ENGINEERING EXCELLENCE THROUGH CONTINUOUS IMPROVEMENT

The Hong Kong Institution of Engineers - Electrical Division

The 24th Annual Symposium

17th October 2006

THE HONG KONG
INSTITUTION OF ENGINEERS
ELECTRICAL DIVISION

The 24th Annual Symposium

Tuesday

17th October 2006

ENGINEERING EXCELLENCE THROUGH CONTINUOUS IMPROVEMENT

at

Ballroom

Sheraton Hotel

Nathan Road

Kowloon

Hong Kong

SYMPOSIUM PROGRAMME

08.30 Registration and Coffee

09.00 Welcome Address

- Ir Prof. K.P. Wong
  Chairman, Electrical Division, The HKIE

09.05 Opening Address

- Ir K.L. Wong, JP
  President, The HKIE

09.10 Keynote Speech

- Ir Edmund K.H. Leung, JP
  Past President, The HKIE

1. Power System

09.40 Enhanced Condition Monitoring in the Main Electrical Equipment for the First Gas-fired Combined Cycle Power Plant for Hongkong Electric

- Ir C.K. Lau, Chief Electrical Engineer
- Ir M.K. Wong, Electrical Engineer
  Projects Division
  The Hongkong Electric Co. Ltd.

10.00 The National Electricity Market of Australia

- Mr Peter K.Y. Chung
  Professional Officer
  TransGrid, Australia

10.20 Discussion

10.40 Coffee Break

2. New Technology

11.10 Intelligent-based Low Voltage Cubicle Switchboard Design for Modern Buildings

- Ir K.C. Lo, Senior Building Services Engineer
- Ir Wallace S.F. Leung, Building Services Engineer
  The Government of the HKSAR

11.30 Energy Saving: The Role of Public Lighting

- Ir Peter K.C. Chan, Chief Engineer
- Ir Honry H.W. Cheng, Engineer, Special Lighting
  Lighting Division, Highways Department
  The Government of the HKSAR

11.50 Energy Conservation – What the Housing Authority is Doing with Lifts and Escalators in Public Housing Estates

- Ir Dr Albert T.P. So, Adjunct Professor
  City University of Hong Kong
- Mr Michael S.W. Kwok, Technical Manager
  Operations Division, KONE Elevator (Hong Kong) Ltd.
- Ir T.K. Ng, Senior Building Services Engineer
  Housing Department, The Government of the HKSAR

12.10 Discussion

12.30 Lunch

3. Transmission & Distribution

14.15 From Innovation to Implementation – Enhancement of Electricity Supply in a Metropolitan City

- Ir Alex W.K. Wong, Acting Maintenance Manager
  East Region
- Mr K.Y. Fung, Electrical Testing & Workshop Manager
  Technical Services Department
- Mr Terence C.P. Chan
  Systems and Quality Development Engineer
  Safety, Health, Environment & Quality Department
  CLP Power Hong Kong Ltd.

14.35 Improvement of Power Quality and Equipment Reliability by Controlled Switching of Gas Circuit Breakers

- Mr H. Kohyama, Manager
  Circuit Breaker Development
- Mr K. Kamei, Manager, High Power Technology
- Mr T. Yonezawa, Chief Engineer
- Dr H. Ito, Manager
  Technology Development Department
  Mitsubishi Electric Corporation, Japan

14.55 Discussion

15.15 Coffee Break

4. New Projects

15.45 Corporate Data Centre – Strategic Thinking Behind the E&M Services Design Infrastructure

- Ir Joseph C.M. Leung, Director
- Ir Albert W.K. To, Director
- Ir P.K. Yip, Senior Associate
  J. Roger Preston Limited

16.05 Kowloon Southern Link (KSL) Project

- Ir K.K. Lee
  Senior Director – Capital Projects
  Kowloon Canton Railway Corporation, Hong Kong

16.25 Discussion

16.45 Summing Up

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

Closing Address

- Ir Roger S.H. Lai, JP
  Director
  Electrical & Mechanical Services Department
  The Government of the HKSAR

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Paper No. 1

ENHANCED CONDITION MONITORING IN THE MAIN ELECTRICAL EQUIPMENT FOR THE FIRST GAS-FIRED COMBINED CYCLE POWER PLANT FOR HONGKONG ELECTRIC

Speakers : Ir C.K. Lau, Chief Electrical Engineer
Ir M.K. Wong, Electrical Engineer
Projects Division
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ENHANCED CONDITION MONITORING IN THE MAIN ELECTRICAL EQUIPMENT FOR THE FIRST GAS-FIRED COMBINED CYCLE POWER PLANT FOR HONGKONG ELECTRIC

Ir C.K. Lau, Chief Electrical Engineer
Ir M.K. Wong, Electrical Engineer
Projects Division
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Paper No. 1

ABSTRACT

The Hongkong Electric Co., Ltd. (HEC) is committed to supplying clean, reliable and cost effective electricity to customers and to meet the anticipated growth of electricity demand in Hong Kong. With this commitment, HEC has entered into the era of "Natural Gas-fired" electrical power generation and the first gas-fired combined cycle power plant is fully commissioned and operational in the 4th quarter of 2006.

As an extension to the existing Lamma Power Station, the new 335MW gas-fired combined cycle unit adopts single-shaft design with the main power train configuration of a gas turbine, steam turbine and generator connected on one single shaft. The generator is of hydrogen-cooled design with static excitation. The initial startup of the turbine generator is by Static Frequency Converter (SFC) technology and the generator is operated at its rated speed by gas turbine using natural gas as primary fuel. The main electrical power generating equipment for the new gas-fired unit comprising a generator, a generator main circuit breaker and a generator transformer delivers 275kV electrical power to the HEC transmission system through Lamma Extension 275kV Switching Station.

To achieve optimum performance and to maintain reliability and longevity of the main electrical equipment, close monitoring and diagnostic of the on-line performance of the equipment is vital in electrical power system design to keep track of equipment operating conditions and to provide information for preventive maintenance. This paper presents the various technologies and new approaches adopted by HEC for condition monitoring in the main electrical equipment of the new combined cycle power plant.

1. INTRODUCTION

The Hongkong Electric Company Limited (HEC) is one of the two power utility companies in Hong Kong responsible for the generation and supply of electricity to Hong Kong Island and Lamma Island. To meet the continual load growth and energy demand over the past two decades, the installed capacity of HEC Lamma Power Station had reached 3,420MW which consists of 2,500MW coal-fired units (3 x 250MW - Units 1, 2 & 3 and 5 x 350MW - Units 4, 5, 6, 7 & 8), one 365MW oil-fired combined cycle unit and 555MW gas turbine sets (1 x 55MW and 4 x 125MW).

To cater for the increase in the anticipated electricity demand in the 21st century and to protect and preserve the environment, HEC constructs the first 335MW gas-fired combined cycle power plant, Unit 9, using clean natural gas as primary fuel as an extension to the existing power station. Figure 1 shows the newly built Lamma Power Station Extension Unit 9 on a piece of reclaimed land connecting to existing power station. The entire development of Unit 9 has come to final stage and the commissioning is completed by 4th quarter of 2006. After completion of Unit 9, the installed capacity of Lamma Power Station will be boosted up to 3,755MW.

SIEMENS

Figure 1 Unit 9 Combined Cycle Power Plant

The main power train configuration of the new combined cycle unit comprises various complicated, state-of-the-art and advanced technologies and equipment forming gas turbine system, steam turbine system, generator system, auxiliary systems and various electrical and control systems for power generation. Each portion and component in respective system plays an essential role for ensuring safe and reliable operation of the power plant.

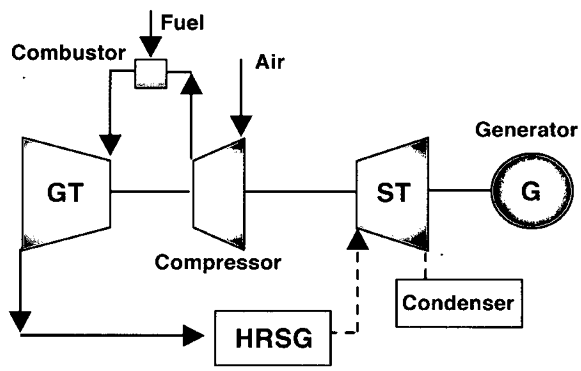
Continuous monitoring and close surveillance of operating conditions and performance of main electrical equipment, particularly for vital equipment such as generator and generator transformer, are of utmost importance in power plant operation. This can give early detection and warning to the plant operators to take prompt corrective and preventive actions to avoid any significant damage or internal fault. For achieving optimum plant performance and enhancing power plant lifetime, HEC adopted advanced condition based monitoring technique in the design of Unit 9 Generator and Generator Transformer for the new combined cycle power unit.

2. MAIN ELECTRICAL POWER GENERATION SYSTEM

2.1 AN OVERVIEW

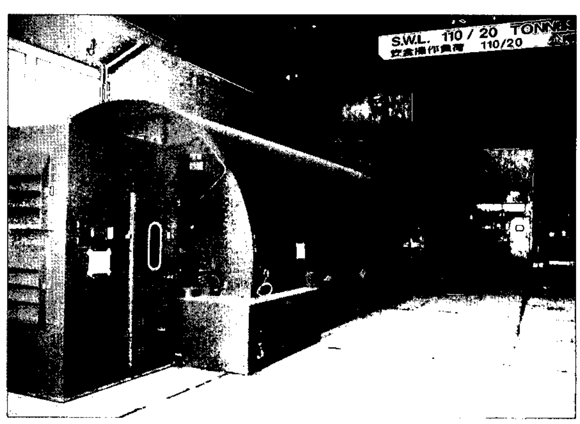
The first new gas-fired combined cycle unit, Unit 9, in Lamma Power Station Extension is a F-class single shaft combined cycle unit manufactured by Mitsubishi Heavy Industries (MHI) with an overall unit efficiency of 56.5% on a LHV basis. It is designed for dual fuel firing using natural gas as main fuel and light oil as backup fuel. The generator is directly coupled to the steam turbine which is in turn connected to the gas turbine to form single-shaft main power train for the combined cycle unit. Figure 2 below shows the simplified block diagram of single-shaft Unit 9 combined cycle unit configuration.

Figure 2 Unit 9 Combined Cycle Power Plant



The main electrical equipment and facilities of the new combined cycle unit consist of a hydrogen-cooled 16kV generator (Figure 3), 16kV generator main circuit breaker (GMCB), static frequency converter (SFC) starting system, 275kV/16kV generator transformer, 16kV/6.6kV unit transformer, other station auxiliaries, MV/LV switchgears and essential power distribution system forming overall electrical system for power generation and unit and station auxiliaries loadings.

Figure 3 Unit 9 Generator



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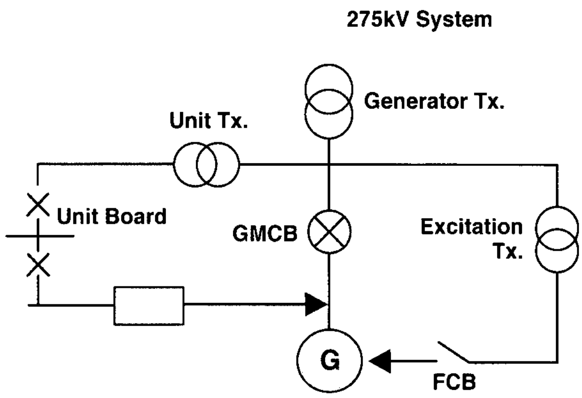
The generator is connected to the generator transformer by means of isolated phase busduct (IPB) through GMCB delivering 275kV electrical power to HEC transmission system by the new Lamma Extension 275kV Switching Station. The simplified single line diagram of Unit 9 electrical power system is shown in Figure 4.

Figure 4 Simplified Unit 9 Electrical Single Line Diagram



3. ENHANCED CONDITION MONITORING IN UNIT 9 MAIN ELECTRICAL EQUIPMENT

3.1 GENERATOR CONDITION MONITORING SYSTEM

In all electrical power generating plants, operation of generator has to be kept within design limits for optimum performance and to maintain reliability of the equipment. In case of generator failure, it will take much longer time for generator repair and replacement work to resume normal plant operation. For many turbine generator failures, corrective action could have been taken to reduce the magnitude of the damage or possibly prevent it altogether if the incipient fault or abnormal operation condition of the generator had been detected earlier.

To lengthen power plant operation life for effective asset management plan and achieve optimum operating performance of essential equipment like generator in the new combined cycle unit, HEC adopts the following advanced condition based monitoring systems in Unit 9 generator design:-

i) Generator Condition Monitor (GCM)

ii) Generator Partial Discharge Monitor (PDM)

iii) Stator Coil End Vibration Monitor (CEVM)

iv) Rotor Winding Short-Turn Detecting System

By collecting and analysing all available information, operating parameters and performance data of the generator through respective condition monitoring apparatus, any potential risk or abnormal conditions of the generator can easily be detected in advance to implement a timely maintenance program and to exercise a proper diagnostic strategy. The major functions of the generator condition monitoring devices include:-

- Remote indication to present quantitative information to the plant operator on the status of the generator at the instant of observation.
- To monitor the healthiness of generator and provide an alarm when the parameter exceeds a certain threshold.
- To store historical information that can be used to locate areas in the generator that is not functioning normally prior to unit removal from service and diagnoses the cause of the malfunction.

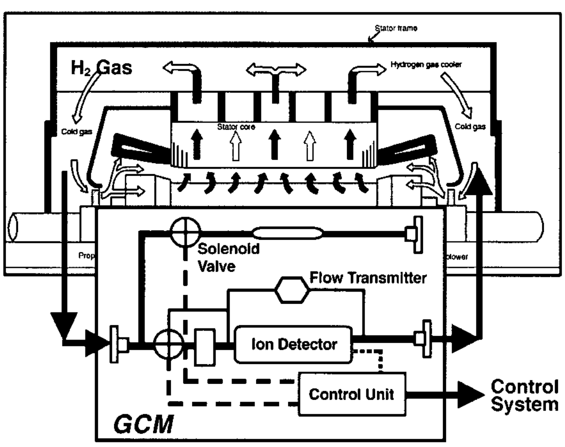
(a) Generator Condition Monitor (GCM)

The installation of a real-time sensitive Generator Condition Monitor (GCM) in the hydrogen-cooled system of Unit 9 generator (Figure 5) is to detect invisible sub-micrometer particles emitted in the early stages of overheating. Excessive heat build-up in the insulated conductors in the generator field or armature can result in thermal decomposition of the winding's ground-wall installation. Such abnormal heat build-up can be caused by strand breakage, connection failure or cooling system deficiencies, etc.

Thermal decomposition of organic compounds such as epoxy paint, core lamination enamel or other insulating materials used in the generator results in the production of a large number of small particles. With the presence of high concentrations of sub-micrometer particles within the generator, local "Hotspot" leading to overheating of generator will occur. The primary objective of the generator condition monitor is to identify excessive build-up of heat in the winding/ core insulation before they result in catastrophic failures of the insulation and thus of the generator itself.

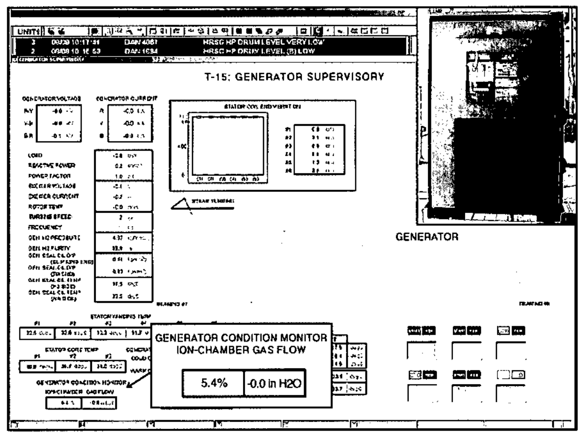
The GCM operates by monitoring the hydrogen gas for the presence of particulates which a small sample of the gas is diverted continuously to the GCM. Detection of particles in hydrogen cooling gas is done through ion-particles interaction process in Ion Chamber Detector (ICD) of GCM by on-line measurement of gas flow rate and output current in ICD.

Figure 5 GCM Configuration Diagram



When decomposition particulates are present in the hydrogen stream, the electrons will stick to the particulates and the particle-ion combination becomes larger in concentration causing reduction in gas flow rate and ion chamber output current because of low ion-particles mobility between the electrodes in ion chamber detector. The GCM will initiate an alarm verification sequence which all hydrogen gas will be passed through filter for removing the sub-micron particles. If the alarm is still valid confirming the presence of particles and existence of overheating, an alarm of "Generator Condition Abnormal" will be sent out to the control system (Figure 6) for corrective action.

Figure 6 GCM Control System



Since the GCM is incorporated into the hydrogen gas system of the generator, it is designed to flameproof, intrinsically safe standard of Ex IIC, CE marked. The installation of the GCM cubicle is under the generator bottom to shorten the hydrogen gas piping for precise measurement. In case generator repair is required, the adoption of GCM can greatly reduce the average repair time from approximate four (4) months to around one week due to early warning at the preliminary fault development stage.

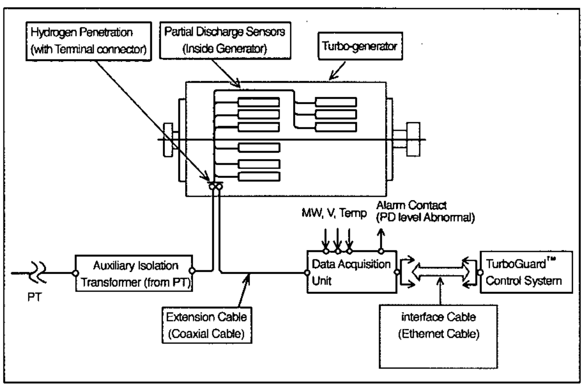
(b) Generator Partial Discharge Monitor (PDM)

Another advanced condition based monitoring system installed in Unit 9 generator is the Partial Discharge Monitor (PDM). Partial discharge is a phenomenon in which the insulation capability of a gaseous substance breaks down locally because of high intensity electric fields. Micro cracks and voids caused by overheating, contamination, deterioration and loose windings in the generator stator winding insulation will lead to partial discharge in the insulation materials and consequently failure of generator stator windings.

For accurate measurement of the health of Unit 9 generator stator winding insulation for long term overhaul planning, HEC employs on-line PD monitoring technique in the generator design by using directional electromagnetic Stator Slot Couplers (SSC) sensors to identify the occurrence of PD in the stator winding. The system configuration of PDM includes PD sensors (SSC), data acquisition unit (DAU) and system controller (TurboGuard Control System) as shown in Figure 7.

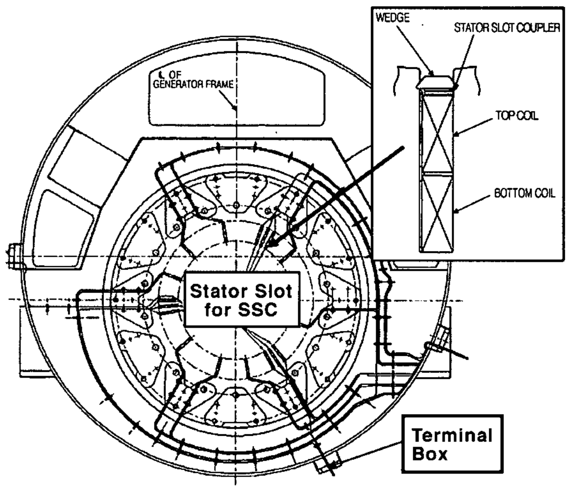
The Stator Slot Coupler (SSC) is of high frequency and antenna type sensor with two ports comprising of an electrode structure printed on an epoxy glass laminate for detection of stator winding partial discharge signals during generator operation. The SSCs are placed in the stator slot embedded directly underneath the stator wedges with no conducting surfaces exposed during assembly of stator windings at generator shop.

Figure 7 PCM System Configuration



With the special design feature of antenna type sensor, the problem of noise is virtually eliminated and it has the characteristic to show the true pulse shape of PD signals in the stator windings for correct diagnosis. Moreover, the two-port characteristic of SSC gives it inherent directional capability for precise measurement. The layout of SSC embedded in stator slot of Unit 9 generator is shown in Figure 8.

Figure 8 SSC Installation Layout

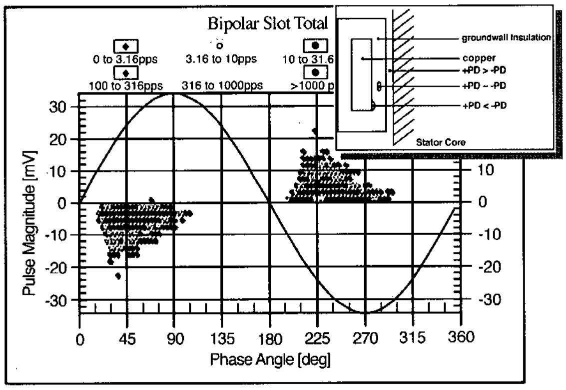


Continuous PD signals detected from the SSCs will be transmitted to the Data Acquisition Unit (DAU) installed under the generator bottom by coaxial cables through a gas-tight termination box. The capability for PD detection using the SSC and DAU is enhanced to include measurement in terms of positive and negative characteristic, the number, magnitude and phase position of the PD pulses from the stator slot, end-winding or under the SSC itself as the end of the slot.

DAU also monitors generator operating conditions such as generator output, generator terminal voltage and stator coil temperature. Once the PD level exceeds the criteria limit, an alarm for "Generator PD Level Abnormal" will be sent to the control system for corrective action. The overall control, analysis and trending of the PD data are performed by a computer-based PD system controller connecting to the DAU at control room.

The system controller is configured with partial discharge system software for displaying and trending any saved PD data for remote monitoring. Based on the PD data obtained from the PD control system, any deteriorated condition of the generator stator insulation (Figure 9) can be closely monitored and the repair work of the stator coil can be carried out during scheduled outage effectively.

Figure 9 PDM Data Analysis

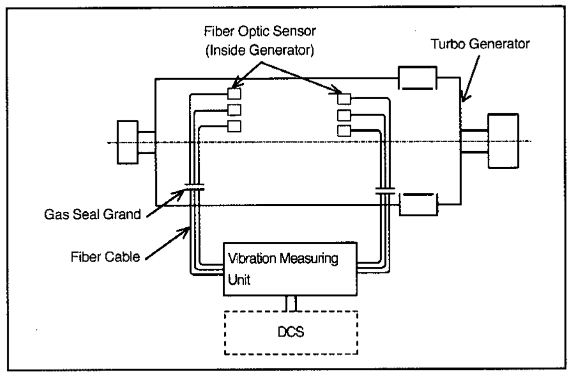


(c) **Stator Coil End Vibration Monitor (CEVM)**

In generator construction design, rigid structural design is applied to generator stator coil end to withstand electromagnetic force arisen during normal operation or in the event of power system failure such as sudden short circuit. As the generator ages, the coil end winding support structure tends to relax resulting in reduced resistance to the 100Hz vibration force naturally found in the stator coil end-turn region. As the vibration amplitudes increase, the stator coil end windings are progressively more fatigue leading to damage of the insulation and fatigue fracture of conductive part of the generator.

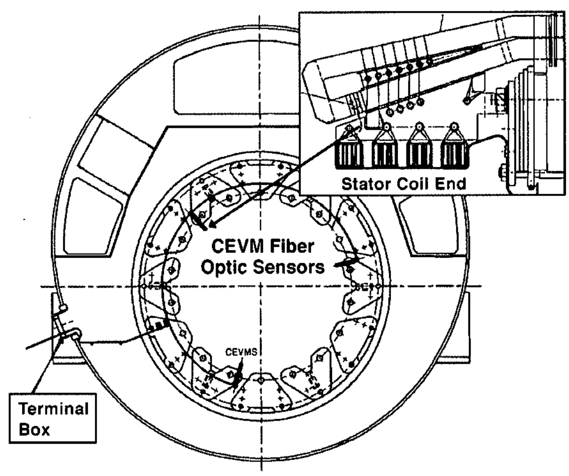
To tackle the above vibration problem, HEC adopts advanced stator coil end vibration monitor technique using fiber optic sensors for vibration measurement in the design of Unit 9 generator stator coil end winding. The overall monitoring system consists of fiber optic sensors and cables, gas seal gland and vibration measuring unit. Figure 10 shows the system configuration of stator coil end vibration monitor for Unit 9 generator.

Figure 10 CEVM System Configuration



Fiber optic sensors are used to measure the vibration level of stator coil end winding under high voltage environment and they are mounted on winding in the direction of vibration to be measured. Figure 11 shows the installation details of fiber optic sensors in stator coil end of the generator.

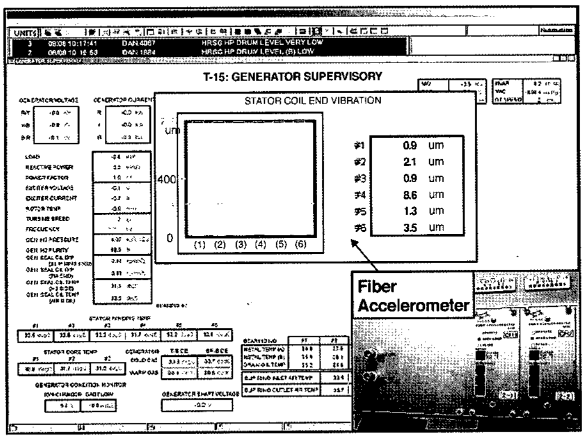
Figure 11 CEVM Fiber Optic Sensor Installation Layout



The sensor is located at the end of a single-strand optical fiber and is excited by the infrared LED light from the vibration measuring unit (VMU). A measurement optical signal and a reference optical signal of different wavelengths will be returned to the VMU for vibration analysis. The measurement signal is generated by effect that light collimated in a graded index lens is reflected in a cantilever beam which is deflected by vibration.

The light is then focused back towards the fiber, but due to angular deflection of the collimated light beam, the focal point will be moved and the intensity of the returned light in the fiber is modulated by vibration. The reference signal is used for compensation of fibres and connectors losses. The vibration (acceleration) signals detected at stator coil end winding by the VMU will be converted to electrical output signal (4~20mA) and transmitted to the control system for continuous monitoring (Figure 12).

Figure 12 CEVM Control System



Once the vibration level exceeds the acceptance criteria, alarm will be sent out to the control system for further corrective action. As the CEVM can monitor the coil end vibration, corrective action such as re-binding of coil ends and re-tightening of core bolts can be planned before hand for the scheduled overhaul. By using the CEVM system, the estimated time required for the repair work can be reduced from more than 4 months to less than 2 weeks.

(d) Rotor Winding Short-Turn Detecting System

Shorted turns in rotor windings are associated with turn-to-turn shorts on the copper winding. The following outlines the possible causes of rotor winding shorted turns:-

i. Electrical breakdown of the inter-turn insulation.

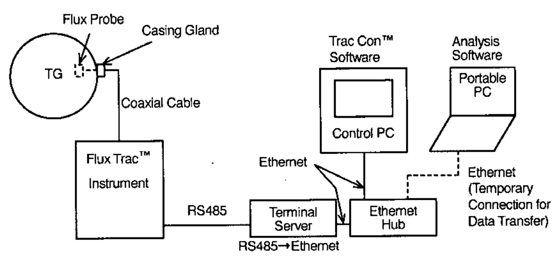
ii. Mechanical damage to the inter-turn insulation leading to adjacent turn to turn contact.

iii. Contamination in the slot which allows leakage currents between turns.

Owing to the presence of shorted turns, the total ampere-turns produced by the rotor are reduced since the effective number of turns has been reduced by the number of turns shorted. This results in the increase in required field current input to the rotor to maintain the same load point and thus increase in rotor winding temperature. The effect of localized heating of the rotor copper winding and arcing damage to the insulation between the turns will occur and eventually lead to failure of generator rotor windings.

To prevent serious damage of generator due to the above shorted turn problem, an on-line rotor winding shorted turn detection system comprising of flux probe, casing gland, "FluxTrac" instrument and control computer is installed in Unit 9 generator. Figure 13 shows system configuration of rotor shorted turn detection system (RSTD).

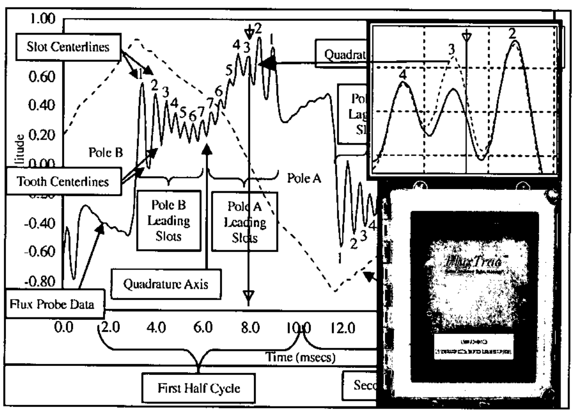
Figure 13 System Configuration of RSTD System



The flux probe is installed in the generator stator wedge and is connected to the casing gland mounted on the generator frame. The flux probe looks at the variation in magnetic field produced in the airgap by the rotor as it spins. The energised rotor winding and the slotted effect of the winding arc cause a sinusoidal signal in the winding face of the rotor. The magnitude of the sinusoidal peaks in the winding face is dependent on the ampere-turns produced by the winding in various slots.

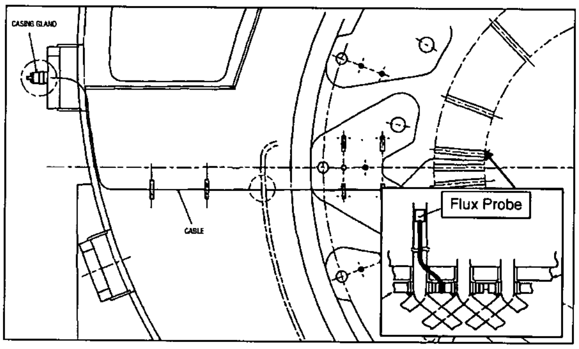
If there is a shorted turn in a slot, the peak of the signal for that affected slot will be reduced and the amount of reduction will be dependent on the magnitude of the short-circuit. The "FluxTrac" instrument acquires magnetic flux data from the air gap mounted flux probe in the generator and then sends the data to the control computer containing data acquisition software for detail analysis (Figure 14).

Figure 14 Data Acquisition Software



The installation detail of flux probe inside the generator is shown in Figure 15. Using the information and data received from the rotor winding shorted turn detection system for shorted-turn coils identification, the operator can immediately investigate any unusual operating conditions such as rotor vibration or change in excitation requirement. This can provide warning of generator rotor short-turn and prompt corrective action such as rotor coil repair can be planned before scheduled overhaul.

Figure 15 Flux Probe Data Acquisition Software



3.2 ON-LINE DISSOLVED GAS MONITORING APPARATUS FOR GENERATOR TRANSFORMER

In addition to new approach of condition-based monitoring systems in Unit 9 generator design, HEC also adopts advanced on-line Dissolved Gas Monitoring Apparatus for the new oil-filled 275kV/16kV Generator Transformer for automatic measurement and analysis of the combustible gases concentration dissolved in the transformer oil to detect transformer inner faults during operation.

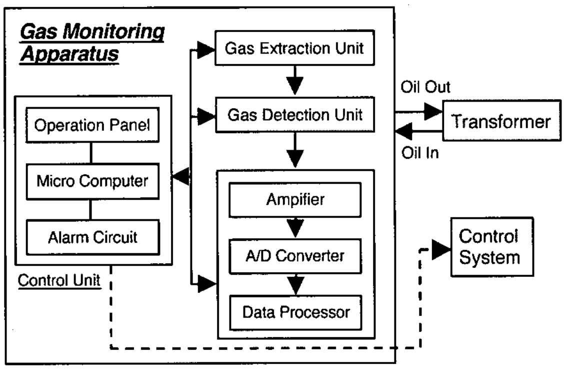
The safe and reliable operations of the generator transformer are of the same essential ranking as that for the generator which is the main skeleton of the power generation and transmission systems for the new combined cycle unit. To avoid any unexpected power outage, it is desired to have proven technique and effective way to detect the very beginning of the degradation process in a transformer.

In the event of any transformer abnormal phenomena such as dielectric breakdown due to arc or partial discharge and local overheating of conductors or zones in the iron core because of leakage flux or eddy current, intense heat is generated inside the transformer. The insulation oil, paper and other solid insulation or structural materials adjacent to this abnormally intense heat become decomposed and break down into combustible gases H_2, CO, CH_4, C_2H_2, C_2H_4, C_2H_6 and other hydrocarbon gases with a characteristic composition which will be dissolved in the insulating oil.

The measurement and analysis of the concentration levels and proportion of these gases dissolved in the insulation oil allows early detection of an existing fault and makes it possible to take the necessary preventive measures before the transformer suffers greater damage.

The dissolved gas monitoring apparatus for Unit 9 generator transformer consists of the gas extraction unit, gas detection unit, data processing unit and control unit equipped with alarm circuit. The block diagram of the gas monitoring apparatus is shown in Figure 16:

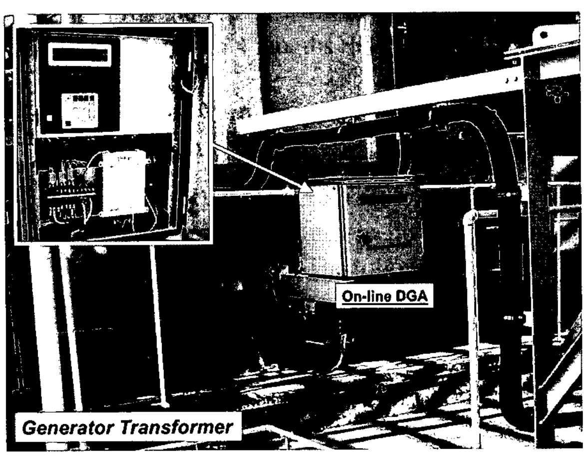
Figure 16 Block Diagram For DGA



The concentration level of Total Combustible Gas (TCG) and each component gas is measured automatically at every preset interval in the control unit of DGA. The measured values will be transmitted to a remote control computer through a modem installed inside the DGA for on-line monitoring. If the concentration of TCG, each gas component and TCG trend exceed the present criteria (caution or alarm) limit, the alarm circuit of control unit will initiate an alarm display message and alarm signal to the DGA and also to the remote control computer for detail analysis and investigation.

The internal arrangement of the DGA on the generator transformer is shown in Figure 17.

Figure 17 On-line Dissolved Gas Apparatus for Gen. Tx.



4. CONCLUDING REMARKS

In the new 335MW gas-fired combined cycle unit, Unit 9, HEC adopts advanced technology and new approach to incorporate condition-based monitoring systems into the design of essential electrical power equipment such as Generator and Generator Transformer in the main electrical system of Unit 9.

Paper No. 1

Advanced condition monitoring devices can provide clear indication, early warning and status of the operating performance of the generator and generator transformer to the plant operator for effective maintenance work strategy and diagnosis planning. Implementation of this new monitoring system can greatly enhance equipment reliability and shorten the required plant outage period for maintenance and overhaul work.

As one of the world class electricity companies with supreme supply reliability, HEC continues to keep abreast of new technology development to further optimize the main electrical power generation system of the power plant in the near future to meet the expectation of the community.

5. ACKNOWLEDGEMENT

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REFERENCES

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SIEMENS

Paper No. 2

THE NATIONAL ELECTRICITY MARKET OF AUSTRALIA

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ABSTRACT

Historically Australian governments owned and operated electricity supply assets and sold electricity at regulated prices. During the 1990s, the participating jurisdictions agreed to establish a fully competitive National Electricity Market (NEM).

Under the agreements, the participating jurisdictions adopted the National Electricity Law and gave effect to the National Electricity Code (Code). New regulators were established to administer the Code, and to manage and operate the NEM. The utilities were disaggregated into separate generation, transmission, distribution and retail corporations, and customers were allowed to choose suppliers.

The NEM began operating as a wholesale market for the supply of electricity to retailers in Queensland, New South Wales, the Australian Capital Territory, Victoria and South Australia in December 1998. Tasmania was physically connected to the NEM in April 2006. The NEM, spanning more than 4,000 km from Queensland to South Australia, is the world's longest interconnected power system in geographical terms.

Electricity reforms have increased the productivity and performance of the electricity industry, resulting in substantial benefits for households, businesses, industries and the economy.

1. THE ECONOMIC REFORMS

Prior to the 1990s, State and territory governments owned and operated Australia's electricity supply assets and sold electricity at regulated prices[1]. Electricity supply in Australia was the responsibility of large state-based utility authorities that managed generation, transmission and distribution as monopoly businesses. There was little interconnection between the networks, and no effective competition at any point of the supply chain[2].

The Special Premiers' Conferences of October 1990 and July 1991 led to the formation of the National Grid Management Council (NGMC), and in the Prime Minister's "One Nation" Statement of February 1992, where plans for developing a coordinated electricity grid spanning the eastern States were articulated[3].

Reviews by the Industry Commission and the Independent Committee of Inquiry into a National Competition Policy for Australia (the Hilmer Inquiry) in the early 1990's identified the significant benefits that were potentially available from introducing competitive market arrangements for the trading of electricity and enabling free and fair trade of natural gas. These findings led to Australian Governments committing to the development of a National Electricity Market (NEM) and implementation of reforms to the electricity and natural gas industries under the National Competition Policy and the related Competition Principles Agreement[4].

In 1995, Australian government, the State governments and the Territories agreed to the National Competition Policy (NCP) reform package with the objective of increasing the competitiveness and growth prospects of the economy[5]. The NCP reforms comprised three components[6]:

- Competition Policy Reform Act to amend the Trade Practices Act (TPA) and state and territory competition legislation
- Conduct Code Agreement (CCA)
- Competition Principles Agreement (CPA)

The cornerstone of the agreed reforms under the electricity agreements was a commitment to establish a fully competitive NEM. COAG communiqués set out specific reform commitments intended to achieve this original vision. The reform commitments included[7]:

- implementing necessary structural changes to allow for the operation of a competitive NEM;
- allowing customers to choose the supplier (including generators, retailers and traders) with which they will trade;
- establishing an interstate transmission network and non-discriminatory access to the interconnected transmission and distribution network;
- ensuring there are no discriminatory legislative or regulatory barriers to entry for new participants in generation or retail supply, and to interstate and/or intrastate trade;
- implementing cost-reflective pricing for transmission services with greater scope for averaging for distribution network services, and transparency and inter-jurisdictional consistency of network pricing and access charges; and
- facilitating inter-jurisdictional merit-order dispatch of generation and the interstate sourcing of generation where it is cost-effective.

Reforms to the electricity sector have, to date, included the dismantling of state owned monopolies, the implementation of a system of third party access to natural monopoly network infrastructure and the establishment of a wholesale electricity trading market. Full retail competition (FRC) has largely been introduced in all NEM jurisdictions, except for Queensland[8].

2. LEGAL FRAMEWORK

The National Electricity Law was enacted in 1996, which gave effect to the National Electricity Code (Code) in each NEM-participating jurisdiction. The National Electricity Market Management Company (NEMMCO) and the National Electricity Code Administrator (NECA) were established as the market operator and the code administrator respectively. The Australian Competition and Consumer Commission (ACCC) was responsible for general competition regulation and access undertaking provisions under the TPA. These arrangements formed the basic framework for the NEM when it commenced operation in 1998.

2.1 NATIONAL ELECTRICITY LAW

The National Electricity Law (NEL) sets out the following:

- National electricity market objective
- National Electricity Rules to have force of law
- Obligations of participant in the NEM
- Functions and powers of the AER
- Functions and powers of the AEMC
- Role of NEMMCO under the National Electricity Law
- Proceedings under the National Electricity Law
- The making of the National Electricity Rules (Rules)
- Safety and security of the National Electricity System
- Immunities

2.2 THE NATIONAL ELECTRICITY RULES (THE CODE WAS REPLACED BY THE RULES ON 1 JULY 2005)

The Rules set out the following:

- The obligation of participants in the NEM
- The Market Rule
- NEMMCO's Market Responsibilities
- Power System Security
- Network Connections and System Standards

- Transmission and Distribution Pricing
- Metering installation and responsibility
- Dispute Resolution
- Reporting requirements and monitoring standards for Registered Participants and NEMMCO

3. THE MARKET OBJECTIVE

The NEM objective is set out in the NEL:

The NEM objective is to promote efficient investment in, and efficient use of, electricity services for the long term interests of consumers of electricity with respect to price, quality, reliability and security of supply of electricity and the reliability, safety and security of the national electricity system[9].

4. THE REGULATORS

In 2003 the Australian, State and Territory Governments agreed to establish a new regulatory framework for the energy sector. As part of this agreement, the AEMC and AER were established and commenced on 1 July 2005. These 2 regulators have assumed NECA's functions since then.

The Regulators are as follows[10]:

- **MCE** - as the national policy and governance body for the Australian energy market including for electricity and gas, with a power to issue statements of policy principles to the AEMC and to direct reviews by the AEMC with respect to rule making and market development;
- **AEMC** - responsible for rule making and market development in respect of electricity and natural gas transmission and distribution networks and retail markets (other than retail pricing);
- **AER** - responsible for enforcement of the rules for the NEM and for economic regulation of electricity and gas transmission and distribution networks and retail markets.
- **ACCC** - responsible for general competition regulation under Part IV of the TPA, as well as responsibility for the consideration and acceptance of access undertakings under Part IIIA of the TPA and access arbitrations; and
- **NEMMCO** - responsible for managing and operating the NEM in accordance with the Rules. The NEM is the mechanism through which electricity is physically traded between registered generators and market customers. NEMMCO is required to balance supply with demand by scheduling the most cost-effective generators into production.

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5. RULE PARTICIPANTS

National Electricity Rules participants are of two general types - businesses that trade in the NEM, and service providers that facilitate the operation of the NEM. All Rule Participants must be registered with NEMMCO[11].

- **Generator** - that supplies electricity to, or who otherwise supplies electricity to, a transmission or distribution system.
- **Customer** - A person who engages in the activity of purchasing electricity supplied through a transmission or distribution system.
- **Market Participant** - A person who has registered with NEMMCO as a Market Generator, Market Customer or Market Network Service Provider under Chapter 2 of the Rules.
- **Network Service Provider** - A person who engages in the activity of owning, controlling, or operating a transmission or distribution system.
- **Trader** - A person who participates in Settlement Residue auctions

6. NETWORK OF THE NATIONAL ELECTRICITY MARKET

The NEM began operating as a wholesale market for the supply of electricity to retailers and end-users in Queensland, New South Wales, the Australian Capital Territory (ACT), Victoria and South Australia on 13 December 1998[12].

When the Queensland to New South Wales interconnector was commissioned in February 2001, the NEM - spanning more than 4000 kilometres from Cairns in northern Queensland to Port Lincoln in South Australia - became the world's longest interconnected power system in geographical terms[13].

Tasmania formally joined the NEM on 29 May 2005 after an extensive program of preparation for NEM participation that commenced in July 2003 when NEMMCO signed a memorandum of understanding with the Tasmanian jurisdiction[14]. Tasmania was physically connected to the NEM when the 360 kilometre Basslink electricity interconnector between Tasmania and Victoria is fully operational on 29 April 2006[15].

7. MARKET STRUCTURE

Physical electricity is purchased via the spot market (this is known as a 'gross pool' arrangement) and dispatched centrally by National Electricity Market Management Company (NEMMCO), the market and system operator. NEMMCO also manages the security of the power system and provides ongoing information to market participants about forecast and actual supply and demand[16].

7.1 WHOLESALE MARKET

The NEM uses regionally-based pricing in which the price at each network connection point is determined in relation to a common regional reference node price. Typically, the cost of supply will increase the further the point of consumption is from the regional reference node. When the network operates below the level of its maximum technical transfer capacity, electricity prices in different regions of the NEM are related to each other by simple real-time loss calculation. But when an interconnector is operating at its maximum transfer capacity, and therefore physically prohibits the transfer of additional capacity between regions, the prices in the different regions may vary.

Trading in the NEM is based on a 30-minute trading interval. The spot price is the price applied to electricity trades through the pool for a particular trading interval in a specific region of the NEM. The spot price is the price used to settle the market, and is the average of the six dispatch price outcomes of generator bidding for the preceding half hour. That is, the spot price is the half-hourly clearing price to match supply and demand[17].

7.2 RETAIL MARKET

Retail markets are regulated by each participating jurisdiction separately where retailers on-sell the energy they purchase to end-user consumers such as households and businesses. Each jurisdiction regulates its retail prices for retail customers. Since the introduction of FRC in all NEM jurisdictions, except for Queensland, customers can choose their electricity retailer. This change has been introduced in the interest of stimulating competition for the benefit of consumers. Electricity consumers can check the prices and choose the retailer that suits them best.

8. TRANSMISSION NETWORK SERVICE PROVIDER'S REVENUE REGIME

The Rules require the AER to set a revenue cap to apply to each TNSP for a regulatory period of at least five years. The Rules provide that the economic regulation is to be of the CPI-X form or some incentive based variant.

In setting the maximum allowable revenue for the regulatory period, the AER makes use of the building block model in according to the ACCC's "Statement of Principles for the

Regulation of Electricity Transmission Revenues".

The building block model consists of two equations which are known as the revenue equation and the asset base roll forward equation. These two equations are used to determine an allowed stream of revenues for each TNSP for as long as it remains regulated. Ignoring any incentive rewards or penalties, these equations together ensure that the present value of the allowed revenue stream is equal to the present value of the expenditure stream of the regulated firm.

Expressed in the simplest form, the building block equations are as follows:

MAR = *return on capital + return of capital + opex + tax*
= *(WACC * RAB) + D + opex + tax*

and

new RAB = *previous RAB - depreciation + capex*

where:

MAR = *maximum allowable revenue*
WACC = *post tax nominal weighted average cost of capital*
RAB = *regulatory asset base*
D = *depreciation*
opex = *operating and maintenance expenditure*
tax = *expected business income tax payable*

An objective of the regulatory regime is to foster efficient investment and operating practices within the transmission sector, and to provide for an equitable allocation between TNSPs and users of expected efficiency gains.

The efficiency incentives are incorporated in the building block model through service standards, opex and capex incentive schemes. This can be expressed in a more precise version of the building block model equations as follows[18]:

forecast revenue = return on capital + return of capital + opex + tax + service standards incentive scheme + opex incentive scheme

closing RAB_{t-1} = opening RAB_{t-1} + actual $capex_{t-1}$ - depreciation $allowance_{t-1}$ + capex incentive scheme

9. TRANSMISSION PRICING REGIME

The transmission and distribution pricing arrangements are provided in Chapter 6 of the Rules. The Rules require the arrangements to be efficient in the use, operation, and maintenance of, and investment in, transmission and distribution systems, and in the location of generation and demand[19].

There are four types of transmission charges in the NEM - connection, overhead and general and system usage charges. These costs are allocated to users (generators, DNSPs, MNSPs and large directly connected customers. The Generators pay cost of connection of generator to grid (Entry charge). The Customers pay connection of to grid (Exit charge), overhead charge (Common service charge), usage charge and general charge. The usage charge is applied on a locational basis using Cost Reflective Network Pricing methodology.

In general, the costs of assets connecting the user to the network are recovered from the relevant connected network user, while remaining asset costs are largely recovered from directly connected loads and DNSPs. In effect this means the majority of transmission costs are borne by consumers[20].

10. REGIME OF DEVELOPMENT OF TRANSMISSION NETWORK ASSETS

The National Electricity Rules require a proposed new transmission network asset to satisfy a regulatory test[21].

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The *regulatory test* is an economic cost-benefit test used by TNSPs in the NEM to assess the efficiency of network investment in order for the investment to be rolled into the regulatory asset base. It consists of two limbs[22]:

- the 'reliability limb' - used for considering reliability driven augmentations, which are based on the service obligations imposed on Network Service Providers (NSPs), involves the application of a 'minimising-cost' test; and
- the 'market benefits limb' - used for all other projects and, like the interconnector limb, involves the application of a NPV analysis.

11. PERFORMANCE OF THE NATIONAL ELECTRICITY MARKET

11.1 RELIABILITY

The reliability standard was set at 0.002 per cent unserved energy (USE) by the Reliability Panel at market start in 1998 and has remained unchanged since that time. The standard describes the minimum acceptable level of bulk electricity supply measured against the total demand of consumers.

In the period since market start in 1998, the long-term averages for unserved energy due to supply shortfall indicate that New South Wales and Queensland remain within the standard (0.0001 per cent and 0.0 per cent respectively). South Australia and Victoria fell outside the standard in the year 2000 when there was a coincidence of industrial action, high demand and temporary loss of generating units in Victoria and their long-term averages remain outside the standard due to that event (0.003 per cent and 0.011 per cent respectively). In every year since 2000, South Australia and Victoria have met the reliability standard[23].

11.2 ECONOMIC BENEFITS

Reforms during the 1990s have increased the productivity and performance of the electricity industry, resulting in substantial benefits for households, businesses, the industry and the economy.

Electricity prices have declined in real terms since the creation of the NEM. Both NSW and Victoria have experienced price reductions of around 50 per cent at the wholesale level, while Queensland has benefited from smaller reductions. Recently, wholesale prices have increased, reflecting the gradual take-up of excess generation capacity, and, in some instances, more commercially orientated bidding strategies by generators. Prices remain well below the levels seen before the reforms.

The ACCC engaged ACIL Tasman to model the impacts of access regulation on the Australian electricity and gas industries. It found that the net present value of increases to GDP from access regulation of the electricity and gas industries (net of avoidable costs) were between $2.2b and $11b between 1998-99 to 2012-13. ACIL Tasman expected around 90 per cent of the aggregate benefits to be attributable to electricity access regulation, due to the relative sizes of the industries. The findings indicate that access regulation has resulted in significant benefits relative to the case where access regulation did not exist[24].

12. A NEW REFORM AGENDA

The Prime Minister of Australia on 15 June 2006 announced[25]:

The establishment of the Council of Australian Government (COAG) Energy Reform Implementation Group (ERIG).

At its meeting on 10 February 2006, COAG agreed that, notwithstanding the important structural reforms undertaken under National Competition Policy and other COAG initiatives since the early 1990s, further reform of Australia's energy sector would yield significant efficiency and energy security benefits.

The COAG ERIG, consistent with the broader directions set by COAG and as outlined in the COAG Communiqué of 10 February, has been tasked with reporting to COAG before the end of 2006 with detailed implementation arrangements for:

- achieving a fully national transmission grid including the most suitable governance and transitional arrangements having regard to COAG's objective of achieving a truly national approach to the future development of the electricity grid, the legitimate commercial interests of asset owners, and the need to promote investment that supports the efficient provision of transmission services
- any measures that may be necessary to address structural issues affecting the ongoing competitiveness and efficiency of the electricity sector, and
- any measures that may be necessary to ensuring there are transparent and effective financial markets to support energy markets.

Glossary

ACCC	Australian Competition and Consumer Commission
AER	Australian Energy Regulator
AEMC	Australian Energy Market Commission
COAG	Council of Australian Governments
Code	National Electricity Code
CPI	Consumer Price Index
DNSP	Distribution Network Service Provider
FRC	Full Retail Competition
IPART	Independent Pricing and Regulatory Tribunal of New South Wales
MCE	Ministerial Council on Energy
NCC	National Competition Council
NECA	National Electricity Code Administrator Ltd
NEL	National Electricity Law
NEM	National Electricity Market
NEMMCO	National Electricity Market Management Company
NER	National Electricity Rules
Rules	National Electricity Rules
TNSP	Transmission Network Service Provider
TPA	Trade Practices Act 1974

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Paper No. 3

INTELLIGENT-BASED LOW VOLTAGE CUBICLE SWITCHBOARD DESIGN FOR MODERN BUILDINGS

Speakers : Ir K.C. Lo, Senior Building Services Engineer
Ir Wallace S.F. Leung, Building Services Engineer
The Government of the HKSAR

INTELLIGENT-BASED LOW VOLTAGE CUBICLE SWITCHBOARD DESIGN FOR MODERN BUILDINGS

Ir K.C. Lo, Senior Building Services Engineer
Ir Wallace S.F. Leung, Building Services Engineer
The Government of the HKSAR

ABSTRACT

Intelligent buildings are at present the development trend of the building industry. To match with this building design development and to fulfill the increasing need for effective and efficient management of building facilities, an intelligent-based switchboard system with digital and computerized features becomes an essential element in the building design.

There are various intelligent digital devices for efficient monitoring of electrical circuits. The adoption of these intelligent devices are common in government buildings nowadays. They are capable of connecting to the Central Control and Monitoring System (CCMS) of the building for efficient monitoring. To facilitate the design development of intelligent-based switchboards, a generic model of intelligent LV switchboard (iLVSB) system with advanced functions is defined for project application.

This paper reviews the design of conventional LV switchboard and the development of electrical meters and instruments. The design and set up of an iLVSB system based on the proposed generic model for a pilot building project is discussed. The pilot project experience shows that the set up of iLVSB system should be customized to suit particular needs of the building. Joint efforts from design engineer, building operator, maintenance team, building users and contractors will help develop the building-specific intelligent power management system.

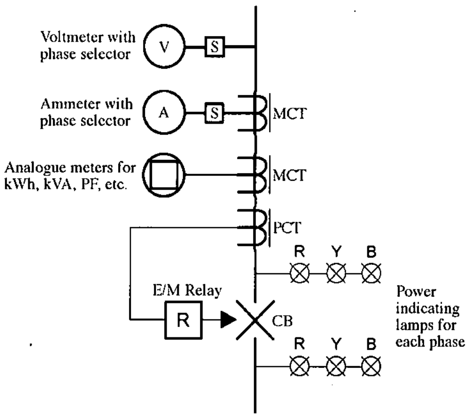
1. INTRODUCTION

Low voltage cubicle switchboard (LV switchboard) is the major equipment in an electrical installation. Regular monitoring, testing and maintenance are essential to ensure the equipment is in correct and safe operation. This paper reviews the development of LV switchboard protection and monitoring devices and introduces a conceptual model of intelligent LV switchboard (iLVSB) system for efficient monitoring and management of electrical installation. A pilot project on application of the iLVSB system is also discussed. With the implementation of iLVSB system, the building operator or facility manager can effectively acquire, monitor and predict the essential parameters of the electrical system for cost-effective facility management and preventive maintenance.

2. DEVELOPMENT OF LV SWITCHBOARD DESIGN IN GOVERNMENT BUILDINGS

LV switchboard enables the central management of electrical installation. In the 1970's, simple analogue type metering devices such as voltmeter, ammeter, kWh meter, maximum power demand meter were installed. Indicating lamps were installed to reflect the conditions of switchboard equipment and availability of power for each phase. Electromechanical type protection relays with various inverse time characteristics were employed for circuit protection. Figure 1 outlines the conventional arrangement of meters, relays and instrumentations in LV switchboard.

Figure 1 Arrangement of Meters, Indicating Lamps and Electromechanical Relays for a Circuit in Conventional LV Switchboard



To collect engineering data for condition monitoring, operation and maintenance personnel need to take record of electrical parameters such as voltage, current, maximum demand and kWh, etc. by logbook periodically. Based on the logbook record, analysis on electrical system could be made. The available spare capacity of the electrical system could also be estimated for determination of allowable expansion. Upon power failure, maintenance personnel could also get preliminary information from the central switchboard by reading the indicating lamps or status of circuit breakers /relays.

There are two types of arrangement for remote monitoring of electrical installations. The first one is remote monitoring within building, basically by using hard wire signal transmission or communication networking. The other one is remote site monitoring from other building by using hard wire connection, telephone network or Internet. In earlier years when digital communication network was not well developed, application of remote monitoring within a single building was very limited as the voltage drop constraint rendered remote readings of analogue data not practical. Although remote site monitoring technology has been well developed in HV and utility applications, the adoption of such facilities was rare for government building projects due to lack of cost effectiveness.

Standalone type digital metering devices were introduced for logging of electrical data in 1990's and became popular in government buildings. Digital meters had greatly enhanced the efficiency and reliability of collecting electrical data from electrical installation.

The advancement of digital communication network has greatly assisted the development of remote monitoring of electrical system in buildings. Nowadays, Central Control and Monitoring System (CCMS) and Direct Digital Control (DDC) are commonly adopted in buildings. Real time electrical data captured by the digital meters could be obtained and displayed in the CCMS workstation in both numerical and graphical format. Such information is useful for performance analysis of electrical installation such as energy audit.

3. DIGITAL PROTECTION SYSTEM

Electromechanical type relay had long been applied for protection of electrical system. In the late 1980's, electronic type protection relay was available in the market. Although electronic type relay enhanced the functions and capability of protection system, they were not commonly used in building projects due to high cost and unstable performance at that time.

Nowadays, the introduction of microprocessor-based digital protection relays enhances the protection system design with better accuracy, stability and flexibility. Various protection characteristics are built-in in the microprocessor and selectable. Therefore, digital protection relay offers the designer or operator flexibility to alter the protection scheme to cope with changes in electrical circuits. Because overcurrent and earth fault protection could be achieved by a single relay instead of four sets of electromechanical type relays, the digital protection relay occupies less space in LV switchboard and the cost becomes more competitive.

Software packages are now available for monitoring and management of digital protection relays. By using such software, the relays status and electrical parameters could be easily obtained from a remote computer workstation. Remote setting of relay characteristic is also achievable.

4. DIGITAL METERING AND INSTRUMENTATION

Digital meters offer great advantages for power system monitoring when compared with the conventional analogue meters. Because all the collected data would be converted to digital format, digital meters can provide clear and specific reading of the RMS value in a single LED or LCD display screen. This feature simplifies the panel design of LV switchboard and facilitates more efficient local monitoring.

Besides digital metering, digital and analogue I/O devices are also intelligent instrumentation with wide applications in electrical installation. Digital I/O devices could collect digital data such as status of a circuit breaker (on/off/trip) and status of battery charger. Analogue I/O devices could collect analogue data such as temperature measurement from thermocouple.

The functions of digital meters and digital instruments could be further classified into the following categories:

4.1 COLLECTION OF REAL TIME RMS ELECTRICAL DATA

With the increasing adoption of digital metering for electrical installation, the 2002 edition of General Specification of Electrical Installation for Government Buildings (EEGS) had incorporated the specification requirements of digital metering devices for intelligent application. There are two types of digital metering devices defined in the EEGS, namely digital multi-function power meter and power analyzer. As required in the EEGS, digital multifunction power meter shall be microprocessor based and capable of collecting real time RMS electrical data such as voltage, current, reactive power, real power and active power etc. Communication of the digital multifunction power meter could be via RS485 or Ethernet connection. The performance requirement of power analyzer in EEGS is similar to digital multifunction power meter but with more enhanced functions such as higher order harmonic measurement and waveform capture capability, etc.

4.2 COLLECTION OF EQUIPMENT STATUS

The monitoring of status could be achieved by collecting the dry contact signal from equipment. The digitized information for equipment status could be communicated to the computer server for remote monitoring. The efficiency on monitoring of electrical system could be greatly enhanced. Monitoring of equipment status for LV switchboard shall include circuit breaker on/off/trip status, status of battery charger. For LV switchboard designed as a motor control center, status monitoring may include motor starter conditions and motor overload trip etc. For generator switchboard, status of generator such as generator running, low oil pressure and high oil temperature, etc. may be under remote monitoring.

4.3 COLLECTION OF POWER QUALITY DATA

The increasing application of non-linear characteristic loads such as variable speed drive, electronic ballast and fluorescent lamp etc. burden the electrical installation with harmonics. Excessive harmonic impurities in electrical installation would result in various adverse effects including voltage /current distortion and high neutral current. Digital meter has the capability to capture harmonic data up to specified order and is an efficient tool for assessing harmonics and performance of mitigation filters. Other common power quality problems such as voltage dip or voltage sag could also be monitored by digital meters.

4.4 COLLECTION OF ENVIRONMENTAL DATA

With the digital and analogue I/O devices, collection of environmental data is easily achievable. Environmental data refer to the operating parameters or surrounding conditions of the LV switchboard, such as temperature, relative humidity and fire status etc. For temperature measurement, thermocouples could be applied at the busbar surface or the switchboard compartment for real time measurement. All the temperature readings are to be converted by analogue I/O device for digital interface. The temperature, relative humidity, water leakage detection status and fire detection status in LV switch room could also be collected for condition monitoring. For specially high security building, even motion detection by CCTV camera or unauthorized intruding status of the LV switch room could be obtained and converted into digital signal for monitoring.

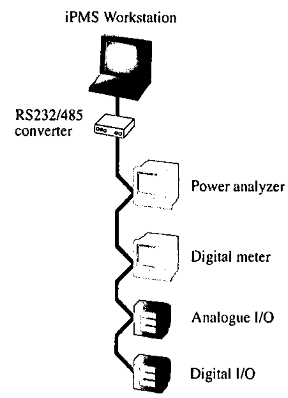
5. INTELLIGENT POWER MANAGEMENT SYSTEM (iPMS)

Intelligent power management system (iPMS) is a computer-based architecture to collect, store, monitor and manage electrical data being collected by the field digital devices. By integrating the digital meters and digital instrument into a computer system, the LV switchboards installed in building becomes an intelligent system for management of the electrical installation.

5.1 COMMUNICATION

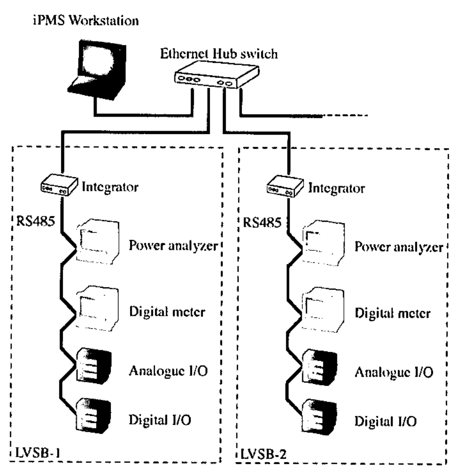
Integration of the field digital devices is achieved by digital communication. The field devices with RS485 outlets such as digital multifunction power meter, power analyzer and digital relay within a single LV switchboard could be connected together to form a simple power system management (Figure 2).

Figure 2 Integration of Digital Devices for Single LV Switchboard



For integrating various LV switchboards into an intelligent power management system, an integrator would connect all digital devices in a LV switchboard whereas integrators for different LV switchboards would further be connected together by a hub switch in 10/100BaseT Ethernet (Figure 3).

Figure 3 Integration of LV Switchboards into an Intelligent Power Management System (iPMS)



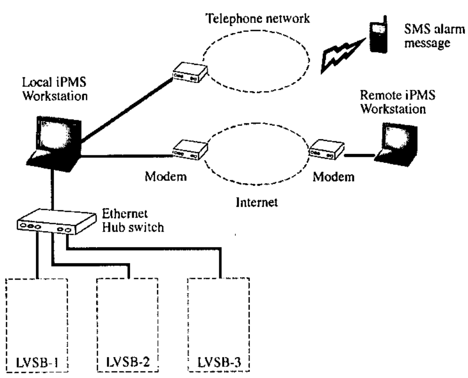
5.2 DATABASE AND APPLICATION SOFTWARE

There are many software packages in the market to perform well organized power management functions such as real time display of electrical parameters, remote settings of digital relay, periodic reporting of system status, waveform display function and trending analysis etc. Most of the market available power management software packages can allow certain level of customization to suit individual project applications.

5.3 REMOTE SUPERVISION

Remote supervision functions such as alarming and web access could be performed. Alarm notification enables faster communication of critical events such as tripping of circuit breaker or equipment failure. Besides alarm notice display in local iPMS computer terminal, the alarm message could be realized by automatically generated e-mail or SMS with preset message record. This function greatly improves the response time for preventive and corrective maintenance (Figure 4).

Figure 4 Schematic on Remote Monitoring and Alarm Notice



5.4 ENERGY MANAGEMENT

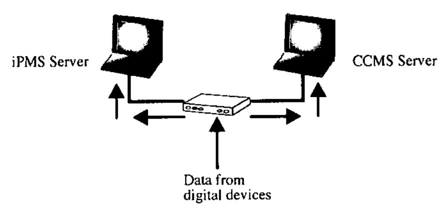
Measurement and recording of cumulative energy consumption for various building services installations or for various floors / zones could allow operators to analyze the energy consumption distribution. These data are useful for identifying Energy Management Opportunities (EMO). Although energy consumption data such as kWh could be recorded in the computer database with specified time-stamp interval, the cumulative kWh data collected in monthly or annual basis may not match with the data collected by the power companies as shown in electrical bills and causes confusion to the building owner. This is because the interval of kWh recording by the intelligent power management system is not synchronized with those by power companies.

A built-in software programme is therefore proposed to correlate the energy data collected by the iPMS and the utility company for producing monthly or annual energy report. The programme is to compare the energy data from the utility company bills and those collected in the iPMS. A correction factor is to be generated and applied back to the collected energy data. By multiplying the correction factor to the collected energy data from iPMS, the distribution of energy use for various building services installations or for various departments would be generated in kWh or monetary term in line with the electricity bills.

5.5 CCMS INTEGRATION

The integration between iPMS and CCMS could be achieved by Ethernet connection or high-level dynamic data exchange (DDE) between iPMS and CCMS computer server. By integrating the two systems in Ethernet hub switch, data collected by the intelligent devices would be transferred to iPMS server and CCMS server simultaneously (Figure 5).

Figure 5 Integration of iPMS and CCMS by Ethernet Gateway



The advantage of integration by Ethernet gateway is that CCMS server would become a redundancy system in case the iPMS computer system is malfunctioned. Such configuration however burdens on the CCMS computer server because decoding of digital signals transferred from the digital devices is required to be carried out by the CCMS server.

Alternatively, the integration between iPMS

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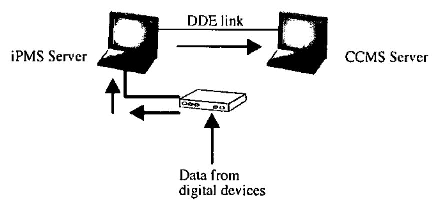
and CCMS would be achieved by DDE (Figure 6). This integration format reduces the burden on CCMS computer when compared with Ethernet connection. System reliability and redundancy could be improved by the use of standby iPMS computer server or local iPMS server located at individual LV switchboard as introduced in the following section.

Figure 6 Integration of iPMS and CCMS by Dynamic Data Exchange (DDE)



6. INTELLIGENT LV SWITCHBOARD (iLVSB) SYSTEM

The review on the latest developed digital equipment and power management softwares shows that the set up of an intelligent system to monitor electrical installation is technically feasible. This intelligent system, defined as an intelligent LV switchboard (iLVSB) system, can be considered as a key component of an intelligent building to achieve the following functions:

(a) Collect, store, present and analyze systematically real-time and historical electrical data for efficient and effective facility management.

(b) Provide active alarm notice upon system abnormality via communication network.

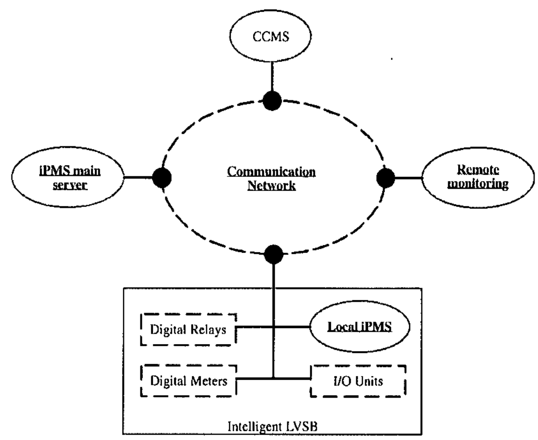
(c) Provide web-based remote monitoring of electrical installation.

(d) Possess third party integration capability such as CCMS integration via DDE.

6.1 MODEL OF iLVSB

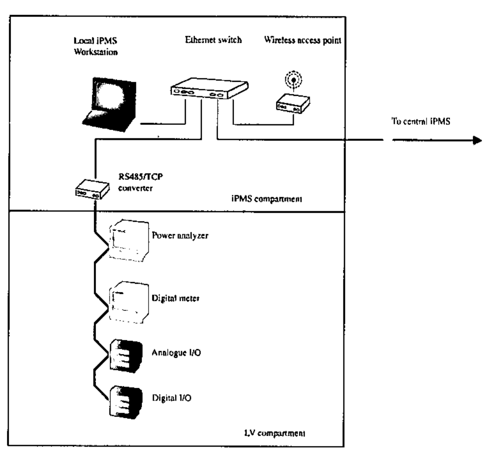
A generic model of iLVSB system is proposed in Figure 7. It encompasses digital protection system, digital meters and instrumentation, open communication network, intelligent power management system (iPMS) and CCMS integration capability. In the model, the iPMS main server is the central human-machine interface within building, while the remote iPMS serves as the platform for remote supervision and monitoring function.

Figure 7 A Generic Model of Intelligent LV Switchboard System



To enhance local monitoring function for individual LV switchboard, a local iPMS is proposed for the iLVSB model (Figure 8). The local iPMS would serve as a master terminal for maintenance personnel to read electrical information at a single location rather than from individual digital meters. Instead of installing permanent iPMS server locally, wireless Ethernet port could be installed readily for portable computer connection with built-in iPMS software.

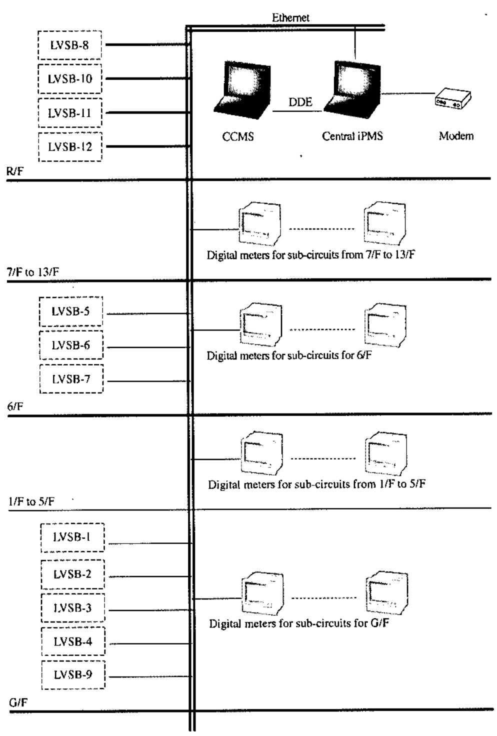
Figure 8 Local iPMS for iLVSB



6.2 PILOT PROJECT APPLICATION

A government health care building has been selected as a pilot project to apply the concept of intelligent LV switchboard system. The total capacity of the electrical installation is 9,000kVA. There are 12 nos. of LV switchboards for electrical distribution. Digital relays are adopted for the protection system. Power analyzer and digital multifunction power meters are designed to collect and analyze electrical parameters. Apart from electrical parameters, temperatures of the busbar, temperature, relative humidity, water leakage and security status of the LV switch room are also monitored. A panel mounted touch screen terminal will be installed as the local iPMS. Digital signals collected from individual LV switchboards and digital meters at sub-circuit boards would be transferred to the main iPMS for central monitoring. Integration with the CCMS would be by DDE. Remote monitoring functions include web access to the iLVSB system and alarm notification by mobile phone network. The simplified schematic diagram of the iLVSB system in the pilot project is presented in Figure 9.

Figure 9 Simplified Schematic Diagram of Pilot iLVSB System



The software package of iPMS would also be customized to suit the particular needs of this project. User information is being collected to group various digital meters to track energy consumptions of different areas /departments.

The cost of setting up the iLVSB system is about HK$0.3M or 6% of the tender price of LVSB installation for this pilot project. With the installation of digital meters and instruments being a common practice, the additional works for setting up of iLVSB will mainly be communication network and iPMS computer server. Given the scale of the building and complexity of the electrical installation, a preliminary appraisal shows that the setting up of iLVSB system in this pilot project is cost effective. Some key benefits derived from the iLVSB system are:

(a) Provide efficient tools for building energy performance evaluation and energy audit.

(b) The historical electrical data could be well managed to facilitate analysis of electrical installation to plan for future expansion and load shedding.

(c) Active alarm notification function to facilitate efficient corrective maintenance and thus reduce down time.

(d) Web-base remote monitoring capability.

The building is now under construction and targeted to be completed by July 2007. The pilot iLVSB system would serve as a useful tool in management of electrical installation and for evaluating the life cycle building energy performance.

7. CONCLUSION

There is rapid development in digital devices and information technology. It is now technically feasible to install intelligent power management system for electrical installation. A generic model of iLVSB is proposed and being applied in a pilot building project. The system could enhance energy performance of a building by efficient review of historical energy consumption profile and reduce down time with enhanced fault diagnosis and alarm notification capability. By applying the proposed model of iLVSB, the design of electrical switchboard system is standardized and project engineers could base on the model to develop the iLVSB system to suit the specific needs of individual projects. Last but not the least, with the ever advancement in IT development and the increasing demand for electrical supply reliability, we could see an increasing trend in the application of intelligent switchboard design in modern government buildings

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Paper No. 4

ENERGY SAVING: THE ROLE OF PUBLIC LIGHTING

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Lighting Division, Highways Department
The Government of the HKSAR

ENERGY SAVING: THE ROLE OF PUBLIC LIGHTING

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Paper No. 4

ABSTRACT

Soaring energy prices, rapid global economic development, fast depletion of natural resources, pollution impacts on the environment are issues now challenging energy sustainability of every modern society. Having recognized the importance of energy saving and efficiency, Lighting Division of Highways Department has undertaken all practicable measures to save public lighting energy whenever opportunities arise, with awareness on equipment life cycle along with other environmental issues. This paper addresses the latest efforts being undertaken and values achieved; and explains the roles of professionals to maximize energy efficiency practice in public lighting.

1. INTRODUCTION

Highways Department manages a territory-wide public lighting infrastructure comprising road lighting networks and many special lighting systems such as those for subways, footbridges, covered walkways, noise enclosures, underpasses, tunnels and public transport interchanges (PTI).

Up to August 2006, there are some 130,000 road lighting points in the SAR roadway and about 1,050 special lighting systems on various roadway structures. There is a demand for more efficient ways to illuminate the roadway infrastructure and to save lighting energy. The desire to reduce energy consumption and technological advances are only some of the driving forces to bring the change. To address this energy theme, it is timely that the latest practices and state of affairs on public lighting are discussed and reviewed.

2. ENERGY EFFICIENT SCHEMES

Acquiring energy efficiency does not imply reduced comfort or safety after all; instead its goal is to review, establish and maintain a better or equivalent standard of service using less energy. The following provides some facts and figures of recent efforts.

2.1 OPERATION PRACTICE & TECHNOLOGY

In past few years, various lighting energy saving schemes[1] have been implemented in many pedestrian subways through combined operation practice and new technology. The example in Ting Kok Road subway (NS208) demonstrated that installation of movement sensors at subway entrances or exits and light dimming control within the subway barrel resulted in about 50% energy cost saving. Lighting level would be dimmed down to 10% level when no pedestrian uses the subway, i.e. applying light on demand only tactic.

The subway NS50 at Jockey Club Road was retrofitted with high efficient luminaires fitted with T5 fluorescent lamp (FL) and compact fluorescent (CF) lamp resulting in about 45% saving in annual energy cost compared with that of before the retrofit (see Figure 1). Saving is even more, 67% for subway NS109, with a shorter subway barrel where a photo-sensor was incorporated in the lighting control circuit to dispense with artificial lighting inside the subway barrel during fine daytime.

These energy efficient practices and techniques implemented in other subways, footbridges, underpasses, PTI and roadway abound. However, those retrofitting projects completed in the earlier stage of the exercise would not achieve the amount of energy saving as stated above, partly due to unavailability of today's standard luminaires and lamp sources from the market at that time. It should be noted that application of computing skills is becoming important to maximise performance of the energy efficient exercise.

Figure 1 Layout of Luminaires Fitted with T5 Inside NS50

2.2 ENERGY EFFICIENT EQUIPMENT

On the other front, Highways Department has taken the rebate advantage offered by the Power Companies for fulfillment to the Demand Side Management (DSM) Program (2000 - 2003) of energy efficient equipment installation. As a consequence, almost 99.9% of highway structures illuminated by low pressure fluorescent lamps have been retrofitted with electronic ballasts by end 2005. Each average energy saving is circa 20% as compared with the electromagnetic type. Average annual energy units of 860,000 kWh have thus been saved following end of the replacement exercise.

In fact, electronic ballasts also have other benefits, such as dimming option, rendering longer lamp life by constant voltage control and higher total power factor over electromagnetic ballasts. Their life cycle cost and reliability will likely improve further in the foreseeable future as their market is now very mature and competitive. Judging from the pace of technological progress, environmental and economic benefits, electronic ballasts for low pressure fluorescent lamps are specified and adopted widely in all FL lighting works.

To improve road lighting efficiency using lamp sources, the last batch of 7,600 road lights with obsolete MBF, SOX or SON-E type lamps have been replaced by more efficient luminaires fitted with lower wattage High Intensive Discharge (HID) SON-T Plus lamps since April 2003, resulting in energy saving of circa 1,964,000 kWh. Despite with lower wattage than their predecessors, these SON-T lamps maintain similar luminance performance due to their higher efficacy, i.e. lumens output per watt.

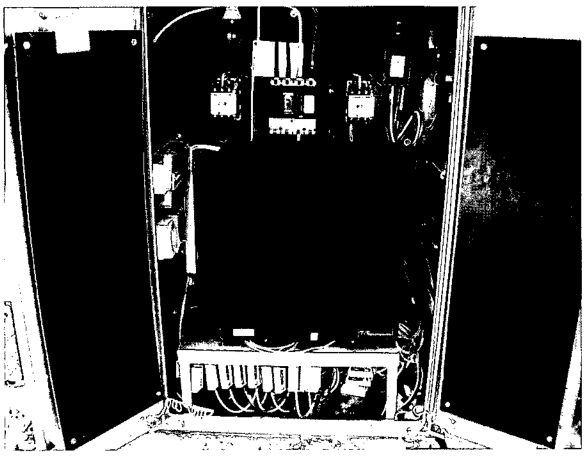
To move further on road lights energy saving, a pilot program has been underway to install electronic ballasts for HID road lights, with 1,500 already in place by end August 2006. It is interesting to note that the development of electronic ballasts for HID lamps replicates what have taken for low pressure fluorescent lamps. Not only they have the benefits of increased lamp lumen maintenance, extended lamp-life, near unity power factor, ease of lamp re-start and less gear components, but electronic ballasts for HID lamps also offer flexibility of light dimming options.

The latest dimmable HID lamp ballasts can allow pre-installation setting of the dimming profile for each individual light point, say for example 10% dimming for the first 5 hours and subsequent 25% dimming for the next 5 hours or set to 1-stage 25% fixed dimming over the whole period for more saving, according to the required road lighting standards and local roadway circumstances.

Dimming would correct the situation where lighting is more than strictly necessary, especially this is the aftermath created by design margin since lamp source from the market is produced in discrete wattage range, i.e. 70W, 100W, 150W, 250W, etc. With vast numbers of road light in the roadway by having different lighting levels at different times of the night and complying with correct lighting standards, there is indeed a good potential in energy saving with HID lamp dimmable electronic ballasts.

Dimming for groups of road light points with conventional electromagnetic ballasts by a central dimmer (see Figure 2) installed adjacent to a road lighting controller has been recently undertaken. In that, 1,500 road lights from circuits of 15 central dimmers have been involved for a 6-month period under a pre-set dimming profile, with energy cost saving of 16.7% reported. It has the beauty of fast installation and without any modification to the existing electromagnetic gear of each light point. With flexibility of electronic ballasts to set dimming profile at each light point, central dimming may lose some of its persuasive performance on comparative grounds, however.

Figure 2 A Road Lighting Central Dimmer



2.3 SOLAR ROAD LIGHT

8 numbers 5-metre pole-mounted solar road lights have been operational at different remote sites of the territory since August 2006, and further 4 are being planned. As the electricity supply from the Power Company is not readily available or uneconomical in the remote areas, this renders solar lights as an option in these locations. The solar light system includes 1 or 2 crystalline silicon photovoltaic (PV) panel(s), a consecutive 3-night back up 85-110 AH deep-cycle battery pack, a charge controller, an inverter circuit and a high efficient luminaire fitted with a 15-23W compact fluorescent (CF) lamp.

Although solar light is totally self-powered and independent of the power grid, the amount of solar radiation, size of PV panel and power output of the battery system adopted have limited its application in footpath or remote roadway, where lighting level required is generally low. Typical road lighting levels measured near the solar light shown in Figure 3 range from 3.5 to 5 lux.

Figure 3 A Solar Light Fitted with a 15W CF Lamp at Ha Fa Shan, Tsuen Wan

Solar light has now moved from the time of novelty to the point where it is maturely proven, but hampered by factors such as weather conditions, roadway wayleave, investment payback time, energy conversion efficiency and costs on recycling and disposal of the battery cells. At present, these may not permit extensive installations in the field. Nevertheless, it is a very noticeable part of the road light system and can serve the purposes of public education and promotion of renewable energy. In the course of time, there could likely be more solar lights in the roadway when major difficulties are resolved, such as the prices of PV panel drop considerably as a result of cost saving from mass production and market competition.

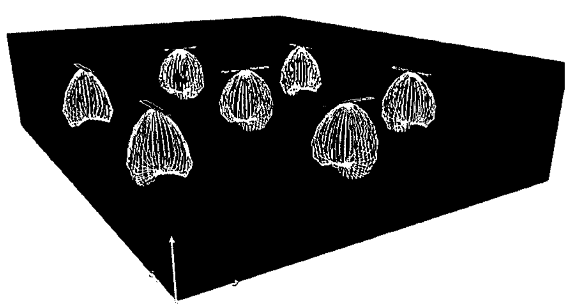
2.4 COMPUTER-AIDED DESIGN

Powerful lighting software programs are now readily available in market or from websites free (such as DiaLux). They can ease design checking against the relevant standards, provide a rapid appraisal of the overall visual environment at desktop level and allow performance assessment and validation of a fully operational scheme. They now become indispensable planning tools to the professionals, experienced or not alike. And they are useful for production of energy efficient schemes in new, upgrading or retrofitting works.

As a first step to plan lighting energy saving, computer modeling and simulation should be fully utilized by professional engineers to complement their field experience and basic concepts[2]. A cost effective design would normally minimize the numbers of lighting point and optimize the lighting layout, creating the correct visual environment with the right amount of lighting energy for the users. With inclusion of the maintenance factor in calculations, it is indeed inappropriate to produce a lighting design with unnecessary large safety margin.

A simple design layout for the under-bridge area (N484), shown in Figure 4, illustrates the power of software tool for calculation and visual presentation. With adoption of appropriate operation practices and latest energy efficient equipment, the design has saved 67% annual lighting energy following the scheme implementation, i.e. annual 6,480 kWh down to 2,160 kWh.

Figure 4 Light of N484 in 3-D Rendering



3. THE IMPORTANCE OF PROFESSIONALISM

Lighting is the field of discipline embracing art, science and technology of vision, photometry and colorimetry, involving application subjects covering all usage of light, environmental and aesthetic effects, means for control and production of light, etc. It has established its wide contribution in illumination on road safety, city beautification, evening leisure activities in concourse, etc. Professional practitioners are not only well-versed in these subjects knowledge, but they must also possess understanding in construction, materials and contract issues to ensure correct lighting in design and operation of the relevant applications.

Turning to today's energy saving challenge, public lighting professionals must be well-prepared to respond to market challenges and imperfections, ensuring lighting standard is met and energy efficient design is in place, minimising equipment life cycle cost from the outset and waste create in the longer term. They have a sober role to promote such messages to developers, consultants and contractors having involvement in public lighting works.

As the pace of technological innovation is startling, particularly the power and opto-electronic fields, it is important that practitioners keep abreast of the latest technological developments for approving, purchasing and adopting the most energy efficient equipment and services from the market. In fact, this is an essential part of life-long continuous professional development (CPD) for every responsible practitioner. With CPD, practitioners are not only better prepared to communicate with the general public on energy saving issue, but they are also more effective in their duties and knowledge succession.

It is imperative that all professional practitioners should take an active role in energy saving with all their skills and knowledge. For the sake of maximum energy saving, they must fully focus on the issue in their day-to-day work and challenge one another to hasten the widespread adoption of energy efficiency practice in their works.

4. LOOKING TO THE FUTURE

The growth in demand for public lighting in the SAR will likely continue in the years ahead. To sustain the current level of performance without a parallel growth in lighting energy consumption is a challenge to the public lighting professionals. Although current best operation and design practices will continue to be adhered and improved for all new and retrofitting schemes, evolving technology such as the super bright light emitting diode (LED) light with good efficacy performance could be adopted in the near future as and when appropriate. This is particularly suitable to applications requiring low lighting requirement, such as covered walkway illumination.

In the course of time, higher efficacy, lower cost, better performance, environmental friendly and more reliable lamp sources will continue to emerge in market. Likewise, this will happen for other energy efficient equipment such as luminaires, electronic control gear, dimmers, sensors, etc. With market forces and environmental pressures, more renewable energy lights will also likely emerge to join the quest for energy saving.

Latest new technologies in telecommunication and electronics have open a new era for management of public lighting. With arrival of the so-called 'Telemanagement System' for public lighting, it will likely bring more flexibility and better control on light demand and level at the right times and places. Other benefits may include cost saving on energy consumption, operation and maintenance effectiveness, field data acquisition and better environmental care. Coupled with current practices, it is not surprised to predict that energy saving at today's level of 20% or more may be achievable.

To tackle the rising costs of energy supply for public lighting, energy efficiency must have a high profile within the lighting sector and must involve all practitioners and the community alike as a cohort activity.

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Paper No. 5

ENERGY CONSERVATION - WHAT THE HOUSING AUTHORITY IS DOING WITH LIFTS AND ESCALATORS IN PUBLIC HOUSING ESTATES

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ABSTRACT

In 2003, Hong Kong Housing Authority (HKHA) decided to work with the industry to conduct a study on energy saving measures for its portfolio of lifts and escalators. This paper discusses the findings of the study, which was carried out by KONE Elevator (HK) Ltd. in collaboration with the City University of Hong Kong, on KONE's lifts and escalators in HKHA's public housing estates. Areas of study include optimization of lift counterweight balance setting, utilization of lift regenerative power, adoption of artificial intelligence based lift group control and alteration of escalator operation speed for energy saving. The findings are generally applicable to lifts and escalators of different makes. Arrangement is being made to put some of the findings into use on a larger scale with a view to yielding more data for ascertaining the viability of application and further development.

1. INTRODUCTION

The Hong Kong Housing Authority (HKHA) owns and manages around 5,000 units of lifts and escalators which consume more than 100 million kWh of electricity annually. A small reduction in the energy consumption of each unit could mean substantial cost saving and positive impact on the environment.

In 2003, KONE Elevator (HK) Ltd., in collaboration with the City University of Hong Kong, proposed to the HKHA a study on potential energy conservation measures for its portfolio of lifts and escalators. HKHA subsequently decided to provide the venue and part of the funding required for the study. Although the study was limited to KONE's equipment in HKHA's buildings, it was hoped that such action and the results of study would provoke interests of the lift and escalator industry in putting more resources and effort into similar areas of research.

The study was wide-ranging with focus on the following areas:

1. The relationship between counterweight balance setting and energy consumption of lift installation;
2. The amount of regenerative energy produced during normal lift operation;
3. Effect of applying artificial intelligence group control system on the energy consumption of a group of lifts;
4. Possibility of energy saving by altering the running speed of escalator; and
5. Possibility of energy saving by adoption of standby mode escalator operation.

2. STUDY 1 - LIFT COUNTERWEIGHT

During lift operation, electrical energy is consumed and converted to mechanical energy for lifting or lowering loads placed inside the lift car. To reduce the size of the traction machine, the counterweight, in general, is

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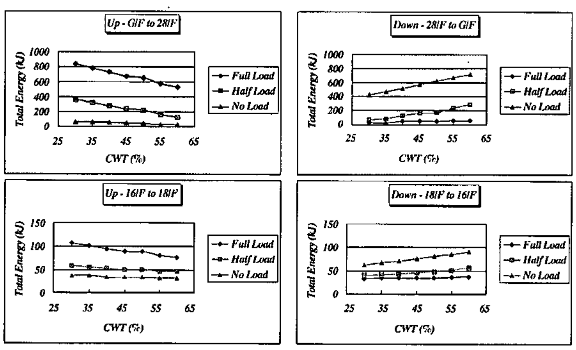
constructed to be heavier than the empty lift car by 40 ~ 50% of rated load. The selection of counterweight balance setting will affect the amount of energy consumed under different traffic and loading conditions. This study aims at investigating the effect of counterweight balance setting on the energy performance of lifts and the amount of energy that can be saved if the counterweight balance is set to an optimal value.

Two lifts (Lifts A and B) of the same group at 1,000kg capacity, 2.5m/s speed and 50% counterweight balance setting in an occupied public housing block were selected for the study. At the original counterweight balance setting of 50%, energy performance of the lifts was studied using dummy weight placed inside the lift cars. Measurements at full-load, half-load and no-load up and down trips for full travel and inter-floor travel were conducted. The counterweight setting was then altered between 30% and 60% at 5% interval for carrying out similar measurements. The energy consumption measured at each setting is summarized in Fig. 1 below.

Figure 1 Energy Consumption vs Counterweight Balance Settings



From Fig. 1, it can be observed that when the lift is moving upwards, increase in counterweight balance setting or decrease in load will reduce the energy consumption. On the contrary, when the lift is moving downwards, decrease in counterweight setting or increase in load will reduce the energy consumption. Hence, if the majority of traffic is "half-load to full-load up", energy saving can be achieved by adjusting the counterweight setting close to the upper limit (i.e. 60%). On the other hand, if the majority of traffic is "half-load to no-load down", energy saving can be achieved by adjusting the setting close to the lower limit (i.e. 30%).

Prior to the commencement of testing work, detailed checking on various lift equipment characteristics and calculations were conducted to ensure the lift system could operate safely under the selected range of counterweight balance setting. Furthermore, a thorough examination and full-load test was conducted by a Registered Lift Engineer to ensure that the lift equipment and all safety devices were in safe working order before release for testing.

After the energy consumption measurements at different fixed loads, the two lifts were released for use by residents for a 24-hour period at each counterweight setting from 30% to 60% with 5% interval. The time-stamped energy consumption, the distance travelled and the weight of passengers inside each lift car were recorded. The total energy consumption and kg-m value were recorded on a second-by-second basis within a 30-minute window and such window was shifted at 5-minute interval. Each particular window would be represented by its own set of accumulated energy and kg-m data.

A benchmarking parameter J/kg/m, which correlates the energy input with the passenger load and distance travelled, was developed to compare energy consumption of different lifts under different traffic and loading conditions. The definition of J/kg/m is shown in Fig. 2 while the sample measurement result is shown in Graph 1. It was found that the optimal counterweight balance setting for the two lifts under study is 35% and the overall energy saving was estimated to be over 13%.

Figure 2 Definition of J/kg/m

Definition of J/kg/m

- In Normal cases,

$$\text{J/kg/m at time } t = \left. \frac{\text{Total Energy used within} \pm 15 \text{ minutes(J)}}{\Sigma \, [\, \text{Load}_i \text{ (kg)} \times \text{Travel Distance}_i \text{ (m)} \,]} \right|_{\textit{Full Trips within} \pm 15 \textit{ min.}}$$

* For *No-Load trip* (i.e. the Load of the trip equals to 0 kg , measured load less than 10kg), $\text{Load}_i \text{ (kg)} \times \text{Travel Distance}_i \text{ (m)} = 1 \text{ kg . m}$

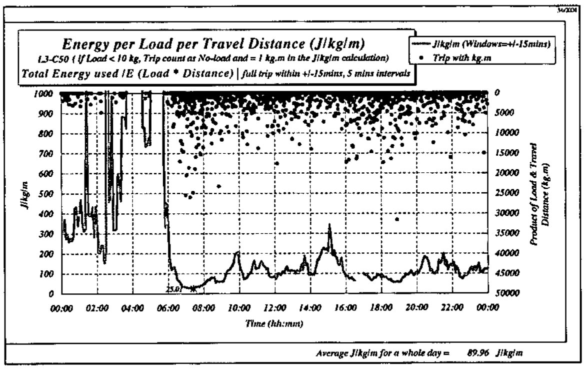
- However, if there is *No trip occur* within the time interval, then the calculating method will be changed to:

$$\text{J/kg/m at time } t = \frac{\text{Total Energy used within} \pm 15 \text{ minutes (J)}}{1 \text{ kg . m}}$$

- *Average J/kg/m within 1 day* will be calculated as:

$$\text{Average J/kg/m} = \left. \frac{\text{Total Energy used within 1 day (J)}}{\Sigma \, [\, \text{Load}_i \text{ (kg)} \times \text{Travel Distance}_i \text{ (m)} \,]} \right|_{\textit{Full Trips within 1 day}}$$

Graph 1 J/kg/m Value for Lift A at 50% Counterweight Balance Setting



3. STUDY 2 - LIFT REGENERATIVE ENERGY

Lift motor inherently regenerates energy during operation, but few studies have ever been conducted on its significance. A study was therefore carried out to investigate the magnitude of regenerative energy produced by different lift systems used in public housing estates. The study covered almost all types of lift motor drives in use, including:

1. DC Ward-Leonard drive (DC WL);
2. DC Thyristor-Leonard drive (DC TL);
3. AC two speed drive (AC-2);
4. AC variable voltage drive (ACVV);
5. AC variable voltage variable frequency drive (ACV^3F)
6. AC variable voltage variable frequency drive with modulated line bridging device (ACV^3F-MLB).

For each type of drive, power was measured during full-load, half-load and no-load up and down trips. It could be observed that for all types of lift motor drives, a large portion of power was consumed during "full-load up" and "no-load down" trips. For the "full-load down" and "no-load up" trips, negative power was obtained. This implied that power was regenerated from the motor in these cases. Although negative power was recorded for all drive types, the magnitude varied from 16% to 52% of the rated motor power.

4. STUDY 3 - ARTIFICIAL INTELLIGENCE GROUP CONTROL

Artificial intelligence group control (AI) system finds lots of application in lift groups installed in commercial and office buildings. The AI system handles traffic by allocating efficiently the lift cars in response to registered car calls and landing calls. However, such system is not commonly applied in residential buildings in Hong Kong. This study aims at investigating the feasibility of reducing lift energy consumption through application of AI system.

In this study, two lifts forming a group to serve the mid-zone floors of a domestic block were involved. The study was conducted in three stages. In the first stage, the lifts were opened for use by residents for a 24-hour period without any AI system being applied. For each lift, the time-stamped energy consumption, the distance travelled and the weight of passengers inside the lift car were recorded.

In the second and third stages, two types of genetic algorithm based AI systems, namely Genetic Allocation System (GENE System) and Multi-target Optimization System (MTO System), were applied in turn to the lift group, and data were collected in the same way as the first stage. The GENE System is a conventional AI system designed for minimizing the average waiting time, while the MTO System is a new AI system designed for minimizing energy consumption of a lift group.

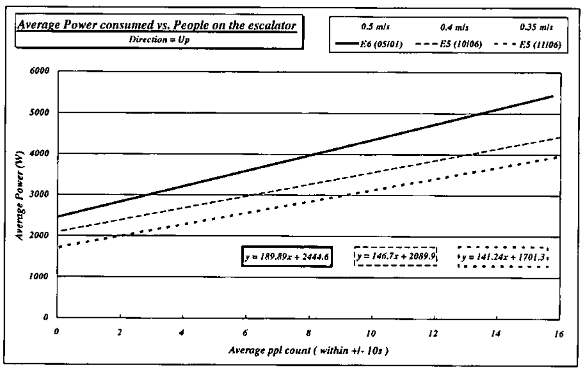
The total energy consumption and kg-m value measured were used for comparison purpose. It was noticed that the energy performance of the lift group was improved after application of the AI systems. The GENE System and MTO System could save about 14% and 16% energy respectively.

5. STUDY 4 - ALTERING ESCALATOR RUNNING SPEED

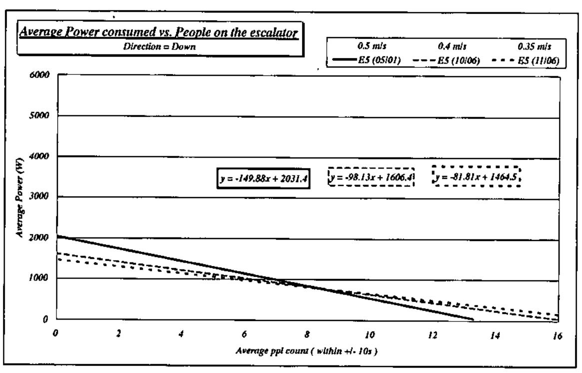
Two units of escalators were studied to find out whether energy consumption can be reduced by altering their running speeds. Power consumption of these escalators at different running speeds in both up and down directions with no load were measured. The results confirmed that escalators consumed more power when the running speed was increased. The relationship was nearly linear. It was concluded that, when there was no passenger, energy could be saved at a lower speed. However, lower running speed will reduce the passenger conveying efficiency. The passengers may walk or even run on reduced speed escalator, and this in turn creates safety problem.

After the no load measurements, the escalators were released for use by the public and similar measurements were conducted and recorded in Graphs 2 and 3.

Graph 2 Average Power Consumption vs No. of Passengers (Up Direction)



Graph 3 Average Power Consumption vs No. of Passengers (Down Direction)



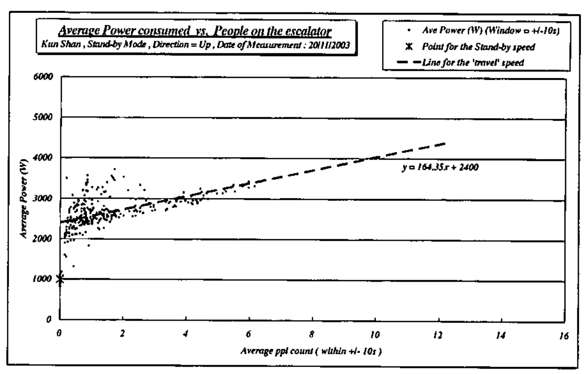
From Graph 2, it could be seen that the power consumption of the escalator was directly proportional to the number of passengers when the unit was running upwards. Besides, power consumption was reduced for lower running speeds with the same number of passengers. However, it took longer for the escalator to bring the passengers to another level when operating at lower speed and this offset the effect of lower power consumption.

Graph 3 showed the opposite trend. When the escalator was running downwards, the energy consumption would be inversely proportional to the number of passengers. The lines for higher running speeds had greater negative slopes, and the three lines met at a point corresponding to 8 passengers. Therefore, for down moving escalator, power consumption could be reduced at a lower speed only when there were less than eight passengers. But this would again be offset by the longer time required to bring the passengers to the lower level.

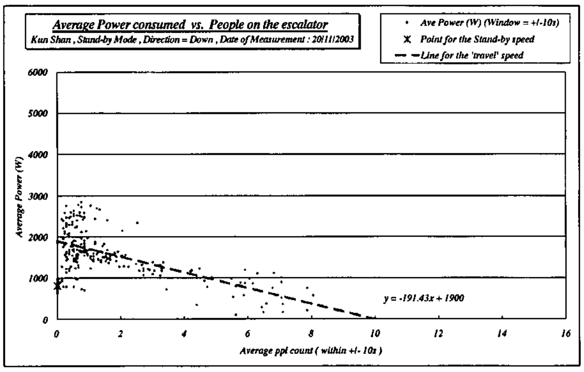
6. STUDY 5 - STANDBY MODE ESCALATOR OPERATION

One unit of escalator was studied to find out whether energy consumption of an escalator can be reduced by using standby mode operation. The escalator operated at a standby speed of 0.25m/s when there was no passenger and would accelerate gradually to the rated speed of 0.5m/s when passenger was detected. Power consumption of the escalator in both up and down directions were measured and recorded in Graphs 4 and 5. The points marked on the y-axis of the graphs represented the performance of the escalator at standby speed, while the line represented the performance at rated speed. It was obvious that less power was consumed under the standby mode operation.

Graph 4 Average Power Consumption vs No. of Passengers (Up Direction)



Graph 5 Average Power Consumption vs No. of Passengers (Down Direction)



7. APPLICABILITY OF FINDINGS

In the first study, different lift counterweight balance settings between 30% and 60% were tested but it was found that there was no universal optimal setting. The optimal counterweight setting depends very much on the passenger traffic pattern. Since every building has its unique traffic pattern, the optimal setting will vary from one lift to another and from building to building. It is essential that a computer model be developed to simplify the optimization process, which may be required from time to time due to variation of the traffic pattern over time.

With the advent of computer software for the evaluation of lift energy consumption at different counterweight balance settings and passenger traffic patterns, the HKHA would embark on optimizing the counterweight balance settings for a larger number of installed lifts for which manufacturer's energy consumption evaluation software is available in order to ascertain the viability and potential of such approach.

The second study showed that power was regenerated from a running lift under either a light load or no load condition for the up trips or a heavy load or full load condition for the down trips. The amount of energy regenerated varied from one drive type to another and not all drive types used in public housing estates could produce sufficient regenerative power for reuse. Further research is necessary to develop a universal machine to tap regenerative power off different lift drives and remove the undesirable harmonic contents for reuse.

The findings of the third study regarding artificial intelligence group control systems lead to the conclusion that energy performance of lift installations can be improved when such kind of system is incorporated into the supervisory control for a group of lifts.

The fourth study on escalators running continuously at lower speed revealed that energy could be saved when there was no passenger but passenger flow was affected particularly when traffic was at its peak. During the study, many passengers simply walked up or down the escalators to make up for the lower running speed and this might lead to safety problem. Such mode of operation is therefore considered not suitable for application.

For the fifth study on standby mode escalator operation, it was found that less energy was consumed at the standby speed when there was no passenger and some additional energy was consumed at the acceleration period. Compared with escalators running continuously at lower speed, the standby mode operation is preferred. However, if an escalator is used frequently, it shall be operated continuously at the rated speed. Standby mode with the escalator coming to a standstill is not considered in the study due to the lack of indication of the travelling direction before the escalator is re-activated.

8. CONCLUSION

According to the findings of the studies on lift installations, it is concluded that alteration of counterweight balance setting is the fastest and most cost effective approach to reduce energy consumption for existing lifts. However, it is essential that lift manufacturers are prepared to develop computer software for the estimation of energy consumption of their own lifts under different counterweight balance settings and traffic conditions so that wider application can be pursued.

For newly installed lifts, three approaches should be adopted at the same time, i.e. optimization of counterweight balance setting, utilization of regenerative energy as well as the implementation of artificial intelligence based group control. The possibility of implementing these approaches would of course depends on whether the required hardware and software have been developed by the lift manufacturers concerned.

For newly installed escalators with significant peak and non-peak passenger traffic, the use of standby mode operation is recommended to save energy. Furthermore, a low-speed standby mode is recommended to enhance passenger safety instead of a total standstill standby mode. To modify existing escalators for standby mode operation, the high cost of modification has to be justified.

Besides the aforesaid findings, the studies led to the development of a benchmarking parameter, J/kg/m, which correlated the energy input to a lift with the passenger load and distance travelled. This parameter provides a direct comparison between the energy performance of different lifts by taking into account not just the energy consumed, but also the passenger traffic and loading they have handled.

Because of the limitation of time and other resources, the sample sizes taken in the study may not be sufficient to provide results with high accuracy. If more measurements had been taken for longer periods, the accuracy of the results could be improved. Although we are unable to put every bit of the findings to immediate use, the study has given us an insight that opportunities do exist in lift and escalator operations to save energy in substantial magnitude. With the concerted effort of lift and escalator manufacturers to apply the findings on a larger scale, more data could be yielded for ascertaining the viability of application and further development.

9. ACKNOWLEDGEMENT

We would like to express our thanks to Ir S.C. Leung and other staff of the Hong Kong Housing Authority, and the joint research team of the City University of Hong Kong, KONE Elevator Ltd. and KONE Elevator (HK) Ltd. who have provided valuable support to the studies. Without their contributions and dedicated effort, it would not be possible for the studies to come to fruition.

NOMENCLATURE

kg-m — The product of passenger load times the distance travelled

J/kg/m — The energy input to carry 1kg passenger load for a distance of 1m

REFERENCE

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Paper No. 6

FROM INNOVATION TO IMPLEMENTATION - ENHANCEMENT OF ELECTRICITY SUPPLY IN A METROPOLITAN CITY

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East Region
Mr K.Y. Fung, Electrical Testing & Workshop Manager
Technical Services Department
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Safety, Health, Environment & Quality Department
CLP Power Hong Kong Ltd.

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Paper No. 6

ABSTRACT

A highly reliable electricity supply is essential to a world class metropolitan city like Hong Kong. CLP Power serves 6 million people in Kowloon, the New Territories, Lantau and most of the outlaying islands of Hong Kong. Its reliability has improved by 68% over the past seven years. This achievement comes as a result of an ongoing commitment to innovation at all levels of the Company.

CLP Power's commitment to innovation includes: (i) encouraging in-house innovative solutions development, (ii) reviewing world-wide innovative best practices and introducing them to the Company, (iii) combining tools, technologies and processes in innovative ways, and (iv) providing a knowledge management platform for knowledge archiving, transferring and development.

In this paper, three of the innovations developed in the recent years will be discussed:-

a. Condition Monitoring and Assessment of Silicone Fluid-filled Transformers

b. Automatic Fault Location System for 11kV Overhead Line

c. Transmission Overhead Line Monitoring and Insulator Cleaning System

1. INTRODUCTION

CLP Power Hong Kong Limited (CLP Power) is the principal subsidiary of CLP Holdings. It is a regulated, vertically integrated electricity business involving generation, transmission, distribution and customer services.

CLP Power has served the territory for more than a century, and has developed hand-in-hand with Hong Kong's dynamic economy, meeting the territory's increasing demand for electricity and providing the power vital for Hong Kong's transformation from a small port to one of the world's most highly developed service economies.

A critical factor in CLP Power's success is its ability to ensure a high level of supply reliability to our two million-plus customers. According to a survey conducted by the Chinese University of Hong Kong (Survey of the Cost Competitiveness of Hong Kong Businesses - October 2004), business executives considered reliability of electricity supply one of the top four factors for success of businesses in Hong Kong.

CLP Power delivers electricity via an extensive network with over 12,300km of overhead lines and underground cables, and 12,600 substations. CLP Power's supply reliability is over 99.99%. In order to achieve and maintain the world-class supply reliability level, the Company has applied innovations from all levels to ensure electricity can be delivered to customers through the transmission and distribution networks. Some innovations on the improvement in overhead line network and transformer reliability are discussed in the paper.

2. CONDITION MONITORING & ASSESSMENT OF SILICONE FLUID-FILLED TRANSFORMERS

2.1 BACKGROUND

Power transformers are key elements for maintaining reliable supply to the customers. Effective condition monitoring, assessment and diagnostic techniques are therefore required to identify potential problems at an early stage for just-in-time maintenance or corrective repair.

With numerous successful cases in identifying incipient faults in mineral oil-filled transformers by applying dissolved gas-in-oil analysis (DGA)[1][2], there is a strong desire to extend this technique to evaluate the conditions of 6,500 units of silicone fluid-filled distribution transformers in the system. As there is no international standard for assessing this type of transformer, an in-house project was thus initiated in 2003.

2.2 APPROACH

To simulate the fault conditions, a test chamber of 1.6m L x 0.5m W x 1.0m H is used as the replica of a transformer. For the simulation of a thermal fault, a high current is injected to the simulated fault point that a hot spot at a copper wire is created by drilling a hole on the wire to reduce the cross section area. The hole is also used to embed a thermal couple to measure the temperature at the hot spot. The temperature is controlled by adjusting the magnitude of the current injected. Tests are simulated at various temperature values in the ranges of 200°C to 1,000°C and the fluid samples are taken in each case.

Another simulation is for discharge faults that are defined as the passage of an arc following the breakdown of the insulation. In this set up, high voltage is supplied to a spark gap. The voltage is adjusted to maintain an arc at the spark gap. Fluid samples are taken for DGA at a constant time interval.

2.3 FAULT MODEL DEVELOPMENT

Various methods were examined in order to find out the simplest way to interpret the dissolved gas composition, in term of fault nature. Based on our testing data, three key gas ratios (CO/H_2, C_2H_2/H_2 and H_2/CH_4) are adopted to predict the types of fault as they show obvious different values for different types of fault. The test data are plotted in Fig.1 and Fig.2 to show the differences graphically.

Figure 1 Test Results in Different Gas Ratio Planes

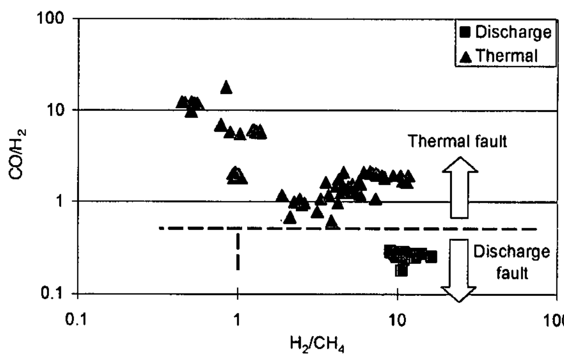
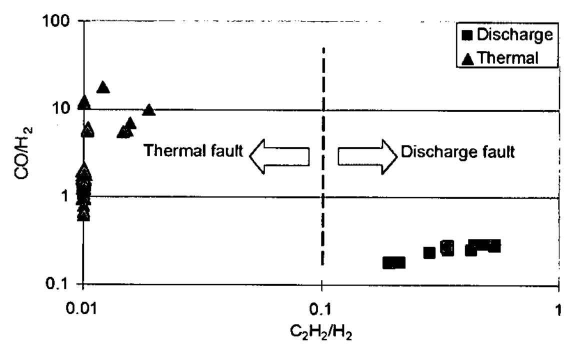


Figure 2 Test Results in Different Gas Ratio Phases



Some boundaries are defined in the charts to distinguish the two types of fault with following conclusions:

For Discharge fault:

$$(C_2H_2/H_2) > 0.1 \quad (1)$$

$$(CO/H_2) < 0.4 \quad (2)$$

$$(H_2/CH_4) > 1 \quad (3)$$

SIEMENS

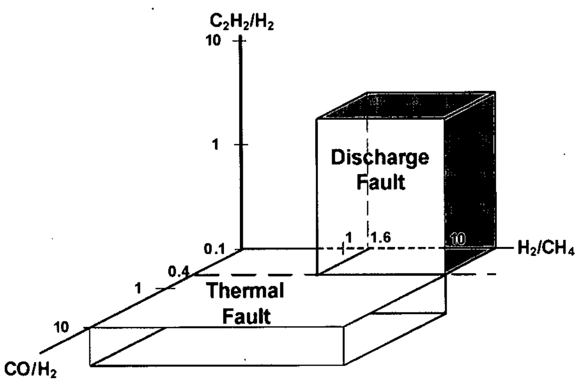
For Thermal faults:

$$(C_2H_2/H_2) < 0.1 \quad (4)$$

$$(CO/H_2) > 0.4 \quad (5)$$

Based on the above criteria, the fault model can be developed and presented in a 3-dimensional graph as shown below:

Figure 3 Fault Model Presenting in 3-Dimensional Graph



2.4 APPLICATION & PERFORMANCE

After the development of fault model, oil samples were collected from the transformers in the system for analysis. The programme scheduled to sample 4,500 units of transformers in 2004-2005 and the remaining 2,000 units in 2006.

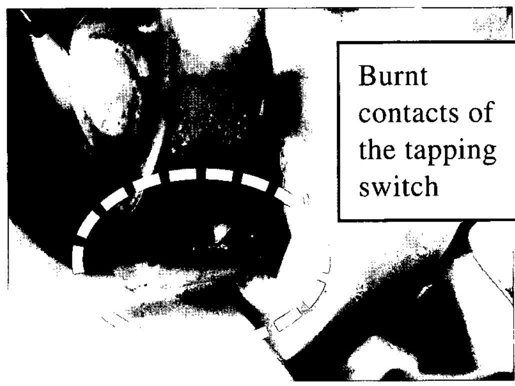
Some samples were found having dissolved gases exceeding the threshold limits. With the fault models, some of the transformers were considered to have incipient internal faults developed inside the transformers. These transformers were eventually decommissioned for internal inspections. The following two cases illustrate the effectiveness of the fault model in condition assessment.

<u>Case 1</u>: A 1.5MVA transformer was found having abnormal gases as shown below:

Dissolved Gases / ppm						
H_2	CH_4	CO	CO_2	C_2H_4	C_2H_6	C_2H_2
906	250	351	7356	41	8	633

According to the fault model, a discharge fault was suspected. Investigations revealed that the off-load tap-changer contact of the yellow-blue phase HV winding became almost open-circuited. The fixed contact of the tapping switch was found seriously burnt, probably due to prolonged discharges occurred at the contact, as shown in Fig. 4.

Figure 4 Faulty Off-load Tapping Switch

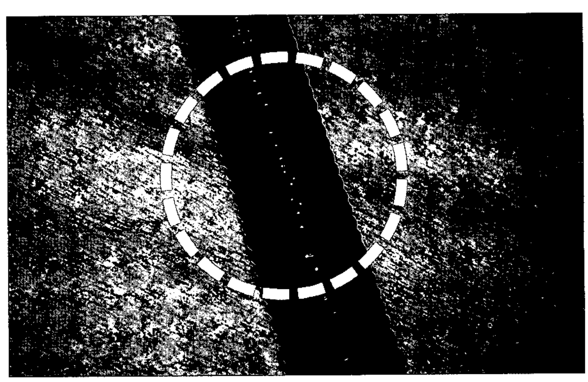


<u>Case 2</u>: Another 1.5MVA transformer displayed abnormal dissolved gas contents as shown in the following table.

Dissolved Gases / ppm						
H_2	CH_4	CO	CO_2	C_2H_4	C_2H_6	C_2H_2
228	121	1206	42236	11	10	0

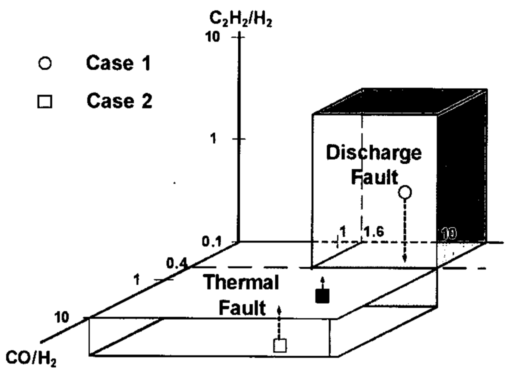
According to the fault model, a thermal fault was suspected. The transformer core was found scratched by the tie-rods and became short-circuited with them. The transformer core was thus having multiple earth-faults causing circulating current in the core. The circulating current created hot spots at the short-circuit points leading to thermal overheating.

Figure 5 Short Circuit of Core with Tie-rod



The DGA results of the above two cases are plotted in the established fault model for verification:

Figure 6 Verification of Faulty Cases in Fault Model



It is proved that the fault natures of the above two cases match with the developed fault model.

3. AUTOMATIC FAULT LOCATION SYSTEM FOR 11KV OVERHEAD LINE

3.1 BACKGROUND

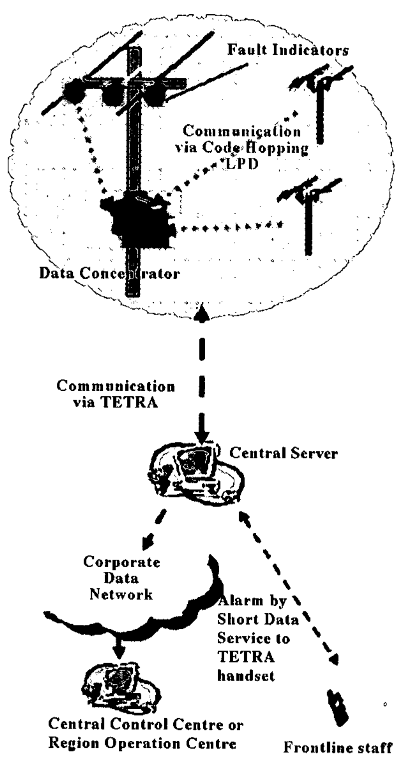
Electricity supply for customers living in rural areas is mainly delivered through 11kV overhead line (OHL) network. These OHLs are susceptible to adverse weather conditions such as lightning strikes or tree branches falling on the line. Upon an OHL fault, the Emergency Services Team will be called out for post-fault line patrol and visually identify the fault location at site before the faulty section can be isolated for repair. However, the line patrol process is time consuming and potentially dangerous to the staff as the task is usually carried out in bad weather and during night time in rugged terrain. In order to shorten the time for supply restoration and reduce the risk involved, the Automatic Fault Location System (AFLS), one of CLP Power's patented systems, was proposed to provide an automated way to simplify the process intelligently.

3.2 DESIGN

The fundamental design of AFLS is to eliminate the need of patrolling the entire line. Originally, the OHL is equipped with a fault detection indicator to detect OHL fault and send out visible alarm signal - flashing light, to the Emergency Service Team at site. Therefore, the most straight-forward and practical solution is to pass this alarm signal to the system control engineers, allowing them to take prompt decision and action for supply restoration.

With this in mind, the design of AFLS was finalized and the system diagram is shown below. When the fault indicators detect an OHL fault, the alarm signal will be passed to the signal concentrator through a short-distance 315MHz wireless low power device. The signal concentrator will then pass the alarm to the AFLS central server through CLP Power's in-house TETRA radio system. Finally the central server will process the data and deliver them to System Control Centre and regional operation centre for their further actions.

Figure 7 Block Diagram of AFLS



3.3 DEVELOPMENT AND CHALLENGES

The final design is simple at a glance, but five major challenges were encountered during the development stage. The first one is to transmit the alarm signal from the fault indicator to the nearby data concentrator. Having considered the development costs and data security of various wireless communication technologies, a compact sized wireless transmitter module adopting the code-hopping technology was developed. This code-hopping technology enables the data to be encoded in more than 7 billion coding combinations to assure the data security. Also, the equipment type-approval was granted by OFTA for the in-house developed transmitter.

The second challenge is the data communication between the data concentrators and the AFLS central server. TETRA radio system, CLP Power's in-house infrastructure, is employed. The distinct advantages of TETRA include low development and operating costs, yet provide a dedicated channel for reliable data communication under all weather conditions.

Concerning the physical outdoor condition where the data concentrator operates, the cubicle is designed to be water and dust resistant and comply with international standards. An in-house designed mounting structure was approved by chartered structural engineer and confirmed that the cubicle is structurally safe to be mounted on the OHL pole even under typhoon conditions.

Furthermore, high efficiency multi-crystal solar panels are utilized to supply reliable and environmental friendly energy for running the equipment in outdoor conditions. Together with the seal-type battery, the power delivered to the cubicle can cater for 10 consecutive days without any sunshine. The design criterion of 10 days is acquired through the comprehensive research on the past 40 years' HK Observatory historical data.

System integration is the final challenge to the entire development. The software protocol is in-house designed to remotely monitor the cubicle data such as the solar panel voltage, the battery voltage, the solar charging condition and the ambient temperature through the tailor-designed man machine interface (MMI). The data are also collected and stored in the central server for system continuous improvement and further development.

3.4 RESULT AND ACHIEVEMENT

Having overcome the major obstacles described above, the AFLS has been successfully implemented and in service since the summer of 2003. In the subsequent typhoon seasons, the system soon demonstrated its incredible value in automating the post-fault line patrol process and eliminating the risk associated with the line patrol under adverse weather conditions, thus enhancing the power supply reliability.

In April 2004, Patent was granted by the Intellectual Property Department to the system design and equipment of AFLS and this is also the third patented system of CLP Power.

4. TRANSMISSION OVERHEAD LINE MONITORING AND INSULATOR CLEANING SYSTEM

4.1 BACKGROUND

In CLP Power, 132kV and 400kV OHL towers are located in hilly areas and are subjected to all kinds of environmental contamination nearby. The insulation levels of OHL insulators are weakened at some locations where the degree of pollution is high. These result in discharge from the insulator surfaces and even tripping of the circuit involved, causing concerns on system security and power quality.

Due to remoteness of the OHL towers, it is very difficult and inefficient for staff to manually monitor the condition of the insulators. An automatic on-line system is therefore required for continuous monitoring and alarm triggering before failure of insulators begins.

4.2 DESIGN

To keep acquiring information on condition of the insulators, and realize on-line monitoring on the integrity of the power lines, a *Transmission Overhead Line Monitoring and Insulator Cleaning System (the System)* is designed.

The components of the System include the followings:

Noise Level Acquisition

As the noise level generated from corona discharge on contaminated insulators can be regarded as an indicator of cleanliness of insulators, a noise sensor (directional microphone) is installed in the System directionally to the insulators to acquire the noise level information.

Humidity Acquisition

Since the ambient noise interferes with the noise generated from corona discharge which may lead to unwanted false alarm, an additional parameter on relative humidity is required for the System to determine whether a warning message is to be initiated.

Solar Cells, Batteries and Battery Charger

The locations of transmission OHL are remote and usually there is no low voltage power supply available at site. To resolve this issue, a local power supply system consisting of rechargeable batteries and solar panels is adopted. The solar panels charge up the batteries during sunny periods and the energy in batteries is drawn during darkness. Even if no solar energy is gained, the system can still be continuously operating for at least 10 days.

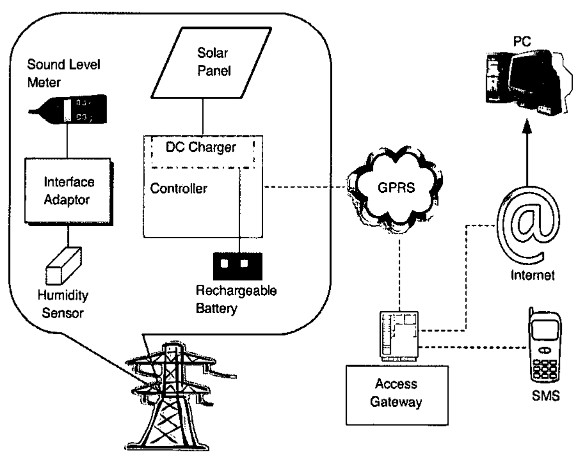
Voltage detection

To ensure the availability of power supply to the System, information on voltage level of the power supply is also captured. An alarm will be initiated if the detected voltage signal is below a preset level.

Communication

To enhance the reliability and accessibility of communication channel, GPRS (General Packet Radio Service) network, a high speed mobile data service available to users of GSM mobile phones, is adopted as the medium of wireless information flow. The coverage of GPRS is as large as GSM, which is a crucial factor for application on OHL. SIM card, modem and emitter are installed in the System so that the digital information, which is converted with a multi-channel Analog-to-Digital Converter, can be transmitted over GPRS network and put on the website with 5-minute intervals. The GPRS adopted is a 2.5G mobile data service with uploading speed of 21kbps[3]. Authorized personnel can view the status of the OHL on the internet. In order to alert engineers about the discharge of insulators, SMS of warning signal, detailing the location of problematic lines, will be sent out.

Figure 8 Block Diagram of Transmission Overhead Line Monitoring and Insulator Cleaning System



Insulator Cleaning

After receiving an alarm signal via SMS, the responsible engineer can arrange insulator cleaning. High-pressure water hoses are pre-installed at suitable positions in OHL poles and towers. Through the water hose, pressurized water is injected by a portable water pump at ground level to conduct insulator cleaning. Small volume of water is enough to restore the insulation level.

4.3 RESULTS AND ACHIEVEMENT

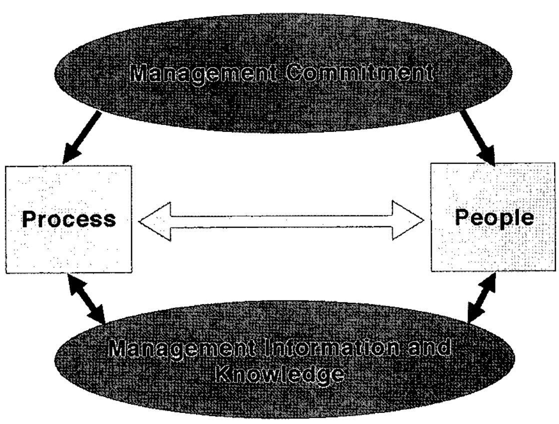
The ambient environment varies from time to time. The traditional way of a time-based fixed-interval maintenance strategy may not be able to maintain the condition of the OHL at an optimum level at all times. There were cases where the conditions of insulators deteriorated dramatically within a short period due to unexpected contaminations or pollutions.

Having adopted the system, we can realize real-time condition monitoring which is an effective way to detect corona discharge across insulators and prevent flashover. In this way, there is no need to check the condition of the insulators manually from time to time, resulting in improvement in resources utilization, supply reliability and power quality.

5. INNOVATIVE CULTURE IN CLP POWER

CLP Power's demonstrated willingness and ability to embrace new techniques, acquire new skills and develop award-winning innovations are the best testament to the vitality of the Company's culture of innovation. This is illustrated in the Innovation Management Model.

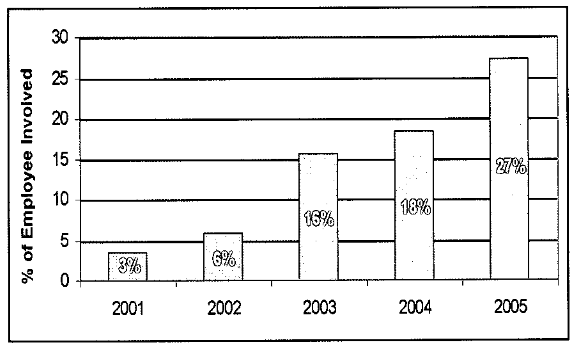
Figure 9 CLP Power's Innovation Management Model



Management Commitment: As outlined above, top management drives the Company's innovation culture. Management deploys and communicates innovation-driven service enhancement strategies to all levels through the Safety, Health, Environment and Quality Steering Committee.

People: Annual training programmes and performance reviews develop and assess the creative attitude of all employees. Innovative ideas and their originators are recognised and rewarded. The percentage of staff participated in innovation project has grown from 3% to 27% in 5 years.

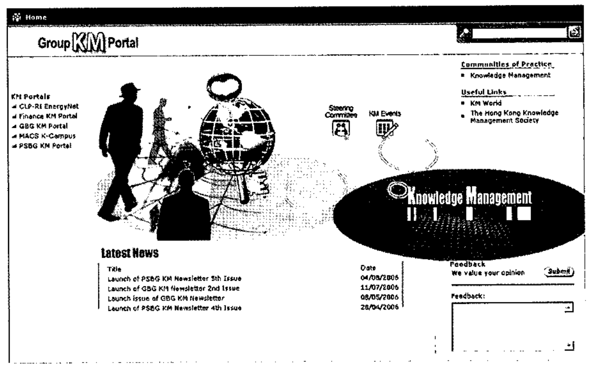
Figure 10 Growth in Percentage of Employee Participation



Process: QCC workgroups formed by frontline staff tackle research and development issues. New ideas generated from the frontline staff are prioritized, selected for further testing or pilot runs, and implemented if successful. Outstanding projects will be demonstrated in the annual QCC Convention.

Management Information and Knowledge: Experience and information is shared through the Company's intranet and at annual Innovation Seminars, Conventions and Knowledge Management Portal.

Figure 11 CLP Power Knowledge Management Portal



6. CONCLUSION

Provision of a reliable electricity supply has become indispensable to a metropolitan city, and Hong Kong is no exception.

By embracing innovations throughout the organization, CLP Power has managed to consistently enhance the reliability of electricity supply by minimizing unplanned outages and dramatically improving response time when outages do occur. The Company's drive to enhance the competitive edge through innovation, as demonstrated by the 3 projects discussed in the paper, enhances Hong Kong's overall competitiveness.

7. ACKNOWLEDGEMENT

The authors would like to thank the management of CLP Power for the support and permission to publish this paper.

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Paper No. 7

IMPROVEMENT OF POWER QUALITY AND EQUIPMENT RELIABILITY BY CONTROLLED SWITCHING OF GAS CIRCUIT BREAKERS

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IMPROVEMENT OF POWER QUALITY AND EQUIPMENT RELIABILITY BY CONTROLLED SWITCHING OF GAS CIRCUIT BREAKERS

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ABSTRACT

Circuit breaker operating characteristics are investigated in the point of operating condition dependence such as ambient temperature, control voltage and operation history for application of controlled switching. Though hydraulic operated circuit breaker shows clear closing time dependence on idle time, spring operated circuit breaker have few dependence. It is also confirmed that adaptive control based on past operation results can significantly improve control accuracy. Field experience with the latest controlled switching system clearly show its advantage in reducing switching transients at application for shunt reactor switching.

Novel controlled switching technology for transformer taking into account a residual flux in transformer cores has been developed and applied to the practical field. Drastic reduction of inrush current and voltage disturbance in no-load transformer energization is described with satisfactory compensation of operating time dependence on operating condition and idle time.

1. INTRODUCTION

Switching of circuit breaker can generate high overvoltage or inrush current, which can give severe electrical or mechanical stress to HV equipment, disturbance of system voltage or mal-operation of secondary system. Controlled switching systems for gas circuit breakers have become an economical solution and commonly applied to reduce switching transients. Since the late 1990's, the number of installations has increased rapidly due to satisfactory service experience with more than 2000 units in operation as of 2001[1].

Since CSS requires accurate operation consistency, it is important to compensate for variations of the circuit breaker operating times under various operating condition. Recent research by CIGRE WG A3.07 also reveals that some hydraulic operated mechanisms generate a considerable delay of the closing time after every few hours of idle time and to be compensated even for daily-operated system[1]. Load conditions such as residual flux in transformer core are also important to reduce switching transients thus to be considered in controlled switching.

This paper will present the latest technology of CSS concerning with the parameters above and reduction of switching surges with several service experience including shunt reactor switching in Hong Kong. Newly developed CSS for no-load transformer switching taking into account a residual flux in iron core is also presented with its successful field evaluation results.

2. COMPENSATION OF CB OPERATION

As well known, operation time of circuit breakers varies depending on operating condition such as ambient temperature, control voltage, hydraulic or pneumatic pressure[2][3]. It also depends on past operations, because wearing of the parts with a number of operation can cause operating time variation. Idle time, which means a time interval between the last operation to the next operation, can give impact of some types of circuit breaker according to condition of lubricant or hydraulic medium.

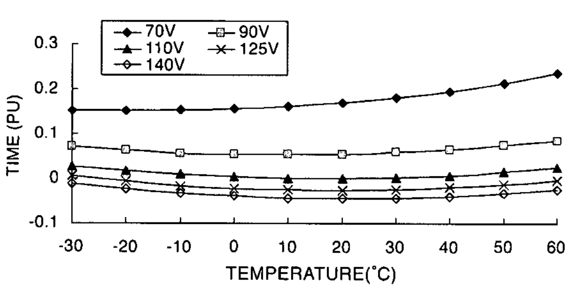
Because a controlled switching system has an algorithm to predict operation time of circuit breaker, it is necessary to evaluate its operating time dependence on these parameters above.

2.1 DEPENDENCE ON OPERATING CONDITION

GCBs are designed using several sliding parts such as contacts and sliding seal rubbing between metal surfaces during close and open operations. Therefore, operating characteristics are affected by the change of friction due to ambient temperature variation. GCBs also have electro-magnetic plungers as operation trigger, so operating time varies according to change in control voltage or resistance as a function of temperature. In case of hydraulic or pneumatic operated GCBs, operating time change according to pressure variation, too.

Figure 1 shows an example of closing time dependence on ambient temperature and control voltage of 275kV spring operated GCB. The dependence can be compensated by synchronous switching controller installed the characteristics, which was obtained at factory or field tests. The data show that voltage and temperature are not independent parameters for the GCB.

Figure 1 Closing Time Dependence on Ambient Temperature



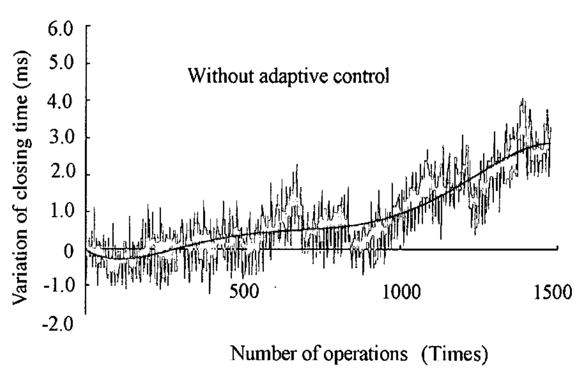
2.2 DEPENDENCE ON OPERATION HISTORY

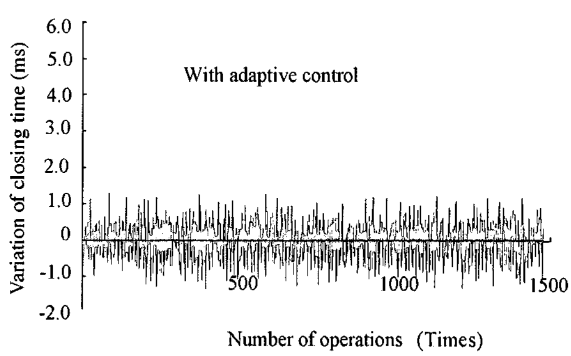
2.2.1 DRIFTS CAUSED BY THE NUMBER OF OPERATIONS

Friction or sticking force on the surfaces of sliding parts can also vary due to long term aging and wear. As the change will progress considerably slowly, the adaptive control can effectively compensate for the drifts of operating time caused by the consecutive operations.

Figure 2 shows the typical drift of the closing time measured with and without adaptive control over 1500 operations of a 121kV spring operated GCB. The variation of the closing time is given by the difference between the predicted closing time and the result. Although the closing time becomes longer with the increase in the number of operations, the closing time could be effectively compensated with good accuracy by the adaptive control. The width of variation was decreased from +4.1/-1.2 ms to +1.2/-1.2 ms.

Figure 2 Drift of Closing Time Observed without Adaptive Control can be Effectively Compensated with Adaptive Control





2.2.2 DELAY AFTER LONG IDLE TIME

The friction force between sliding parts varies with the change of the properties of the lubricant due to long-term operation in the field. This is one reason for the change of the operating time after a certain idle time. Another reason for the delay in hydraulic drives is ascribed to the dissolved air in the hydraulic fluid that can appear as bubbles when a pressure is released during operation. The bubbles in hydraulic fluid may delay the response of hydraulic piston movement at the next operation. Figure 3 shows an example of the closing time delay of 204kV hydraulic operated GCB[2].

Compared with a hydraulic mechanism, a spring operating mechanism designed to minimize the friction shows relatively small idle time dependence. Figure 4 shows the idle time dependence of a 145kV spring operated GCB. The spring operating mechanism applied to this breaker has a lubricating coating on its main sliding parts and has significantly small idle time dependence up to 1000 hours. Therefore, idle time compensation is not required when the CSS with this spring operated mechanism is used for daily-operated switching of a capacitor bank.

As the drives, of which operating times have idle time dependence, show the increase of the closing time after at least several ten hours, a requirement of idle time compensation can be judged from a measurement up to 100 hours.

Figure 3 Closing Time Dependence on Idle Time (204kV Hydraulic Operated GCB)

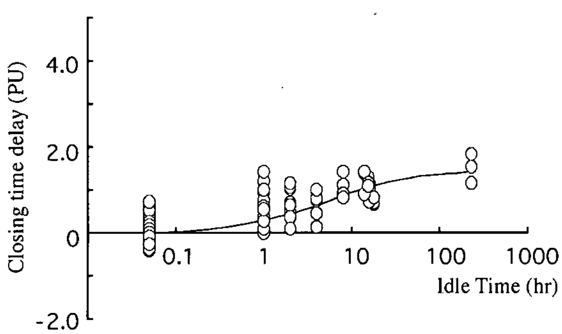
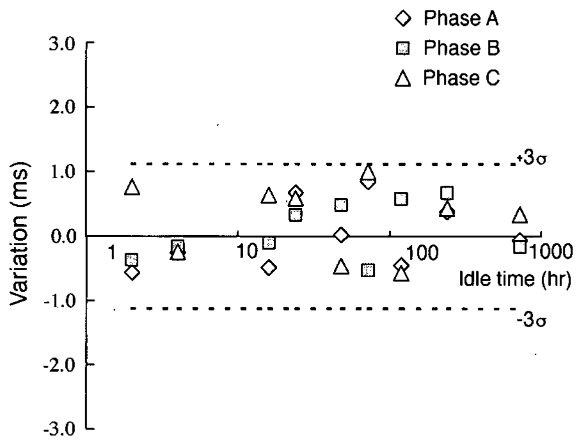


Figure 4 Closing Time Dependence on Idle Time (275kV Spring Operated GCB)



3. APPLICATION TO REACTOR SWITCHING

Load current of shunt reactor is typically up to several hundreds amperes, so GCBs can interrupt it thermally at its zero point even in the case that contact gap is very short. When the current is interrupted in very short gap, re-ignition by steep TRV will occur and high frequency and amplitude of re-ignition overvoltage will appear in the circuit. The overvoltage can give damages to shunt reactor windings or secondary systems, so it has to be eliminated.

On the other hand, energization of shunt reactor having iron cores can generate high inrush current, which can cause significant voltage disturbance in the system. From the point of power quality, this inrush current has to be eliminated, too.

Controlled switching system is now considered as an effective solution to reduce the switching transients and has been applied widely in the world.

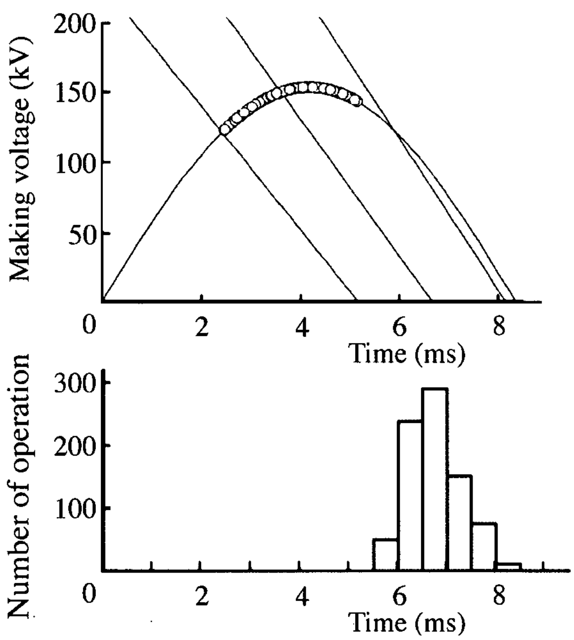
3.1 REDUCTION OF INRUSH CURRENT[2]

As shunt reactors have few residual flux even in the case with iron cores, the optimal closing target is peak of each phase voltage. Figure 5 shows making voltage and closing instant distribution (a), closing time variation and control error at actual field operation (b) of 204kV shunt reactor switching in Japanese system for a year using the hydraulic operated circuit breaker described above with a switching controller having the compensating function.

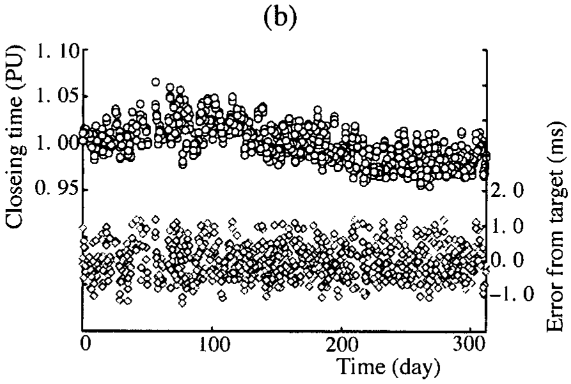
The circuit breaker was operated with various ambient temperature from 4 to 33 degrees C and idle time from 1 to 110 hours. All the control error were within its inherent mechanical scatter of +/- 1.2 ms, which shows satisfactory compensation of each characteristics including idle time dependence.

Figure 5 Distribution of Making Voltage and Closing Instant, Variation of Closing Time and Control Error

(a)



(b)



3.2 ELIMINATION OF RE-IGNITION

The occurrence of re-ignition is determined by TRV amplitude after current interruption and dielectric withstand between GCB gap at the instant. Dielectric withstand at the current interruption instant is determined a time from contact separation to current interruption, which is called arcing time. Figure 6 shows a relation between re-ignition occurrence versus arcing time. Dielectric recovery between gap is obtained by interruption test at factory, and TRV peak can be calculated by network analysis, therefore, the optimal arcing time to be controlled can be analyzed before field installation. Because interruption current is small and hot gas generated at interruption is a small amount, dielectric recovery characteristic between gap in shunt reactor switching is similar that under cold gas condition, i.e. no-load operation. Therefore, dielectric recovery characteristics can be calculated from electric field between gap and open operation characteristics, when interruption test is not available in such a case of retrofit of existing GCB.

Figure 7 shows voltage and current waves in controlled de-energization of practical 275kV shunt reactor in Hong Kong using spring operated GCB. The GCB is controlled to open non simultaneously upon current waves of each phase, and no re-ignition overvoltage was observed.

Figure 6 Re-ignition Occurrence versus Arcing Time in Shunt Reactor De-energization

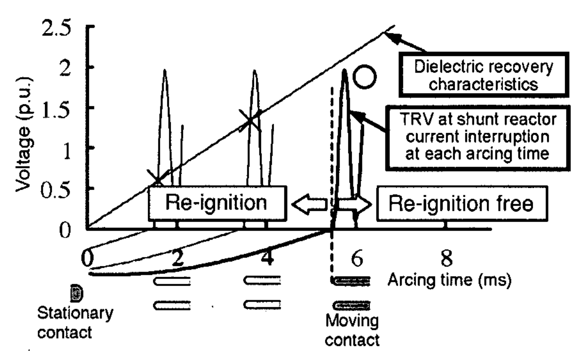
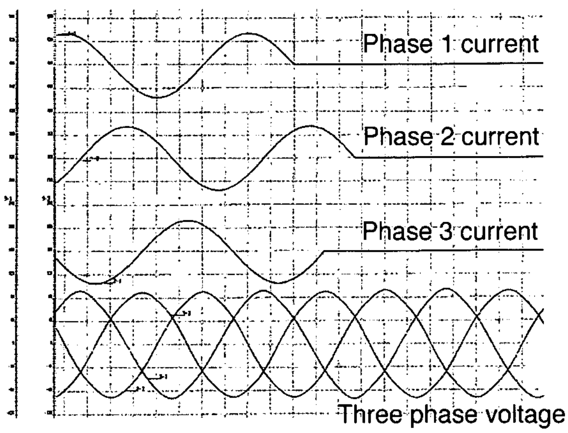


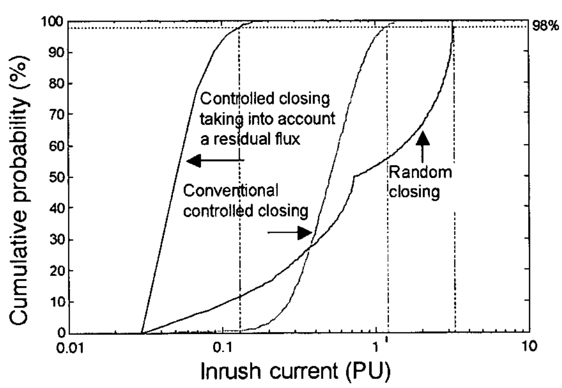
Figure 7 No Re-ignition was Observed at Controlled De-energization of 275kV Shunt Reactor with Spring Operated GCB



4. APPLICATION TO TRANSFORMER SWITCHING

Energization of no-load transformer can also generate very high inrush current close to fault current, which can give high electrical and mechanical stress to transformer windings. Inrush current can also cause significant voltage disturbance and lead mal-operation of protection relays.

Figure 8 Cumulative Probability of Inrush Current Amplitude in Random Closing and Controlled Closing

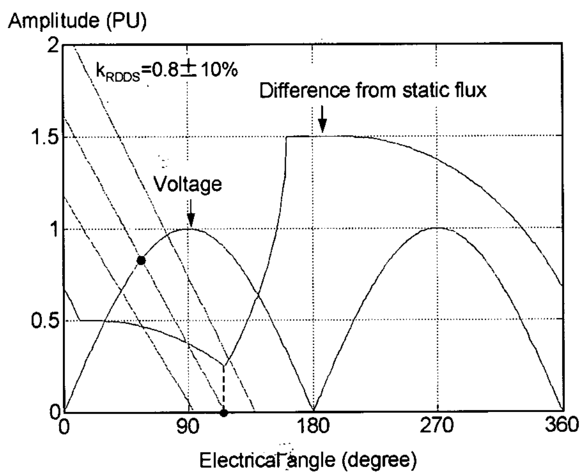


Network simulations by EMTP have been performed for transformer energization in the case of 3 phase simultaneous closing and controlled closing with and without considering residual flux. As shown in figure 8, evaluating from 98% probability, inrush current by controlled switching taking into account a residual flux is 1/30 of a random energization and 1/10 of conventional controlled switching. Controlled closing taking into account a residual flux is concluded as the best solution to reduce an inrush current to a satisfactory level[4].

4.1 SWITCHING SEQUENCE

The optimal target for the first phase is calculated as a function of the residual flux and circuit breaker characteristics. Figure 9 is an example of a calculation for the optimal target in the case of 0.5 PU of residual flux and application of a circuit breaker whose RDDS is 0.8 times dV/dt at voltage zero and mechanical scatter is +/-1.0 ms.[3] The optimal closing target is calculated as 116 electrical degrees after voltage zero of the phase.

Figure 9 Optimal Target for The First Phase Dependence on a Residual Flux



In practical three phase transformers, the flux in each iron core will vary after the first phase energization depending on the first phase voltage. Therefore, the optimal closing targets for the other two phases can not be fixed by residual fluxes of these two phases. An effective closing strategy was previously proposed as shown below.[5],[6]

(a) Close one pole at the optimal instant when the steady state flux meets the residual flux of the phase.

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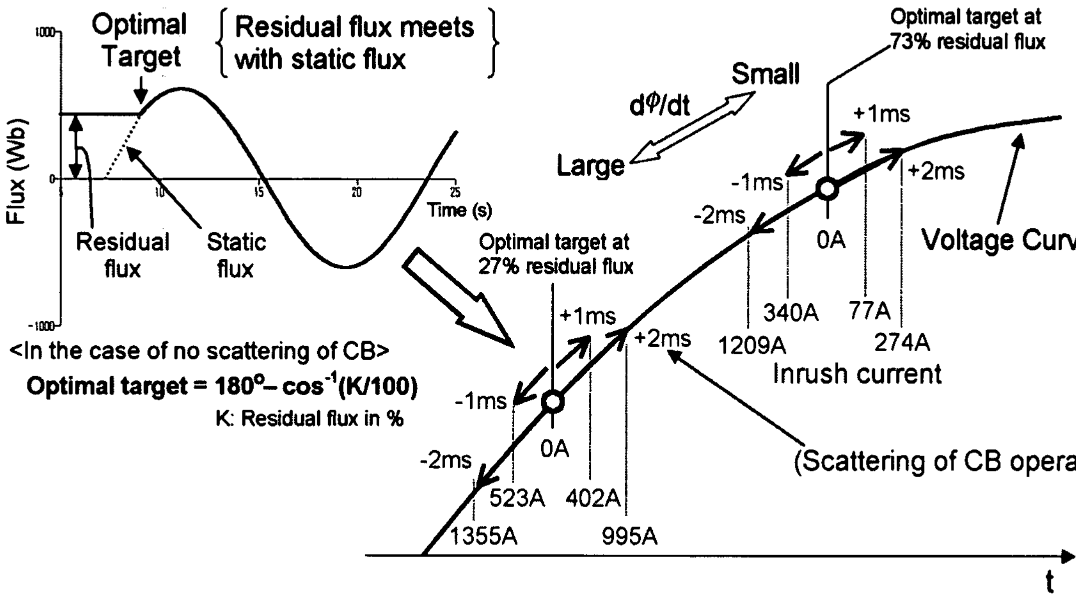
Figure 10 Maximum Inrush Current Dependence on Residual Flux Values



(b) Close the remaining two phases simultaneously after several cycles at the voltage zero instant of the first phase when fluxes in these two phases lose asymmetry and are equal to the steady state at the instant.

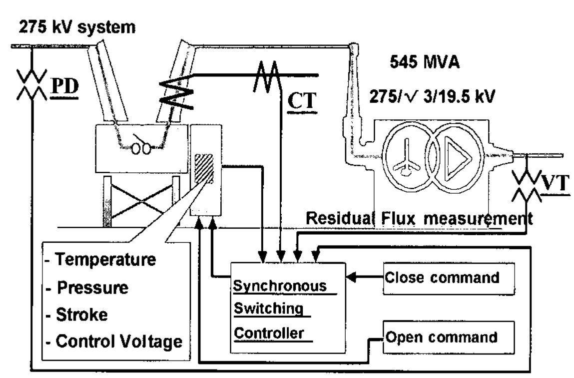
Here, it is not necessary to be simultaneous, because fluxes in all phases are determined after closing two phases of a transformer.

The same mechanical scatter of circuit breaker will generate a smaller flux error in the case of a target for larger residual flux because of a difference in the static flux slope at these two instants. Figure 10 shows the maximum inrush current in the case that the residual flux for the first phase is 0.27 PU and 0.73 PU.

4.2 EVALUATION IN THE PRACTICAL FIELD

The effectiveness of the system in reducing the inrush current was evaluated in field conditions.[7] The configuration of the system is shown in figure 11. The voltage signal of the transformer terminal is supplied by the VT at the secondary side of the transformer and translated to primary terminal voltage in the switching controller for calculation of residual flux. The evaluation consisted of 4 parts, listed below, which were suggested by CIGRE WG A3.07 as a guideline for installing controlled switching systems.[8]

Figure 11 Configuration of CSS for Transformer



4.2.1 EVALUATION OF CB CHARACTERISTICS

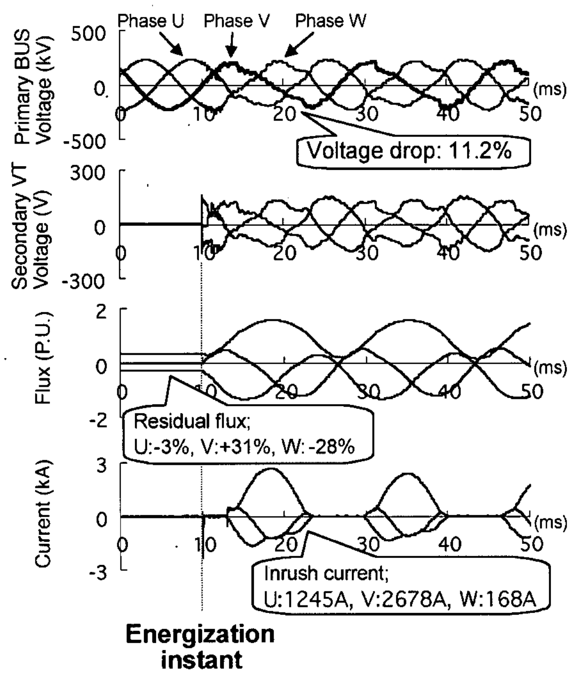
The closing time dependence on temperature, hydraulic pressure, control voltage and idle time were confirmed on a prototype circuit breaker at the factory. Mechanical scattering and RDDS were also confirmed at the factory. An average closing time of the circuit breaker was measured by no-load operation at the site to determine the actual operating conditions at the site. All the parameters were set in the controller, which is installed in the local control box close to the circuit breaker.

4.2.2 RANDOM ENERGIZATION WITHOUT CONTROLLED SWITCHING

The transformer was energized randomly without controlled switching to confirm the inrush current generation and voltage disturbance. Residual flux is also measured for reference data. To prevent severe voltage disturbance, an energizing network was constructed.

Figure 12 shows an example of the voltage, current, and flux in the cores in the case of three phase simultaneous energization. All three cores were magnetically saturated and high inrush currents of 1250 A to 2680 A appeared with a maximum 11% voltage drop in the primary BUS of the transformer even with an energizing network.

Figure 12 Voltage, Current and Flux Measurement at 3 Phases Simultaneous Energization

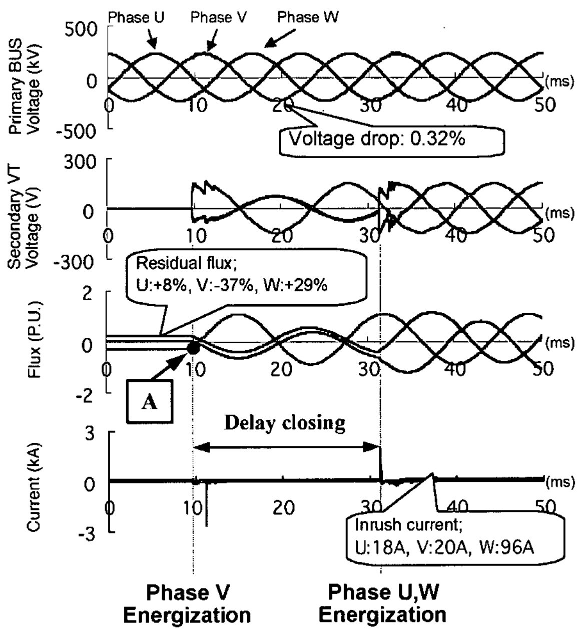


4.2.3 ENERGIZATION WITH CONTROLLED SWITCHING

The transformer was energized by the controlled switching sequence to confirm its effectiveness. To support the evaluation, system voltages, currents, residual fluxes and CB closing times were also measured and recorded.

Figure 13 shows an example of controlled energization of the transformer. The switching controller detects the phase with the maximum residual flux (Phase V) at the last de-energization and is set as the first phase to close. The first phase was closed at the instant when the residual flux meets the static flux shown as point A in the figure. The second and the third phase (U and W phases) are closed 1.5 cycles later than the first phase at the instant of voltage peak of the first phase. Inrush currents were reduced to below 100 A and the voltage disturbance on primary BUS was negligible. All deviations from the targets during 10 operations were within +/- 0.8 ms, which is a satisfactory value for the point of voltage disturbance.

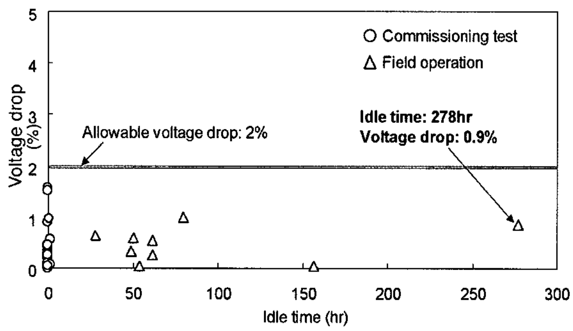
Figure 13 Voltage, Current and Flux Measurement at Controlled Energization Taking into Account of a Residual Flux



4.2.4 EVALUATION OF RELIABILITY IN THE FIELD

The system has been operated in the field for a half year to confirm EMC, climatic, and long-time reliability in practical operation. Voltage and current waves, circuit breaker operating conditions, and residual flux at each operation were recorded in the switching controller and sent to the factory for analysis. Figure 14 shows voltage disturbance calculated from inrush currents. While the circuit breaker with up to 278 hours idle time was operated with satisfactory accuracy, longer idle time can be supposed in practical operation. Further sampling and analysis of the operation data are planned to be consecutively performed.

Figure 14 Voltage Disturbance by Controlled Energization of Transformer by CSS taking into account a Residual Flux



5. CONCLUSION

Characteristics of circuit breakers have been evaluated for practical operation of controlled switching systems. The field data show that operating condition dependence of circuit breaker operation time is satisfactory compensated with adequate methods. A controlled switching system for transformers taking account of a residual flux has been developed and shown to have satisfactory performance in the field. Inrush current with the associated voltage disturbance has been successfully reduced by the system. These results can give further reliability to controlled switching systems and support common application of it.

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Paper No. 8

CORPORATE DATA CENTRE – STRATEGIC THINKING BEHIND THE E&M SERVICES DESIGN INFRASTRUCTURE

Speakers : Ir Joseph C.M. Leung, Director
Ir Albert W.K. To, Director
Ir P.K. Yip, Senior Associate
J. Roger Preston Limited

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ABSTRACT

Many international corporations and multinational firms are expanding their businesses and territory using Hong Kong as a base. Their IT infrastructure is planned to serve from this Hong Kong hub to other offices, facility operations for PRC and other Asia Pacific Regional offices. The corporate data centre built for these facilities is becoming their critical nerve centre and the building E&M supply infrastructure such as utility multi-path supply, emergency generator backup and telecom have to be planned to suit such need. The paper will discuss and address (i) The preparedness of the base building infrastructure for corporate tenants with data centre (ii) The various configuration of the electrical, UPS, PDU and other MEP design within a main equipment room - e.g. parallel redundancy, distribution redundancy, N+1, N+N, S+S. The design approach adopted to each of the above services configurations making reference to Uptime Institute (USA) will also be generally discussed.

1. INTRODUCTION

The corporate data centre acts as the key data hub for many cross-country departmental communications of the world's corporation. It will usually be a corporate decision to build or expand a data centre alongside a major facility. It involves key figures at corporate levels in a corporation from IT, businesses, operation down to user groups. This paper intends to address some of the key design and planning considerations involved in the process as a MEP designer from site selection through to completion. All these considerations would play a pivotal role in finalizing the Client's leasing agreement (of the preferred site/ building) whereby lengthy negotiation is usually expected upfront to incorporate those key design provisions. The corporate data centre itself could well be a standalone operation, a back-up site and / or a Disasters Recovery Centre (DRC), and their size could well be ranged from 3,000 sq. ft. to 100,000 sq. ft.

2. SELECTION OF DATA CENTRE SITE (DUE DILIGENCE REVIEW)

Without a good E&M infrastructure, data centre could not function as it is designed for unless a substantial amount of money and effort are spent to further enhance and upgrade the related base building E&M engineering systems. A due diligence study of potential sites is therefore highly recommended. The prime objective is, therefore, to select a site with highly reliable, robust and flexible E&M infrastructure that will enable a cost effective and resilient design of a corporate data centre. At the onset of hunting an appropriate site, the following, as a minimum, needs to be considered:

2.1 DATA CENTRE WITHIN A BUILDING

As a rule of thumb, data centre should not be located directly below any open roof as water leakage will pose high hazard to IT equipment. In addition, thermal transfer of solar heat through the ceiling will impose additional burden to the already high cooling load demand which will further increase the installation cost and running cost.

The data centre envelope shall have good air tightness to avoid condensation/unwanted infiltration and also it shall be designed in such a way that external environment (sunlight, typhoon, etc.) shall not cause detrimental fluctuation in the interior operating conditions, such as space temperature.

In some of the high-rise building, mechanical floor may be located at the mid-zone of the building. Preferably, data centre should not be located directly above or below this mechanical floor as frequent start-stop of mechanical equipment will induce high electromagnetic interference (EMI) to sensitive IT equipment. If it is unavoidable, it is recommended to carry out an EMI field measurement in order to resolve to any mitigation measures that may be required.

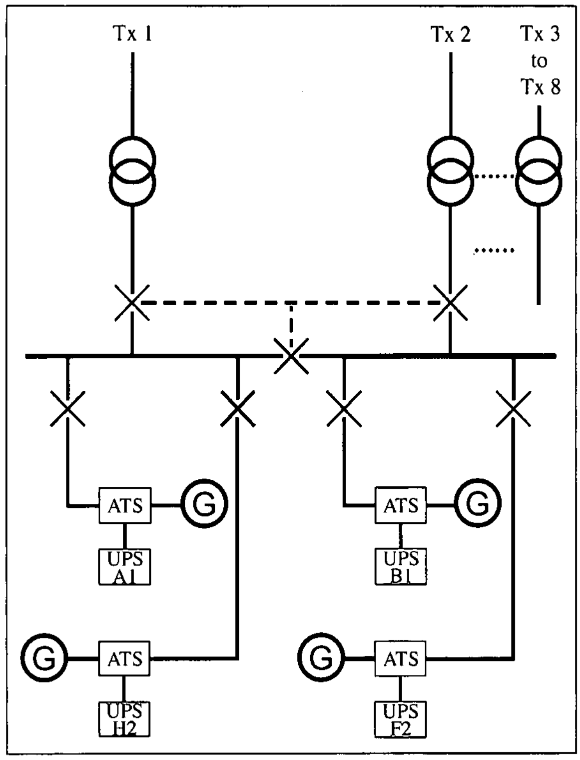
Also, it is a well-known phenomenon that single core conductor induces high electromagnetic flux that will affect IT equipment as well as CRT monitor (though it is a trend of using LCD monitor nowadays). It is highly recommended not to locate a data centre immediately adjacent to, directly above and below to any transformer rooms.

2.2 POWER SUPPLY SYSTEM INFRASTRUCTURE

A highly reliable and resilient power supply system is a must for the proper operation of a data centre. An appraisal of base building electrical distribution system should be carried out. Take an example of a Large Corporate Data Centre and hopefully the strategic review during the due diligence process would illustrate our technical concern.

i. Power supply for mission critical equipment should have dual source (both supply mains and cable routes) which provides additional security to UPS / generator. Preferably the best is to have dual HV incoming feeds from two different zone substations upstream.

Figure 1 Typical Transformer with Backup Genset Arrangement (Also Refer to Fig 4)



ii. Generator would usually be required to support critical equipment in case of power failure. For some of the corporates, they may consider to install their own generator set as they will have the ultimate control of this piece of important equipment, discarding long-term pain of untimely base building genset scheduled maintenance. Space should therefore be identified to accommodate this bulky equipment with due consideration of environmental impact, delivery routes etc., down to refueling arrangement of the fuel storage tank.

iii. Assessment of single-point-of-failure of electrical distribution system must be carried out in order to identify any weak points which might cause catastrophic shutdown and mitigation measures may be required during detailed design stage. (e.g. Modifications of main switchboards, adding of ATS and / or additional cable feeds)

2.3 CHILLED WATER SUPPLY SYSTEM AND BUILDING MANAGEMENT SYSTEM

There are a number of systems commonly adopted including seawater cooling, fresh water cooling and direct air-cooled radiators. Different systems will have its technical merits and therefore should be reviewed on a case-by-case basis. The following, however, outlines some of the key considerations:-

i. As stated above, assessment of single-point-of-failure is of paramount importance and hence should be critically reviewed at the onset of selection process. Any shortfall should be recorded for future design consideration.

ii. Confirmation of sufficient cooling load from base building chilled water system for Day-1 and Day-2 data centre requirements.

iii. BMS - Sophisticated building management system (BMS) is commonly used in Hong Kong. Some of the BMS system will have the capability of remote access via web browser. Preferably, critical monitoring signal should be repeated to the data centre so that the operation staff will have first hand information of the status of the E&M supply network. If this is not feasible, repeat the critical signals by using hardwire should also be considered. This should be agreed with landlord during the lease negotiation process in order to avoid any argument in future.

2.4 VERTICAL TRANSPORTATION AND LIFT ZONING

A comprehensive review of vertical transportation system will be important for the efficient operation of a corporate data centre say within a building complex. If an efficient vertical transportation system is provided, it will reduce the waiting time (and hence idling time from employer point of view) for operation staff. Most importantly, it will facilitate a speedy delivery of critical component and equipment for replacement. The size of lift cab should be sufficient for bulky IT equipment transportation such as main frame, switchboard, UPS and CRAC.

The data centre requires 24-hour access at the highest security level, the strategy behind involve liaison and agreement with the landlord for the following:-

- 24-hours access for data centre personnel with full security screening and authorization.
- Maintenance access could well be by means of services lift but same level of security shall be maintained at all time.
- The lift bank serving the data centre shall still be operational 24-hours and so during due diligence review, this provision must not be overlooked.

2.5 FIRE SERVICES AND FIRE ALARM SYSTEM

An adequate fire services protection system will not only protect the precious human life but will also protect the heavy investment (IT Property) of the computer system as well as those mission critical equipment. A thorough study of base building fire services provision is a must though buildings in Hong Kong normally has a high standard of fire services protection system installed according to the statutory requirements and in most cases comply with the Corporate Insurance Policy. In addition, study to investigate whether appropriate method of fire alarm tripping of air conditioning system to avoid major disruption of air conditioning system due to isolated fire alarm or false alarm incidents. Fire fighting and provisions within data centre are discussed in the latter sections.

It is highly recommended that a due diligence survey for both building provision and E&M infrastructure be carried out as soon as a potential site is identified. An appropriate site with adequate level of E&M provision will not only reduce installation and running cost in future, it will also help to increase the reliability, adaptability to future changes and create a trouble-free operation of the data centre.

3. USER REQUIREMENTS

The first step is to obtain from the Client / users, the numbers of racks, major IT / security / voice equipment etc. to be located inside the Data Centre. This is to determine the power and cooling load estimation. Then the requirement of redundancy / tier / service level requirements shall be clarified with the Client if these are company global standards according to different class / operation status of the particular corporate data centre so prescribed. In general, the higher the redundancy and resilience, more space and cost to build are anticipated.

The above might seem to be a short address of client's IT corporate policy and design philosophy, but it is the most important interpretation process for the MEP designer to define the scope of E&M infrastructure services design for any corporate data centre.

4. SCOPE DEFINITION WITH CLIENT'S IT DEPARTMENT

Once the site is selected and the user brief defined, it is necessary to co-ordinate with the IT department in order to iron out all the necessary design details and plans for Day-1 and future expansion inclusive of their intended geographical coverage. Design information collected during the site selection process and the successful interpretation of the client's IT technology brief will then form the basis of E&M system approach. The following represents some of the key design criteria which are required to be established with all the team members at the onset of design development stage:

4.1 DATA CENTRE LAYOUT AND SYSTEM REQUIREMENTS

The next step is to determine the E&M plant capacity and data centre layout.

- Reconfirm the number and arrangement of equipment rack layout and power consumptions. (Day-1 and Day-2 requirements).
- Determine fully diversified dual supply to equipment rack from source-end up to equipment side complying proven international standards.
- Project the heat dissipation estimation for equipment rack. (Day-1 and Day-2 requirements).
- Determine the server equipment and main frame positions.
- Establish requirement and specification for parallel / distributed redundancy configuration for UPS system.
- Agree on fire services protection requirement, e.g. choices of gas suppression system such as Inergen, FM200 or pre-actioned sprinkler and VESDA (also to satisfy corporate insurance and life safety policies).
- Determine the raised floor height to accommodate services, unrestricted airflow (if down blow type CRAC is selected) and for future expansion. For upflow type CRAC, air distribution direction and mixing of air from "Cold and Hot" aisle shall be carefully planned.
- Agree and fix the phased and scheduled relocation of the existing IT / data equipment, if any.

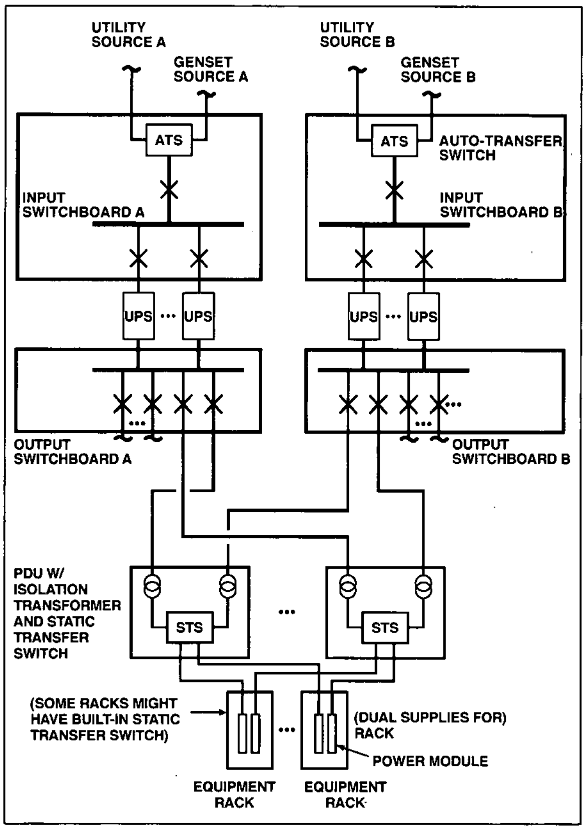
4.2 E&M INFRASTRUCTURE AND DESIGN STRATEGIES

The following plant / component selection and supply strategies shall then be determined.

- Battery type requirement (VRLA) and backup time / resilience requirement.
- Genset backup requirement and backup time / fuel consumption (independent unit and / or base building gensets).

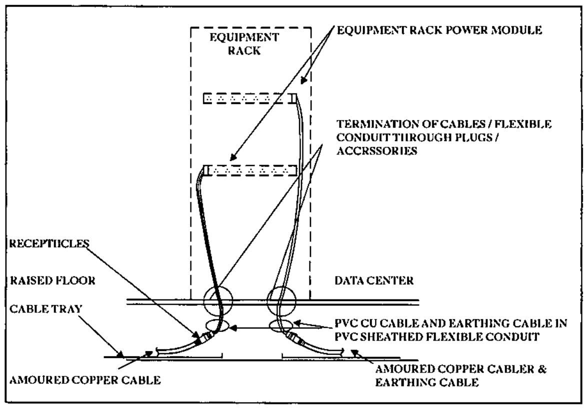
- Redundancy arrangement for power supply system.
- Redundancy arrangement for CRAC, UPS, PDU, etc.
- Dual chiller water routing and/or dual cooling media for computer equipment and CRAC.
- Requirement and specification for PDU (power distribution unit), STS (static transfer switch) and isolation transformer. [See Fig 2]

Figure 2 Simplified Schematic to Supply Critical Load on N + N Configuration with Dual Utility, Dual Genset Sources, (N+1) UPS Modules and PDUs Dual Feed to Each Equipment Rack



- Requirement of PDUs that should be strategically located to provide "Salt & Pepper" arrangement to data / IT equipment and to the critical loads. [See Fig 3]

Figure 3 Typical Dual PDU (A+B) Supply Arrangement for Equipment Rack Inside Data Centre



- Provision of clean earth to each equipment rack and equipotential bonding systems to the raised floor system. Clean earth should not be contaminated by dirty earth.
- Dual chilled water risers from building infrastructure.
- Dual power supply feed (both normal and essential feeds) from building infrastructure.

4.3 SYSTEM OPERATION REVIEW AFFECTING DESIGN

Review shall also be conducted for Data Centre operation which would reflect upon the E&M design at design stage. The following are some key issues.

- For multiple transformers supply scenario in the case of large data centre, a multi-transformer backup design matrix shall be established to assess the implication due to transformer failure or WR2 inspection. [See Fig 4]

Figure 4 Sample Multi-Transformer Backup Matrix

Transformer Number	Connecting to UPS/PDU Zone Number		Backup from other transformer in case of failure of one transformer or WR2							
			TX 1	TX 2	TX 3	TX 4	TX 5	TX 6	TX 7	TX 8
TX1	A1	H2			■					■
TX2	B1	F2				■				
TX3	A2	G1	■				■			
TX4	B2	E1		■				■		
TX5	C1	G2			■				■	
TX6	D1	E2				■				■
TX7	C2	H1	■				■			
TX8	D2	F1		■				■		

Paper No. 8

SIEMENS

- Regular E&M system checks and maintenance shut down.
- Drain tests for UPS battery system (at regular interval).
- Emergency shut down and automatic restoration after power failure.
- Regular statutory and regulatory inspections (e.g. WR2 and FS Form 251)
- Requirement of remote site monitoring system, both in Hong Kong and overseas.
- Alarm paging system, auto-SMS to cell phone and interface with BMS.

4.4 RISK MANAGEMENT REVIEW

Lastly but not the least, risk management review shall also be exercised at design development stage.

- Potential flooding risk.
- Life and fire safety review.
- Sabotage and holdups
- Building fabrics related deficiency and ageing problem.

5. DATA CENTRE AIR-CONDITIONING

Computer room air-conditioning and the heat exchange system used for various type of precision control computer room air-conditioner (CRAC) require a different design treatment. It involves the technical evaluation of the main chiller plants used (and its redundancy), dual chilled water supply routes to the corporate data centre, and finally the selection of CRAC with single or dual coil (single or twin fans, etc.) The description of CRAC is not within the context of this paper.

Computer equipment operates more efficiently and reliably in a constant temperature (usually 21°C±1°C) environment with adequate airflow to directly remove the high intensity heat generated by the array of data racks. Humidity control (usually 55±10%) is also very important to minimize formation of static electricity (if too dry) and to avoid moisture content build up in a data centre & environment.

Different configuration of CRAC matching the chiller systems are briefly illustrated below as concepts of cooling redundancy [See Fig 5, 6 & 7]

- Various configuration of chiller system plant with dual cooling media (chilled water and condensing water)
- Single coil or dual coil CRAC
- CRAC arrangement can be N+1 or higher depending on the actual room layout and the effective airflow amongst hot racks when certain CRAC fails

Figure 5 CRAC Supplied by Dual Water-Cooled System with Single Coil

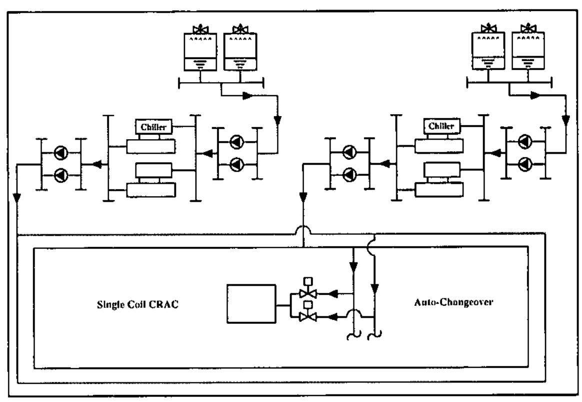


Figure 6 CRAC Dual Supply by Water-Cooled Chiller and Air-Cooled Chillers with Single Coil

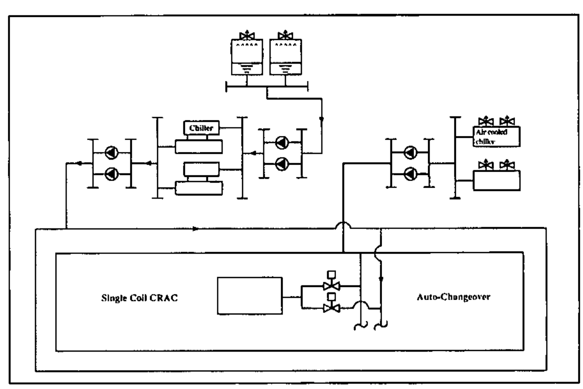
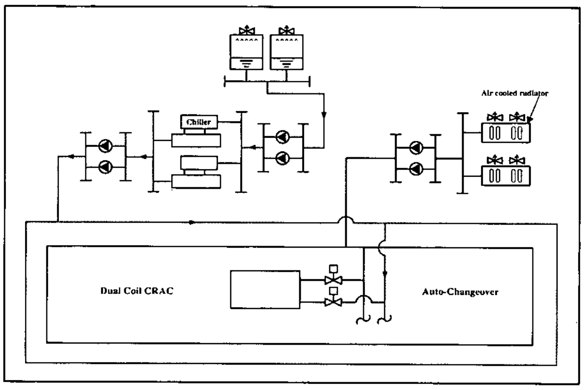


Figure 7 CRAC Dual Supply by Water-Cooled Chiller and Air-Cooled Radiator with Dual Coil



6. FIRE SERVICES DESIGN

FM 200 /Inergen gas flooding extinguishing system and Pre-action sprinkler system are commonly used in Hong Kong for protection in corporate Data Centre instead of wet sprinkler system, the technical comparison are as follows:

6.1 COMPARISON OF FM200 AND INERGEN GAS FLOODING EXTINGUISHER SYSTEM

Description	FM-200	Inergen
Gas composition	HFC-227ea	52% N2, 40% Ar, 8% CO_2
Ozone Depletion Potential (ODP)	0	0
Global Warming Potential (GWP) (CO2=1)	2050	0
No Observed adverse effect level NOAEL	9%	N/A
Lowest Observed adverse effect level LOAEL	>10.5%	N/A
Extinguishing Concentration	≧7%	≧37.5%
Storage Container Pressure at 20°C	25 bars	150 bars
Toxicity LC_{50} or ALC	>80%	non-toxic
Relative Storage Space	1	6
Gas discharging time	10 seconds	60 seconds
Equipment installation cost	Lower	Higher

6.2 COMPARISON OF GAS FLOODING SYSTEM AND PRE-ACTION SPRINKLER SYSTEM

Description	Gas extinguishing system	Pre-action Sprinkler System
System type	Gas total flooding system (No pitching needed)	Pre-action recycling valve system (Pipe pitching to drain location)
Assume operation area	Entire compartment	216 m^2
Extinguishing media	Inergen / FM-200 gas	Water
Storage space	More space required for gas cylinder	Same building sprinkler tank
Residue in premises	No residue	Water
Installation Cost	High	Low
Maintenance Cost	High	Low
Equipment damage	Very Little	Yes

LC50 is the concentration lethal to 50% of a rat population during a 4 hour exposure. , ALC is the approximate lethal concentration. CO2 gas flooding system is not recommended for data centre (human occupied area).

FM 200, a halocarbon, and Inergen, an inert gas, they both extinguish fires by interrupting the flaming process chemically and reducing the fire oxygen's content. They are more environmentally friendly. They contain no chlorofluorocarbons so they do not harm the ozone layer.

From environmental point of view, both FM 200 and Inergen are clean agents. FM 200 is made of all man-made substances while Inergen is a non-chemical agent and contains naturally occurring substances. FM 200 has a medium to high global warming potential but Inergen requires more steel to make the high-pressured steel cylinders for its storage. Therefore Inergen requires more energy for its manufacture, storage and transportation. Pre-action sprinkler system is most natural and green environment issues with media of water.

7. EXPANDABILITY

The project designer shall take full account of the IT expansion plan which might run fast from Day-1 to full provision in future.

- Review with user to determine the allowance for future expansion.
- Review base building infrastructure on electricity power and cooling capacity.
- Any space for new transformer, new genset, new chiller, new risers etc. (upfront structural integrity check may be necessary at due diligence review stage)
- Allow space and flexibility for data centre to expand either horizontally or vertically (Hub room alignment check)
- Determine whether to design the Day-1 capacity capable enough to cater for Day-2 operation from time, cost and spatial point of view.

- Otherwise, to allow space for additional power supply equipment (UPS / PDU / STS / isolation transformer) and CRAC etc.

- Chilled water pipe size, pre-action sprinkler pipe size, gas pipe size, containment size and service routing / space shall be designed to easily modify to Day-2 expansion without major system interruption.

8. PROGRAMME AND TESTING AND COMMISSIONING

8.1 MILESTONE DATES

The work programme for data centre shall clearly identify all the critical milestone dates of authority utility companies submissions and approvals and adequate lead time shall be provided for

- Pre-ordering of mission critical E&M plants (UPS, CRAC, PDU, Genset, etc.)

- Attended overseas Factory Assessbly Tests (FAT) before shipment.

- Decommissioning of existing data centre, if required for the case of existing data centre relocation.

- The data centre will usually require 1 - 3 months early handover and shall be fully serviced and environmentally enabled for IT personnel setting up their data racks and structural cabling system as a follow on activity.

- Equipment rack layout shall be designed and co-ordinated to assure clear delivery routes for both Day-1 and Day-2 installation.

The project of this nature will certainly involve a highly complex and tedious T&C programme and therefore adequate time / scheduling shall be allowed in programme. Documentation on approved T&C procedures, T&C results and equipment performance must be clearly documented for future FM hand over and effective maintenance management.

In light of the data centre involving specialist vendors, there are various procurement method describe as follows for your consideration. Contract strategy shall also be established on procurement of such which would require a different level of engineering design treatment due to their specialization and design requirements and market availability. Options are,

- Supply contracts for CRAC, UPS, PDU, batteries, STS, genset with pre-qualified specialist vendors, or

- Supply and installation contract for CRAC, UPS, PDU, batteries, STS, or

- Packages E&M contract for the entire data centre for single point of co-ordination, single point of responsibility and information security protection

8.2 INTEGRATED SYSTEM TESTS (PULL-THE-PLUG TEST)

i. The IST to be conducted for a large data centre is meant for performing a detailed scheduling of system response tests during a power failure or loss of system supply condition. This IST (also known as "Pull-the-plug" test) is to be performed after all individual systems are being properly tested and commissioned. The IST tests also serve a few other purposes:-

   - To verify all those interlocks/initiation alarms and/or system changeover action between systems under a live System power failure test.

   - To rehearse with the anticipated system behavior under a real power failure situation and its restoration process.

   - To review the "cause and effect" of each event that takes place and are fully logged.

   - To provide an early familiarization process with the client FM team.

The IST will also give a better picture to the Trades contractors by involving them in the IST preparation (during the commissioning process) from the earliest stages of T&C through to final performance verification test and handing over.

ii. This process involves the direction to be given to almost all parties to conduct the IST at scheduled time slots. The overall programme of the IST shall be carefully integrated into the master programme of the works. The IST will be conducted after and upon complete demonstration of correct interface/interlocked and system performance tests of each of the works packages. The key activities will involve:-

- Compulsory attendance from all trades contractors, specialist data cable vendors, MEP Engineer, Client - IT and the Landlord FM.
- They should all provide proper and qualified attendance.
- All scheduling is well discussed and mutually agreed between all relevant parties to avoid abortive work.
- All preparatory testing instruments such as load banks, chart recorders inside data centre, fuel oil to generator set... etc. are to be properly set in position.

iii The tests likely to be conducted for the Corporate data centre would include, for example:-

- Power failure simulation tests at busbar / cable riser submains.
- Generator starting and essential supply auto-changeover and stability review.
- UPS/PDU/CRAC performance under such situation with BMS log.
- Loss of one essential chilled water leg of the dual mains.
- Observe CCTV/Security/ Fire services system response.
- Resumption of normal power supply.
- Other MEP system automatic restoration

9. CONCLUSION

Each data centre by experience will have its unique characteristics reflecting both their corporate culture and design protocol. The design team shall exercise best judgement to satisfy such need by creating a safe, reliable, flexible and resilient electrical and mechanical services infrastructure responding to their need. On one hand the corporate appears to thumb down their design requirements onto the project team, while viewing from the angle of corporate governance, appreciation shall be given to those stipulations as they must have gone through lengthy corporate review of both technical and risk management evaluations. The data centre shall last as it is intended to be with day-1 design easily configured to its ultimate performance capability. Professional anticipation of their needs is the key and they can only be achieved by full partnering with Client's team and project team. Bearing in mind the data centre shall operate on a 24 x 7 basis, traditional electrical and mechanical design approach would not be able to adequately cover such stringent and fool proof operation. The engineers are put to test with the skill and knowledge, and usually with a very challenging programme to build world class data centres for many world's corporation in Hong Kong.

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[JRP/DM/DC/0071].

Glossary

CRAC	Computer Room precision type Air Conditioner
UPS	Uninterruptible Power Supply system
ATS	Automatic Transfer Switch
STS	Static Transfer Switch
PDU	Power Distribution Unit with power supply condition and power quality display
FM	Facility Management Team
FM200	A kind of gas-suppression system for fire fighting

Paper No. 9

KOWLOON SOUTHERN LINK (KSL) PROJECT

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ABSTRACT

When completed, the 3.4 km long KSL will link up the KCRC East Rail and West Rail at the southern end. Through KSL, residents in the Northwest New Territories will be able to travel on rail to reach the Tsim Sha Tsui area. Similarly, rail passengers from Northeast New Territories will also be able to reach the future West Kowloon development area through cross-platform interchange at Hung Hom Station. This paper describes the many challenges posed by the construction of an underground railway through one of the busiest and most congested areas in Hong Kong, connections with two operating railways and ways of overcoming these challenges. The paper also touches on the evolution in the management of new railway projects in KCRC since the West Rail days.

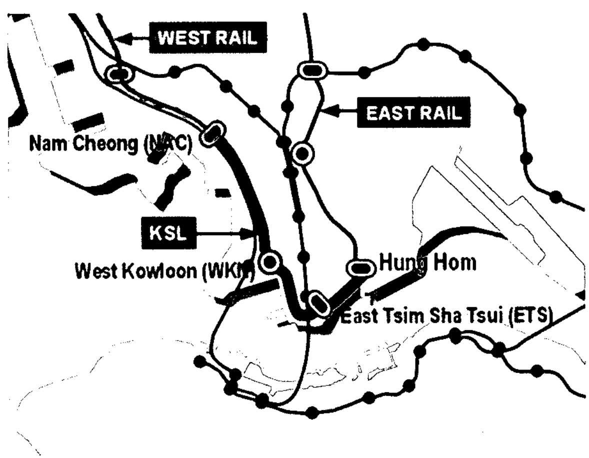
1. INTRODUCTION

In September 2002, the Hong Kong Government invited the KCRC (the Corporation) to proceed with the detailed planning and design of the Kowloon Southern Link (KSL), one of the priority railway projects recommended in the Government's Railway Development Strategy 2000 (RDS-2000).

The Government gazetted the authorised KSL scheme on 24 June 2005 and construction of the HK$8.3 billion project commenced in the fourth quarter of 2005, with completion scheduled for 2009.

The KSL will run entirely underground and link the existing East Rail - East Tsim Sha Tsui Station with the West Rail - Nam Cheong Station, connecting these two railways at the southern end (Fig. 1). This new 3.4 km long rail link aims to serve the strategic function of allowing passengers of West Rail to have direct access to East Rail and vice versa, and will have one intermediate station - West Kowloon Station.

Figure 1 Kowloon Southern Link Alignment



West Kowloon Station will be situated at the northern end of Canton Road. The new station will feature an underground concourse and an island platform (a central platform with tracks either side). An extensive pedestrian subway system will connect the station directly to nearby commercial buildings and shopping arcades.

Although the length of KSL is relatively short, its implementation throws up many challenges, as it will be constructed in a highly developed urban area of significant importance commercially and for tourism.

Paper No. 9

2. CONSTRUCTION CHALLENGES

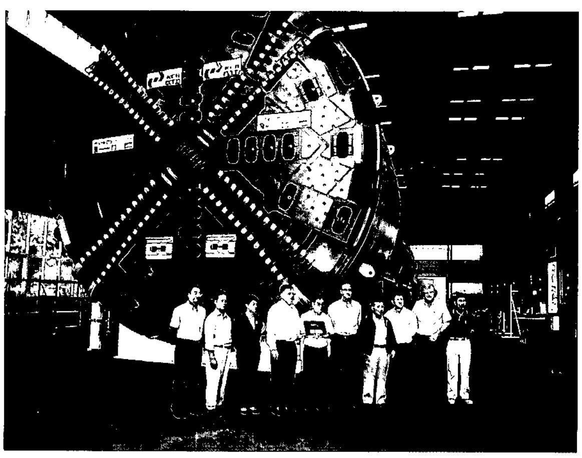
2.1 DISRUPTION OF TRAFFIC AND BUSINESSES

During construction of the Tsim Sha Tsui Extension and the extensive subway network along Mody Road and Middle Road from 2000 to 2004, precious experience was learnt in striking the balance between work progress and community activities.

With the successful experience in West Rail and Lok Ma Chau Spur Line projects, it was decided to adopt the tunnel boring machine (TBM) method for the construction of the tunnels running under Canton Road and Salisbury Road. This will minimise ground level construction activities substantially and reduce disruption to normal traffic and businesses in the vicinity.

The 8m diameter slurry type TBM (Fig. 2), used in Hong Kong for the first time for railway construction, is specially designed to drive through different ground conditions and to negotiate tight curved alignment of 185m radius under the Former Marine Police Headquarter.

Figure 2 Tunnel Boring Machine



2.2 TUNNELLING UNDER EXISTING BUILDINGS AND STRUCTURES

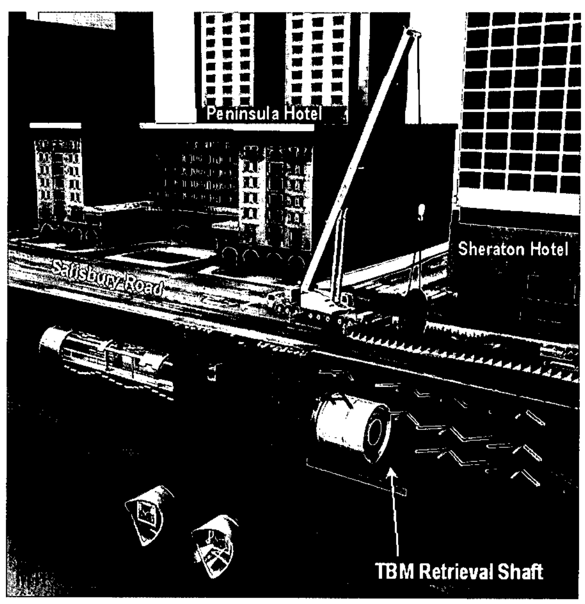
At the southern end of the alignment, the bored tunnels will pass over the existing MTRC Tsuen Wan Line (TWL) tunnels with a minimum clearance of about 1.8m before connecting to the existing tunnels south of the East Rail ETS Station (Fig. 3).

The protection of the MTRC tunnels during construction poses a major technical challenge to the project as any tunnel movement or distortion may paralyse the cross-harbour service of the TWL.

The proposed protection measures, which include horizontal pipe piling and ground stabilisation by jet grouting, were verified by three-dimensional analyses that the movements of the MTRC tunnel would be well within acceptable limits.

An Automatic Deformation Monitoring System (ADMS), which was applied previously at East Rail tracks adjacent to MOS Rail and LMC Spur Line, will also be adopted. The system provides real-time monitoring of the MTR tunnels during the tunnel boring period. The system has been enhanced by interlinking with Short Message System (SMS) such that short messages will be automatically sent to key personnel for immediate action in case the pre-set movement levels are reached.

Figure 3 Tunnelling Over MTRC Operating Tunnels



2.3 ENVIRONMENTAL ISSUES

The tunnel works at the southern end of the KSL alignment in Canton Road and Salisbury Road will be constructed immediately adjacent to the Hong Kong Cultural Centre, Space Museum, a number of prestigious hotels and other buildings, all of which are highly susceptible to noise and vibration. Statutory noise limits in controlling groundborne noise are very stringent that the limit is as low as 40dB(A) during night time.

Although the use of the TBM tunnelling method already provides significant environmental benefits over the traditional cut-and-cover tunnel, there remains a concern on the level of groundborne noise generated by the TBM during its boring operation, in particular, when penetrating through hard or mixed ground strata.

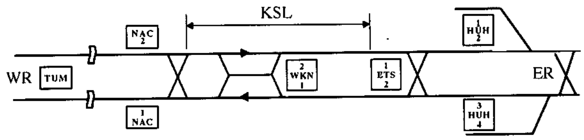
Due to limited local information, extensive studies were carried out in the planning and tendering stages to assess the probable groundborne noise level which would likely be generated and the mitigation measures that might be required. Research in similar US projects were conducted and experience was shared with overseas institutions.

The data collected has provided important guidance in the selection, design and operation of the TBM. Tailor-made slurry type TBM is finally selected which is believed to be capable to meet the engineering and environmental requirements.

3. CONNECTING TWO OPERATING RAILWAYS

First time in the railway history of Hong Kong, implementation of the KSL project presents the unique challenge of constructing a new railway to connect two operating railway lines, namely West Rail and East Rail (Fig. 4).

Figure 4 West Rail and East Rail Interchange



During the tunnel construction stage, the operational risks affecting the two adjacent operating railways will be significant and a comprehensive suite of protection measures would be established before and after the breakthrough of the KSL tunnels into the operating railways.

3.1 OPERATIONS PLANNING

As both WR and ER trains will terminate at the existing Hung Hom (HUH) Station when the KSL is completed, an efficient and yet cost effective interchange design and operational arrangement needs to be provided at HUH to serve the two railway lines which have different operating characteristics.

The interchange arrangement at HUH needs to cater for the 12-car ER and initial 7-car WR trains. As a result, the train stop locations and the associated platform train interface provisions will be revised to suit. Passenger circulation elements will be enhanced to cater for the anticipated high volume of cross platform movements.

ER is currently carrying over 900,000 passengers per day and running 24 trains per hour per direction. WR is carrying around 190,000 passengers per day and operating at 16 trains per hour per direction. When KSL is operational, any failure of one of the two ER platforms at HUH will result in serious disruption to the ER domestic and cross-border services.

Therefore, a tailor-made degraded operation arrangement has been devised to enable the changeover of one platform from WR to ER, in case one of the two ER platforms is unavailable for use. The WR service will still be maintained at today's service standard of 16 trains per hour.

This arrangement will involve a sequential changeover of the overhead line and signalling systems from WR to ER, followed by the authority of control. A number of system interlocks and checking will be incorporated in the system to ensure an efficient changeover process within 15 minutes, and to avoid any risk of human error in the process.

3.2 SYSTEMS MIGRATION

When the KSL comes into operation, WR trains will use platforms 2 & 3 at HUH Station, while ER trains will stop at platforms 1 & 4.

ETS Station will thus become a through station of West Rail.

As West Rail will be extended from NAC to HUH, all the existing ER railway systems between ETS and HUH stations have to be converted to the WR design. The migration of each railway system has been carefully planned and developed in great detail to support the finalisation of the overall project programme for contract procurement.

3.3 SIGNALLING SYSTEMS - INTERFACE AND OVERLAY

It is absolutely essential to maintain the passenger service of both ER and WR at all times. In order to achieve a seamless transition from ER operations to WR operations for the ETS-HUH section, the WR signalling system will be overlaid onto the current ER signalling system before the existing system is de-commissioned.

This presents a huge challenge, as it is necessary to maintain ER operations on this section of track during the installation of the WR signalling system. A pre-requisite of such an exercise would be to identify and mitigate the potential electromagnetic compatibility (EMC) of both systems, as well as interface and operational impacts on existing operations.

As the platform 3 at HUH station is required to be inter-operable as both a WR platform (normal operation) and a ER platform (degraded operation), the design of the signalling and traction power systems have to allow for an efficient and yet safe switch-over from one line to the other. An Independent Safety Assessor has been engaged for a review of the design and operation of this pioneering shared platform arrangement in metro railways.

4. CONTINUOUS IMPROVEMENT IN RAILWAY ENGINEERING

4.1 TRACTION ENERGY CONSUMPTION

For most railways, traction energy consumption accounts for a significant portion of the overall operating expenditure. Thus a small percentage of traction energy saving would lead to a considerable cost reduction, which is not only beneficial from a financial perspective, but is also in support of environmental friendliness and sustainable development through consuming less electricity.

Since the operation of WR, substantial experience and data were obtained from the use of the train control and signalling system i.e. Alcatel's SelTrac system. The SelTrac system adopts a target-speed control algorithm that allows trains to steadily cruise around a defined target speed. Based on this feature, a comprehensive optimisation study using simulation tools and real-life trial runs was conducted. The objective is to identify a speed control envelope that enables the train to consume less traction energy, at the expense of slightly longer inter-station run time, while maintaining the overall end-to-end journey time.

The results of the study reveal that there are potentials to reduce the traction energy consumption by carefully adjusting the speed control envelope in accordance with the inter-station distance, the speed limit and length of each respective track section. The current plan is to enhance the original WR train control algorithm by 2006, based on the identified speed control envelope. This control algorithm will be implemented on KSL. The overall energy saving for WR/KSL is envisaged to be in the order of 10%.

4.2 FLOATING SLAB TRACK

The aim of floating slab track system on WR was to achieve at least 14dB(A) reduction in the re-radiated noise, in order to satisfy the EIA requirement for an overall wayside operating noise level of 64dB(A). Through a series of design developments, laboratory verification tests, and industry surveys carried out during the design stage, the final system delivered attenuation at 12.5Hz and was successful in accomplishing its objectives.

The knowledge attained, and consequently, its benefits, was directly transferred to projects such as MOS Rail, which faced similar challenges. The "learning" cycle was much reduced on the new projects. With the increasing demand to achieve better performance in KSL and future projects, the challenge had led to further improvements of the Floating Slab Track (FST) system.

A customised design of the FST system was developed "in house" for the ultra sensitive track section at the Hong Kong Cultural Centre along the Salisbury Road for KSL. The attenuation of the new design is at 10.5Hz, which required a softer bearing and much greater mass. However, the latter must be accomplished without affecting the tunnel size of the TBM, which would not only increase the cost of the project but also could cause surface disruption if a cut & cover tunnel construction had to be utilised.

The new FST system will undergo rigorous tests during the development stage. Actual field verification will be done prior to the revenue service to ensure the objectives are met. Lessons learnt and feedback from maintenance had also been incorporated into the new design, such as accessibility for bearing inspection, simpler mountings etc. The knowledge was pooled from all concerned parties with the intention of delivering a better end product through continuous improvement.

4.3 WHEEL / RAIL INTERFACE

Because there was a concern that rail top contamination would affect wheel/rail adhesion, improvements were incorporated into the design of the trackside rail lubrication system. For WR, MOSR, and TSTE where rail lubricators are equipped with contact-less sensors, the processor timing was refined in order to permit only one application per passage, which minimised the risk of over lubrication.

Additionally, the control mechanism for the amount of lubricant delivered in each application was also adjusted to ensure no unnecessary lubricant build-up while still maintaining sufficient lubrication along the entire length of the curve. This was achieved through a continuous monitoring of the behaviour of the wheel/rail contact patch along the transition into the curve. Furthermore, at selected lubricators such as on curved tracks ahead of terminus, a directional control function was also added such that lubrication would only be applied in the desired and specific direction of traffic.

In LMC, the trigger system for the rail lubricator was further changed to contact-type, which would require the pressure applied by wheel passage to trigger the applicator. Hence, the risk of continuous application of rail lubricant when a stationary wheel is sitting directly on top of the trigger mechanism was eliminated. The same technology will be adopted on KSL. With the on-going improvement of the rail lubricant delivery system, the work has improved the maintenance and safety of the operating railway.

4.4 EMC ASSURANCE PROCESS

A more vigorous assurance process for Electromagnetic Compatibility (EMC) has been adopted. EMC audits are now conducted by "in house" EMC engineers, supplemented by on-site measurements on conducted and radiated interference. It is also a pre-requisite to have all findings from EMC audits to be satisfactorily closed prior to obtaining a no-objection to opening a new line for revenue service. This approach has proven to be effective for MOSR, and will be adopted for KSL.

5. EVOLUTION IN PROJECT MANAGEMENT

5.1 RESIDENT SITE STAFF

Before KSL, civil construction contracts were supervised by resident site staff (RSS) employed by consultants. KCRC deployed a separate project manager team, as the Employer's representative under the contracts. The RSS arrangement has shown deficiencies in a railway environment for effective management and timely delivery of projects due to:

- duplication of some roles and responsibilities between RSS and KCRC staff
- insufficient understanding of railway operation and constraints by RSS
- complex design and construction interfaces with multiple railway system contracts which are supervised directly by KCRC staff

As an outcome of project review, KCRC has decided to adopt the Design-and-Build contract strategy for KSL and future projects. Accompanying this change, all site supervision staff are employed directly by KCRC. This will streamline the design review and contract administration process to meet the need of fast-paced projects.

5.2 INVOLVEMENT OF OPERATING & MAINTENANCE STAFF

The early involvement of O&M staff in new projects is believed to be one of the key factors leading to the smooth handover of projects upon completion.

O&M staff has been involved in design review, Hazard & Operability (HAZOP) studies and maintaining Hazard Log. They could transfer lessons learnt from operating lines to enhance the design and avoid recurrence of problems previously encountered, and to ensure hazards are designed out or mitigated to a level which is As Low As Reasonably Practicable (ALARP).

For previous projects involving extension from existing operating lines such as Tsim Sha Tsui Extension and Lok Ma Chau Spur Line, the O&M staff has contributed significantly to the seamless integration and migration of systems without affecting the service of operating railways.

6. CONCLUDING REMARKS

More railway projects are being planned in the coming years to further extend the Hong Kong rail network both within urban areas and to the boundary linking with the Mainland China railway networks. The experience and the expertise accumulated from the implementation of major projects during the last 10 years has well equipped KCRC to take on these new challenges.