^2 power density.

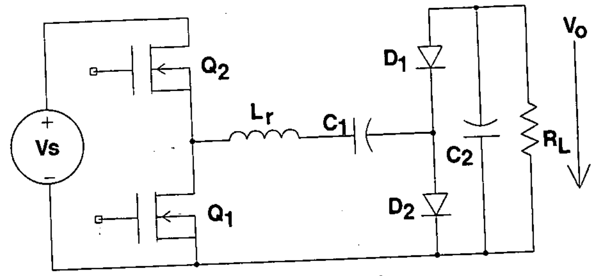
Figure 1 Basic Switched-capacitor Resonant Converter



a. Double mode

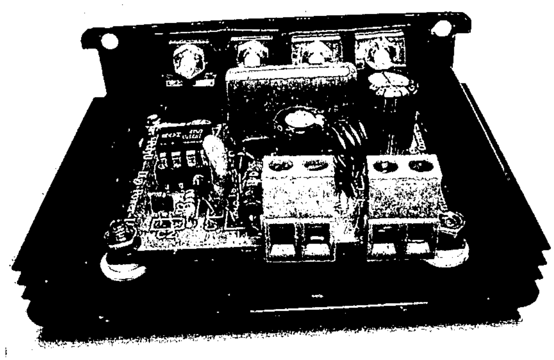


b. Half mode



c. Inverting mode

Figure 2 A High Power Density Switched-Capacitor Converter



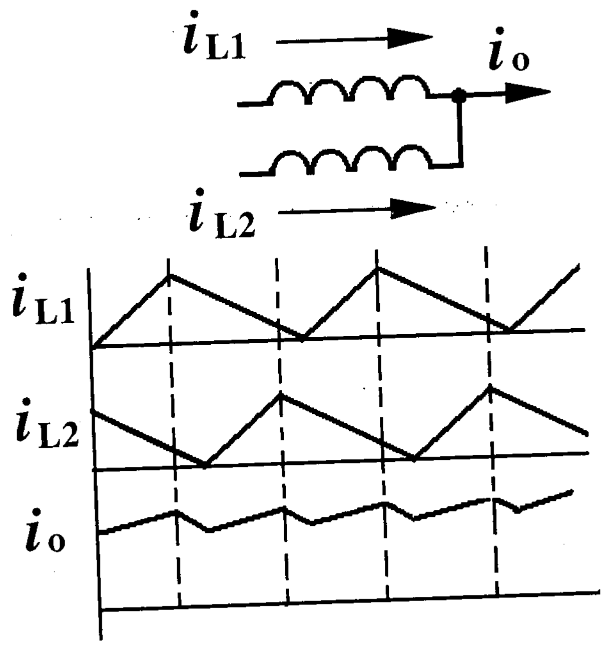
The higher order version of the converter includes the fractional and multiple voltage conversions [13]. For any order, the converter consists of two transistors Q_1 and Q_2 and switching-capacitors and power diodes. Higher order circuit requires more capacitor and diodes for which are connected in series or parallel corresponding to transistor switching states to give necessary voltage conversions.

4.4 POWER CONVERTER DEVELOPMENT

The material cost is under a challenge. The average bill of material (BOM) cost is now reduced to less than US$0.1/W. The power density of recent power converters is around 0.5-2W/cm^2. Compared with 50Hz linear power converters, there is more than 100 times improvement in power density. The efficiency is also improved by using interleaving and synchronous rectifier. The former is usually interleaved magnetic design. Fig. 3 shows the concept which reduces the requirement of the inductor significantly. The latter is using

Mosfet to replace power diode because low on-state resistance Mosfet can be selected to reduce the conduction loss whereas on-state voltage of power diode is relatively fixed and cannot easily be reduced and therefore the loss for high current is excessive.

Figure 3 Concept of Interleaved Inductor Circuit Design



5. HIGH FREQUENCY MAGNETICS

5.1 MAGNETIC LOSSES AND LEAKAGE

Transformer and inductor are energy storage components for power electronics. Because of high frequency operation the losses for the magnetic device such as hysteresis loss, eddy current loss and copper losses increase.

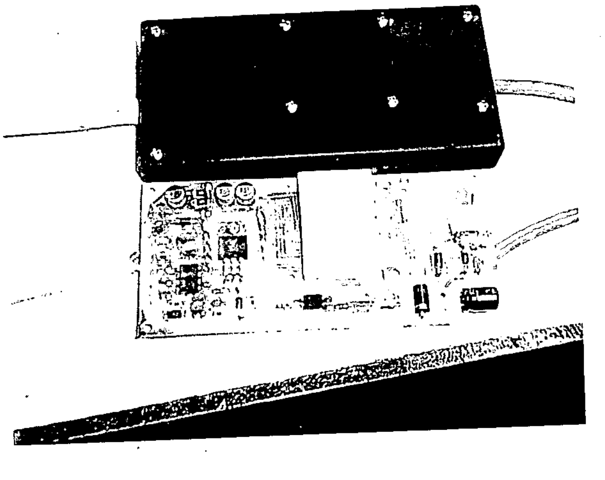
There is no direct method for minimization of the magnetic losses and they increases with frequency and flux level. There are a number of methods proposed for hysteresis and eddy current modeling [14-15] and lumped modeling [16]. The copper losses are usually reduced empirically using multiple stranded wire which reduces the eddy current and proximity losses. The losses have a strongly relation with the strand number, number of layer of copper winding, and pitch size. Refs [17,18] shows a comprehensive description of the single strand and multiple strand losses. The above method allows the accurate estimation of the losses in the magnetic devices and reduces the design and manufacture cost and time.

The leakage inductance of a transformer affects the operation of the transformer. It increases the overlap of the semiconductor devices in the secondary circuit and hence reduces the output voltage. It also increases the switching losses due to the parasitic inductance. The leakage inductance is also part of the resonant inductance for the resonant converter and therefore accurate estimation of the inductance is beneficial to the overall design. The general equations of leakage inductance for multiple layer and multistranded transformer have been reported and an optimization feature has been found [19].

5.2 LOW PROFILE MAGNETICS

The size of the transformer or inductor usually dominates the whole size of the converter units. They are usually with considerate size and are ones of the tallest components in a circuit board. Using planar transformer techniques [20], the transformer or the inductor can be reduced in height and therefore the whole converter geometry can be more flexible. Fig 4 shows a low profile power supply which a planar transformer is used for the construction of the magnetic device.

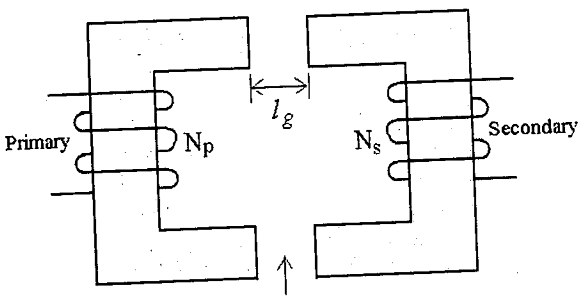
Figure 4 Low Profile Power Supplies



5.3 CONTACTLESS MAGNETICS

Power converters based on contactless transformer is to isolate the primary and secondary circuits physically. The contactless transformer is just a transformer with a large air-gap as show in Fig 5. Converter design is required to consider the leakage inductance and the power transfer across the gap with the variation of frequency and air-gap. This converter has been reported widely [21].

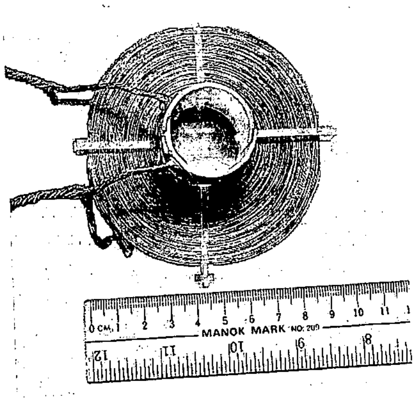
Figure 5 Gapped-transformer



5.4 AIR-CORE TRANSFORMER

As the frequency of operation increases, the permeability required for the transformer decreases. It is therefore possible to use coreless transformer for high frequency power conversion. Magnetic design reviewed that a high frequency of several Mega Hertz may be needed and that is not feasible for power electronic converter design. Using self-resonant techniques [22-23], air-core transformer can be successfully developed. The power converter developed can also achieve high efficiency. Fig 6 shows an air-core transformer using spiral winding.

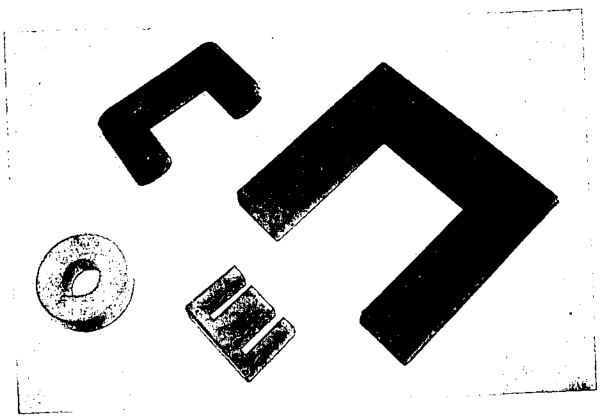
Figure 6 A 100W Air-core Transformer



5.5 POLYMER-BONDED MAGNETICS

Polymer bonded magnetic materials offers many advantages compared to the conventional type of magnetics including shape, weight, physical property and cost. This is a new type of materials. It will form a new era of power conversion and is also a new area of research. The material is a polymer-based magnetic powder that is good for low permeability and high frequency power conversion. It offers flexibility in shape, size and low cost and ease to manufacture [24].

Figure 7 Polymer-bonded Magnetic Core for Ring, U, E and Square U Cores



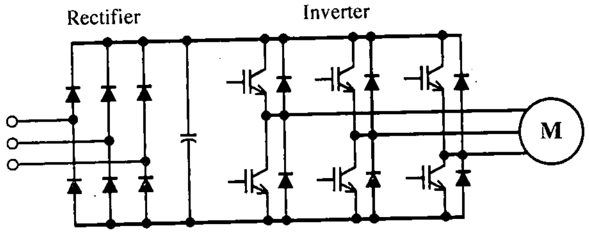
6. MOTOR DRIVES AND INVERTERS

Electric machines are driven by an inverter which is to provide suitable AC switching signal for the motors. The inverter topology varies with the requirement and machines.

6.1 BASIC INVERTERS

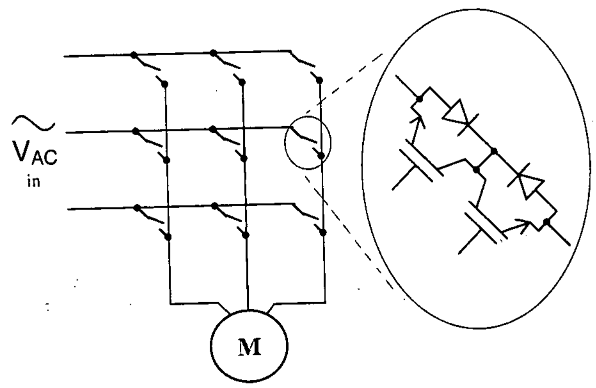
In general, the full-bridge is used for induction machines. The basic circuit for a motor drive is a 3-phase inverter as shown in Fig 8. It consists of a rectifier that converts AC to DC. The DC voltage is converted to an AC to drive the machine. Pulse-width modulation (PWM) is usually used to give AC voltage to the machines.

Figure 8 Basic Circuit for Inverter Motor Drive



Recently, matrix converter as shown in Fig. 9 has been used in motor drive and AC power supplies [25]. Each input phase has a connection to three output phases through bi-directional transistors. Its main advantage is the elimination of the DC link capacitor. However, it requires totally 18 transistors that are substantial more switching devices than the conventional circuit.

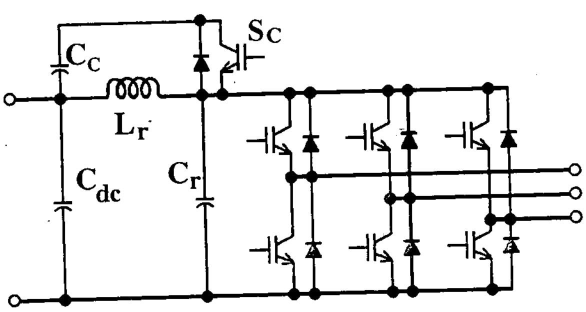
Figure 9 Matrix Converter



6.2 RESONANT INVERTERS

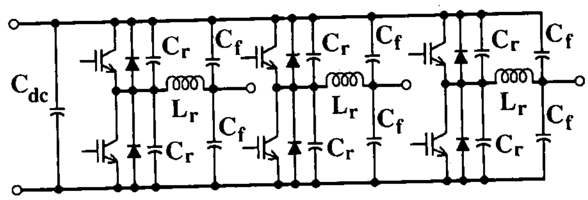
Two resonant topologies can be found in industrial inverters. They are the resonant link inverter [26] and the resonant pole inverter [27]. Fig 10 shows the resonant DC link inverter with the resonant clamp. Fig 11 shows the resonant pole inverter.

Figure 10 Resonant DC Link Converter with Resonant Clamp



Resonant DC link inverter is basically to resonate the DC link voltage using resonant inductor L_r and resonant capacitor C_r such that when the inverter transistor is to switch under zero resonant voltage to eliminate the switching loss of the inverter and EMI. Because the resonant voltage is high, around twice of the input voltage, a clamping circuit is usually used that is formed by C_c and S_c so that the maximum resonant voltage is controlled to 1.3 of the DC input voltage.

Figure 11 Resonant Pole Inverter



Resonant pole inverter is to use C_r and L_r to resonate the voltage across the switching devices to zero when they are turning on and off. Each inverter leg has a resonant circuit formed by L_r and C_r. Because the condition of the zero-voltage resonance is limited by the load condition, an improved variable frequency modulation has been developed and used in industrial drives [27].

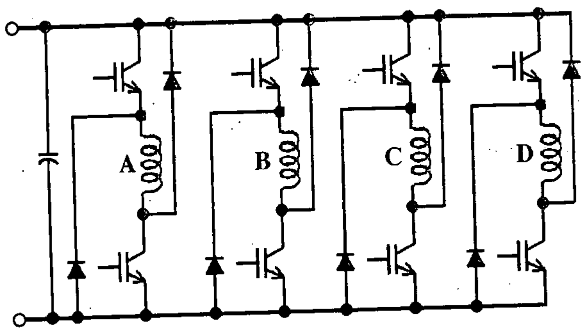
Paper No. 8

6.3 SWITCHED-RELUCTANCE MOTOR DRIVES

Switched-Reluctance Motor (SRM) and Permanent Magnet Brushless Motor (PMBLM) are now receiving attention. Classical motor, although still has a large market share, such as synchronous motor and DC motor which requires brushes or slip rings reduces the reliability and requires frequent maintenance. Induction motor is also brushless but complicated electronics and control method are needed to operate it on high performance variable speed and variable voltage operation such as vector control. Its low-speed torque is also low and therefore there are limitations for motor drive.

SRM and PMBLM were not popular in the past because it must be used together with power electronic switching inverter. With the rapid development of power electronics, these motors become more popularly used in industrial environment. Fig. 12 shows an SRM drive for the 8/6 (8 stator poles and 6 rotor poles) motor.

Figure 12 SRM Driving Circuit for 8/6 Motors

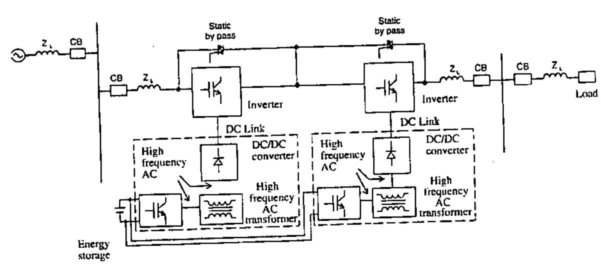


7. IMPACT OF POWER ELECTRONICS FOR THE FUTURE

7.1 POWER SYSTEMS

Power Electronics can improve the effectiveness of power transmission and distribution. High power inverter and converter have been used in HVDC and FACT. It has also gained its attention because the large scale of blackout happens in many occasions. Many power grid infrastructures in various countries require power electronics to improve the fault tolerant, dynamics and stability and energy efficiency. In the power distribution, the power electronics has been used together with energy storage in carrying out the voltage dip restoration, power quality compensation and uninterruptible power supply. Protection devices are made of power electronics circuits. Fig 13 shows a new development of voltage dip restorer. It is using a special square wave modulation method such that the dynamic response is very fast and can response to a voltage dip within a fraction of a cycle [28].

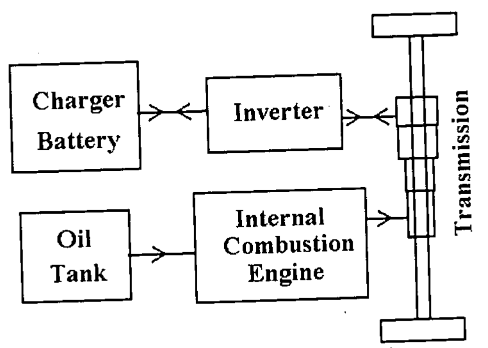
Figure 13 Fast Response Voltage Dip Restorer



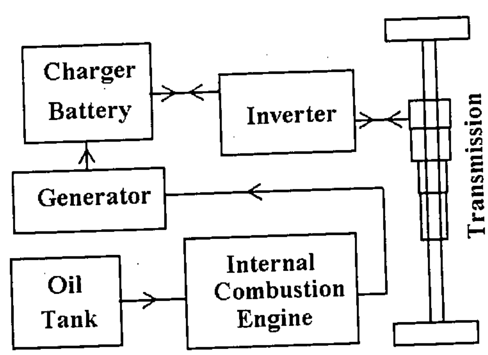
7.2 AUTOMOTIVE

Electric vehicle or the hybrid electric vehicle gives opportunities for power processing used in the vehicle. Hybrid Electric vehicle can be classified into parallel and series contributions as shown in Fig 14. For both configurations, the inverter and charger are needed for the motor control and battery. The parallel configuration has a mechanical connection between the internal combustion engine (ICE) and the electric machine. The electric machine provides the function of generator and additional torque during heavier load requirement. The series configuration has the electric machine as the main traction drive and the ICE is to provide the electric power to the machine and battery. Mechanical subsystem can be reduced as direct drive can be used. The recent development of integrated starter generator (ISG) has integrated the 3-phase electric machine to the ICE. It allows the faster starting compared with conventional starter. It also makes frequent start and stop much easier and the regenerative braking can also be realized instead of the low efficient conventional alternator.

Figure 14 Hybrid Electric Vehicle



a. Parallel configuration



b. Series configuration

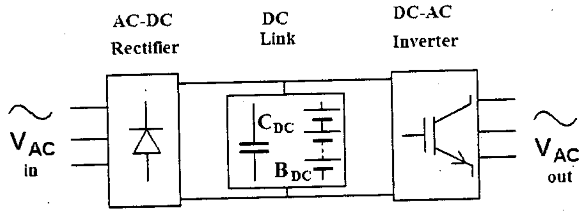
The change of the power net from 12V to 42V gives opportunities for power processing. The new model of commercial vehicle is using 42V and there are a number of DC/DC power converters needed. Even for the conventional petrol car, there are many power converters and actuations for various motion controls and they are all driven by inverters.

7.3 ALTERNATIVE ENERGY

Power electronics is an important processing method for alternative energy source and subsystems. Most of energy generated by alternative energy source must be reconditioned so that it can be used for general public or connected to the grid. Circuits and systems that are available in the past are mostly concentrated on the slow power switching devices such as thyristor, bipolar transistor and they are not reliable, slow dynamic response and difficult to design. The electricity generated by alternative energy or the associated energy storage system is output in DC such as photovoltaic cell and fuel cell. Certain systems may also generate the power in AC forms, such as induction and synchronous generators and their output voltage or frequency may not be maintained fixed or easier to be controlled [28]. Therefore power processing is needed.

Many of the above discussed topologies are now used for DC-DC or DC-AC converters. For AC-AC power conversion, there are matrix converter, back-to-back converter system and variable frequency to constant frequency (VFCF) converters, Fig. 15, available.

Figure 15 VFCF Converter



8. CONCLUSION

The impact of power electronics has been found in various industry and applications. Power electronics allows high efficiency and high speed processing. With the rapid development in power devices, the amount of energy or power it can handle is increasing daily. The system integration with the power electronics is now undergone in all industries.

The consolidation of the power electronics with the power system and energy storage has made a great impact in the industry. It significantly improves the system performance and reliability. The power electronics is heavily penetrating the industry especially the distribution.

The development of the integrated starter-generator, hybrid electric vehicle and electric vehicle is based on power electronic processing. The 42V power net system arouses the need of power converter in the vehicle. More electric vehicle is now a current trend and all moving parts are controlled by electric actuators.

Standard power supply solution is being used in all equipment power sources. It makes the design and production simpler and the production cost can be reduced. Intelligent power module for power processing unit of motor drives and inverters are being used that significantly improves the reliability and maintenance cost and time.

Electromagnetic interference is one of the side products of power electronics. International regulation is imposed on products to reduce the influence of the electromagnetic noise generated. Green manufacturing including low unwanted harmful materials and ability for component recycling is an area of serious concerns. California energy star requirement for low standby and light-load power consumption is a good start for use of power electronics in all power processing. It is believed that SiC and AlGaN will be an important development in power semiconductors in the near future and its impact on high power and high efficiency power processing cannot be underestimated.

It is concluded that technology challenges and

Paper No. 8

the desire for improvement in performance and safety will place a high premium in power electronics. Education should be geared to new application and technology.

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Paper No. 9

HIGH TEMPERATURE SUPERCONDUCTING FAULT CURRENT LIMITER FOR APPLICATION IN THE ELECTRIC POWER NET

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ABSTRACT

The deregulated and liberalized electrical energy market on the one hand and the continuously increasing demand for electric energy in densely populated areas leads to higher power transmission capabilities and interconnections of the distribution and transmission net. This causes reduced net impedances and results in increasing fault currents. Generally, a low net impedance is very favorable to limit reactions to the grid and to improve the grid stability, it also reduces losses and the demand of reactive-power. On the other hand high fault currents are increasing the equipment costs for cables, bus bars and switching equipment.

Resistive type superconducting fault current limiters (SFCL) utilize a current-driven transition from the superconducting state to the normal state to limit short circuit currents in electric power grids thus. The SFCL needs not triggering and recovers automatically after the short circuit has been opened. SFCL based on thin film switching elements limit the fault current already during its rising edge to below a peak value of about 2.5 times the nominal current.

First application of SFCLs may, for example, be found in the expansion of old systems or in coupling and separating networks as a consequence of higher power demand. In this way expensive, additional feeder equipment and new installations can be avoided. The increasing short circuit currents caused by IPP power plants can be effectively limited by use of SFCL.

Function models and prototypes of SFCLs ranging between 1 MVA to 10 MVA class have been successfully tested world-wide even in first pilot applications. New cost efficient conductors, steel based templates coated with High Temperature Superconducting (HTS) YBaCuO (YBCO) layers are approaching the market and will strongly promote the market prospects of SFCLs.

1. INTRODUCTION TO HTS ACTIVITIES WORLD-WIDE

Cooling superconductors with liquid nitrogen now raises the likelihood of efficient solutions and thus a high market potential. The use of high-temperature superconductors in power engineering means in general a reduction in size, weight and electrical losses, and an increase in power density and economy as well as solutions which are environmentally sustainable and thrifty with resources. Work is currently underway worldwide on the first, close-to-application prototypes for cables, transformers and motors. In addition to these classic types of equipment, superconductivity also makes completely new kinds of applications possible, such as fast, self-regenerating current limiters and superconducting magnetic energy storage (SMES) for improved power quality. The time-to-market is primarily determined by the availability of inexpensive conductor material and an efficient "invisible" cooling technology.

Presently the world-wide efforts are concentrated on HTS high power density cables, fault current limiters and synchronous machines as motors and generators. There are three major cable projects in the US involving cable lengths from 200m to 610m. Transmission powers range from 69 MVA (13.2 kV) to 240MVA (138kV). All the projects are in good progress and will be tested at utility sites in course of year 2006. The high current density in the superconductor means that compact cables can be made with a power density level up to three times higher than in conventional cables. In conurbations it therefore becomes possible to increase the capacity of existing cable routes in conduits (retrofitting) [1]. Additionally the cables have advantages to control the power flow because of their low impedance.

Paper No. 9

SIEMENS

Successful results have already been demonstrated in the field of synchronous machines rated from 4-5 MW [2] for ship propulsion [3] at about 200 turns as well up to fast running two pole generators operating at 60 Hz considered for compact power units driven by gas turbines. Larger units are under manufacturing i.e. a 36.5 MW ship propulsion motor and a 100 MVA generator [3] designed for power plant operation.

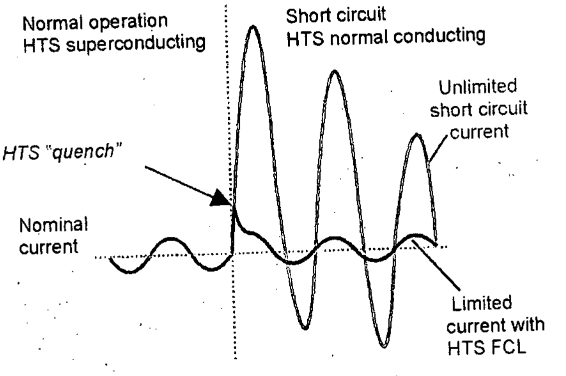
Generally, the high current density within a compact rotor design generates a large magnetic flux in the stator winding. Therefore, air-gap windings without iron teeth are used. Together with the low-loss excitation of the field windings, this allows a significant reduction of the electric losses, weight and volume of the machine. This design also results in a low synchronous reactance $\chi = 0.3\text{-}0.5$ about one forth of a conventional machine. All these advantage, the insensitiveness against sudden load variations and the high reactive power capability predestine HTS technology first of all for isle grid installations in mobile power generation, such as applications on ships, where weight and space reductions are paid with a premium.

Resistive fault current limiters are using the effect that a superconducting material is driven from the superconducting into the normal conducting state. Most of the present designs under development use this physical fact that an over current well above the so called critical current (i.e. the current carried at a voltage drop of 1 µV/cm at a temperature of boiling nitrogen 77K (-196°C) in a given magnetic field induces a transition to the resistive state which is called a "quench". Correspondingly a short circuit current in a electric network causes such a normal, high-impedance state. This transition is extremely fast (up to 40 MA/s) and can be used to control such faults very efficiently.

2. FAULT CURRENT LIMITER

Figure 1 qualitatively shows the current versus time in a circuit using a SFCL in comparison to the full prospective short circuit current.

Figure 1 Short Circuit Current with and without a SFCL



Principally there a two types of SFCL: the resistive SFCL we report on and the inductive solution:

- In case of the resistive type the superconductor is directly switched in the current path to be protected and limits the short circuit current.
- In case of the inductive type the superconductor is magnetically coupled to the current path.

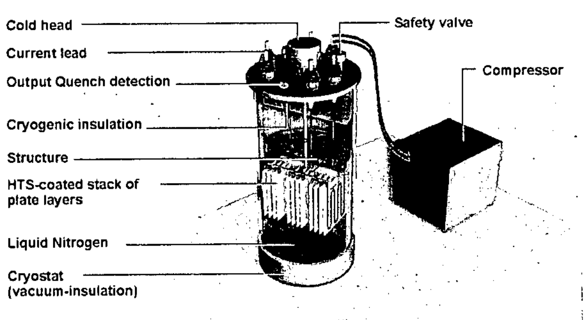
The inductive principle has disadvantages regarding size and weight [4]. Therefore, the today development concentrates to the resistive type, world-wide.

3. RESISTIVE FAULT CURRENT LIMITER

The main components of a SFCL device are shown in Figure 2. Superconducting elements connected in series and parallel are immersed in a liquid LN_2 bath. The switching elements are connected to the grid via optimized Cu-current leads. The number of the switching elements depends on the current the elements can carry and the voltage drop each element can sustain in case of the fault. Furthermore, the design is influenced by the quench threshold of the switching elements and the transient over currents in the grid, which have to pass the limiter. The response of the SFCL during the first rise of the fault current is mainly controlled by the critical current density of the HTS material used for the switching elements. In case one uses:

- Bulk HTS materials (thickness t = 0.10 - 10 mm) in from of tubes [5] or thick plates [6] having critical current densities between $j_C = 10^3$-10^4 A/cm^2 the current limiting starts at peak currents $I_D \sim 10$ - 15 the nominal current I_n.
- For thin film HTS material coated to a substrate (t = 0.2-2 μm) with j_C above 10^6 A/cm^2 one observes a very fast limitation at $I_D \sim 2$ - 3 I_n. within the first quarter cycle as shown in Figure 1 [7].

Figure 2 Typical Design of a Resistive FCL (in this case a thin film type using plate layers as switching elements)

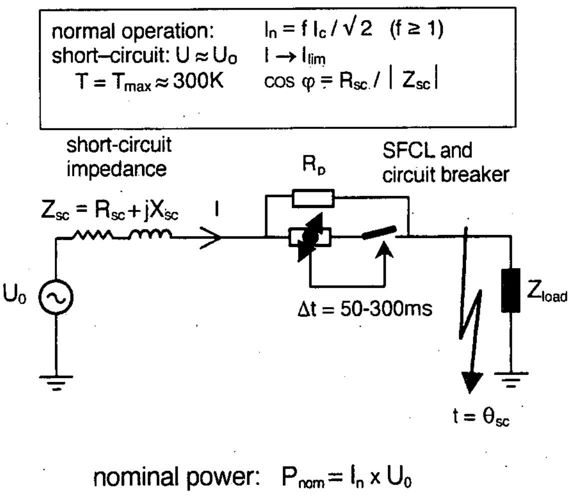


The limited current I_{lim} is mainly determined by the thickness of a metallic shunt layer and can be adjusted to about 0,1 - 5 I_n as long as the protection against hot-spots is maintained.

The selection of the material mainly control the recovery time of the limiter. Immediately after the fault the voltage rises across the FCL to nominal voltage and the electric power heats the switching elements up. In order to prevent damage to the HTS the temperature of the elements should not exceed a maximum of about 350 - 400°C. The time elapsed in between is typically 50-100ms. After this time interval the SFCL has to be disconnected from the grid by a circuit breaker in series. In case of the thin film type the recovery time is about 2s, while in case of bulk material it can take more than 30s. The complete circuit diagram of a FCL protected system is shown in Figure 3. In order to adjust the limited currents to the grid protection schema a parallel impedance can be introduced.

After opening the circuit breaker the evaporated nitrogen has to be recondensed by a cryocooler consisting of a cold head and a compressor.

Figure 3 Circuit Parameters Influencing the Behaviour of a SFCL



4. TEST OF MODELS AND PROTOTYPES (AC)

The Table 1 sums up all the major current limiter projects and project partners, the type of materials used as well as the design ratings. All the devices tested so far cover the medium voltage range up to 12 kV and ratings up to 12 MVA nominal power. Figure 4 shows the 10 MVA (10kV) SFCL [5] which was pre-tested at the German institute FGH (Forschungsgemeinschaft für elektrische Anlagen und Stromwirtschaft e.V.) in Darmstadt.

The rod shaped bifilar double helix elements consisting of 2212 BiSrCaCuO material (2212-BPSCCO). The rod length and diameter are 30 cm and 5 cm respectively while the total length of the superconductor after machining the double helix is 5.4 m. Height and diameter of the cryostat are about 2.35 m (including feedthroughs) and 0.8 m respectively. 90 2212-BPSCCO rods have been connected in series, successfully pre-tested, and undergone a 1 year pilot test in a RWE substation in Netphen in the north of Germany until spring 2005.

Table 1 Major HTS Fault Current Limiter Projects World-wide

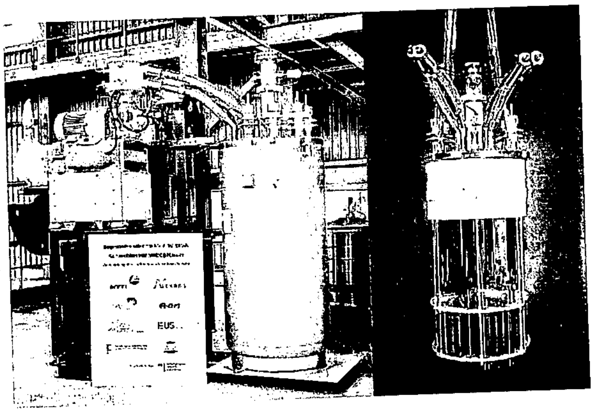
Company	Country	FCL-type	Material	Data	Test in	Remarks
ABB	Switzerland	resistive	Bi-2212 bulk	6.2 MVA / 8kV	2001	1-phase
ACCEL[1)]	Germany	resistive	Bi-2212 bulk	10 MVA / 12 kV	2003	3-phase
KEPRI[2)]	Korea	resistive	YBCO thin film	2.3 MVA / 6.6 kV	2004	3-phase
IGC Superpower[3)]	USA	resistive	Bi-2212 bulk	tbd / 138 kV	2006	3-phase
Siemens[4)]	Germany	resistive	YBCO thin film	1.2 MVA / 7.2 kV	2001	3-phase
				1 MVA / 1 kV	2003	DC
IEECAS / Utility[5)]	China	inductive	2223 Bi-tape	10.5 kV, 300 A	2005	3-phase

1) Nexans SC, ATZ Adelwitz TZ, RWE Net, E.ON, ACCESS, EUS GmbH, Uni Hannover, FHG Mannheim, FZ-Karlsruhe, Germany (funded by German ministry of education and science)
2) Korea Electric Power Research Institute (funded by the DAPAS Program: Dream of Advanced Power Systems by Applied Superconductivity Technologies)
3) IGC Superpower, American Electric Power, Nexans Superconductors
4) TU Braunschweig, TU München, Univ. Göttingen, FZ-Jülich, (funded by German ministry of education and science)
5) Institute of Electrical Engineering, Chinese Academy of Sciences, Beijing, Semiconductor bridge type, test in Chang Cha substation beginning of 2005

Certain manufacturer favours the thin film type SFCL and presented the first three phase SFCL in 2001. The switching elements consist of highly polished ceramic plates coated with YBaCuO (YBCO) superconductor (thickness typically 200 nm) and an Au shunt layer using physical vapour deposition methods. Spiral type conductor strip-lines have been etched to increase the nominal voltage of a sapphire wafer to about 600 V_{rms}, giving a nominal electrical field strength of about 8 V/cm. As a whole 21 4" wafer plates have been used for each phase to reach the nominal current of I_n = 100A at a voltage of 7.2kV i.e. a nominal power of 1.2 MVA. The device is shown in Figure 5 mounted in a container including all the control and protection systems. The measurements covered all the 1-, 2-, and 3-phase faults and revealed that the maximum peak current is limited to 400 A = 2.8 I_n. In total the device has performed more than 40 faults without any degradation. The recovery period was about 2s after the breaker has opened.

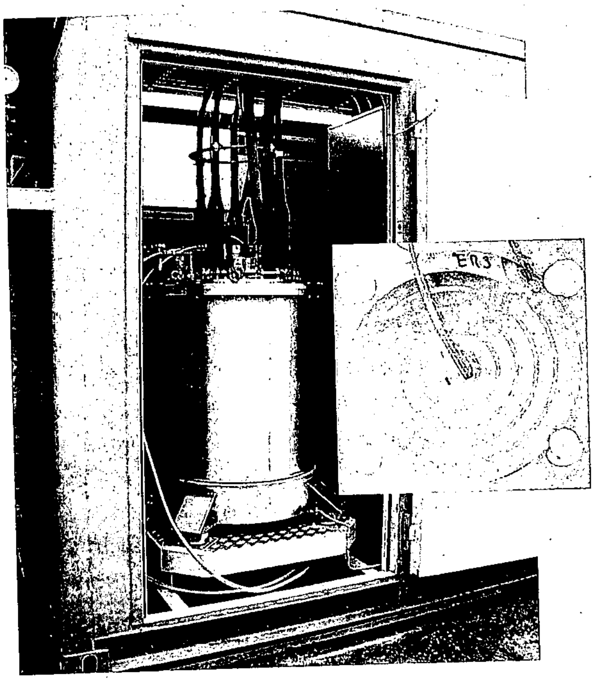
Generally all the tested SFCL devices have successfully undergone the AC voltage breakdown and lightning voltage tests.

Figure 4 Cooling Unit and Cryostat including 90 (3x30) Elements of a Rod Shaped Switching Elements of the 3 phase Bulk Type 10 MVA FCL Successfully Tested in 2004.



Presently there is one project running in the USA [8] and one project is in preparation in Germany, both aiming to high voltage (HV) SFCL limiters. According to the questionnaire discussed with the utilities a SFCL working at the transmission voltage level would be very desirable regarding the short circuit problems. Besides, considering the cost level of HV switchgear including infrastructure measures are comparable to that of future HTS FCL respectively. Especially most of the largest cities have severe problems to manage the high short circuit currents due to the increasing power demands. ConEdison in New York e.g. reports short circuit currents near to 80kA. Similar problems are found in Korea. Present solutions mostly take reactors into consideration which cause voltage drops and waste significant energy with increasing number of these passive elements.

Figure 5 1.2 MVA SFCL installed in a Container. On the Right One of the Switching Elements is shown consisting of a 4" Sapphire Wafer with Spiral YBCO Coating and the Shunt Layer (100nm Au)



The following table 2 lists the data of an HV Matrix SFCL:

Table 2 Available Data of an HV Matrix SFCL

Nominal voltage:	138 kV
Nominal current:	400 A
Short circuit current	45000 A
Limited current (max):	up to 24000 A
Recovery	under load (400A)
Fault duration:	5 times re-closing (80ms -130s)

The project data show that the requirements are very demanding. Especially the long fault duration because of re-closing procedures require additional elements or a high electric field strength for the individual element. Another difficulty is to manage the high voltages especially the partial discharges or the high electric field strengths when the voltage rapidly changes within the switching element assembly. A second point is the reproducible manufacturing and quality control of the bulk type HTS switching elements used. The variations of I_c within several hundreds of elements has to be better than 5%.

5. FAULT CURRENT LIMITERS UNDER DC CONDITIONS

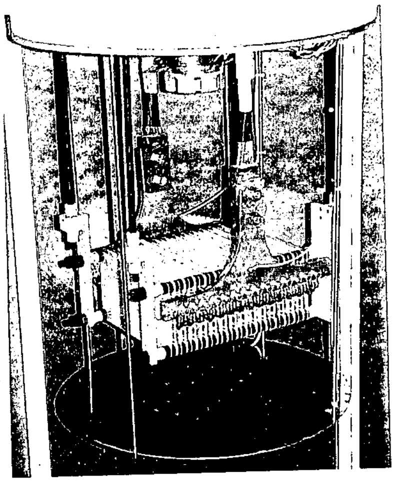
The major difference between operating a SFCL in AC and DC power systems, pertain to the end of the limitation period, when the short circuit is interrupted by a conventional circuit breaker. In AC circuits arcing in the circuit breaker stops not later than the next zero-crossing of the current. In DC circuits, the power circuit breaker has to carry the limited current at nominal voltage for a substantially longer period until the arc is extinguished. This arcing time also imposes an additional heat load on the SFCL, which possibly influences the design of the switching elements.

Paper No. 9

In contrast, quench current and resistance increase of a resistive SFCL are expected not to change fundamentally in going from AC to DC network. The quench current, i.e. the peak current reached during the first microseconds after occurrence of the fault, is mainly determined by the materials properties and by the current rise time, which in turn depends on the overall inductance of the circuit. Yet the short circuit currents and the current rise time can be significantly higher in DC-circuits due to the missing "limiting" impedance of transformers.

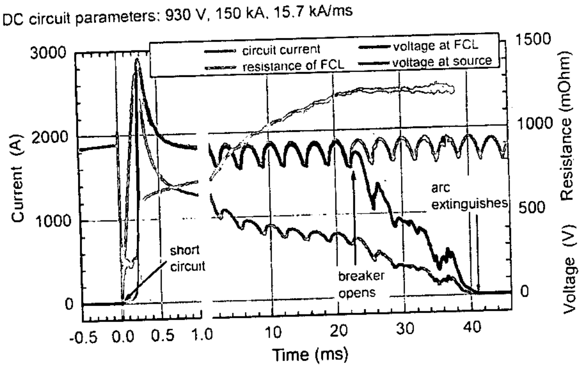
The facilities of an independent test institute (IPH: Institut Prüffeld für elektrische Hochleistungstechnik GmbH) in Berlin (Germany) were used for the power test of a 0.9 MVA (1 kA) SFCL and based on the thin film design. In this case they used larger switching plates of 200x200mm^2 in dimension having a nominal switching power of 150 kVA. 14 such switching elements were staked together in parallel to accomplish the nominal current of about 1 kA, looking like a compact stack of PC cards as shown in Figure 6.

Figure 6 0.9 MVA Thin Film FCL (Siemens) with 14 Mounted Switching Plates (200x100mm²) for DC Application



The unlimited current of the test system was about 150kA (source voltage U_0 = 900V DC). Using a conventional space consuming arc gap Cu-fusible clearing device the current could only be limited to 100kA. The insertion of the SFCL demonstrated the following: The current ramps up after the fault to a peak current of 2730 A = 2.7·*Ic*. The limited current settled to 700 A = 0.7·*Ic* after 22.5 ms where the circuit breaker opens. After another 15 ms, current and voltage drop off to zero as the arc extinguishes. The temperatures of the switching elements reached roughly 250 K.

Figure 7 Test of a 1 kA Superconducting DC Fault Current Limiter for Marine Applications



These severe DC test experiments clearly show the high potential and the technical feasibility of SFCL.

Presently one of the most promising applications of this device is the coupling of sub-grids in stand-alone power systems, e.g. in DC-systems for marine applications [9], which are supplied from batteries.

6. APPLICATIONS OF SFCL IN POWER GRIDS

6.1 VOLTAGE QUALITY

Modern production processes such as the manufacture of semiconductors require a high level of voltage stability and quality. On the other hand, system perturbations are increasing due to the greater use of power electronics and rising power consumption of individual items of equipment. In order to avoid system perturbations and, at the same time, keep fluctuations in the supply voltage at permissible levels, the short-circuit power at the point of connection should be considerably higher than the power of the biggest individual load (factor > 100). The result of this can be that large loads have to be connected to the next higher voltage level and possibly even to the 110 kV level. An economic alternative would be to couple together several medium-voltage levels. The associated increase in short-circuit currents can be avoided by using HTSL current limiters. This prevents overloading of existing installations, especially older ones designed for low short-circuit currents. It also negates or delays the need for investment or renewal.

If a HTSL current limiter is used in the bus coupler, it is possible to implement the "clean bus/dirty bus" principle by assigning the buses in an appropriate manner. Sensitive loads can then be separated from parts of the supply system in which faults occur frequently and, at the same time, the total load can be optimally distributed among the feeder modules.

An example for application in the Medium Voltage (MV) is shown in Figure 8 for an application proposed by the German utility RWE [10]. If the bus bars of a MV substation are coupled via a SFCL the short circuit power can doubled. A further improvement can be obtained, if low impedance transformers in series with SFCLs are used. The most economical short-circuit-voltage of the transformers would be 10 %. In consequence the short-circuit power will increase to 300 MVA and 400 MVA respectively. By application of SFCLs in the transformer feeders the admissible short-circuit capability of the substation can be obtained. In this way the short-circuit power of the station is increased nearly three times in total. By this means also voltage-disturbing customers and high loadings can be connected directly to the MV station and the connection to the higher voltage level can be avoided. Compared to the investment costs for a connection to higher voltages level, the 110 kV grid (cf Figure 9) e.g., the installation of the SFCLs in the way suggested will be an economical solution, reasonable costs for the SFCL presumed.

Figure 8 MV Substation with Bus Bars Coupled via SFCL and Low Impedance Transformers in Series with SFCL [10]

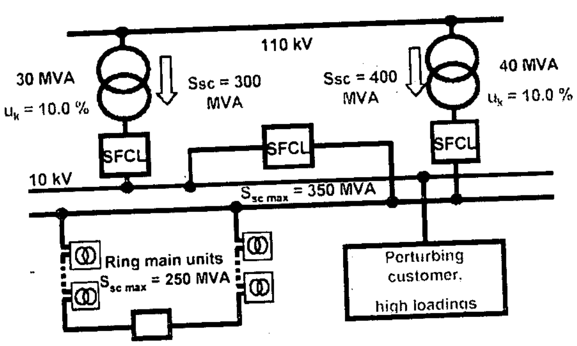
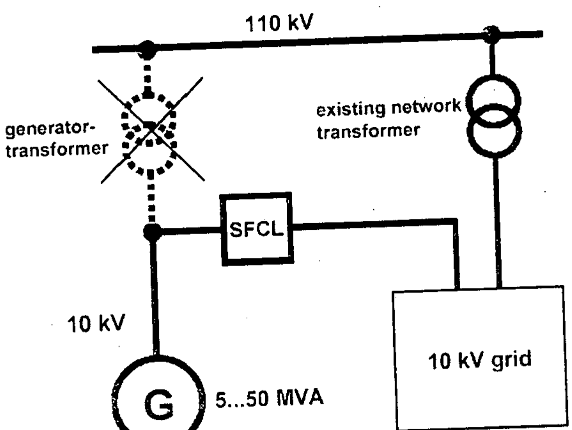


Figure 9 A 5...50 MVA Generator Connected to the MV Grid via a SFCL [10]



6.2 SUPPLY SYSTEM EXPANSION

Older installations are often dimensioned for lower short-circuit currents. This applies not only to the switchgear and transformers but also to the dynamic strength of foundations and other secondary installations. Increasing the incoming power in order to cover load increases is only economically viable in such cases if system segments are separated or if short-circuit-current limiting reactors are used. The use of HTSL current limiters in the incoming feeder or in the bus coupler enables existing power systems to be expanded and also improves the reliability of supply and the voltage quality because, in contrast to the reactor, there is no voltage dip across the coupler.

6.3 COUPLING OF NETWORK CLUSTERS

Power systems in the distribution range and the lower transmission range (110 kV level) are operated as electrically isolated network clusters that are fed with power from the higher-level power system. If further separation is necessary due to increasing short-circuit power, this is usually associated with high investment costs for additional feeder modules. What is especially interesting is the possibility of coupling networks or increasing the short-circuit currents if a voltage level is reduced or lost.

Paper No. 9

Regarding to High Voltage a very attractive application is related to coupling of 110 kV sub-grids within the RWE grid. The 110 kV system is subdivided into different sub-grids to cope with a rated short-circuit current of 31.5 kA. Today, with regard to the transformer capacity feeding into the 110 kV sub-grid the (n-1)-criterion has to be fulfilled and an outage of one transformer to be taken into account. The surplus of transformer capacity can considerably be reduced by coupling two 110 kV sub-grids and by installing SFCLs into the bus coupler bay of the two 110 kV stations in question. In case of a transformer outage in one sub-grid the other sub-grid is able to deliver the reserve power and in case of a fault the SFCL limits the short-circuit current to admissible values. This solution saves two

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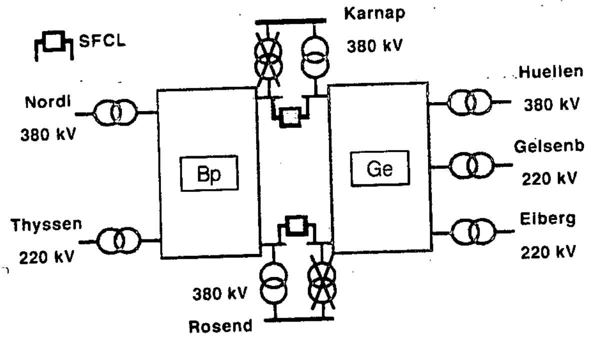
expensive HV transformers which can be substituted by a HV SFCL at comparable or even less cost (Figure 10).

Figure 10 Two 110 kV Sub-grids Coupled via SFCLs [10]



6.4 POWER STATION INCOMING FEEDERS

Operators of small power stations, e.g. regenerative power generation installations such as wind power stations, often have to take suitable measures to make sure that the permissible short-circuit currents – especially in the case of highly utilized distribution stations – are not exceeded. Today, in certain instances, this can only be done by using I_s limiters (for restricting sudden short-circuits), which have a series of disadvantages, or by connecting equipment to the 100 kV level. HTSL current limiters could be the most reasonable alternative here.

The trend towards smaller power units in the power station sector through the increased use of gas and steam turbines with a connection at the 132 kV level directly in the load centers often, especially in the USA, leads to overshooting of the permissible short-circuit currents of the installed equipment. From the power station point of view, the compromise of feeding the power generated by the gas and steam turbine into separate power system groups is not the most cost-effective solution.

6.5 NEW SYSTEM CONCEPTS

In the long term, short-circuit currents can be restricted to the rated current of the incoming feeder in new power supply systems by using HTSL current limiters in all power supply modules. Instead of sudden short-circuit currents, only a peak current amounting to three times the design current occurs if HTSL current limiters with YBCO thin-layer technology are used. Instead of circuit-breaker equipment, inexpensive load interrupter switches can be used in all outgoing feeder bays. In addition, the requirements regarding switchgear resistance to accidental arcs and regarding the dynamic loads on the whole system are reduced considerably.

Such new concepts with only restricted feeder modules require new communicative protection concepts, short times for fault detection, and rapid step-enabling of the affected outgoing feeder bay. In addition, planning must take into account the fact that the power sub-systems of the overall power system are operated with opened bus couplers.

If a power sub-system is added to an existing power system (transformer feeder modules with subordinate power system), the new power sub-system can be configured with reduced short-circuit resistance if HTSL current limiters are used in the coupler bay and incoming feeder bays.

7. RECENT DEVELOPMENTS AND FUTURE EXPECTATIONS

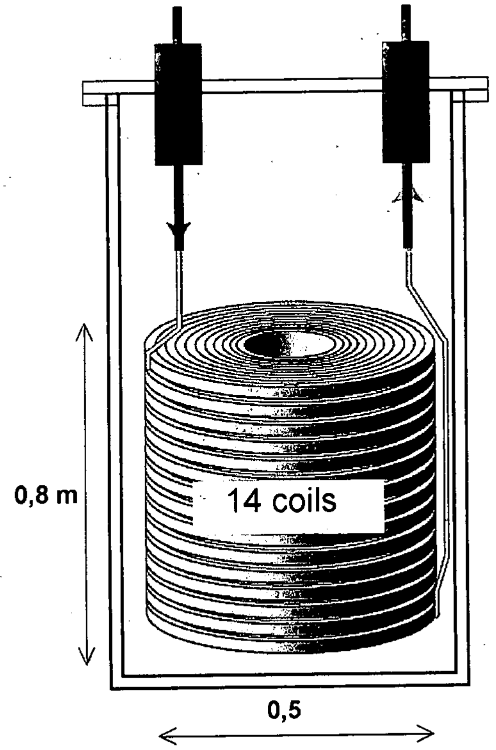
7.1 HTS-MATERIALS

At present new robust and flexible tape conductors are becoming available in long length, which may greatly influence the introduction of the SFCL and other HTS equipment into the market. These so-called coated conductors or 2[nd] generation conductors are thin film based conductors. The thin film YBCO layers are not deposited to a ceramic plate but on a buffered metallic (e.g. stainless steel) tape within a continuous deposition process. The major manufacturers expect that these YBCO tapes will be available in kilometre length in the next three years and could approach a prize of 20 US$/kAm if the turnover significantly increases. One manufacturer has developed first designs and switching elements. Figure 10 shows a rough design for one phase of a medium voltage SFCL. The core piece is the robust stack of 14 bifilar wound coils, containing a total of 560 m of tape sufficient for a 42 MVA SFCL carrying a nominal current of 2 kA and tripping at a threshold of about 2 x I_n. Cost estimations have shown that such YBCO based SFCL reach a cost basis comparable to that of a conventional power circuit breaker. A further assumption in this calculation is that are also low cost refrigerators available on the market.

7.2 REFRIGERATORS

Generally refrigerators for operation in SFCL devices are available today. The main improvements needed pertain to efficiency, reliability, lifetime, and cost reduction [11]. At present one Watt cold power costs about 50 $/kAm (77K) which has to be reduced in the medium and long-term to about half this value. Promising developments are under way – oil free pulse tube or Stirling refrigerators – which will solve the problem reliability and maintenance. One of the reasons is, that in the last years the focus of the HTS technology was put to the materials. Clearly as far as the HTS market is still developing and there is no large other market for cryocoolers the makers and users of HTS equipment have to find a way to promote novel cryogenic device development. Currently the refrigerator manufacturer, generally smaller companies, cannot not afford to develop new types of refrigerators for a still uncertain market. To overcome this classical chicken and egg problem, the major refrigerator manufacturers are directly involved in the running pilot projects mostly funded by the individual governments.

Figure 11 One Phase of a 42 MVA SFCL. The Stack of 14 Bifilar Coils needs 560 m of 4 cm wide YBCO Tape. The SFCL consists of 3 Separate Cryostats



8. IMPACT TO PROTECTION AND ELECTRICAL STANDARISATION

The SFCL will never simply substitute a conventional power breaker. New integration issues have to be addressed, adapted to the grid requirements, and converted into standards. In the last three years the interest of the engineers in SFCLs markedly increased and their impacts are discussed within the CIGRE groups [12] and at the IEEE PES meetings [13]. One of their task is to find out proper application where the use of an FCL is more cost efficient than conventional measures. The other point is to develop installation procedures, testing standards and protection schemes which allow a reliable integration of the novel devices in the electric grid.

All these tasks have to be carried out in parallel

Paper No. 9

SIEMENS

to the device development in a tight co-operation between manufacturers and utilities.

9. REQUESTED DEVICE PROPERTIES

If HTSL current limiters are to be a useful addition or alternative to existing equipment, the following requirements, among others, must be placed on the devices:

- In the event of a fault, the current must be restricted so that it remains considerably below the crest value of the unaffected short-circuit current in order to achieve a reduction in the dynamic load on installations and equipment.
- The over voltage occurring during the restriction process must be non-critical.
- Re-availability (recovery time) must be in line with the requirements of the application.
- The HTSL current limiter must be intrinsically safe, i.e. it must also work as a fuse in the event of overloading.
- It must be possible to integrate HTSL current limiters in existing power systems.
- The overall current limiter system must have as little losses as possible. This relates to current-dependent losses (power supply and AC losses) as well as to current-independent losses (cryogenic temperature controller) and especially to the efficiency of refrigeration machines.
- HTSL current limiters must be require as little maintenance as possible in order to be compatible with concepts pursued today.
- The useful life must be in line with that of the usual installations and equipment today.
- The environmental compatibility of the overall system must be guaranteed.

10. OUTLOOK

For an emerging HTS technology commercialisation is mainly dependent on the costs of the superconducting material, the cryogenics as well as on the anticipated market volume. Moreover, the reliability has to be demonstrated which is at least the most important step for such a very conservative field as power engineering. The liberalisation of the energy market has lead to a strong emphasis to profitability and does not promote expensive medium or even long-term developments.

Compared to the situation 10 years ago the international activities in the HTS sector markedly shrunk. On the other hand the running projects show an excellent performance because they are mainly controlled by the industry. Additionally in the last 6 years the price of the presently available 2223 BPSCCO conductor could be decreased by a factor three from 500 $/kAm to 150 $/kAm due to R&D improvements and is expected to further decrease to about 20$/kAm within the next 5-7 years when the high performance YBCO-tapes are available in technical lengths.

In the medium voltage range the SFCL has a good potential for operation in feeders or couplers in connection with expansions of existing networks or the coupling of network or bus bars. For the latter case there is also a very broad application potential in the high voltage (135 kV) network. In the long term, if reliability has been proven, new networks might be possible, which are optimized for the main benefit offered by SFCLs: high short circuit power and low short circuit currents simultaneously. For such systems novel switchgear – and protection concepts have to be developed in parallel.

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Paper No. 9

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