THE HONG KONG
INSTITUTION OF ENGINEERS
ELECTRICAL DIVISION

The 32nd Annual Symposium

Thursday

30th October 2014

POWERING INTO THE FUTURE

at

Ballroom

Sheraton Hotel

Nathan Road

Kowloon

Hong Kong

SYMPOSIUM PROGRAMME

08.30 **Registration and Coffee**

09.00 **Welcome Address**

— Ir Siu-Kwong Ho
Chairman, Electrical Division, The HKIE

09.05 **Opening Address**

— Ir Victor C.K. Cheung
President, The HKIE

09.10 **Keynote Speech**

— Professor T.S. Zhao
Chair Professor
Mechanical and Aerospace Engineering
Hong Kong University of Science & Technology

1. Powering Our Future

09.40 **How the Internet of Things will Enable Utilities and Consumers to Collaborate to Improve Cost and Reliability of Supply**

— Mr Wayne Pales
Head, Smart Grid Programme
CLP Power Hong Kong Limited

10.00 **After the Fuel Mix Public Consultation, How Should We Move On?**

— Ir T.C. Yee, General Manager (Corporate Development)
— Ir Y.C. Wu, Manager (Strategic Development)
The Hongkong Electric Co. Ltd.

10.20 **Discussion**

10.40 **Coffee Break**

2. Energy & Asset Management

11.10 **Listen to Your Assets – Developing More Effective Asset Management Strategies**

— Mr H. Peter Dunker, Head, T&D Asset Services
— Dr Ramon Nadira, Head, Network Services
— Mr Juan C. Ledezma, Product Lifecycle Manager, Network Services
Siemens Ltd.

11.30 **Implementation of Energy Management Systems in Public Rental Housing Estates**

— Ir Dick L.S. Chan
Senior Building Services Engineer
Hong Kong Housing Authority
The Government of the HKSAR

11.50 **The Buildings Energy Efficiency Ordinance and its Codes – Key Driver of Building Energy Efficiency**

— Ir Patrick Y.F. Cheung, Chief Engineer
— Ir Dominic S.K. Lau, Senior Engineer
— Ir David W.H. Li, Engineer
Electrical & Mechanical Services Department
The Government of the HKSAR

12.10 **Discussion**

12.30 **Lunch**

3. New Design in Mass Transit

14.10 **Regenerative Energy Storage System Makes Trains Go Greener**

— Ir Dr Tony K.Y. Lee
Chief of Operations Engineering
Mr Anson S.K. Chan
High Voltage and Mechanical System Engineering Manager
Operations Division
MTR Corporation Limited

14.30 High Speed Train Design for Express Rail Link

— Ir C. L. Leung, Chief E&M Engineer
— Ir M. F. Cheuk, Construction Manager - Rolling Stock
Projects Division
MTR Corporation Limited
— Mr Ding Sansan, Vice Chief Engineer
CSR Qingdao Sifang Co., Ltd.

14.50 Discussion

15.10 Coffee Break

4. Innovations & Technology Developments

15.40 Distributed Electric Springs for Smart Power Grid Stability

— Professor Ron S.Y. Hui
Chair Professor of Power Electronics
Department of Electrical & Electronic Engineering
University of Hong Kong

16.00 Application of Computerized Power System Analysis

— Ir Michael M.F. Waye, Director
— Ir Sally M.W. Yuen, Assistant Vice President
Parsons Brinckerhoff (Asia) Ltd.

16.20 Discussion

16.45 Summing Up

— Ir C.L. Leung
Symposium Chairman
Electrical Division, The HKIE

Closing Address

— Professor Norman C. Tien
Dean of Engineering
Faculty of Engineering
The University of Hong Kong

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Mr Juan C. Ledezma
Ir Dick L.S. Chan
Ir Patrick Y.F. Cheung
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Ir Dr Tony K.Y. Lee
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Paper No. 1

HOW THE INTERNET OF THINGS WILL ENABLE UTILITIES AND CONSUMERS TO COLLABORATE TO IMPROVE COST AND RELIABILITY OF SUPPLY

Speaker: Mr Wayne Pales
Head, Smart Grid Programme
CLP Power Hong Kong Limited

HOW THE INTERNET OF THINGS WILL ENABLE UTILITIES AND CONSUMERS TO COLLABORATE TO IMPROVE COST AND RELIABILITY OF SUPPLY

Mr Wayne Pales
Head, Smart Grid Programme
CLP Power Hong Kong Limited

Paper No. 1

ABSTRACT

In recent years the terms "Internet of Things" and "Smart Grid" have worked their way into many people's vernacular.

The Internet of Things (IoT) is a concept where every day physical objects are connected in a way that they can identify themselves to other devices as well as to other data sources so more informed decisions could be made.

Beecham Research released a graphic[1] of an IoT ecosystem mapped into industry sectors, refer Figure 1, and within that makes reference to the Energy sector and the Home & Consumer Sector.

Smart Grid is the Energy sector's interpretation of the "Internet of Things". When references are made to capabilities such as; self-healing networks, and condition monitoring, they are based on the same concept; that physical objects are now able to communicate information about itself, and identify itself to other objects and data sources, so more informed decisions can be made.
`
Over the last twelve months the Consumer & Home sector has seen some major announcements by large Consumer focused organizations in relation to leveraging the concept of Internet of Things for in-home appliances such as; air-conditioning, entertainment systems, lighting, etc.

This paper describes how the convergence of IoT across the Energy and Consumer & Home sectors could help optimize asset and grid performance, and at the same time, empower consumers to save money, and additionally, reduce impact on the environment.

1. INTRODUCTION

Smart Grid can be considered as the Utility industries interpretation of the larger Internet of Things (IoT).

Kevin Ashton claims the phrase *Internet of Things* started its life in a presentation he delivered at Procter & Gamble in 1999[2]. Since this phrase was first used there continues to be numerous definitions, but for the purpose of this paper the following definition is applied:

"The Internet of Things (IoT) is a computing concept that describes a future where everyday physical objects will be connected to the Internet and be able to identify themselves to other devices…No longer does the object relate just to you, but is now connected to surrounding objects and database data. When many objects act in unison, they are known as having "ambient intelligence.""

Andres Carvallo claims to have defined the term Smart Grid on March 5th 2004 whilst Chief Information Officer of Austin Energy. As with *IoT* the term *Smart Grid* continues to have multiple definitions. For the purpose of this paper the following is applied:

"The smart grid is the integration of an electric grid, a communication network, software and hardware to monitor, control, and manage the creation of the distribution, storage and consumption of energy. The smart grid of the future will be distributed, it will be interactive, it will be self-healing, and it will communicate with every device."

Both describe a similar concept, whereby physical objects will be connected and able to identify themselves to other devices and data sources, so more informed decisions could be made, whether that is by humans or machines.

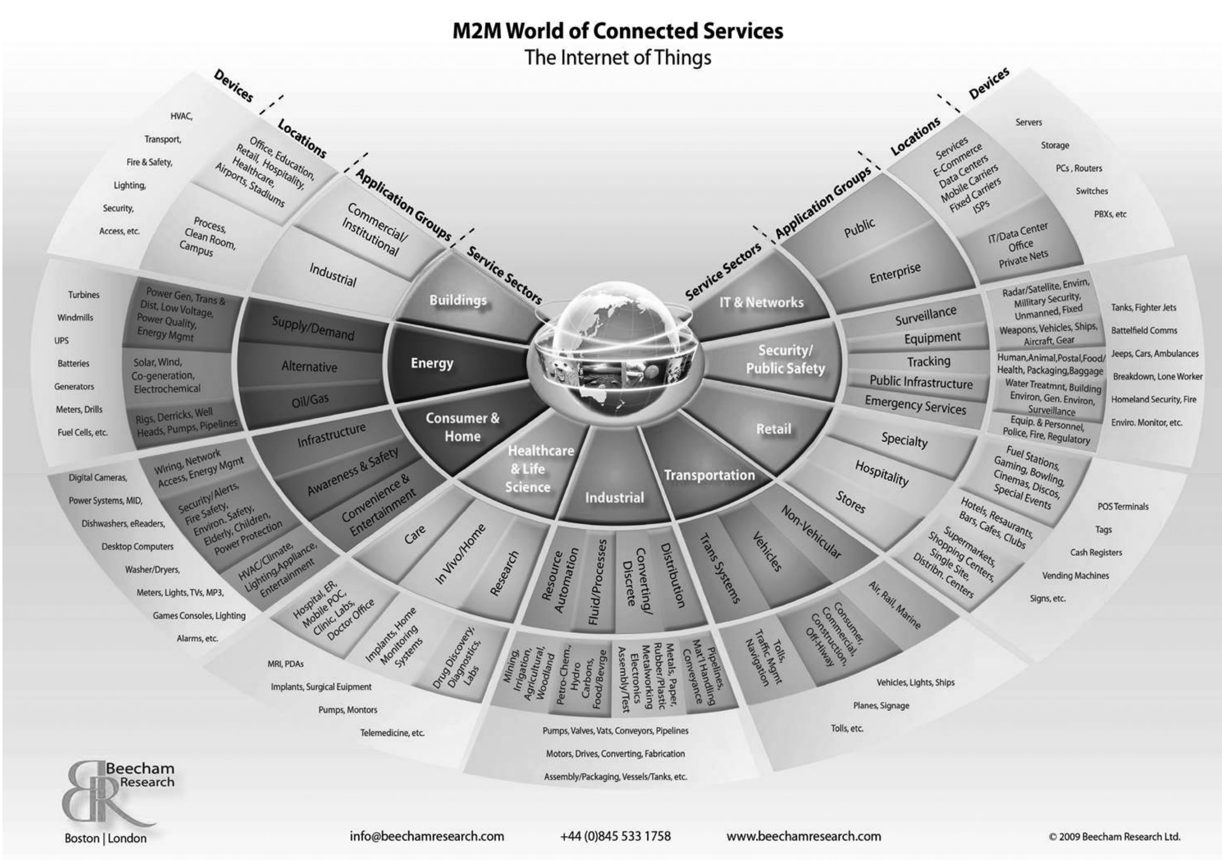
The physical implementation of the Internet of Things will be different across industry sectors as can be seen in Figure 1 below.

With the growth in investment in IoT by both the Energy and Consumer & Home sectors, there are opportunities to create new and improved products and services to optimize grid performance whilst empowering consumers to save money and reduce impact on the environment.

2. HOW IOT IS TRANSFORMING THE TRADITIONAL ELECTRICITY UTILITY

Historically a Utility has various levels of visibility into its low voltage network but, with the exception of large customers, would have little insight into what is happening at the edge of its network, i.e. at the customer's premise,

Figure 1: Internet of Things Across Sectors



and virtually no insight as to what is happening beyond its network, i.e. within the customer's premise.

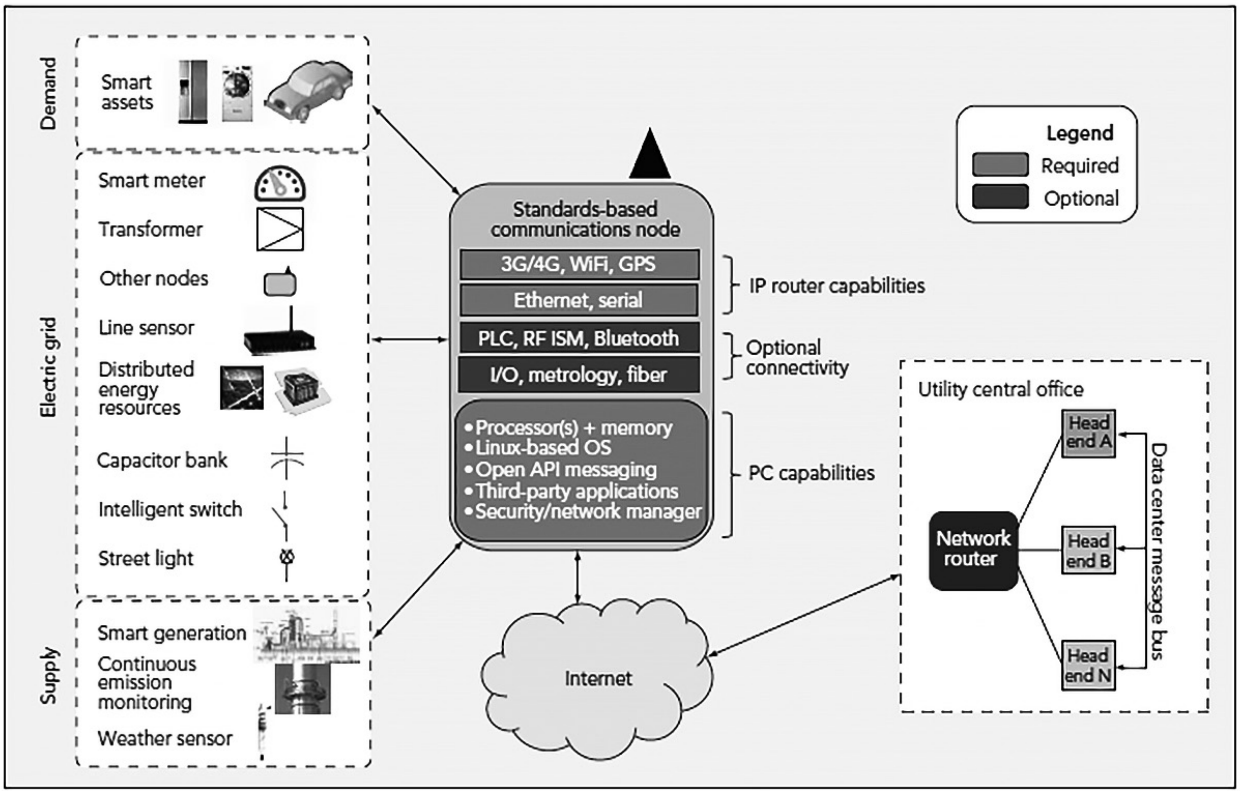
With the continued reduction in cost of compute and networking, many Utilities are now implementing devices at the edge of its network, such as, Smart Meters. Smart Meters are IP-enabled devices that use the same communication protocols as are the foundation of the Internet.

The benefits of having such devices at the edge of a Utilities network, and embedding digital throughout the Grid, enables a level of visibility and control that was not previously possible. This visibility will lead to improvements in the safety, quality, and reliability of power supply and optimize how assets are managed, as well as drive down overall cost of service. Additionally, it will enable new and improved products and services that empower the customer to make informed decisions about their energy use (to save money) and reduce environmental impact.

As a result of IoT within the power industry, many Utilities are rethinking their overall grid architecture, Duke Energy is one of such Utilities exploring distributed intelligence. Figure 2 describes their vision for the utility "Internet of Things' platform, where the architecture integrates data from multiple sources across a wide range of assets and enables distributed intelligence.

Similarly CLP Power has recently published its 2020 Smart Grid vision, refer Figure 3. By 2020, we see the traditional power grid having 'digital' embedded throughout. This will provide much higher fidelity 'situational awareness' overall and also extends

Figure 2: Duke Energy's Vision of Utility "Internet of Things"



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to integrate with consumer driven technologies. Specifically, it will provide:

i. Timely visibility & integration of external Events

ii. Timely Event information processed at the 'Edge'

iii. Timely insights distributed to field workforce

iv. Cross Business Unit visibility of Events

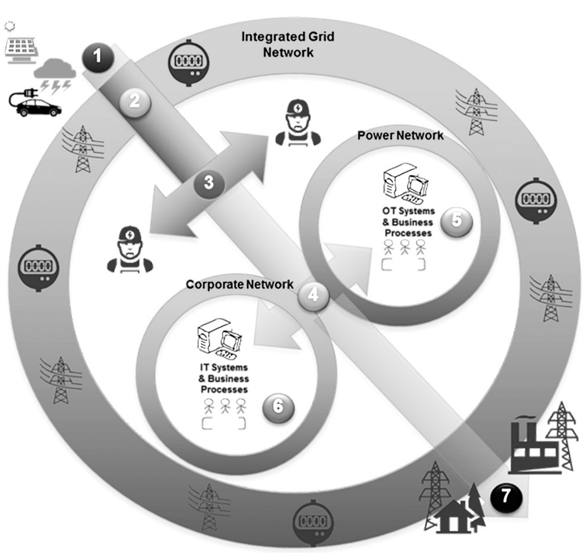
v. Analytics delivering insights for Grid & Asset Management

vi. Analytics delivering insights for Customer Operations & Engagement

vii. Insights that can be shared with customers & partners

The goal is to ensure the right information is delivered to the right person/place at the right time for action to be taken.

Figure 3: CLP Power's 2020 Smart Grid Vision



This creates the ability to have a level of collaboration with energy consumers beyond what is possible today, by integrating the grid with consumer technologies, deliver greater possibilities for energy conservation and grid optimization.

3. GROWTH IN THE IOT CONSUMER & HOME SECTOR IS DRIVING NEW OPPORTUNITIES FOR COLLABORATION

The topic of IoT in the Consumer & Home Sector is very broad. In the context of this paper, reference to the Consumer & Home Sector specifically focuses on the ability to measure and manage consumption of electricity at an appliance level, such as Heating, Cooling, Lighting, etc. This will be referred to as the Home sector from this point in this paper.

There are typically two sources of funding for IoT in the Home sector, those by the Utility, and those by the Consumer.

Before exploring the new opportunities that will come about from the growth in IoT in the Home sector we must first understand the drivers, both from a Utility perspective and the Consumers' perspective.

3.1 ENERGY EFFICIENCY & CONSERVATION TO SAVE MONEY AND SAVE ENERGY

For many years, both the Public and Private Sector, has been implementing a combination of new energy optimization-focused: regulations, products and services. All of which are aimed at raising awareness, within their respective communities, to optimize the use of electricity.

Energy efficiency has relied heavily on regulation to drive changes to building codes, appliance standards, etc. Energy conservation relies on people changing their behavior. Whilst this has achieved different levels of success throughout the world, new research[5] published has found that many people want services that help them to save energy and save money, without it using up any of their 'discretionary time' (the part of the day outside working hours). Customers are saying they want to have *set and forget* energy saving services and have it provided by others, rather than analyze the data themselves on a daily basis.

3.2 DEMAND RESPONSE TO OPTIMIZE GENERATION ASSET INVESTMENTS

Utilities must balance supply with demand. Growth in; distributed generation, energy storage, electric vehicles; air conditioning, and, more affordable consumer electronic devices are seeing a shift in consumer demand patterns. These patterns are less predictable as they were in the past. Left unchecked this would result in a grid with a low load factor that would drive up the unit cost of energy due to investment in infrastructure to cater for peak demand and high operational costs. Additionally, this could lead to issues with the safe and reliable supply of electricity.

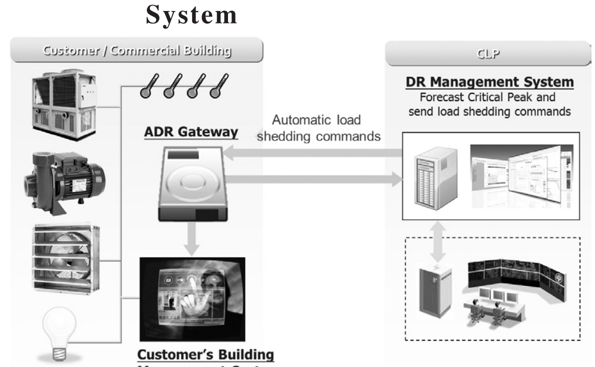
Maximum demand for electricity in many Countries is weather driven and occurs just a few hours a year. As energy cannot yet be cost effectively stored at scale, a Utility, to satisfy these few hours of peak demand, must ensure they have adequate Generation infrastructure. The rest of the year much of this may go un-utilized, but even when un-utilized it needs to be maintained and ready for operation at a moments notice.

Hong Kong is no different and between the months of June and September experiences system peaks that are a result of hot and humid weather, usually just as a typhoon is approaching.

CLP Power is currently implementing an Automated Demand Response (ADR) capability for its large commercial and industrial (C&I) customers.

With ADR, CLP installs a series of technologies at the customers' premise that enables it to automatically reduce energy consumption of major equipment, like chillers, Air Handling Units (AHU) and boilers through Building Management Systems (BMS). The degree of change is pre-agreed with the customer and if, for any reason, the customer does not want to take part in that particular event they can opt-out. Figure 4 illustrates how this works.

Figure 4: Overview of CLP Power's Automated Demand Response System



Immediately following a demand response event, each customer's energy saving (kWh) is calculated and financial incentive will be paid to the customer according to that kWh saving.

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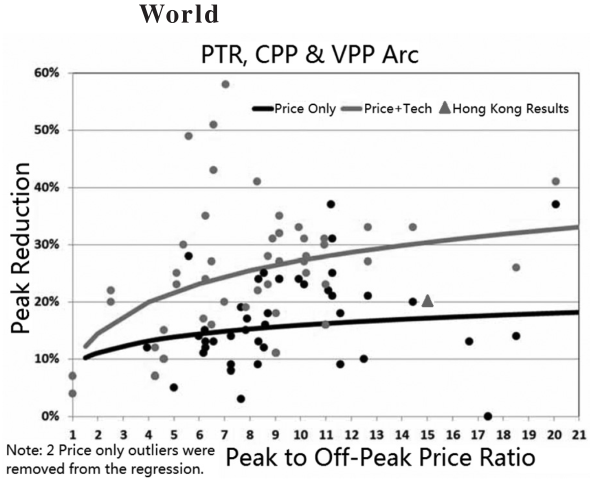
ADR remains to be too costly to implement with residential and small business customers, so for those customers just smart meters are being installed to allow a utility to capture their usage at time intervals (e.g. as every thirty minutes), and then be able to provide data in a timely fashion to the consumer via channels such as web and mobile. In this case, the consumer will be offered financial incentives to encourage reduction in energy use during peak time.

CLP Power is currently running a pilot to understand if customers will, conserve or shift energy consumption, during critical peak periods to reduce pressure on the system. The customer encouraged with a rebate. In August 2013 CLP ran Hong Kong's first demand response event and as can be seen in Figure 5[6], residential customers demonstrated that, in line with what has been experienced elsewhere in the world, people in Hong Kong are prepared to reduce their energy consumption.

Figure 5: CLP Power's Customers Behave Similar to Others Around the World



The graph in Figure 5 shows two lines; the black line is where only price incentives were given, and the grey line where price incentives and in-home technologies were used. This supports the hypothesis that customers want to take part in such events, but want to rely on technology so they can *set and forget*.

3.3 DEMAND SIDE MANAGEMENT TO OPTIMIZE GRID PERFORMANCE AND NETWORK INVESTMENTS

Utilities are also exploring how it can influence electricity demand at specific locations in the network to enable it to:

- Optimize its investment in network assets; and,
- Improve safety and reliability of supply.

There are typically three scenarios Utilities are exploring:

- Reducing a customer's demand during times when a part of the network is under pressure due to very high usage to avoid reliability issues;
- Reducing a customer's demand during times when a part of the network is under pressure due to an incident on which reduces its ability to meet normal demand; and,
- Flattening the demand on a daily basis to reduce maintenance costs and to extract greater value from network assets to optimize network costs.

3.4 UTILITY-LED INVESTMENTS IN THE HOME ENERGY SECTOR

In many countries around the world, including Hong Kong, it has been the residential segment whose changes in buying habits of home appliances and energy use patterns have driven peak demand fastest.

As mentioned previously, many Utilities have been investing in Smart Meters, in part to empower customers to make more informed decisions about their energy usage, as well as offer greater product choice by being able to design tariffs based on any combination of consumption, demand, and time of use.

As described, a number of these products are focused on encouraging customers to reduce critical peak demand, and has been adopted by many utilities to encourage customers to reduce electricity consumption during peak periods and to combat supply and demand imbalances.

Whilst these financial incentives have proven to change customer behaviour, a series of programmes have shown that with the addition of being able to remotely control customer's electricity load at an appliance level yields even greater demand cut.

As a result of this a growing number of Utilities are exploring how, Utility-funded in-home technologies can deliver an increased ability to reduce critical peak demand and avoid further investments in generation, transmission and distribution.

There are a number of Utilities, such as NRG Energy and its subsidiaries Reliant and Green Mountain Energy, National Grid, Austin Energy and Southern California Edison that are partnering with IoT Home Energy providers, such as Nest's Thermostat[7], to deliver demand response programmes[8].

Other examples include Honeywell's Thermostat where they have partnered with South Sioux City in Nebraska[9] to deliver residential demand response programmes.

Partnered with smart metering, which can record a customer's usage at time intervals, such as every thirty minutes, they can then calculate the reduction in energy consumption during these times of critical peak demand and provide customers financial incentives.

3.5 CONSUMER LED INVESTMENTS IN THE IOT CONSUMER & HOME SECTOR

For a number of years there have been a number of *false starts* where there has been an expectation of rapid adoption of IoT in the Home Energy sector without it materializing. It is still uncertain as to the scale and pace of this adoption and will differ from country to country and household to household, but with recent announcements from market leaders such as:

- Apple's announcement to release a Homekit[10];
- Samsung's recent acquisition of SmartThings[11];
- Google's recent acquisition of Nest[12]; and,
- Microsoft has introduced a home automation accelerator[13]

In addition we have seen the introduction of intelligence devices that can be controlled by these home automation systems, for example:

- Quirky's partnership with GE to introduce a wi-fi enabled Air Conditioner that can be remotely controlled with its Wink app[14]; and,
- Phillip's launched a sub-US$15 lightbulb that is Zigbee-enabled

and allows remote control via a mobile application.

These are just some of the growing examples of devices that are becoming available, with so much investment from so many Companies it can be hypothesized that in the coming decade we will see a significant increase in the adoption in consumer led investments in IoT in the Home Energy sector.

4. CONVERGENCE WILL LEAD TO SERVICE INNOVATION

Utilities continue to explore the most cost effective ways to deliver demand response programmes.

Recent research[15] has indicated that customers do not want to have to spend their discretionary time looking at consumption data and trying to work out how to save energy and save money. Instead many want to set and forget and in many cases this same study has shown consumers will even pay a premium to have these services managed for them.

Examples of new Services that could emerge by the convergence of technologies in the Energy sector with the Home Energy sector include:

4.1 DEMAND RESPONSE WITH DIRECT LOAD CONTROL

As customers introduce Internet connected devices into their homes we will see Utilities begin to offer a wide range of Demand Response programmes where customers enter into an arrangement with the Utility allowing them to remotely change the settings to certain devices during times of peak energy demand in exchange for financial incentives.

The customer will have preset the parameters so they are never uncomfortable and they would always have the ability to opt out of an event. This creates an increased level of certainty for the Utility that they can secure demand cut, significantly increasing the load they have under management.

At scale this could allow a Utility to leverage its own Demand Response Management System to send commands to tens of thousands of devices to reduce the load during a few hours of critical peak demand.

A Utility would further leverage its Smart Metering technology to inform the customer of the overall reduction in consumption at their premise and calculate the appropriate financial incentives. The customer, doing nothing other than a one off setting of preferences could then enjoy ongoing financial incentives without any further involvement.

The integration between these two sectors is key, as whilst a customer can leverage their in-home technology to control equipment such as their Air Conditioning unit themselves, it is only by integrating this with a Utilities Demand Response Management System and Smart Metering system that a customer can earn financial incentives whilst helping the Utility to deliver reliable and safe supply at the most optimal price.

4.2 SET & FORGET ENERGY CONSERVATION TO SAVE MONEY AND REDUCE ENVIRONMENTAL IMPACTS

Again, a customer with Home Energy technologies can perform a variety of energy conservation activities themselves, however for a Utility it is not just about how much energy is being consumed, but when it is being consumed.

Services could be offered that allow a Utility to monitor device level consumption as a result of a consumer's investment in Home Energy solutions and provide a range of product offerings such as:

- Offering customers services to help manage within a certain monthly budget. Advising customers that their current patterns will exceed a preset budgeted amount and highlight high use appliances;
- Offer different products to better suit the consumers' lifestyle whilst helping the Utility optimize the use of its network. For example, introducing time-based pricing but also services to help customers minimize their use during time of peak demand. This could simply be a notification service to advise the customer they are entering a peak period and they have X number of air conditioners all running at a low temperature and providing advice on how to change this.

5. FACTORS THAT WILL INFLUENCE THE PACE OF ADOPTION

The adoption of IoT in the Home Energy sector will progress at various paces around the world.

In terms of service innovation created as a result of the convergence between these two sectors most Utilities are focused on direct load control of heating and cooling equipment as this is the major contributor to peak demand. As the weather gets hotter or colder people will change their energy usage to ensure they remain comfortable.

For this reason it is important to understand the different ways consumers typically implement heating and cooling technologies. In the future it is expected that appliances such as Air Conditioning will have wi-fi built in, for the pre-installed base they can be broadly placed into three categories.

5.1 CENTRALLY CONTROLLED THERMOSTATS

This is where a residential home has its heating and cooling managed via a single, centrally controlled thermostat.

As has been observed, with solutions from the likes of Nest and Honeywell, this is where we are most likely to see the fastest growth in service innovation as a result of convergence between the Energy sector and Home Energy sector service innovation between a Utility and the Consumer.

5.2 INDIVIDUAL UNITS WITH A PLUG SOCKET

Another wave of products that we can expect will support a convergence between the Utility and a Consumer is any device, such as a single unit Air Conditioner; that is powered via a removable power plug. This allows a piece of technology to be easily placed between the plug and the socket to connect it to a network. This enables the power to be remotely turned on and off.

An example of a successful implementation of this technology can be seen with ConEd in New York and their CoolNYC[16] residential demand response programme where they have over 10,000[17] New York City Air

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Conditioning units part of their demand response programme.

5.3 INDIVIDUAL UNITS WHERE THE POWER IS DIRECTLY CABLED

These are the most difficult of devices to retrofit with network connectivity. Within this category these devices can be remotely controlled within the home via infra-red or by changing the settings at the actual device itself giving no ability for remote control.

Organizations such as Google[18] are looking into this challenge to connect split HVAC systems either to the Internet or to a Utilities smart meter. This is the least mature area and will likely to be the slowest segment to grow.

6. CONCLUSION

The growth of the Internet of Things in both Energy and Home Energy sectors will naturally lead to convergence. This will result in the introduction of new products and services that allows customers to save energy and save money with minimal impact on their 'discretionary time'. In addition, the Utility will be able to improve supply reliability whilst optimizing its cost to serve.

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Paper No. 2

AFTER THE FUEL MIX PUBLIC CONSULTATION, HOW SHOULD WE MOVE ON?

Speakers: **Ir T.C. Yee**
General Manager (Corporate Development)
The Hongkong Electric Co., Ltd.
Ir Y.C. Wu
Manager (Strategic Development)
The Hongkong Electric Co., Ltd.

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ABSTRACT

The HKSAR Government Environment Bureau launched a 3-month public consultation on the future generation fuel mix targeting to improve both air quality and carbon intensity from the early 2020s. The consultation ended on 18 June 2014 and about 86,000 responses from individuals and different stakeholders have been submitted to the Government. Between the two options proposed in the consultation document, there had been heated debates and diverse views during the consultation period. This paper presents an overview of the key issues on electricity supply reliability, affordability, environmental performance, and future market regime raised in the consultation. It then tries to draw some pictures on the way forward.

1. INTRODUCTION

The HKSAR Government Environment Bureau conducted a 3-month public consultation on Hong Kong's future fuel mix for electricity generation from 19 March to 18 June 2014. The consultation document proposes two options on Hong Kong's future fuel mix, namely (1) Mainland grid purchase and (2) increasing local gas generation, for the public to consider.

During the consultation period, there had been heated debates and diverse views between the two options. This is natural as the issues surrounding the future fuel mix are highly complicated and technical, while the information available for decision making is quite limited. In fact, one of the bitterest criticisms of the public consultation has been that there is insufficient information for the public to make an informed choice between the options.

Before one can seriously consider the two options, he/she needs to understand quite a number of inter-related issues on the fuel mix policy in general and the two proposed fuel mix options in particular. Hopefully, this paper can contribute in this aspect and help readers make a better informed decision.

2. THE NEW FUEL MIX POLICY

2.1 NEW BALANCE OF THE ENERGY POLICY OBJECTIVES

The HKSAR Government's energy policy has always been to ensure that the energy needs of the community are met safely, reliably, efficiently and at reasonable prices, while minimising the environmental impact of electricity generation. As noted by the Government in the consultation document, these four policy objectives of safety, reliability, affordability and environmental performance are competing objectives in that the achievement of one may come at the expense of others.

It should note that the introduction of the new fuel mix policy, or more specifically the pursuit of one of the proposed options, is a shift in the balance between the Government's four policy objectives. By adopting either of the fuel mix options, Hong Kong is effectively shifting the balance towards better environmental performance to improve air quality and combat climate change while creating new challenges in the other three policy objectives, in particular affordability and reliability.

2.2 UNCERTAINTIES AND RISKS

Any change will unavoidably bring uncertainties. Being the most fundamental requirement, any uncertainty on the four key policy objectives should be clearly identified and evaluated in making the future fuel mix decision. Particular attention should be paid to the fact that, given the potentially long planning horizon for the required infrastructure, there will be considerable risks in inadequate infrastructure capacity, cost overrun and delay in completion. Such risks must not be overlooked.

2.3 POSSIBLE EFFECTS ON FUTURE MARKET REGIME

The Government has indicated that it will engage the public to review the post-2018 regulatory framework for the electricity market. The outcome of the public consultation on the future fuel mix will have important implications for this review. In fact, if the proposed fuel mix options are to be pursued, some of the existing coal-fired generation units may have very low utilization in the future. Early retirements and mothballing of these under-utilized coal-fired generation units may be necessary. There may be significant economic implications and complicated stranded cost issues may arise.

It is likely that constraints on future electricity market development will be imposed by the fuel mix decision. For instance, power companies may, in relation to their implementation of the chosen fuel mix, have entered into long-term contracts which are difficult to change and incur stranded costs for new infrastructure. These will reduce flexibility of possible market changes.

3. THE TWO FUEL MIX OPTIONS AND THE SURROUNDING ISSUES

3.1 A CLOSER LOOK AT THE TWO OPTIONS

The following table summarizes the 2023 fuel mix under the two proposed options in the consultation document and how they compared with Hong Kong's 2012 actual fuel mix and 2015 fuel mix projected by HK Electric.

Figure 1 2023 Fuel Mix Projection

FUEL MIX		IMPORT		NATURAL GAS	COAL (& RE)
		NUCLEAR (DBNPS)	GRID PURCHASE		
Existing (2012)		23%	--	22%	55%**
OPTION 1*	Importing more electricity through purchase from the Mainland power grid	20%	30%	40%	10%
		Total: 50%			
OPTION 2*	Using more natural gas for local generation	20%	--	60%	20%
Projected 2015 Fuel Mix	Second Technical Memorandum under Air Pollution Control Ordinance(Cap.311) and Air Quality Objectives	~20%	--	~40%	~40%

* The above fuel mix ratios aim at providing a basis for planning the necessary infrastructure for electricity supply. Flexibility should apply to actual deployment of each fuel type, having regard to the circumstances happening on the ground.

** Inclusive of a small percentage of oil

Option 1 proposes that about 30% of Hong Kong's electricity demand will be met by purchase from the Mainland power grid, or in practice from China Southern Power Grid (CSG) which is the only electricity grid operator in southern China. In comparison with the projected 2015 fuel mix, the proportions of nuclear electricity imported from Daya Bay Nuclear Power Station (DBNPS) and local gas generation will be kept at the 2015 level, which are 20% and 40% respectively. In essence, Mainland grid purchase will replace local coal generation and the total import from the Mainland, i.e. from DBNPS and the CSG grid, will account for around 50%.

When considering option 1, one should bear in mind that the proposed 30% grid purchase from the Mainland is a very large quantity of electricity of about 15 billion units per year, which is even greater than the total amount of hydro power transmitted from the Three Gorges to the entire Guangdong province in 2012. To ensure the huge amount of electricity is transferred reliably, the interconnection between Hong Kong and Mainland must be greatly enhanced, probably by constructing a long cross-boundary transmission link with capacity of several thousand megawatts plus adequate redundancy. Due to the project nature of the transmission link, the construction time will be long in the order of about ten years, with huge financial commitments to be made in one go and high demand for land in both Hong Kong and Guangdong. The infrastructure under option 1 will be massive, expensive, complicated and challenging to build. There will be considerable uncertainties for infrastructure under option 1.

On the other hand, option 2 follows the existing trajectory of increasing local gas generation: the proportion of local natural gas generation will be increased from around 40% in 2015 to 60% to reduce local coal generation. Import from the Mainland will remain unchanged at 20% with DBNPS being the only power source outside Hong Kong.

The challenges and uncertainties for infrastructure construction under option 2 will be much lower. Option 2 requires the installation of new combined cycle gas turbine (CCGT) units with much shorter lead time of four to five years, which can be installed at the existing power stations on the previously allocated land and typically have unit capacity of several hundred megawatts. The units are to be installed in a gradual unit-by-unit manner in response to the dynamic demand condition. The financial commitments are accordingly made only on an as-needed basis and the installation works are subject to less uncertainty.

3.2 SUPPLY RELIABILITY

As one of the most densely populated vertical cities in the world and an international financial hub, reliable electricity is of utmost importance to Hong Kong. Hong Kong has a high-density and high-rise living environment, and heavy reliance on elevators and mass transit transportation; air-conditioning is considered indispensable by many; computer and control systems are the lifeblood to our financial and commercial activities; and telecommunications is essential for connecting people. There is without a doubt that electricity has penetrated into every aspect of our daily lives, and is critical to the lifestyle and business activities of Hong Kong.

Hong Kong's two power companies have been planning, building and operating their generating plants and networks to the highest international standards to suit Hong Kong's local environment. These endeavors have led Hong Kong to be one of the few cities in the world with top electricity supply reliability for many years. Indeed, World Economic Forum has ranked Hong Kong as the number 1 among 148 economies in respect of electricity supply quality. HK Electric has sustained a reliability rating in excess of 99.999% since 1997, and the average power interruption recorded is of a world-class standard of less than 1 minute per customer per year. Hong Kong people expect the highest reliability standard to be maintained at all times - they simply cannot afford to compromise on the reliability of the electricity supply.

Self-sufficiency in electricity has been in place in Hong Kong since the very beginning. Even for nuclear power which Hong Kong is unable to generate itself and must import, the nuclear generation plants at Daya Bay and associated transmission facilities are carefully engineered so that they are under tight control from Hong Kong and act like an extension of the Hong Kong power systems. Based on such arrangement, Hong Kong has enjoyed world class electricity reliability over the years. The increased use of natural gas as fuel in local electricity generation under option 2, with the Hong Kong power companies having full control and holding full responsibilities, is best placed for the high reliability to continue.

On the other hand, option 1 is demanding a massive and reliable transfer of 15 billion units per year of electricity through the complex CSG power grid. This unprecedented arrangement will undoubtedly give rise to complex issues of system stability and capacity adequacy.

Firstly, the supply reliability of CSG is not at par with Hong Kong. The average power outage of CGS's urban customers is 2.31 hours in 2013. One of the reasons for this is that the CSG power grid mainly consists of overhead power lines which are more vulnerable to external factors like adverse weather. Secondly, Guangdong's installed capacity is still insufficient to meet its maximum demand, and the province is heavily reliant on electricity import, including import from CLP Power, to maintain its supply adequacy. Finally, the consultation document puts forward back-up generation capacity, and in particular extending the useful life of existing power plants, as a possibility to cater for emergency. However, the feasibility and cost-effectiveness of such an arrangement are probably low. It is unrealistic to assume that the existing ageing coal-fired generation units in Hong Kong can be kept for back-up support, as their useful lives cannot be extended indefinitely. Any back-up capacity will require teams of operators for routine maintenance and on-call operation, and spare parts and fuel stock will need to be kept, such redundancy being wholly uneconomical. Regardless of the type of standby generating plants Hong Kong can provide, restoring 30% of electricity supply from an interruption, even assuming the remaining 70% Hong Kong supply could survive and there are readily available generating plants with the required capacity, can easily take hours if not days. There can be no assurance that the backup provision will be able to provide relief to an emergency in a timely manner to maintain Hong Kong's electricity supply.

Apart from direct reliability threats, there are also concerns on delay in completion of transmission infrastructure required under option 1. There is possibility that, in case of delayed completion of the transmission infrastructure for electricity import, Hong Kong will experience a temporary but unacceptable period of having insufficient generation capacity for maintaining reliable supply.

Comparing with option 2, option 1 is untested and highly uncertain, and there are grave concerns on its possible adverse impacts on Hong Kong's supply reliability. There are serious doubts on its technical arrangements and implementation, system risks, and the non-availability of local back-up generation to cater for emergency. Even if it will ultimately be possible for painstaking arrangements to be made to reduce the impact on reliability at additional costs, the question remains why Hong Kong should accept an option with higher reliability risk and then incur a great deal of effort and costs to reduce such risk.

3.3 AFFORDABILITY

Though with no indigenous fuel, Hong Kong's electricity tariff is highly competitive. According to the consultation document, Hong Kong's electricity tariff for representative domestic customers with monthly consumption of 250kWh is well below those of other metropolitan cities including Singapore, Tokyo, Sydney, London and New York. In fact, the electricity tariffs in Hong Kong are affordable and account for only 1.77% of the average total household expenditure based on Census & Statistics Department's survey.

While it is unavoidable that electricity tariff will have to increase under the new fuel mix, it is likely that option 1 is less affordable than option 2. The engineering complexity, the huge demand for land in both Guangdong and Hong Kong, together with the need for extensive negotiations amongst CSG, the power companies in Hong Kong and the different levels of governments will give rise to significant project uncertainties, likely leading to unmanageable time and cost over-run. Furthermore, under option 1 Hong Kong will be in a very poor position to bargain for fair, reasonable and competitive import prices. The option will effectively make CSG a monopolistic grid supplier not subject to the HKSAR Government's scrutiny. Under option 1, Hong Kong will become a captive buyer which has no choice but to continue to import grid electricity to satisfy its demand at grid supply prices, quality, terms and fuel mix controlled by CSG.

For option 2, the rapid gas infrastructure development along the Guangdong coast, the increasing liquefied and piped natural gas supply to Asia, and the commencement of off-shore gas field production in the South China Sea all have the effect of increasing natural gas supply. Gas prices have come down from their historical peaks and will likely be stabilized at the present level with room for further reduction. A fact worth noting is that, given that local gas generation will have a fuel mix proportion of around 40% in 2015, the required increase in local gas generation will only be around 20 percentage points to meet the 60% target set out for option 2 by the Government by 2023.

3.4 ENVIRONMENTAL PERFORMANCE

It should be noted that the primary objective of revamping fuel mix in 2023 is to improve air quality and combat climate change. As a result of

Guangdong's rapid and tremendous development in the past years, air pollution has become an issue with increasing regional interrelations and interactions. Sharing the same air shed, Hong Kong and Guangdong have enhanced their cooperation in air pollution, for example in the areas of regional air quality monitoring and coordination in emission reduction targets. To evaluate the environmental effectiveness of the two proposed fuel mix options, a regional approach must be adopted. More importantly, any change in fuel mix must result in improvements in air quality and greenhouse gases (GHG) emissions, both locally and regionally, or otherwise there is no justification for making the change.

Option 2 increases local gas generation progressively to replace coal generation. It also increases the absolute amount of gas generation in the whole Greater Pearl River Delta (GPRD) region. Therefore, it brings certain, measurable and considerable benefits to emissions reduction not only in Hong Kong but also in GPRD.

On the other hand, the environmental improvement associated with option 1 is unclear. If one examines the matters more carefully, he/she will most likely be concerned if the total emissions in the GPRD will increase rather than decrease.

Power system usually dispatches generation units based on the different characteristics of generation sources and their economic and environmental merits. For instance, renewable energy (RE) cannot be stored; hydro power can be stored temporarily but not for long; nuclear energy has to be generated in a rigid fashion with its output kept constant as long as possible... etc. Hence, when dispatching different generation sources to meet the changing electricity demand over different seasons of a year and different hours of a day, the grid requires nuclear energy and RE (e.g. wind or hydro) to be dispatched as base generation and low-efficiency highest polluting coal energy to be dispatched as the lowest-priority. In effect, therefore, the nuclear energy and RE will be fully consumed regardless of whether Hong Kong imports any electricity from CSG.

In order to ascertain the actual fuel source of the electricity for import to Hong Kong, we need to apply the concept of "Marginal Fuel", or the additional fuel to be used to meet the additional demand. Based on the grid's energy dispatch arrangement, the additional generation for meeting the proposed grid power requirement to Hong Kong will most likely come from coal, which is also Guangdong's dominant fuel for electricity generation.

It is likely that option 1 is merely a transfer of emissions from Hong Kong to the Mainland, or the typical "not-in-my-backyard" (NIMBY) approach. With reference to high GHG emissions of the grid power purchased by Macao from CSG, it is believed that the additional generation for meeting the proposed grid power requirement to Hong Kong will most likely come from coal. Not only will there be no improvement to the air quality in the GPRD, but also total GHG emissions will increase.

3.5 FUTURE MARKET REGIME

As mentioned, the fuel mix decision may significantly affect the future market regime. There are views that option 1 may better facilitate future changes in market regime, e.g. introduction of competition or some form of contestable power generation. However, a careful examination indicates that option 1 may create more significant hurdles for changes in market regime when compared to option 2.

The cross-boundary transmission link under option 1 involves huge upfront capital investments to be committed in one go. To attract such investments, high certainties in revenues through long-term contracts guaranteeing transmission tariff and volume, are necessary. Most likely, option 1 will bring long-term contracts for utilization of the transmission link and purchase of electricity from CSG.

It is important to realize that under option 1 any potential for competition will be substantially limited by the long-term contracts for grid power purchase (~30%) in addition to those for nuclear power purchase (~20%) and gas purchase (~40%). With 90% of the market share locked in by these long-term contracts, there can hardly be any meaningful competition. The increasing reliance on grid import for local emissions reduction (if there is any) will eventually lead the Hong Kong electricity market to end up with a single bulk supply from CSG at a price it dictates. This inertia will become a massive obstacle towards further revamping the market regime.

In addition, the large scale cross-boundary transmission infrastructure associated with option 1 will, in view of higher potential stranded cost and involvement of a larger number of concerned parties, more seriously impede the ability to change the future electricity market.

In contrast, option 2 allows flexibility in scaling up (or, if necessary, down) future supplies. Option 2, which relies on local gas generation to curb emissions, can easily adapt to changes in future demand since the new CCGT units, with much shorter lead time of four to five years and smaller capacity of a few hundred megawatts each, can be installed at the power stations on the previously allocated land with comparatively lower capital commitment on a gradual unit-by-unit basis in response to the dynamic demand condition. Constraints on future market regime, if any, can be expected to be relatively low.

4. WAY FORWARD

Hong Kong's ground-breaking fuel mix policy, which is to be drawn up from the public consultation, is important: it will affect not only the development of the power sector in Hong Kong but also Hong Kong's very status as Asia's World City. As we have argued, prior to making a decision, the effects of the chosen fuel mix option on reliability, affordability, environmental performance and future market regime have to be considered carefully with the associated uncertainties and risks duly taken into account.

HK Electric firmly believes that keeping the generation of electricity local, while increasing the proportion of natural gas generation to 60% in the fuel mix is the best option for Hong Kong. This option will maintain the world-class standards of supply reliability that underpin Hong Kong's status as an international financial hub while minimising tariff increases, bringing certain, measurable and considerable environmental benefits as well as allowing higher flexibility for implementation necessary changes to the future market regime. Through extensive engagement with stakeholders, HK Electric understands that many people are sharing these views and an overwhelming majority of the public are in support of option 2 to increase local natural gas generation.

It has been widely reported by the media that some 86,000 responses to the consultation had been made to the Environment Bureau. This high level of participation by the public is uncommon, especially for an issue which is highly technical and complicated. This enthusiasm highlights that there is a clear voice in the society for increased local gas generation and the issue is urgent. Actions need to be planned and taken now rather than later. The public is expecting the HKSAR Government to announce the results of the public consultation as early as possible. The public and the electricity industry alike await the Government a policy decision to give a clear and certain roadmap for Hong Kong to combat global climate change and improve local air quality, and to define the possible constraints for changes to the future market regime.

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Paper No. 3

LISTEN TO YOUR ASSETS - DEVELOPING MORE EFFECTIVE ASSET MANAGEMENT STRATEGIES

Speakers: Mr H. Peter Dunker, Head, T&D Asset Services
Dr Ramon Nadira, Head, Network Services
Mr Juan C. Ledezma, Product Lifecycle Manager, Network Services
Siemens Ltd.

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Paper No. 3

ABSTRACT

To develop effective asset management strategies it is imperative to know at least three key operational parameters: (1) the current condition of the assets, (2) their importance in relation to the functioning of the system they are embedded into, and (3) the impact of not having the assets available at a certain point in time. Because of the meshed nature of power delivery systems, for a particular asset there are clear interdependencies between the latter two parameters and those for other interconnected assets.

In this paper we deal with the subject of assessing the condition of a given asset by gathering and interpreting information derived from the asset itself, or by "listening to the assets," if you will. We describe our recent research in this area and show an example for a particular asset class. We also discuss how this information can be used, together with one of the two other operational parameters mentioned above – importance – to provide actionable asset management recommendations at the asset level.

1. INTRODUCTION

Owners and operators of transmission and distribution networks face numerous challenges in regards to the effective management of their assets. These challenges include:

- Maximizing the performance of both the individual assets as well as of the overall network.
- Determining the right to time to perform an asset intervention (long-term maintenance, refurbishment, replacement).
- Predicting/anticipating asset failures.
- Determining whether or not to follow the time-based maintenance schedule recommended by the OEM.
- Assessing the risks of not following the recommended maintenance schedules.

Addressing these challenges starts by **Listening to your assets!**

Many traditional asset management strategies (such as time-based maintenance schemes) often ignore the actual condition of the equipment. In Figure 1 below we refer to these strategies as Incidental/Basic Asset Management strategies, which essentially involve performing isolated reactive/corrective interventions on the assets (such as preventive maintenance, replacement, refurbishment, etc.) based on elapsed time or some measure of equipment utilization (e.g., number of breaker trips).

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Figure 1 Asset Management Approaches

It is clear that asset management strategies can be improved by leveraging the "power of data," that is, by capturing, processing, analyzing, and ultimately acting upon information about the assets themselves (i.e., listening to the assets) as well as about their functioning within the system these assets are embedded into. This is the concept behind the advanced asset management approaches at the top of Figure 1. In these approaches, sometimes known as Asset Performance Management (APM) strategies, operation and maintenance actions are determined by considering, among other parameters, the condition of the assets and the risks associated with asset failure.

A significant outcome of the implementation of APM strategies is that the classical trade-offs between capital expenditures (CapEx) and operational expenditures (OpEx) in power delivery systems are significantly impacted. For example, if asset failure can be predicted with better precision, then system redundancy can be reduced (for a given level of system reliability performance.) This would result in lowered CapEx requirements but likely higher OpEx budgets (due to the need to perform additional maintenance actions on some key equipment), with the concomitant technical, financial (e.g., cash flows), and regulatory (e.g., tariff) implications.

2. WHY DOES ASSET CONDITION MATTER?

Let's use a simple example to illustrate the importance of condition assessment in asset management. Two circuit breakers of the same model, same manufacturer, and same commissioning date are installed in very similar environments. If only this information is considered, the same maintenance plan and asset management should be in principle suitable for both assets. However, from an operating standpoint, one of the circuit breakers has been required to clear several faults, some of them of very high currents, while the other has been subject to a relatively few number of operations and always under normal conditions or within nominal design parameters. A condition assessment of these two assets will most likely reveal that the first breaker has a higher risk of not performing its intended duty than the second one and, therefore, both assets require different asset management strategies.

There are different ways in which assets can tell us about their condition. Under the traditional but by now largely outdated approaches, the asset only told us about its operational state, that is, in operation, failed, or in repair. Using this information, asset management is clearly an indirect practice in the sense that it is mainly corrective. This approach, of course, is really far from optimal, since it often results in high failure rates and increased capital expenditure requirements in terms of necessary redundancy (back up) and spare parts inventories.

Next, employing more structured approaches and collecting and analyzing more data in a careful manner enabled the widespread implementation of preventive maintenance and the time-based plans proposed by manufacturers (the second layer of Figure 1). However, this approach is still very reactive in the sense that it does not factor in the condition of the assets and forced outages may unquestionably occur before any action has been taken. Financial and operational planning is more adequate under this approach – certainly more efficient than corrective maintenance - but still not an optimal solution.

Condition Base Maintenance (CBM) and Reliability Centered Maintenance (RCM)[1] are the next stage in the evolution of asset management practices. They intend to consider - in near real time - the condition of the asset to determine whether an intervention (long term maintenance, refurbishment, replacement) is required before the occurrence of a forced outage resulting in an interruption of service. In addition to maintenance and operational records of the assets, a significant amount of online and offline condition monitoring information is required to be processed in order to estimate the right moment for an intervention.

It is important to point out that relying exclusively on real time information processing and analysis to detect impending failures might not be enough to respond in a timely manner to certain outages, even if they are a consequence of an already identified deterioration process. In general, it is imperative to use both online and offline information within a Predictive Maintenance (PM) process which basically intends to estimate the current and future condition of the asset. PM not only contributes to increased reliability and efficiency, but also supports maintenance planning and budgeting, as well as the formulation of effective asset management strategies and policies.

Studies have shown that only between 5% and 30% of forced outages are random. This means that anywhere between 70% and 95% of forced outages are predictable and therefore preventable by means of interventions. This represents a tremendous opportunity for asset owners and operators.

As mentioned above, advanced asset management strategies (such as CBM and PM) rely on estimations of asset condition, both in the present and projected in the future. In turn, asset condition is estimated from online and offline information such as maintenance and operational records, sensor signals, chemical readings, etc. The volume and diversity of data and information that needs to be processed is quite vast, making the assessment of the condition of the assets quite a challenge. A simple and effective way to manage this complexity is the use of a composite (proxy) indicator generally known as Condition Index or, more commonly, Health Index (HI).

HI is a numerical representation of the estimated condition of a given asset. In principle, HI should:

i. be indicative of the suitability of the asset for continued service,

ii. contain objective and verifiable measures of asset condition,

iii. be understandable,

iv. be readily interpreted, and

v. be correlated with the asset risk of failure and remaining useful life.

The development of the Health Index metric is quite a complex matter, as it is usually customized (tailor made) for

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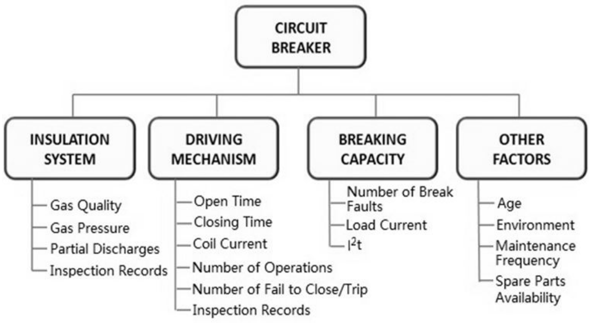
every asset type and for every system/utility. Figure 2 below shows some of the factors that could be considered in the development of a health index for a specific asset type (gas-insulated circuit breakers).

Figure 2 Typical Parameters Used in the Determination of the Health Index for GIS Circuit Breakers



A suitable grading and weighting system needs to be developed for creating a composite health index. One important feature of this system is that it must have the ability to forecast the evolution of the health index in time. This will be the base for replacing the standard preventive maintenance with a state-of-the-art predictive maintenance.

In the following example we consider a specific GIS circuit breaker. On a specific date, the equipment went through an exhaustive inspection and testing to determine its condition, yielding the following results:

- Insulation:

Gas purity	99.50%
Gas pressure	620kPA
Partial discharge warning alarms	10
Partial discharge failure alarms	0
Partial discharge critical failure alarms	0
Gas leakage history	none
Last inspection results	normal
Last maintenance results	normal

- Driving mechanism:

Open time	104ms
Closing time	230ms
Open current coil	3A
Close current coil	3A
Compressor pressure	345kPA
Number of operations	245
Number of fail to close/trip	0
Number of control system failures	0
Last inspection results	normal
Last maintenance results	normal

- Breaking capacity:

Number of breaker faults	0
Historical maximum current	2000
Historical maximum i^2t	1000

- Other factors:

Age	27.5 years
Environment	indoor air conditioning
Inspection frequency	once a year
Maintenance frequency	once every four years
Spare parts availability	partial stock

Based on this data as well as on other available information (such as equipment specifications) and using a proprietary formula, the HI of this circuit breaker was assessed at:

$$HI_{Breaker} = 3.33$$

(on a scale of 0 to 10, where 10 is the worst possible condition).

Further, using forecasting techniques we determined that the Health Index four years from the testing date would be 3.78.

All of this means that the circuit breaker is currently in a good condition. Moreover, it is forecasted that the breaker's condition will logically deteriorate over the next four years but still will remain in a good condition by then.

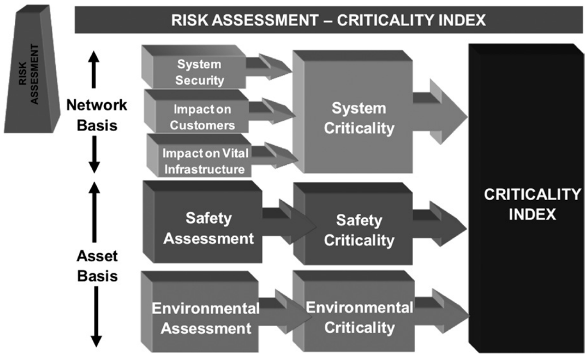
3. WHY DOES ASSET IMPORTANCE MATTER?

The second element required for the determination of effective asset management strategies is the importance of the assets. Importance can be measured in terms of Importance Indices, Criticality Indices, and/or Risk, among other ways. Importance is integrated with asset condition to generate actionable recommendations at the individual asset level.

Importance indices can be qualitative or quantitative. Among the quantitative methods are: i) the use of Failure Modes and Effects Analysis (FMEA) and/or Failure Mode, Effects, and Criticality Analyses (FMECA) to obtain, respectively, a Risk Priority Number (RPN) and a Criticality Index[2], and/or ii), power system simulations. RPN and Criticality Indices can be used as a numerical estimate of asset importance, and contingency analysis, as part of system simulations, could reveal how important an asset is from the standpoint of network operation and/or reliability.

The risk associated with an asset is the sum of all the consequences of potential/future outages, usually expressed in monetary terms. The risk is often linked to a failure rate or failure frequency, which may be affected or not by the asset condition. Figure 3 shows the typical factors that are considered in the estimation of the asset risks. These factors are combined together to derive a Criticality (or Importance) Index.

Figure 3 Typical Risk Assessment Factors



Importance/criticality measures provide a quantitative estimate of how important the assets are in terms of their failure rates. That is, in a condition and risk-based approach, failure rates are not necessarily constant as they depend on asset condition. This is shown in Figure 4 below. Assets can then be sorted in terms of their criticality in order to prioritize intervention plans.

Criticality and importance indices are also helpful for prioritizing limited OpEx budgets. In this case, however, the risk assessment must go beyond the calculation of the importance indices to also include an estimation of the costs associated with the consequence of asset failure.

An important consequence of linking asset risk to asset condition is that the techniques used for future condition estimation (aging functions, for example) also lead to risk forecast estimation. Thus, **listening to your assets** will also enable you to estimate future risks and prepare a plan for

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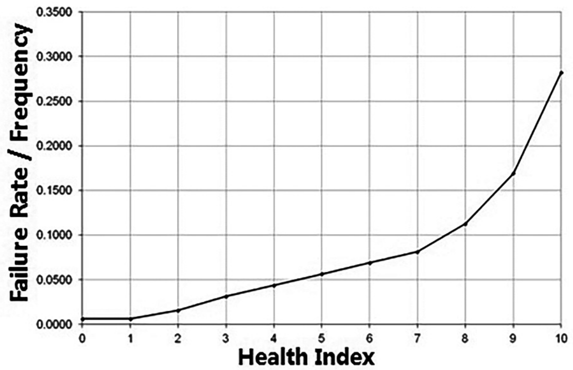
optimal asset management, where the trade-offs between risks and the cost of asset intervention are most appropriate. This model must be correlated with the health index forecast thorough the relationship between the health index and the failure rate/frequency.

Figure 4 Example of Risk Function (Health Index vs. Failure Rate)



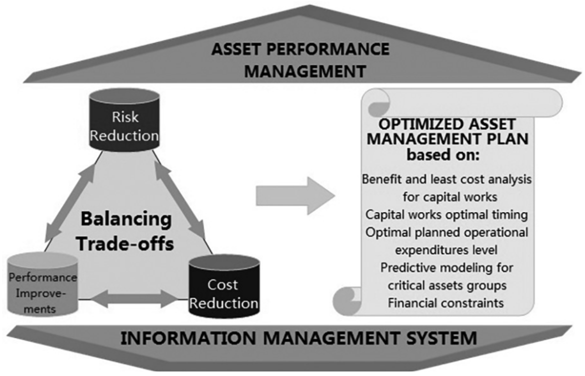
4. COMBINING CONDITION AND IMPORTANCE FOR DEVELOPING MORE EFFECTIVE ASSET MANAGEMENT STRATEGIES

The final stage is to combine the results of asset condition assessment and importance to produce more effective asset management actions, strategies, and plans. These outputs should provide an adequate balance of risk mitigation, expected network performance, and maintenance/intervention costs.

Reliability-Centered Asset Management (RCAM®)[3] is a proven Siemens methodology for linking asset condition (in terms of Health Indices which are based on aging, deterioration, wear and tear) and asset importance (priority in the grid, usually obtained from FMEA analysis or system simulations) to develop, continuously improve, and optimize operational maintenance strategies.

In this article, we describe an enhanced approach which consists of formulating asset management plans based on asset condition - quantified via a Health Index - and asset risk, estimated in terms of monetary values and with failure rate/frequency linked to the HI (see Figure 5 below). The higher (worse) the HI, the more the risk, and one or more interventions will likely be recommended along the lifetime of the asset when the total cost (risk cost plus intervention cost) is the least. The plan will be based on cost and benefits analysis and will optimize the amount and timing of the required capital and operational expenses. Predictive maintenance will be used then to minimize the consequences of asset failures.

Figure 5: Asset Performance Management



5. CONCLUSION

Asset Performance Management is an effective methodology for enabling asset owners and operators to not only **Listen to their Assets** but also to leverage this "data power" to develop optimized asset management strategies. In fact, the latest infrastructure asset management standards[4] recognize the benefits of this methodology and recommend its use. We certainly also do so, and practice it every day.

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Paper No. 4

IMPLEMENTATION OF ENERGY MANAGEMENT SYSTEMS IN PUBLIC RENTAL HOUSING ESTATES

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IMPLEMENTATION OF ENERGY MANAGEMENT SYSTEMS IN PUBLIC RENTAL HOUSING ESTATES

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ABSTRACT

It is globally recognised that emission of Greenhouse Gases (GHG) is the main cause of climate change and GHG is emitted during the combustion process of fossil fuels. Hence, reduction of combustion of fossil fuels is the key approach to reduce emission of GHG.

Based on information in Hong Kong Energy End Use Data 2013, fossil fuels are the major sources of primary energy in Hong Kong, buildings consumed 68% of primary energy, and around 80% of energy consumed in buildings is in the form of electricity. Hence, reduction of electricity consumption in buildings would effectively reduce the overall emission of GHG in Hong Kong.

Over the years, Hong Kong Housing Authority (HKHA) has been continuously implementing a series of energy saving measures in lighting, lift and water pump of public rental housing (PRH) domestic blocks. HKHA has also installed grid-connected photovoltaic systems in all newly constructed PRH domestic blocks. The generated electricity is used to offset part of electricity consumption of communal services.

Apart from the above, HKHA has also implemented the following new energy saving initiatives:

i. A pilot installation of LED bulkheads lighting at public corridors, staircases and lift lobbies of typical floors of Lok Ching House in Kai Ching Estate to evaluate the performance of LED lighting; and

ii. A pilot installation of lift regenerative power in all PRH domestic blocks of Kai Ching Estate.

These pilot installations are being tested and evaluated at the moment.

Since 2001, HKHA has established a simple energy management system based on a **territory-wide "Electricity Consumption per Flat per Year"** approach to monitor the energy performance of individual PRH domestic block. Nevertheless, this simple system has the following deficiencies:

i. Unable to give a clear picture of past energy performance of individual block as well as sound diagnosis of its energy management opportunities;

ii. Blocks with low absolute figures but actually poor energy performed will be ignored;

iii. Inconsistent approach by different staff may lead to disparity in resources allocation and monitoring.

The launch of ISO 50001 Energy Management System (EnMS) in June 2011 offers HKHA a very good opportunity to address the above deficiencies and refine its energy management policy.

This paper gives a detailed account of HKHA's experience gained in the recent development and implementation of ISO 50001:2011 EnMS in PRH estates.

1. BACKGROUND

It is globally recognised that excessive emission of Greenhouse Gases (GHG) is the main reason behind for climate change. As the majority of GHG is emitted during the combustion process of fossil fuels, reduction of the use of fossil fuels would be a direct approach to reduce emission of GHG.

In Hong Kong, fossil fuels are the major sources of primary energy. Based on information in Hong Kong Energy End-Use Data 2013, buildings consumed 68% of primary energy, and around 80% of energy consumed in buildings is in the form of electricity. Obviously, reduction of electricity consumption in buildings will have significant effects in cutting down the overall emission of GHG (carbon footprint) of Hong Kong.

Over the years, the government of Hong Kong Special Administrative Region (HKSAR) has committed to combat climate change through the development of different energy efficiency schemes such as the launch of Energy Efficiency Labelling Scheme in 1995 to promote the use of energy efficient appliances, the launch of Voluntary Hong Kong Energy Efficiency Registration Scheme for Buildings (HKEERSB) in 1998 to encourage the adoption of energy-efficient building designs, the launch of Building Energy Efficiency Ordinance (BEEO) on 21 September 2012 to legislate the requirements of energy efficiency in the design and operation of buildings.

To support energy policy of the central government of HKSAR, Hong Kong Housing Authority (HKHA) has been continuously implementing a series of energy saving measures in lighting, lift and water pump of public rental housing (PRH) domestic blocks for years. Such as modifying lighting circuit to fully utilize day-lighting, using T5 tube for all Exit/Directional signs, wider use of electronic ballast in public lighting, replacing energy inefficient motor drive (e.g. DC M-G drive, AC 2-speed drive etc.) with ACVVVF drive in lift installations during the process of lift modernization programme, using Variable Speed Drive (VSD) fresh water booster pump system to replace those pneumatic water booster pump systems at their end of service.

As a result, HKHA has successfully reduced the average electricity consumption in communal services from 877kWh per flat per year in 2001/02 to 678kWh per flat per year in 2013/14, a drop of 22.7% in thirteen years. Figure 1 below shows the total and average per flat electricity consumption of PRH domestic blocks during past years.

Figure 1 Total Electricity Consumption and Per Flat Annual Electricity Consumption in Communal Services of All PRH Domestic Blocks from 2001/02 to 2013/14

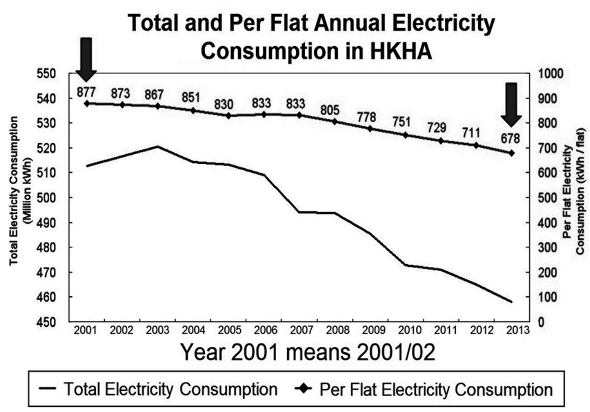

Table 1 below shows the comparison study by Green Peace on average electricity consumption of communal building services installations per flat per annum in selected private residential estates with that of a typical PRH domestic block as reported by a local newspaper in June 2010. The energy performance of a typical PRH domestic block shows significant variance when comparing with the selected private residential estates.

Table 1 Comparison of Average Per Flat Electricity Consumption of Communal Building Services Installations in Selected Private Residential and PRH Estates

Residential Estate	Annual Per Flat Electricity Consumption of Communal Services (kWh per flat)
Private Estate A	6,834
Private Estate B	6,725
Private Estate C	4,359
Private Estate D	3,409
Private Estate E	3,294
Private Estate F	3,127
PRH Block	807

2. EXISTING ENERGY MANAGEMENT SYSTEM IN HKHA

2.1 THE EXISTING HKHA ENERGY MANAGEMENT SYSTEM

In 2001/02, HKHA commenced to adopt a simple Energy Management System (EnMS) by applying a territory-wide "**Electricity Consumption per Flat per Year**" approach based on the monthly electricity bills from some 1,200 PRH domestic blocks to monitor the energy performance of each individual PRH block (Figure 1 refers).

Until 2010/11, HKHA has enhanced the EnMS by adopting a "Reference Index (RI)" approach of which RI is the average communal energy consumption per flat of all PRH blocks in a particular financial year as a benchmark for comparing with the energy performance of an individual PRH block in that financial year. Should the energy consumed per flat per year in a particular block is found greater than 150% of the RI of current year, HKHA would carry out energy review for this block in order to identify reasons behind for the excessive energy consumption and take follow-up action(s) as necessary. So far, the results are encouraging as over 90% of the PRH blocks could meet the criteria. For those PRH blocks exceeding 150% of the RI, reviews would be conducted and specific energy saving measures would then be implemented. A total saving of energy around 10% was recorded in the last three-year period.

Nevertheless, this system has the following deficiencies:

i. Unable to give a clear picture of past energy performance of individual block as well as sound diagnosis of its energy management opportunities;

ii. Blocks with low absolute figures but actually poor energy performed will be ignored;

iii. Inconsistent approach by different staff may lead to disparity in resources allocation and monitoring.

As such, HKHA has to explore a pragmatic, comprehensive and cost effective approach to monitor the energy performance of some 1,200 nos. of domestic blocks. The launch of the new ISO standard on Energy Management

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System in June 2011 (i.e. the ISO50001 EnMS) has offered HKHA a very good opportunity to revamp the current EnMS in a more systematic manner but with minimal additional resources.

2.2 PARTIES INVOLVED IN THE ENERGY MANAGEMENT SYSTEM IN HKHA

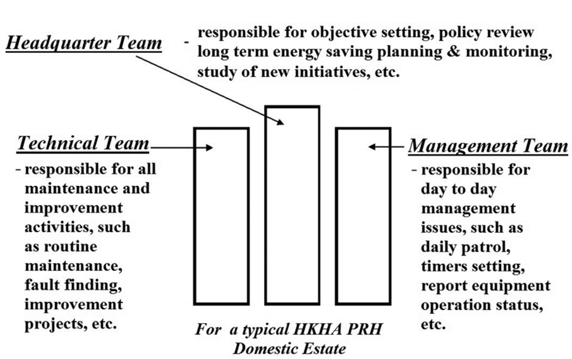
HKHA has approximately 1,200 nos. of PRH domestic blocks categorized in over 30 block types in 170 PRH estates. To exercise effective implementation and monitoring of EnMS in PRH estates, the following parties are involved:

i. The Headquarter Team - responsible for overseeing the operation of the EnMS, steering of exploration and implementation of new energy saving measures;

ii. The Technical Team - responsible for ongoing maintenance, improvement and implementation of endorsed energy saving measures of communal BS installations; plus provision of technical support to Management Staff at PRH estates;

iii. The Management Team - responsible for day to day operation and management issues at PRH estates;

Figure 2 Division of Responsibilities Among Involved Parties in a Typical PRH Estate



3. THE ISO 50001 ENERGY MANAGEMENT SYSTEM

3.1 BENEFITS

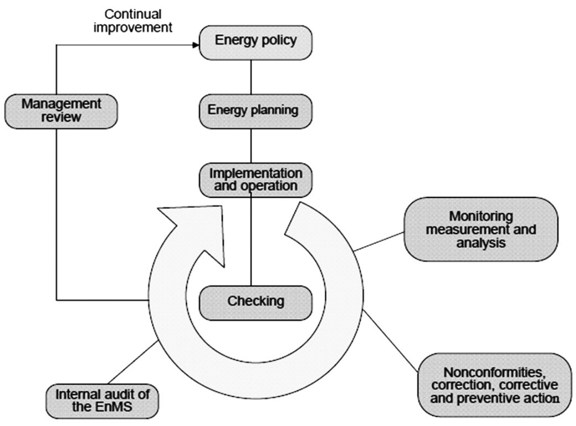
The Standards of ISO 50001 EnMS provides adequate guidelines for all types of organization to establish their own EnMS and subsequent implementation processes to improve their energy performance in a continual improvement mode. It also enables organizations to establish a sustainable, reliable and consistent EnMS even with the passage of time and staff movement.

3.2 FRAMEWORK OF THE ISO 50001 ENERGY MANAGEMENT SYSTEM

Based on the requirements of ISO 50001 EnMS, a **Plan-Do-Check-Act (PDCA)** continual improvement framework shall be adopted as the foundation framework for development of the organization' energy management system.

The **Plan-Do-Check-Act (PDCA)** continual improvement model is depicted as below:

Figure 3 Plan-Do-Check-Act Model of Energy Management System



4. IMPLEMENTATION OF THE ISO 50001 ENERGY MANAGEMENT SYSTEM IN HKHA

ISO 50001 EnMS is new to HKHA as it was only rolled out in June 2011. As such, there are no precedent cases that HKHA can make reference to during the development of the EnMS.

4.1 THE HKHA CONCERNS

In order to suit HKHA's unique organizational / operational features and ensure the project is successful, HKHA has to address the following two key areas during the development and implementation of the EnMS.

i. Large Property stock under HKHA;

ii. Large and Diverse Stakeholders;

Here below are the actions taken by HKHA to address the above concerns during the study and planning of the EnMS.

4.1.1 LARGE PROPERTY STOCKS

The following measures have been taken to ensure the EnMS can be effectively implemented across 1,200 domestic blocks in some 170 PRH estates

a) Gap Assessment

To identify both the capital and resources requirements for implementation of ISO 50001 EnMS, an Independent Certifying Body (ICB) was appointed to conduct Gap Assessment in 2012. This gap assessment including checking of existing BS maintenance manuals, site inspections on setting of the timer control of public lighting, and inspecting daily operation and maintenance of communal BS installations, etc. The results of assessment indicated that HKHA's existing EnMS had been in the right direction but would require appropriate adjustments in documentation and related measures.

b) Pilot Implementation at Kwai Shing West Estate

Facing with a large property stocks in hand, a gradual approach was adopted by selecting one of HKHA managed PRH estates i.e. Kwai Shing West Estate (KSWE) for pilot implementation which commenced in January 2013, and followed by a series of activities such as internal audit in March 2013, pre-audit by ICB in May 2013, certification audit by the ICB in June 2013. Eventually, certification for this pilot estate was successfully obtained on 27 June 2013.

As advised by the ICB, KSWE was the first existing domestic estate with certification of EnMS to ISO 50001 in Hong Kong.

With the certification of ISO 50001 EnMS at KSWE, there was a significant reduction of energy use of 15.9 % in the communal building services of all PRH domestic blocks in the estate. The annual electricity consumption of all domestic blocks at KSWE was 3,009,198kWh in 2012/13 and dropped to 2,531,377kWh in 2013/14.

c) Full Implementation in Two Phases

With the successful experiences gained at KSWE, HKHA has committed to extend certification to cover all existing PRH domestic blocks by April of 2015 in two phases. With this manageable size of property stocks, staff's effort can be more focused in getting success in the implementation of the system.

SIEMENS

Phase One comprising 621 PRH domestic blocks in 92 PRH estates has commenced the implementation since October 2013 with scheduled certification in October 2014 while Phase Two comprising 539 PRH domestic blocks in 75 PRH estates has commenced the implementation since April 2014 with scheduled certification in April 2015.

4.1.2 LARGE AND DIVERSE STAKE HOLDERS

Over 2,700 staff from both HKHA and out-sourced agents have been involving in the routine management and maintenance of some 1,200 PRH domestic blocks. As their scope of services and professionalism are different, it is necessary to tailor-make several action plans to suit their nature of works.

a) Division of Work

To implement the new EnMS in HKHA, a dedicated team comprising two professionals and three technical staff has been deployed at headquarter level for steering and development of ISO 50001 EnMS. This headquarter team steers the right direction as well as the generator of momentum for this EnMS. Major duties of the key stakeholders are grouped as follows:

I) Duties of the Headquarter Team:

i. To develop and update system manuals, templates and guidelines to assist all staff concerned to implement ISO 50001 EnMS;

ii. To coordinate all activities related to ISO 50001 EnMS;

iii. To offer briefings/trainings on the implementation procedures of ISO 50001 EnMS to all concerned staff;

iv. To provide guidance and line up all annual energy review reports prepared by technical staff; and

vi. To prepare the Annual Energy Management Review Report for senior management endorsement.

II) Duties of Technical Staff:

i. To collect energy data of electricity consuming devices / plants (e.g. lighting, lift, water pump, etc.) and their operation patterns in the estates under their purview;

ii. To input all data collected into respective data files and pass to headquarter team for onward action;

iii. To establish energy baselines, identify energy management opportunities and possible variation in energy consuming loads, project energy performance indicators (EnPIs), set energy objectives, energy targets and energy management action plan etc. for estates under their purview;

iv. To prepare the Annual Energy Review Report for each estate with reference to its energy performance in the year; and

v. To identify any anomalies in the communal building services installations if there are significant fluctuation of energy consumption in a particular month without justified reasons.

III) Duties of Management Staff:

i. To implement energy saving measures (such as timer setting) and observe BS equipment operation status as stipulated in in-house instructions;

ii. To plot and observe any anomalies (i.e. significant deviations or spikes) in the 24 months electricity consumption trends of each domestic block based on the electricity bills records; and

iii. To provide monthly electricity bills to Technical Staff for annual review.

b) Standardization

To overcome difficulties due to large property stocks and limited resources in the implementation of ISO 50001 EnMS, we have adopted a standardized approach by establishing a number of standard templates/data files with simplified procedural guidelines for technical and management staff to follow. With data files duly completed by technical staff for each estate, a BECEM report (See 4.2.1 for details) would be generalized by headquarter team and then returned to the technical staff of the respective DMO for their onward preparation of annual energy review report (AERR). In general, the AERR report would be prepared by technical staff for each of the PRH estates under their purview. To align the contents of AERR reports prepared by different teams of technical staff, a standard template with adequate guidelines for AERR report has also been developed.

c) Tailor-made Training and Briefing

To provide adequate guidance to large and diverse stakeholders, two types of training briefings (i.e. one for BS technical staff and one for housing management staff) were conducted to address their needs and interest.

d) Compilation of Energy Management System Manuals

The principle of the EnMS and the procedural guidelines of all activities involved in the proper implementation of the EnMS are consolidated and compiled into TWO system manuals i.e. the Energy Management System Manual and energy Management Process Manual which have been uploaded onto the HKHA intranet for reference by all staff involved from HKHA and the outsourced Property Services Agencies (PSAs).

e) Detailed but Straight-forward Instructions

In addition to the established two system manuals, tailor made instructions and checklists have also been prepared to give a straight-forward procedures and guidelines to staff concerned.

f) Step by Step Progress

Except the experiences gained from the pilot estate i.e. Kwai Shing West Estate, there was no other precedent cases for reference by HKHA, a “step-by-step” with bi-weekly/monthly review was adopted during the implementation stage in Phase One.

4.2 DEVELOPMENT AND IMPLEMENTATION OF THE ISO50001 ENERGY MANAGEMENT SYSTEM

Subsequent to the detailed study on the requirements of ISO 50001 EnMS, a detailed **“Plan-Do-Check-Act” (PDCA)** framework for implementation of EnMS in PRH domestic blocks was formulated as follows:

4.2.1 PLAN

To perform full functions as required under **Plan**, a mathematical model has been specially developed with the following features:

i. To store all building information and energy data such as number of PRH domestic blocks and their block types in the respective estate, number of domestic flats, construction floor area, internal floor area of domestic flats and non-domestic premises, normalized monthly electricity bills and monthly diesel fuel consumption (if any) of each of the PRH domestic blocks;

ii. To calculate the Energy Utilization Indexes for each of the PRH domestic blocks (based on the input in (i) above) for establishing the respective **energy baselines**;

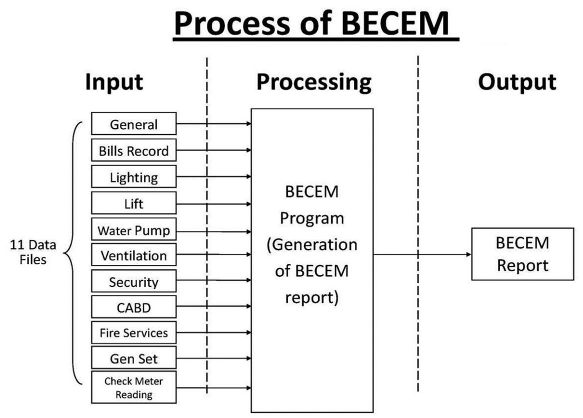
iii. To facilitate the identification of **significant energy uses** from the estimated annual energy consumption of each of the communal building services installations; and

iv. To act as a powerful tool to estimate saving from each identified energy management opportunity by comparing the estimated energy consumption before and after its implementation.

The BECEM

It is a mathematical model called **"Building Energy Consumption Estimation Model" (BECEM)** and its process is shown in Figure 4 below.

Figure 4 Process of the BECEM



Technical staff have to fill in all necessary data in the following eleven data files for each PRH estate:

i. General Data File - for all general building information such as type of blocks, construction floor area, internal floor area of domestic and non-domestic tenants' premises; no. of domestic flats, no. of floors, height of the block, etc.;

ii. Bills Record Data File - for electricity consumption data record of past years;

iii. Lighting Data File - for quantity, type and locations of light fittings, power ratings data and operation patterns;

iv. Lift Data File - for capacity, speed, power ratings, daily operation hours, operation patterns etc. of each lift;

v. Water Pump Data File - for types, power ratings, operating patterns of each water pump;

vi. Fire Services System Data File - for types, power ratings of each fire water pumps, power rating of control panels and fire alarm panels;

vii. Ventilation System Data File – for types, power ratings, operating patterns and locations of each ventilation fan;

viii. Security System Data File - for type, location, power ratings, daily operating hours and numbers of the security equipment/devices;

ix. CABD System Data File - for location, type of equipment/devices, power ratings, daily operation hours etc. of the CABD equipment/devices;

x. Generator Set Data File - for the average monthly fuel consumption of each generator (if any);

xi. Check Meter Data File - for the monthly check meters reading of electricity consumed by non-communal building services installations found in each block (if any).

Subsequent to the completion of data input for these 11 system data files, BECEM report could be generated for each PRH domestic estate.

4.2.2 DO

With the BECEM report in place, Energy Baselines can be established. Incorporating the identified energy management opportunities as well as scheduled additional loads (if any), the Energy Performance Indicators (EnPIs) can be predicted. Energy objectives and energy targets would then be set accordingly for the building up of **energy management action plans** for onward implementation.

4.2.3 CHECK

The ongoing operation and energy performance of all the PRH estates are regularly **checked** via monitoring, measurement and/or analysis of the following key activities:

i. Monthly review of the energy consumption trend of each block shall be conducted to identify any irregularities.

ii. Energy measurements of major communal building services installations of the PRH domestic block shall be conducted to ascertain the three significant energy uses.

iii. Internal audits by in-house auditors and external audits by ICB shall be conducted annually to ensure sustainability, accuracy and compliance of the EnMS.

iv. Annual Energy Review for each PRH estate and Annual Energy Management Review for all PRH estates shall be carried out at the end of each financial year.

4.2.4 ACT

The following actions (whenever necessary) shall be taken according to findings as highlighted in the endorsed Annual Energy Management Review:

i. Change in overall energy baselines;

ii. Change in the Departmental Energy Policy;

iii. Change to EnPIs;

iv. Change in Departmental objectives, targets or other elements of the EnMS; and

v. Change in resources allocation

As such, the Plan-Do-Check-Act (PDCA) continual improvement framework has been fully exercised through the above procedures.

4.3 LATEST DEVELOPMENT

Certification Audit for Phase One estates was completed satisfactorily in August 2014 and the ISO 50001 EnMS Certificate for Phase One estates was granted in September 2014. HKHA is now pursuing to obtain certification for Phase Two estates by March / April 2015. From thereafter, the certified ISO 50001 EnMS system shall be fully operated in all existing PRH domestic blocks.

5. CONCLUSION

The pressing need of reducing excessive emission of carbon for combating climate change have become a global agenda. It has already reached the critical moment for each of us to take immediate and concrete action in combating climate change.

With the previous efforts in the implementation of different energy saving measures, the Energy Consumption has already hit a historic low figure of **678kWh per flat per year** in the last financial year, against **877kWh per flat per year** in 2001/02, representing an energy saving of approximately 1.7% in each financial year with 2001/02 as the base year. By April 2015, with the full implementation of EnMS to ISO 50001, the current momentum of reduction of energy consumption should be continued.

Having successfully implemented ISO 50001 EnMS in large stock of PRH domestic blocks, HKHA are always prepared to share experience gained with private buildings owners / management agents.

In short, the better we manage our energy, the greater chance we can have a sustainable environment for our future generation.

Paper No. 5

THE BUILDINGS ENERGY EFFICIENCY ORDINANCE AND ITS CODES – KEY DRIVER OF BUILDING ENERGY EFFICIENCY

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ABSTRACT

Buildings are major energy consumers in Hong Kong, and with them powering into the future their climate change impacts would likely top our agenda in the years to come. To address these impacts, energy shortage and associated environmental issues in particular, the Electrical and Mechanical Services Department (EMSD) of Government of the Hong Kong Special Administrative Region (HKSAR) is enforcing the Buildings Energy Efficiency Ordinance, Cap 610 (BEEO) that has come into full operation since September 2012. As a key driver of building energy efficiency, the BEEO requires the compliance with its Building Energy Code (BEC) in respect of the design of building services installations in newly constructed buildings and for major retrofitting works (MRW) in existing buildings. For existing commercial buildings, the BEEO also requires the carrying out of energy audit for their central building services installations according to the BEEO's Energy Audit Code (EAC). This paper briefly introduces the BEEO and its BEC & EAC, including the BEC's new lighting power density (LPD) requirements that are effective progressively starting in Aug 2014, which were based on a review in end 2013 that had referenced to LPD standards in developed countries and had accounted for the LPD performances observed in the submissions for MRW under the BEEO. Also, it highlights EMSD's observations on the rooms for improvement to the inputs to the submitted Executive Summary forms regarding the energy audit findings in demonstrating EAC compliance, which if properly addressed would enhance the energy audit achievements.

1. INTRODUCTION

The BEEO establishes both the energy efficiency standards of a building for its design and the means to evaluate its energy efficiency performance in operation. For building design, the BEC governs the design standards in respect of energy efficiency of building services installations, whereas for building operation, the EAC governs the steps in conducting energy audit of its central building services installations (CBSI, which refers to the building services installation not solely serving an individual unit of the building).

EMSD maintains a dedicated web-site at http://www.beeo.emsd.gov.hk/ for the BEEO, in which its most current information including the codes, technical guidelines, forms, circulars etc. can be found.

Figure 1 Snapshot of the BEEO Web-site

2. BEEO SCOPE OF COVERAGE

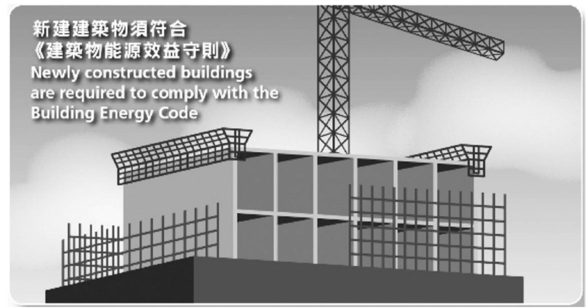
2.1 TYPES OF BUILDINGS

The BEEO governs, in respect of BEC compliance, most types of buildings of both private and government sectors, including buildings for commercial (e.g. office, shopping complex etc.), hotel, municipal, community, education, hospital, railway station, airport passenger terminal usages etc. For industrial buildings, residential buildings and composite buildings, the common area and the portion not for residential or industrial use are governed. On the other hand, residential units and industrial units are not governed.

2.2 NEWLY CONSTRUCTED BUILDINGS AND EXISTING BUILDINGS

The building services installations in a newly constructed building i.e. a building in respect of which a consent to the commencement of building works for superstructure construction is given after 21 September 2012, should comply with the design requirements of the BEC, and the compliance is applicable to all subsequent retrofitting works irrespective of whether the works are regarded as major retrofitting works or not.

Figure 2 BEEO Applicable to Newly Constructed Buildings



As for an existing building, i.e. a building in respect of which a consent to the commencement of building works for superstructure construction is given on or before 21 Sep 2012, the BEC requirements have to be complied with only for major retrofitting works.

Figure 3 BEEO Applicable to Major Retrofitting Works

2.3 MAJOR RETROFITTING WORKS (MRW)

Major retrofitting works (MRW) refer to :

- the addition or replacement of a building services installation in retrofitting works covering an aggregated floor area of 500m2 or above (under the same series of works within 12 months) in a common area or a unit, or

- the addition or replacement of a main component of the CBSI (including a chiller at rating 350kW or above, or a complete electrical circuit at rating 400A or above, or motor drive & mechanical drive of a lift or an escalator).

2.4 ENERGY AUDIT

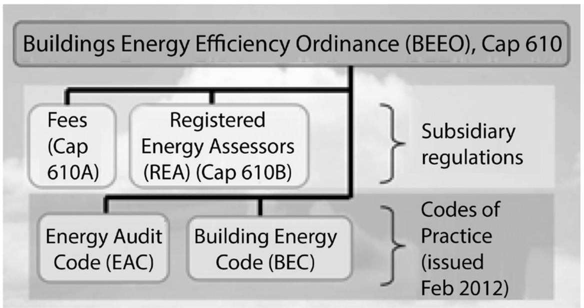
The BEEO requires the carrying out of energy audit for the CBSI in commercial buildings and commercial portions of composite buildings every 10 years in accordance with the steps specified in the EAC. After the audit, the building's energy utilization index (EUI, in MJ/m2/annum & kWh/m2/annum) that reflects the building's energy intensity or energy performance is to be identified and exhibited.

Figure 4 BEEO Applicable to Energy Audit in Commercial Buildings

3. BEEO COMPLIANCE HIERARCHY

The BEEO prescribes the responsibilities of the developer, owner or responsible person of a building or a unit of the building, and the Registered Energy Assessor (REA), with requirements of submission and certification to demonstrate the compliance at different stages of the building, from design to occupation approval and subsequently during normal course of operation. Under the BEEO are two subsidiary regulations, one on REA and the other on the fees for the submissions.

Figure 5 BEEO Compliance Hierachy



3.1 BEC REQUIREMENTS AT DESIGN CONDITIONS

The BEC requirements are the energy efficiency standards at corresponding design conditions, and not the actual operational settings such as lighting level, air-conditioning room temperature etc., which are left to the discretion of building operators to suit the operational needs of individual buildings and installations.

3.2 NEWLY CONSTRUCTED BUILDINGS

The developer of a building, at building design stage (within 2 months after obtaining the aforesaid consent to the commencement of building works issued by HKSAR Government's Building Authority), is required to:

- submit to EMSD a "stage one declaration" certified by an REA to declare that the building services installations to be provided by the developer are designed and will be installed and completed in accordance with the BEC.

Subsequently at the occupation approval stage (within 4 months after obtaining an "occupation permit" issued by the Building Authority when the building is ready for occupation), the developer is further required to:

- submit to EMSD a "stage two declaration" certified by an REA to declare that the building services installations provided by the developer in the building at or before the time when the declaration is made have been designed, installed and completed in accordance with the BEC; and

- apply for a Certificate of Compliance Registration (COCR) from EMSD for the building.

The declarations are to be completed in specified forms and be accompanied by supporting documents specified in the forms. Based on the merits of the declarations, EMSD will issue accordingly a COCR to the developer. EMSD maintains a register of COCRs, which is available at all times at the BEEO web-site at http://www.beeo.emsd.gov.hk/ for the public's inspection.

The aforesaid COCR for newly constructed buildings is subject to renewal every 10 years, and for the renewal the owner of the building is required to:

- engage an REA to certify that :

    - the design (but not the operational performance) in respect of energy efficiency of the CBSI (no need to include the installation only serving an individual unit) is maintained at a level not lower than the standard in the BEC version applicable to the COCR (issued by EMSD 10 years ago) of the building, and

    - if MRW have been undertaken for certain portions of the CBSI, the design of the installation is maintained to a standard not lower than the latest BEC version applied to this part of the installation; and

- submit an application to EMSD for the renewal.

It is estimated that the BEEO, having had addressed to the barriers to energy efficiency, can generate an energy saving in newly constructed buildings in the order of 2.8 billion kWh in the first 10 years.

3.3 MAJOR RETROFITTING WORKS

For all prescribed buildings under the BEEO, irrespective of newly constructed or existing buildings, the owner of the CBSI in the building, and the responsible person of a unit or a common area in the building, within 2 months after completion of MRW, are required to :

- engage an REA to certify that the replaced or additional installations of the MRW comply with the latest BEC; and

- obtain a Form of Compliance (FOC) from the REA for the said works.

In the course of operation of a building with a COCR (i.e. a newly constructed building), the owner of the CBSI (usually the owner of the building) and the responsible person (usually the owner or tenant) of a unit or a common area in the building are required to ensure that when a building services installation is replaced or added (irrespective of whether it falls into the scope of MRW or not), its design shall comply with the standard not lower than that applied in the original BEC applied to this installation.

3.4 ENERGY AUDIT

The owner of a prescribed building (i.e. a commercial building or a portion of a composite building that is for commercial use) must, in respect of the CBSI of the building, cause an energy audit to be carried out in accordance with the EAC at least once every 10 years.

The first energy audit for the CBSI of a building issued with a COCR (i.e. a newly constructed building) is to be carried out within 10 years after the issue of COCR.

For existing buildings, the first energy audit for the CBSI is to be carried out according to a timeframe within 4 years from 21 Sep 2012 as prescribed in schedule 5 of the BEEO, in four batches according to building age, the newer the earlier. As in 2014, the 2nd batch buildings, the buildings with occupation permits issued between 1978 and 1987, have the deadline of carrying out of energy audit of 20 Sep 2014. For the 1st batch buildings, the deadline was 20 Sep 2013.

The owner of the building is required to:

- engage an REA to conduct the energy audit;
- obtain from the REA an Energy Audit Form and an energy audit report (with recommendations of energy management opportunities (EMO) identified in the audit); and
- exhibit the valid Energy Audit Form bearing the building's EUI in a conspicuous position at the main entrance of the building.

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Figure 6 Energy Audit Form at Main Entrance

By the disclosure of the EUI, it is expected a benchmarking effect will be exerted on the building operators to improve the building's energy efficiency, as the building's energy performance can be easily compared with that of other similar buildings. As for EMO, their implementation will not be mandatory, in consideration of the wide variety of EMO in terms of scope and cost. Nevertheless, the REA's analysis and recommendations of the EMO in the energy audit report will be conducive to the implementation of some if not all of the EMO, as the energy saving from EMO is itself an incentive.

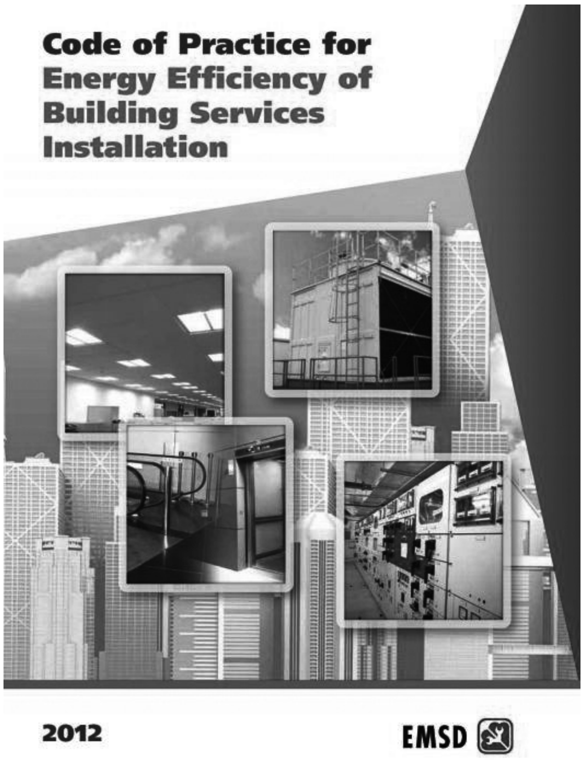
3.5 REGISTERED ENERGY ASSESSOR (REA)

The BEEO opens up a new role of professional engineers, the REAs, who upon appointment by the developer, owner or responsible person have the obligation to perform the certifications and carry out the energy audits. The qualifications required as an REA are prescribed in the Buildings Energy Efficiency (Registered Energy Assessors) Regulation, Cap 610B.

4. BEC TECHNICAL REQUIREMENTS

To give an overview, the key technical requirements of the BEC (Rev. 1) are extracted as follows:

Figure 7 Code of Practice for Energy Efficiency



4.1 LIGHTING INSTALLATION

- Max allowable lighting power density (LPD) (see paragraph 7.)
- Min allowable no. of lighting control points (i.e. switching devices) for office space
- Lighting control points for lighting to which the BEEO is applicable to be independent from those for lighting to which the BEEO is not applicable
- Not applicable to lighting exterior to building, lighting not of fixed type, signage lighting and lighting solely for decoration

Figure 8 Lighting Installation

4.2 AIR-CONDITIONING INSTALLATION

- Load calculation per specified outdoor and indoor conditions (e.g. max 35°C outdoor DB)
- Allowable air distribution system fan power per unit volume flow (e.g. max 1.6 W/L/s for CAV)
- Allowable percentage power of full load, of power drawn by motor of variable flow fan at 50% design flow (max 55% of full load)

- Air distribution ductwork leakage limit

- Piping system to cater for variable flow

- Allowable percentage power of full load, of power drawn by motor of variable speed pump at 50% design flow (max 55% of full load)

- Allowable piping system frictional loss (e.g. max 400Pa/m for above 50mm diameter)

- Allowable coefficient of performance of chiller and unitary air-conditioner (e.g. min 4.7 for water-cooled screw chiller at 500 to 1000kW cooling)

- Min allowable thickness of thermal insulation to pipework & ductwork

- Energy metering (e.g. for chiller at 350kW cooling) to measure power and energy input/output

- Energy efficient system control, including temperature, off-hours, zone

Figure 9 Air-conditioning Installation

4.3 ELECTRICAL INSTALLATION

- Allowable power distribution loss (e.g. max allowable circuit copper loss)

- Allowable motor efficiency (e.g. min efficiency of 87% for 2-pole motor with rated output power at 5.5kW to less than 7.5kW)

- Allowable motor sizing ratio (max 125%)

- Allowable design total power factor (min 0.85 for circuit at or above 400A)

- Allowable design total harmonic distortion of current (e.g. max 12% for designed circuit current at 400A to below 800A)

- Balancing of single-phase loads (max allowable unbalance 10%)

- Metering & monitoring facilities requirements (e.g. sub-main circuit at or above 400A to facilitate measuring V, A, kWh, kVA, TPF & THD)

Figure 10 Electrical Installation

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4.4 LIFT & ESCALATOR INSTALLATION

- Allowable running active electrical power of motor drive (e.g. max 36.1kW for traction drive lift at 2.5m/s to below 3m/s rated speed and 1350kg to below 1600kg rated load)
- Allowable lift decoration load (e.g. max 50% of rated load or 600kg, whichever lower for lift with rated load less than 1,800kg)
- Shutting off of ventilation/air-conditioning of lift car during idling
- Min allowable total power factor
- Max allowable total harmonic distortion
- Metering & monitoring facilities requirements

Figure 11 Lift & Escalator Installation

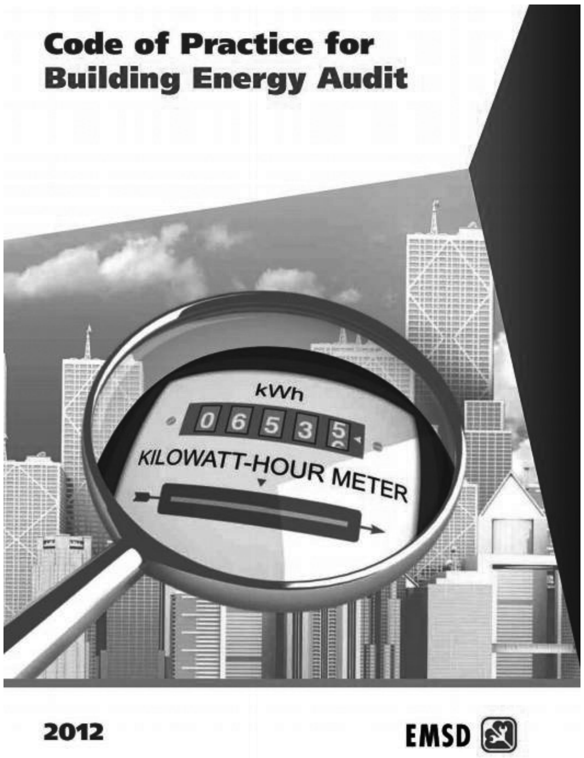
4.5 PERFORMANCE-BASED APPROACH

The performance-based approach provides an alternative approach to comply with the BEC. This approach focuses on estimating the total energy consumption of a building using an energy simulation software. With this approach, the energy savings from energy efficient features and renewable energy installations can be evaluated and made known to the building owner at the building design stage for his/her cost and environmental benefits consideration. The performance-based approach also provides certain relaxation from some of the above introduced BEC requirements, which are prescriptive in nature. For example, a lighting installation, with a combination of photo sensors and occupancy sensors to adjust the intensity of electric light to account for the availability of daylight and presence of occupants, can be allowed to have a LPD higher than the prescribed requirement, subject to the building's design energy not exceeding its energy budget dictated by compliance with all the prescriptive requirements.

5. EAC TECHNICAL REQUIREMENTS

To give an overview, the key technical requirements of the EAC (Rev. 1) are extracted as follows:

Figure 12 Code of Practice for Building Energy Audit



5.1 KEY STEPS OF AUDIT

(i) Information Collection

(ii) Review of energy consuming equipment

(iii) Identification of EMO

(iv) Cost benefit analysis

(v) Recommendations

(vi) Compiling energy audit report

5.2 CONTENTS OF ENERGY AUDIT REPORT

- Executive summary (Form EE-EAes)
- Energy audit scope
- Descriptions of building characteristics and equipment/ systems
- Energy consumption & performance evaluation
- Indication of key characteristics of air-conditioning equipment/ systems
- Indication of total lighting power
- Analysis of the building's historical energy consumption
- Indication of the building's EUI (on Energy Audit Form to be displayed)
- Indication of the CBSI energy supply to the building's units
- Findings from review & site inspection of energy consuming equipment, & potential EMO identification
- Evaluation of potential EMO
- Recommendations of EMO and further studies

5.3 EXECUTIVE SUMMARY FORM EE-EAes

The executive summary Form EE-EAes (currently version V.1) plays a vital role in the demonstration of EAC compliance. It serves to record as a summary of the energy audit findings. Snapshots of portions of Form EE-EAes (V.1) are shown in Tables 1 & 2 below. These required inputs target on the REA's appreciation of the audited building's technical characteristics and operation characteristics, and it is in strong belief that with the good appreciation the corresponding energy performances such as LPD, flow performance, chiller plant COP, cooling towers heat dissipation performance, EUI (in terms of W/m2, W per L/s, kW heat/kW power, kWh/m2) etc. can be assessed with better accuracy. With the proper assessment, the data can be compared across buildings with due regard to each building's corresponding specific usage and operation norm characterized by the range of categorized major usages for office, shopping & leisure, back of house, car park, occupant density, single or multiple ownership etc. In addition the energy savings from the identified EMO can be better evaluated for enhanced cost benefit analysis. For a property management corporation in particular, the data can help to compare and benchmark the corporation's portfolio of buildings, based on which the corporation can devise the strategic measures for collective improvement.

Table 1 Snapshot of Form EE-EAes(V.1) showing Information requiring Input in respect of Building Type, Usage and Operation (certain contents in the form are simplified for this snapshot)

(I) Building Type, Usage & Operation (Please tick where applicable and insert N/A for non-applicable items.)					
1) Type of building					
(a) Please choose the type (tick one item only) of building of the building entity^2 audited :					
☐ Commercial building		☐ Commercial portion of composite (commercial & residential) building		☐ Commercial portion of composite (commercial & industrial) ^3 building	
(b) Please indicate the portion of the building entity being common area^4 :					%
(c) Please indicate the no. of blocks^2 of the building entity :					no. of blocks
2)	Total internal floor area^5 of the building entity (m^2) :				
3)	No. of floors^6 of the building entity :				
4)	Major type of building façade (tick one item) :			☐ Curtain wall	☐ Non-curtain wall
5)	Date(s) of issue of occupation approval (dd/mm/yyyy)^7 :				
6)	Type of central air-conditioning^8:	☐ Cool air	☐ Chilled water	☐ Condenser water only	☐ N/A
7)	Summary of operation characteristics of categorized major usages of CBSI-served areas :				
	Operation characteristics / Major usage	%tage area of total of building entity ^9^27E	%tage AC area of total of building entity ^10^27E	Average weekly operating hours (hrs/week) ^11^12	Daily average no. of occupants^12
	(a) Office				
	(b) Shopping & leisure				
	(c) Back of house area				
	(d) Restaurant				
	(e) Car park				N/A
	(f) Others^13				
	Total^14^27E			N/A	
	Daily average occupant density (m^2 per person) ^15^27E				

Table 2 Snapshot of Form EE-EAes (V.1) showing Information requiring Input in respect of Chillers, Chilled Water Pumps, Air-conditioning Fans, Lighting LPD etc. (certain contents in the form are simplified for this snapshot)

(II) Central Building Services Installation[^19]							
1) Air-conditioning Installation							
(a) (i) Chillers, Heat Pumps, Boilers, Other Heating [^20^34]							
Type of equipment (Chiller, Heat Pump, Boiler, Other heating) [^21]	Cooling (for heat rejection) (A/FW/SW/FE)[^22]	Compressor (Ce/Se/So/Re) [^23]	Refrigerant (R134a/ R123/ R407c/R410a etc.) [^24]	Rated Capacity (kW)	Rated input power (kW)	Quantity	COP (kW / kW) [^25]
Total for cooling[^26], of all chillers / heat pumps							
(a) (ii) Unitary air-conditioners [^20^34]							
Type of equipment [^21] (Room type, Split type, Packaged type)	Cooling (for heat rejection) (A/FW/SW/FE) [^22]	Compressor (Se/So/Re) [^23]	Refrigerant (R134a/ R123/ R407c/R410a/ R22 etc.) [^24]	Rated Capacity (kW)	Rated input power (kW)	Quantity	COP (kW / kW) [^25]
Total for cooling [^26], of all unitary air-conditioners							
(b) Air-conditioning pumps				Pump rated motor power (kW)	Pump rated flow (L/s)	Quantity	Performance (W per L/s)
(i) Chilled water pumps	Primary circuit, sub-total of all pumps[^27]						
	Secondary circuit, sub-total of all pumps[^27]						
	Total, of all chilled water pumps[^27A]						
(ii) Condenser water pumps	Fresh water, sub-total of all pumps[^27]						
	Sea water, sub-total of all pumps[^27]						
	Total, of all condenser water pumps[^27B]						
(c) Heat rejection				Fan rated motor power (kW) [^27C]	Rated heat rejection capacity (kW) [^27C]	Quantity	Performance (kW/kW) [^27C]
Sub-total, of all cooling towers[^27C]							
Sub-total, of all radiators[^27C]							
Total, of all heat rejection equipment[^27C]							
(d) Air-conditioning fans				Fan rated motor power (kW)	Fan rated flow (L/s)	Quantity	Performance (W per L/s)
Sub-total, of all AHUs & FCUs (excluding primary air AHU) [^27]							
Sub-total, of all primary air AHUs, fresh air and return air fans (for conditioned areas) [^27]							
Total, of all air-conditioning fans[^27D]							
(e) Chilled / Heated water plant sequencing control provided ?				☐ Yes ☐ No			
(f) Overall representative indoor room temperature set point in summer (°C) :							
(g) Major type of air-side system (CBSI) : (may tick more than one item, if it serves 20% or more of AC area of building entity)							
☐ Chilled water AHU (VAV/CAV) ☐ Chilled water FCU ☐ Unitary air-conditioner ☐ Not applicable							
(h) Is power supply to air-side system AHU/FCU fans mainly on account of the building owner or tenants ? (please tick only one item) :							
☐ On account of the building owner ☐ On account of tenants ☐ Not applicable							
2) Central Mechanical Ventilation				Fan rated motor power (kW)	Fan rated flow (L/s)	Quantity	Performance (W per L/s)
Sub-total, of all exhaust and intake fans for car park[^27]							
Sub-total, of all exhaust and intake fans for toilets, pantries, un-conditioned areas etc. [^27]							
Total, of all central mechanical ventilation fans[^27B]							
Total internal floor area of areas served by central mechanical ventilation (m^2) :							
3) Lighting Installation (Lighting power below to be based on rated luminaire wattage, and to include decoration lighting of the building owner but not external lighting)							
Sub-total lighting power, of all luminaires with T5 fluorescent lamps (kW)							
Sub-total lighting power, of all luminaires with fluorescent lamps other than T5 (kW)							
Sub-total lighting power, of all luminaires with compact fluorescent lamps (kW)							
Sub-total lighting power, of all luminaires with incandescent lamps (tungsten filament, tungsten halogen etc.) (kW)							
Sub-total lighting power, of all luminaires with LED (light emitting diode) lamps (kW)							
Sub-total lighting power, of all luminaires with other types of lamps, if any (kW)							
Total lighting power, of all luminaires (kW) [obtained by summing up all figures above[^27E]] :							
Total internal floor area of areas having CBSI lighting installation (m^2) :							
Total lighting power density (kW/m^2) [obtained by dividing total lighting power by total internal floor area (having CBSI lighting) above[^27E]] :							

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5.4 ROOMS FOR IMPROVEMENT OF INPUTS

The inputs to Form EE-EAes lay the backbone for but do not give the details of the EMO, which are left to the discretion of individual REAs and building owners based on their available resources of funding, staff, time, etc. Most importantly, the quantified inputs can easily demonstrate the compliance with the EAC requirements, as opposed to EMO that usually require certain detailed study from preliminary identification to finalization.

Given the inputs being a demonstration of compliance, deviations from requirements have been however noted in some of the submitted EE-EAes forms, and as such there are rooms for improvement, examples as follows :

- paying attention to corresponding remarks for the form (34 nos. in total, numbering ^1 to ^34);
- for a building without common area (as interpreted in the BEEO), such as a single owner building having no deed of mutual covenant, a "0" should be inserted in sub-item (I) 1) (b) [Table 1];
- proper apportioning of the percentage areas in sub-item (I) 7) [Table 1], with due regard that the "Total" under the column with heading "%tage area of total of building entity" may not necessary be 100%, as it refers to spaces served by the CBSI (which may not serve the whole building) and as such the spaces not served by the CBSI should be excluded in the %tage figure;
- each row in sub-item (II) 1) (a) (i) [Table 2] for chillers should cater for and be the summary of equipment of the same configuration (e.g. all scroll-compressor R410a air-cooled chillers to be summarized in a single row), and likewise for each row in sub-item (II) 1) (a) (ii) for unitary air-conditioners;
- the capacity and power demand of standby equipment should not contribute to the inputs in sub-items (II) 1) to 5) [Table 2] for chillers, air-conditioners, pumps, fans etc.; and
- differentiation between "AHUs & FCUs (excluding primary air AHU)" and "primary air AHUs, fresh air and return air fans (for conditioned areas)", and have the corresponding data inserted in the appropriate rows for sub-item (II) 1) (d) [Table 2].

6. TECHNICAL GUIDELINES

Supplementing the BEC and the EAC, corresponding technical guidelines (TG), namely TG-BEC and TG-EAC in short, were also issued to assist in the understanding of the BEC and EAC requirements against the legislative background of the BEEO.

7. BEC REVIEW

Around end 2013, after having fully implemented the BEEO for over a year, the stringency of the BEC's requirements on maximum allowable LPD was reviewed. Having referenced to LPD standards in developed countries, and LPD data collected from the submissions under the BEEO for MRW, and having consulted local professional institutions and trade associations, the LPD requirement is slightly tightened for enhanced energy efficiency, and a new version, the Rev. 1 version BEC incorporating the new LPD standards has been issued in Feb 2014. The Rev. 1 LPD for certain common space types are listed below alongside the LPD in the initial version BEC.

Table 3 Comparison of Rev. 1 LPD and Initial Version LPD of the BEC

Type of Space	Maximum Allowable LPD (W/m^2)	
	Initial version	*Rev. 1*
Car Park	6	*5*
Corridor	10	*8*
Entrance Lobby	15	*14*
Lift Lobby	12	*11*
Office	15	*13*
Plant Room / Switch Room	12	*11*
Public Circulation Area	15	*13*
Restaurant	20	*17*
Retail	20	*17*
Staircase	8	*7*

The Rev. 1 LPD is promulgated in EMSD Technical Circular No. 1/2014 issued in Feb 2014, with grace periods of 6 months and 9 months allowed respectively for newly constructed buildings and for MRW, so as to allow ample time for the REAs and the trade to develop their acquaintance. Accounting for the grace periods, the Rev. 1 LPD applies to lighting installations covered in a stage one declaration (for newly constructed building) signed by the developer on or after 28 Aug 2014, and to lighting installations covered in a FOC (for MRW) signed by the REA on or after 28 Nov 2014.

8. CONCLUSION

With the implementation of the BEEO that serves as the key driver of building energy efficiency, Hong Kong has taken the very major step forward in addressing to the impacts of climate change brought about by energy consumption in buildings. This mandatory approach reinforces the roothold of the minimum energy efficiency standards in the BEC and the minimum energy audit requirements in the EAC, and paves the way for further enhancement of the standards. EMSD will review and tighten the standards at suitable time intervals, and the tightening will further trigger a new round of improvement in the pursuit of building energy efficiency in the combat of climate change.

9. ACKNOWLEDGEMENTS

Sincere thanks are extended to members of the Technical Taskforce on Mandatory Implementation of the BEC and its working groups (member organizations including the HKIE Electrical Division) in offering their expertise advice and support in the development of the BEC & EAC.

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[1] HKSAR Government (2010) *Buildings Energy Efficiency Ordinance (Cap. 610)*

[2] EMSD (2014) *Code of Practice for Energy Efficiency of Building Services Installation 2012 (Rev. 1)*

[3] EMSD (2013) *Code of Practice for Building Energy Audit 2012 (Rev. 1)*

[4] EMSD (2014) *Technical Guidelines on Code of Practice for Energy Efficiency of Building Services Installation 2012 (Rev. 1)*

[5] EMSD (2013) *Technical Guidelines on Code of Practice for Building Energy Audit 2012 (Rev. 1)*

Paper No. 6

REGENERATIVE ENERGY STORAGE SYSTEM MAKES TRAINS GO GREENER

Speakers: **Ir Dr Tony K.Y. Lee**
Chief of Operations Engineering
Mr Anson S.K. Chan
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ABSTRACT

As the mass public transport system, MTR is the second largest electricity consumer in Hong Kong following the Government of HKSAR, consuming around 3% of the total generation of the two power companies. With the fast development and enhancement of power electronics equipment, most of the passenger trains in MTR have equipped with efficient traction control system to enable regenerative braking and produce regenerative power back to the traction systems. The energy will be consumed by the motoring trains in the vicinity but still a considerable amount of the energy cannot be effectively utilised especially in the period with infrequent headway. This paper presents the opportunities as to how MTR can apply the regenerative energy storage systems (ESS) in the 1.5kV DC traction network using super-capacitor (Electric Double Layer Capacitor or EDLC) and Lithium-ion (Li-ion) batteries as a reservoir to momentarily store up the train regenerative energy and discharge back to the lines so as to enable MTR trains run greener.

1. INTRODUCTION

As a major mass transportation in Hong Kong, MTR has to serve around 5.2 million passengers and deploy about 8000 train trips every day (Heavy Rail + Light Rail). As every single train trip takes electric power from the power companies, the total energy for train operations of one single day consume is up to 2000MWh. MTR has been exploring various technologies to enhance energy efficiency. In the past decades of years, the power electronics were becoming more and more reliable and efficient for power control. The traction control systems for the modern trains are able to regenerate braking power back to overhead line (OHL) via the electrical braking (i.e. braking by electromagnetic field).

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Figure 1a Principles of Electrical Braking

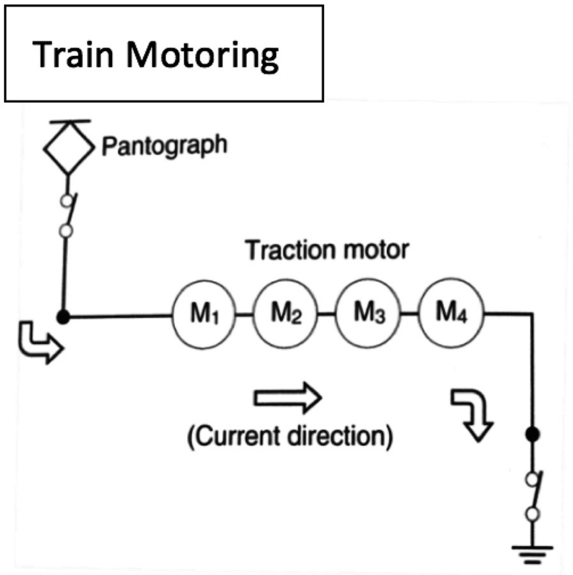

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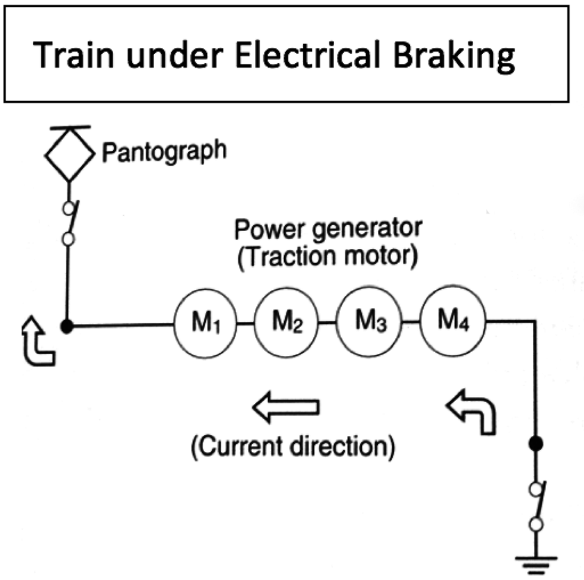
Figure 1b Principles of Electrical Braking



This kind of back feeding energy will be consumed by other trains running in the networks but the efficiency depends on the availability of other trains in powering. A considerable amount of energy would still not be effectively utilized by trains especially during light load conditions in non-peak hours. Unlike the AC traction network where the regenerative power can directly feed back to the power grid via the power equipment, there would be no room for discharging the redundant regenerative energy in the DC traction systems. The OHL voltage in DC traction system will rise till upper setting limit of train is reached, which then triggers the diversion of the energy to train borne resistors for dissipation in the form of heat or switches to mechanical brake (= frictional braking). To capture the redundant regenerative energy in DC traction systems, MTR is going to adopt energy storage technology by using super-capacitor (EDLC) and Li-ion batteries to store and discharge the regenerative power back to the OHL system. By using computer stimulation, the potential amount of annual energy saving of the ESS installations in two major operating lines, namely Lantau Airport Railway (LAR) and Tsuen Wan Line (TWL), would be discussed.

2. RISING SURGE OF ENERGY COST

Due to the effect of coming Hong Kong 2015 Emission Caps to control gaseous emission in 2015 which will be tightened by 34% to 50% on pollutants compared to 2010, mixed fuel with higher portion of nature gas in higher cost would be anticipated. Together with the surge of price increase in other fuel clauses, the electricity cost was significantly increased in the past years. As forecasted and announced earlier by China Light &Power Co., with the depletion of the supply in the Ya Cheng Gas reserve, the projected net electricity tariff increase would be amounted to 6.9% p.a. compared to that of 2013 and there will be around 40% cumulative increase in the following five years as shown in Figure 2.

As one of the largest power consumers in Hong Kong, MTR spends over a billion HK dollars a year to provide the required train services. The electricity cost of MTR was already increased sharply in the past five years as shown in Figure 3.

Figure 2 Estimated Net Tariff Projection in Coming Five Years

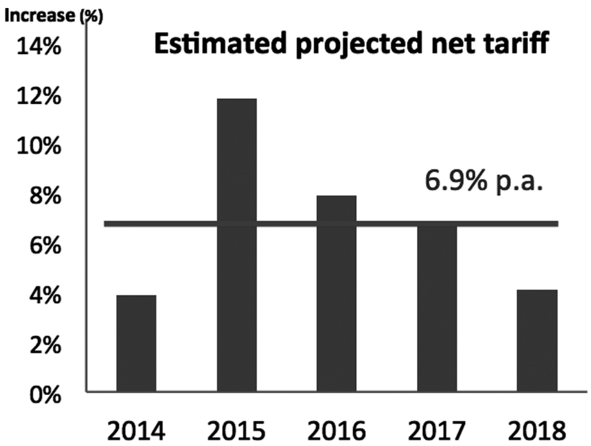


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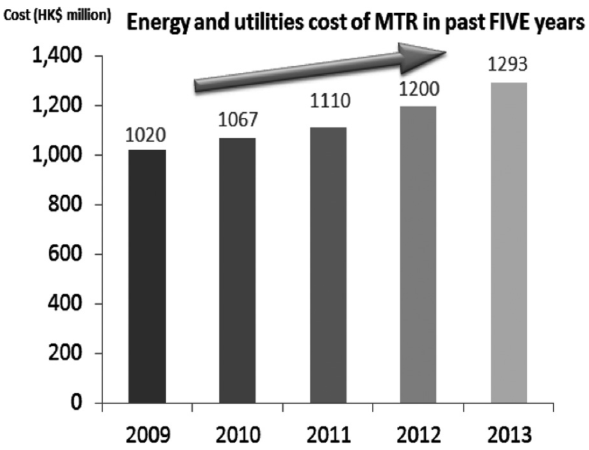
Figure 3 Energy and Utilities Cost of MTR in Past Five Years



To prepare for the coming challenges in trimming down the energy cost and achieve energy optimization to prevent global warming, application of innovative technology to MTR would be the best way out.

3. UTILIZATION OF REDUNDANT REGENERATIVE ENERGY

Regenerative braking enables trains to convert mechanical energy into electrical power and feed back to the OHL system. The redundant regenerative energy which could not be absorbed instantaneously by the trains in the vicinity or the power system would be undesirably dissipated in form of heat.

The efficiency of the regenerative braking of a train is simply described in terms of the ratio "Total regenerative energy" / "Total motoring energy". The typical figures of LAR and Urban Lines (URL) are shown in the following table.

Figure 4 Regenerative Braking Ratio Table

LINE	Max. Regenerative Current At 1.5kVDC/(A)	Regenerative Ratio / (%)	Typical Headway / (sec.)
Urban Lines (URL)	3,000	~45	120 - 240
Lantau Airport Railway (LAR)	5,700	~33	240 - 600

3.1 TRACKSIDE ENERGY STORAGE SYSTEMS

There are two different major types of technical systems that can better utilize the bulk redundant regenerative power, namely the inverter substation and energy storage system. Nonetheless, the former requires additional transformer units, power inverters and circuit breakers, which pose much spatial constraint to a retrofit project. A more direct approach is to install an ESS of moderate size to capture and temporarily store the redundant regenerative power in high energy density equipment via super-capacitors or Li-ion batteries. The ESS has its beauty with total isolation from the AC networks, leaving no additional AC equipment required and no interference affecting the AC power quality. The reservoir for the redundant regenerative energy can also compensate the line voltage under substation outage conditions.

The basic principle of an ESS is illustrated in the following figure.

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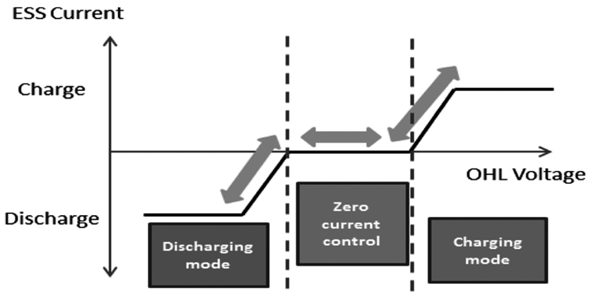
Figure 5 Basic Principle of an ESS



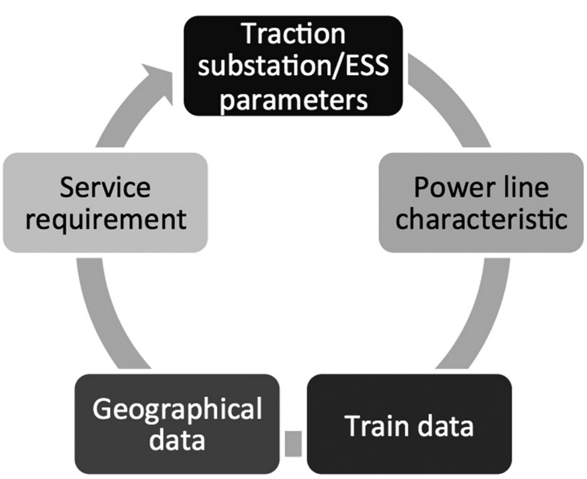
By means of the charging and discharging cycle of the ESS, the redundant regenerative energy can be saved for train consumption again.

4. FEASIBLITY STUDIES

4.1 COMPUTER SIMULATION

The amount of regenerative energy that can be captured by an ESS could be simulated by a computer simulation which consists of several elements as illustrated in Figure 6.

Figure 6 Major Simulation Elements

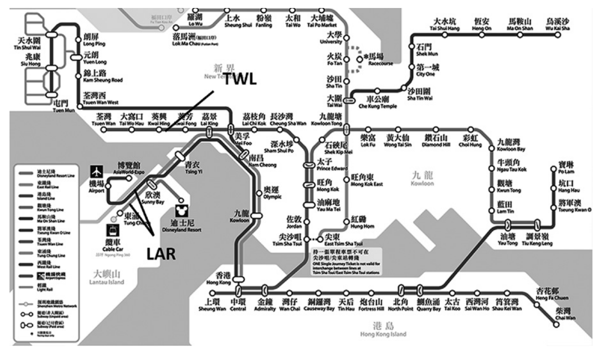


These elements would be mutually affected each other and the computation shall have to be under an integrated visual environment for simulations.

4.2 LINES UNDER STUDY

Lantau Airport Railway (LAR) including Airport Express Line and Tung Chung Line, and Tsuen Wan Line (TWL) are representing two different service patterns and train characteristics in MTR.

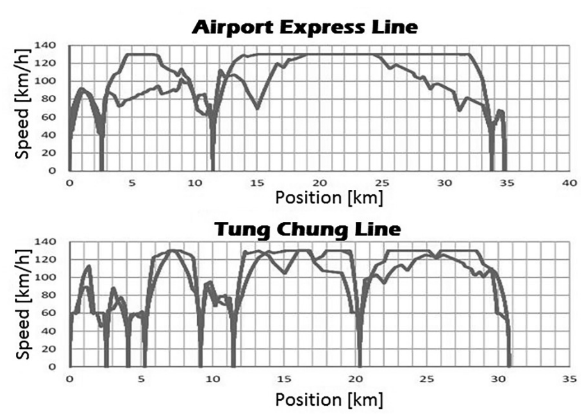
Figure 7 Route Map of MTR Network



4.3 ESS IN LANTAU AIRPORT RAILWAY (LAR)

LAR is a line that connects Hong Kong airport and new town Tung Chung on Lantau Island to city areas. The route length is around 35km. Figure 8 shows the charts of typical speed profile along the lines.

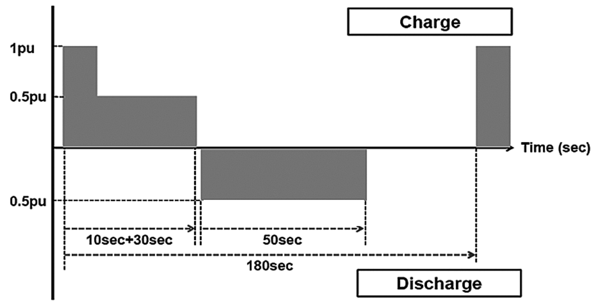
Figure 8 Train Speed Profiles Along LAR



Different lines in the chart illustrating different % of train coasting.

For the LAR simulation, Li-ion battery was used for the ESS. The battery has its duty load pattern as exhibited below.

Figure 9 Duty Cycle of Li-ion Battery

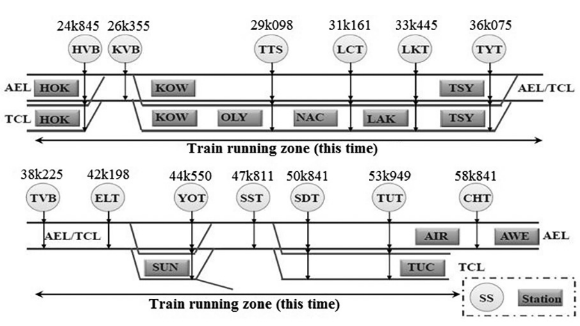


In general, the batteries act as a large reservoir to store the redundant regenerative energy, so the bigger the battery capacity is, the more energy that can be captured. However, the battery capacity is mostly limited by the commercially available rating of equipment which ranges from hundreds of kW to a few thousands of kW.

The simulation is for the study of installing ESSs in every traction substation along LAR and also for that of a single ESS installation in each traction substation. The ESS with typical ratings of 500kW and 1,000kW was used for simulation.

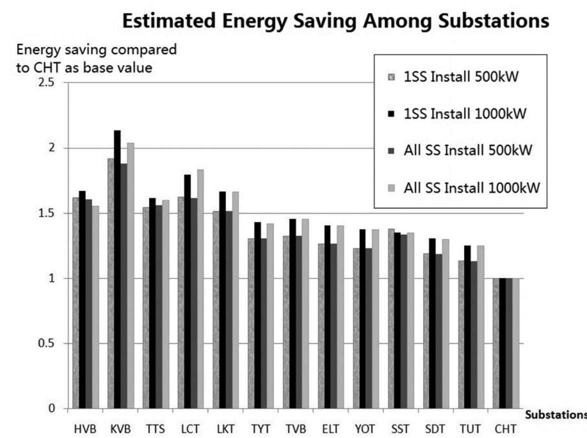
The simplified layout for the traction substation locations is depicted in Figure10.

Figure 10 Substations Along LAR



Apparently the effectiveness of each ESS would be affected by the route geographical profile and train patterns. Figure 11 shows the simulation results for each substation along LAR that is varied from the highest spot at Kowloon Ventilation Building (KVB) with an energy reduction of around two fold compared to the lowest spot at Chek Lap Kok Traction Substation (CHT) which is used as base value in Figure 11.

Figure 11 Estimation of Energy Saving Among Substations Compared to CHT as Base Value



The results show that doubling up of the equipment rating from 500kW to 1,000kW would gain more than twice of the return.

Figure 12 Percentage Increase on Energy Saving for Capacities of 1,000kW Over 500kW

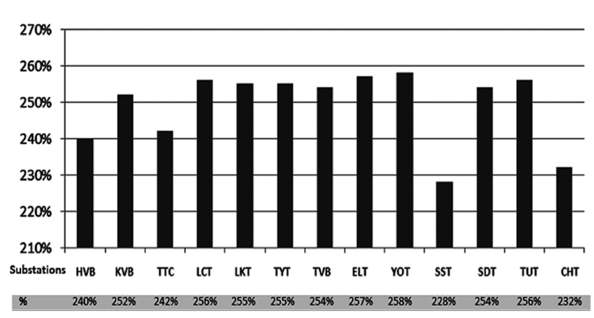


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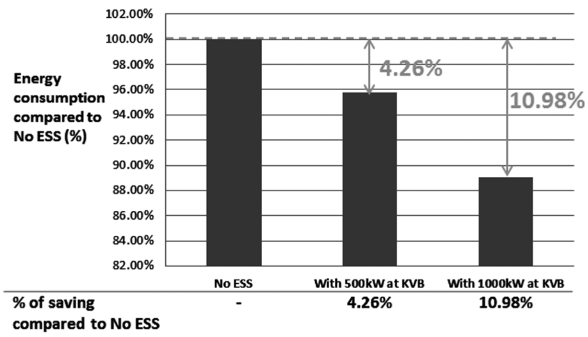
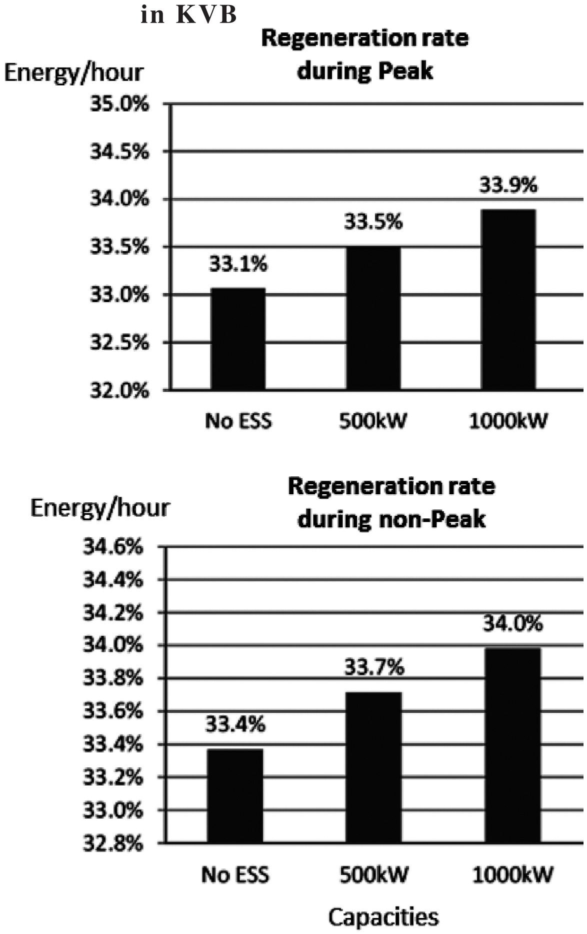
Figure 13 Estimated Percentage of Energy Saving in KVB



Among the 13 substations, KVB is the most effective one which is able to capture and reuse most regenerative energy up to the saving of 10.98% for a year. The estimated improvement in terms of regenerative ratio with KVB ESS is shown in Figure 14.

Figure 14 Regeneration Rate for Capacities of 500kW and 1,000kW Installed in KVB



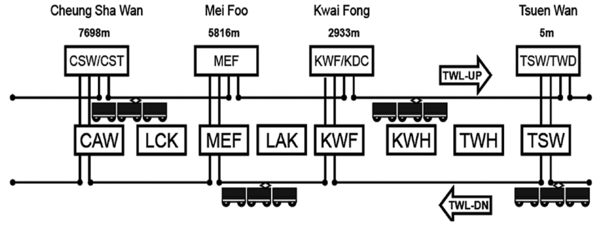
With the full implementation of ESS along the line, the regenerative ratio is expected to be approaching 40%. It is an attractive figure but when the capital cost and life cycle cost are taken into account, the rate of return could become marginal. MTR has therefore selected the most effective location (i.e., KVB) for ESS pilot installation on LAR to get well prepared for possible future challenges arising from any fuel crisis.

4.4 SUPER-CAPACITOR (ELECTRIC DOUBLE LAYER CAPACITOR OR EDLC) IN TSUEN WAN LINE (TWL)

The other proven ESS is using super capacitors (EDLC) which can offer a high current density and a speedy charging/discharging cycle. The technology of EDLC is based on the formation of double layers with the thickness of the order in nanometres and the porous materials providing an enormous surface area to optimise the energy storage capacity in a very compact size.

TWL, one of the busiest metro lines on URL with peak-hour headway of 120 seconds and off-peak headway up to 250 seconds, was selected for the study covering the substations from Tsuen Wan (TSW) to Cheung Sha Wan (CSW), which could well represent the train pattern on URL. The simplified TWL under the simulation is shown in Figure 15.

Figure 15 Substations Along TWL (TSW to CSW)



Four substations namely Tsuen Wan (TSW), Kwai Fong (KWF), Mei Foo (MEF) and Cheung Sha Wan (CSW) are distributed along the route. The running curve forming the fundamental data for the DC simulation study is shown in Figures 16 and 17.

Figure 16 Run Curve of Trains for TWL

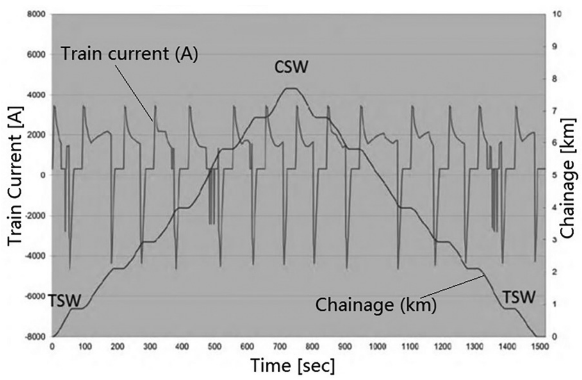
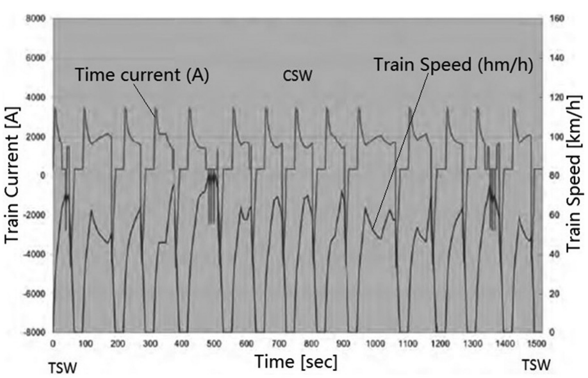


Figure 17 Train Speed Profiles Along TWL



These curve data have been arranged along with specific headway interval respectively for the simulation of regenerative power.

As URL substations have very limited spare space for additional ESS installation, it would not be that all the substations are feasible to have the ESS installed. For the purpose of simulations aimed at a pilot project, the traction substation at Tsuen Wan Depot (TWD) with sufficient space for the ESS and is at the end of line where typically the OHL system has low receptivity, was selected.

The computer program simulated two scenarios for peak-hour headway of 120seconds and off-peak headway of 250 seconds with EDLC capacities of 10MWs, 15MWs, and 20MWs.

The simulation results are summarized in the following figures.

Figure 18 Estimated Amount of Energy Saving in 120s and 250s Headways

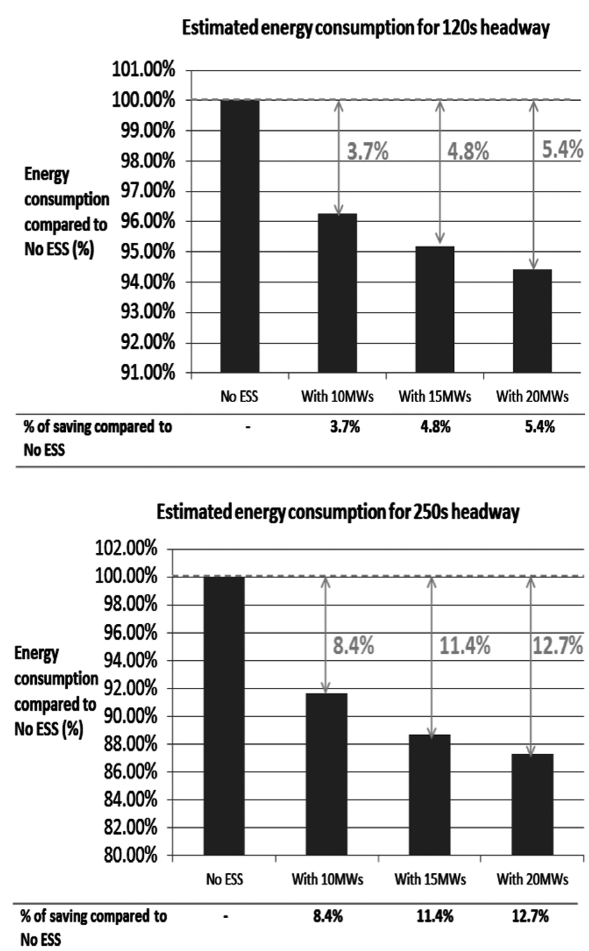


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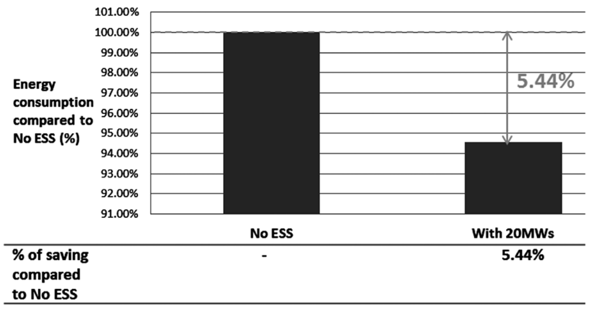
Figure 19 Estimated Percentage of Energy Saving in TWD



By computer simulations, the estimated annual saving will be around 5.44% in TWD if one unit of 20MWs EDLC is installed. But for the case in TWD, the increase of the ESS capacity would not have the same percentage of increase in the energy returned.

5. CONSTRAINTS FOR ESS RETROFIT PROJECTS

Unlike green field projects, there are constraints to be overcome for the pilot installation on existing lines. MTR has encountered different hurdles. They are:

5.1 SPATIAL CONSTRAINT IN INSTALLATION SITE

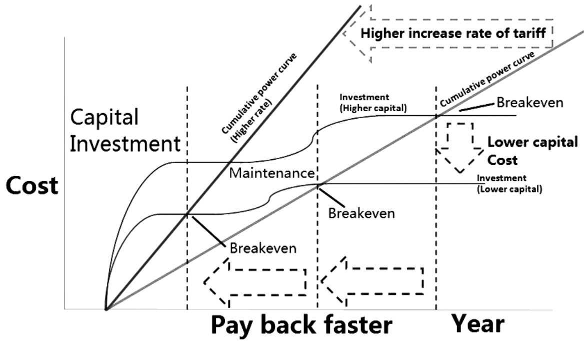
An ESS consists of a chopper panel and storage devices at the size of 9m×2m×1.2m. Spacing is a prime consideration for retrofit projects. Separating chopper and energy storage panel into smaller panel with cables connecting among them is one of the options for resolving this constraint.

5.2 RATE OF RETURN FOR THE ESS INSTALLATION

The expected life of either EDLC or batteries is less than 15 years. The life cycle is a half shorter than that of general E&M equipment. The relatively high investment cost and the short return period made the internal rate of return for an ESS marginally attractive.

However, the situation will change with the rate of electricity tariff rise and capital cost of investment which are two major factors determining rate of return. Payback period in different scenarios of the projects are shown in Figure 20. Capital cost of installation of ESS will become lower for mass scale and technology maturity that can result in faster payback. Fuel mix is having a larger portion of natural gas in coming future and electricity tariff is expected to be higher. The rise is more vulnerable to fuel price, so higher increase rate of tariff may also possible. These two situations can enable ESS installation much more attractive.

Figure 20 Payback Period in Different Scenarios



As the studies are based on the computer simulation results, the effectiveness of the ESS would need further validation. The estimated figures in energy saving may differ from the actual ones when the installation comes to reality. Therefore, a pilot project can give more field data for the assessment of their effectiveness.

6. BENEFITS OF REGENERATIVE ENERGY STORAGE SYSTEM TO MTR

6.1 ENERGY OPTIMISATION

It is estimated that the ESS installations would bring about an annual saving of 10.98% and 5.44% in KVB and TWD respectively. Facing the increase of electricity tariff in the coming years, the early adoption of the ESS can help MTR to further save the energy consumption and in turn contribute to the combat against global warming.

6.2 LESS TRAIN MECHANICAL BRAKING

The adoption of the two energy storage systems will help MTR in reducing the usage of frictional brakes of trains, thereby minimising passenger discomfort due to the possible bad smell generated in the tunnel. With the reduction in the usage of frictional brakes by which energy is dissipated as heat, it will also help to lower the tunnel ambient temperature.

6.3 FIELD EVALUATION OF ENERGY STORAGE SYSTEMS

The usage of super-capacitor and rechargeable Li-ion batteries systems in existing operating rails provides the first application experience in MTR. The effectiveness of these two retrofit projects can be used to assess future installations.

7. CONCLUSION

This paper presents the opportunities as to how MTR can apply the ESS in the 1.5kV DC traction network using super-capacitor and Lithium-ion batteries as a reservoir to momentarily store and discharge back the train regenerative energy to the operating railway. As a pilot run, the feasibility of installing ESSs has been studied and estimated to have 10.98% and 5.44% annual energy saving at KVB and TWD by computer simulations. The amount of energy supposed to be wasted could be re-used by the trains in the network, making MTR trains go much greener.

Paper No. 7

HIGH-SPEED TRAIN DESIGN FOR EXPRESS RAIL LINK

Speakers: Ir C. L. Leung, Chief E&M Engineer
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Projects Division
MTR Corporation Limited
Mr Ding Sansan, Vice Chief Engineer
CSR Qingdao Sifang Co., Ltd.

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ABSTRACT

The MTR Corporation Limited is entrusted by the Hong Kong Government on the design and the construction of the Hong Kong Section of the Guangzhou-Shenzhen-Hong Kong Express Rail Link ("XRL"), including the procurement of 9 high-speed trains for the operation between Hong Kong and Guangzhou. The 26km line is the extension of the Mainland's 16,000km National High-Speed Rail Network into Hong Kong.

High-speed train design differs from conventional mass transit or regional trains in many aspects in order to cope with the aerodynamic, and other issues arose from high speed operation. This paper will introduce the design of high-speed trains and the measures taken to assure safe train operation.

1. INTRODUCTION

The Guangzhou-Shenzhen-Hong Kong Express Rail Link (Guangshengang Express Rail Link) connects the Mainland China and Hong Kong through the passenger dedicated line. This Guangshengang Express Rail Link is a part of the planned Beijing-Guangzhou-Shenzhen-Hong Kong High-Speed Railway serving the rapid transit from Guangzhou South Station to West Kowloon Terminus in Hong Kong.

The whole length of the Guangshengang Express Rail Link is 142km, of which the Hong Kong Section is a tunnel of 26km. The Hong Kong Section runs from the terminus in West Kowloon, heading north to the Shenzhen/Hong Kong boundary where it connects with the Mainland Section.

The Guangshengang Express Rail Link is a part of the National High-Speed Rail grid which is composed of 4 north-south corridors and 4 east-west corridors connecting together with upgraded existing lines in Mainland China, a total of 12,000km in length as built at this stage. The total planned high speed network is up to 16,000km. The Guangshengang Express Rail Link Mainland Section is constructed and built in accordance with the requirements of TB 10621-2009 (Code of High-Speed Railway). To maintain the technical compatibility and interoperability of the network, the Hong Kong Section is also constructed to align with the TB requirements

The Guangshengang Express Rail Link adopts the active protection concept and the line is fully protected by the signalling "Automatic Train Protection" (ATP) system, with multiple levels of backup and redundancy. The ATP signalling system is a highly reliable 3-layer signalling system. Each layer is provided with redundancy to protect train operation:

1st Tier System: CTCS-3 (Chinese Train Control System – 3) is comparable to ETCS-2 (European Train Control System – 2);

2nd Tier System: CTCS-2 system is comparable to ETCS-1 (European Train Control System – 1);

3rd Tier System: Line Side Signals.

In addition, the Guangshengang Express Rail Link adopts dedicated passenger line operation. It is a segregated line without mixed traffic with freight trains or sharing with the road vehicles. This same operation principle has been adopted in other countries with high speed railway such as Japan, which has an excellent high speed train safety record.

2. HONG KONG HIGH-SPEED TRAINS

Various types of high speed trains have been approved by National Railway Administration to operate in the National High-speed Rail Network. They are all named under Hexie Hao （和諧號） with different type numbers at three different operating speeds. CRH1, CRH2A, CRH2B, CRH2E and CRH5 have a maximum speed of 250km/h; CRH2C and CRH3 have a maximum speed of 350km/h; CRH380A, CRH380B and CRH380C have a maximum speed of 380km/h.

The 8-car high-speed trains purchased for Guangshengang Express Rail Link (Hong Kong high-speed train) are manufactured on the basis of CRH380A high-speed Electric Multiple Unit (EMU) technology platform and will operate between West Kowloon Terminus and Guangzhou South Station as shuttle service. The CRH380A EMUs have been designed and developed by China South Locomotive & Rolling Stock Corporation Limited (CSR) in accordance with the "Technical Specification for New Generation EMU running at 350kph" （時速350公里新一代動車組技術條件）issued in 2009 by China Railway Corporation (CRC) – formerly known as Ministry of Railways (MOR).

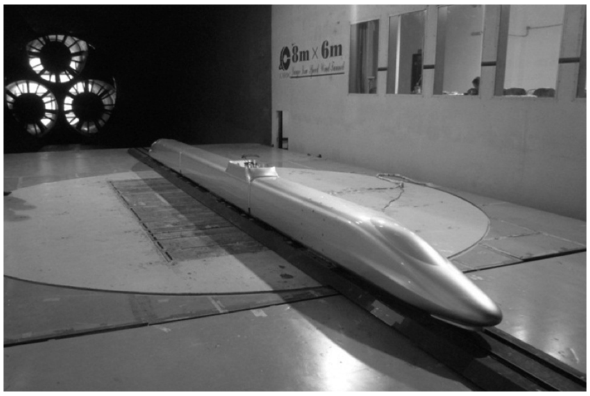
Figure 1 Hong Kong High-speed Train

3. MAIN TECHNICAL INNOVATION

3.1 STREAMLINED HEAD SHAPE

The aerodynamic design of high-speed train is critical to running resistance, stability and riding comfort. The Hong Kong high-speed train has incorporated a slender head of 12-meter long, enhancing the degree of streamlining, featured with rotary parabolic surface to optimize the aerodynamic performance. The cross sectional area of the head changes linearly in each of three sections to reduce the pressure pulse generated during trains passing. Moreover, the shape of nose faring can effectively reduce the train passing pressure as well as end-car lifting force by guiding the air flow focusing on downward direction. The double-arched curved surface at the cab exterior portion can also reduce the aerodynamic noise at the top of the train cab. Comparing to the previous design of trains running at 200km/h, the streamlined head design for the Hong Kong high-speed train brings further reduction in aerodynamic drag, noise, lifting and lateral force.

Figure 2 Wind Tunnel Test on Train Model



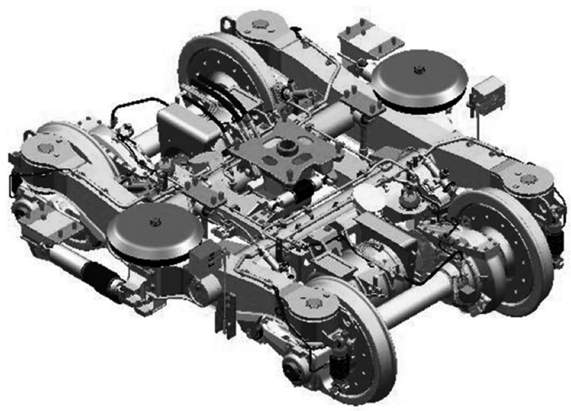
3.2 AIR TIGHTNESS

The air tightness strength on carbody structure of high-speed running trains is crucial for passengers to enjoy a pleasant train ride. To improve the capability to endure high external pressure variation, the carbody shell of the Hong Kong high-speed train uses aluminium alloy sections with varying structural thickness to reduce the stress on critical locations. Also, large radius of the transition arch between the roof and sidewalls is applied to reduce the side force and thus the overturning moment acting on the train. On the other side, in order to achieve the required air tightness for high-speed train, airtight welding structures are applied on the carbody shell. Also, bodyside doors are designed to have multi-point-pressing-mechanism which ensures good sealing performance being maintained at high speed running. Moreover, the ventilation device is equipped with high static pressure fans to effectively prevent pressure changes in saloon during train passing or running through tunnels at high speed. The design allows the Hong Kong high-speed train to sustain external air pressure as high as 6kPa and achieve air tightness with air pressure changing from 4kPa to 1kPa for more than 180s. Also, the rate of air pressure transient can be maintained below 200Pa/s while the train is running in open or tunnel sections.

3.3 HIGH SPEED BOGIE

As a critical component for train dynamic performance, the train bogie is always one of the key focuses on the high-speed train design in regard to the train's stability and reliability. In order to increase the speed of the Hong Kong high-speed train, the dynamic performance of train under effects of aerodynamic excitation, wheel-rail interface and interaction between train cars are analysed by precise dynamic modelling to optimize the stiffness of primary suspension system, parameters of yaw dampers and lateral dampers. Also, the damping of primary suspension system and both stiffness and damping of secondary suspension system are refined to enhance the riding comfort. In addition, the unsprung weight is reduced so as to maintain the advantage of low wheel-rail interaction force and wheel wear rate. Safety integrity is also demonstrated by the proven bogie frame design, redundant yaw damper provision and stability detection system.

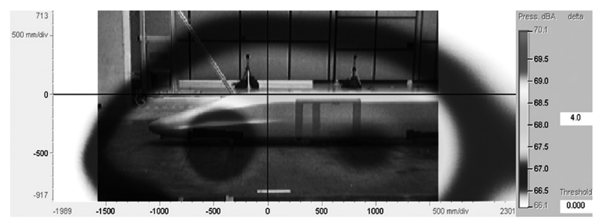
Figure 3 High Speed Bogie



3.4 VIBRATION AND NOISE CONTROL

As the running speed increases, the aerodynamic noise, pantograph and wheel-rail noise will increase dramatically. Effective mitigation on noise generation and propagation for high-speed train is therefore critical to ensure riding comfort and minimize the environmental impact. For reducing aerodynamic drag and noise generation of the Hong Kong high-speed train, the train head shape and pantograph with good aerodynamic performance are used, and the exterior surfaces of the bodyside doors and windows, roof equipment, bogie area and inter-car connection are also smoothened to streamline the air flow on the train. For medium-to-high frequency noise propagation, it is mainly tackled by enhancing sound insulation performance for the multi-layer construction and applying new types of acoustic insulation and absorption materials so as to improve the entire sound insulation/absorption performance. For low frequency noise propagation, it is mainly tackled by increasing stiffness of structural members, improving resilient mounting connections and damping characteristic of materials. With the mitigation measures implemented, the Hong Kong high-speed train can meet the interior and exterior noise performance requirements.

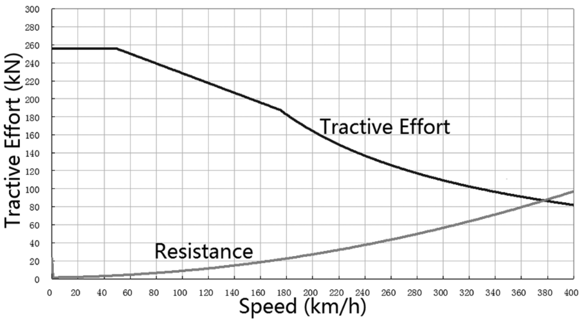
Figure 4 Noise Measurement Result of the High-Speed Train



3.5 TRACTION AND BRAKING

The capability and efficiency of the traction and braking systems are crucial for the train performance in high speed safe running. To achieve the operating speed of 350km/h, the Hong Kong high-speed train is equipped with a traction system having a total traction power of close to 10,000kW. The hybrid braking system consisting of electrical regenerative braking and pneumatic braking is adopted on the train, and priority is given to the regenerative braking so as to recover energy and minimize the brake pad wear. Moreover, the friction brake system is provided with sufficient heat capacity and floating brake pads are adopted to ensure even contact with brake discs in meeting the demanding requirements during friction braking. Parameters of the braking friction pairs are reasonably selected and optimization of the deceleration control curve is implemented to effectively achieve the required jerk rate and a smooth train stop. The regenerative braking of the Hong Kong high-speed train can achieve an energy feedback rate of up to 90%.

Figure 5 Tractive Effort Curve and Resistance Curve at Level Track



Same design of the traction and brake system in CRH380A attained very high reliability figure during its service in Beijing-Shanghai High-Speed Railway since 2010, it had accumulated a safety operation mileage over 210x10^6 km.

3.6 ENERGY CONSUMPTION

The Hong Kong high-speed train has excellent energy efficient design. The train is characterized by low running resistance and high regenerative braking utilization. The energy consumption per 100km is less than 4.38kWh, which is smaller than other high speed trains of similar type. The regenerative braking achieves with a maximum energy feedback rate of 90% and thus reduces the brake disc and brake pad wear and consumption.

4. CONCLUSION

The Guangzhou-Shenzhen-Hong Kong Express Rail Link is an integral part of National High-Speed Rail Network which connects Hong Kong with the major cities in Mainland China. The design of the high-speed train procured for this project is based on technology platform of CRH380A. There are a number of design aspects in high-speed train which makes it different from mass transit or regional train. The CRH380A train model has good records since its operation in 2010. The Hong Kong high-speed trains will provide safe, reliable, fast and comfortable journey serving passengers travelling between Guangzhou, Shenzhen and Hong Kong.

Paper No. 7

Paper No. 8

DISTRIBUTED ELECTRIC SPRINGS FOR SMART POWER GRID STABILITY

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Department of Electrical & Electronic Engineering
University of Hong Kong

DISTRIBUTED ELECTRIC SPRINGS FOR SMART POWER GRID STABILITY

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ABSTRACT

This paper begins with the explanation for the need for a change of control paradigm of power systems and then addresses some potential issues arising from increasing penetration of intermittent renewable energy sources, such as wind and solar power, in future smart grid. Electric springs, an emerging technology pioneered at the University of Hong Kong and Imperial College London will be introduced as a possible solution to tame the intermittent nature of renewable power. Their features in voltage and frequency stability, reduction of energy storage requirement and making non-critical loads adaptive to future smart grid will be illustrated.

1 INTRODUCTION

According to the United States Environment Protection Agency (EPA), the carbon dioxide (CO_2) concentration in the atmosphere has risen from the pre-industrial figure of 280 parts per million (ppm) to over 400 ppm in 2014[1]. It is projected that such a figure will exceed 450 ppm in the next two decades. In July 2014, Mr. Ban Ki-moon, the Secretary-General of the United Nations, gave a warning that "Time is not on our side" when he was introducing a new United Nations-backed report outlining pathways major industrial economies can use to cut their carbon emissions by mid-century[2]. The warning of the urgent need for tackling climate change issued by the United Nations is also echoed by the US Environmental Protection Agency (EPA). A CO_2 concentration of 450ppm is considered by some scientists as a critical point for more drastic climate changes. EPA has listed the following as areas of concerns regarding climate changes[3]:

- Increase Earth's average temperature
- Influence the patterns and amounts of precipitation
- Reduce ice and snow cover, as well as permafrost
- Raise sea level
- Increase the acidity of the oceans

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Among these five concerns, the last one about acidity of the oceans should not be ignored. It is stated in [3] that "*Oceans become more acidic as carbon dioxide (CO_2) emissions in the atmosphere dissolve in the ocean. This change is measured on the pH scale, with lower values being more acidic. The pH level of the oceans has decreased by approximately 0.1 pH units since pre-industrial times, which is equivalent to a 25% increase in acidity. The pH level of the oceans is projected to decrease even more by the end of the century as CO_2 concentrations are expected to increase for the foreseeable future.*

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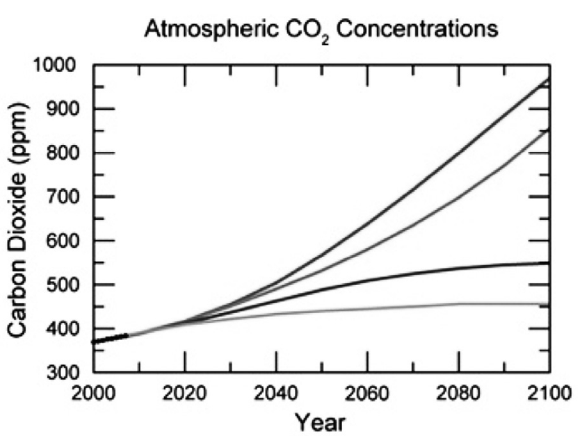
Ocean acidification adversely affects many marine species, including plankton, mollusks, shellfish, and corals. As ocean acidification increases, the availability of calcium carbonate will decline. Calcium carbonate is a key building block for the shells and skeletons of many marine organisms. If atmospheric CO_2 concentrations double, coral calcification rates are projected to decline by more than 30%. If CO_2 concentrations continue to rise at their current rate, corals could become rare on tropical and subtropical reefs by 2050." [End of quote].

In summary, increasing CO_2 concentration will increase the acidity of sea water, which will in turn affect the bottom level of the food chain, with serious implication of global shortage of food and the consequential famine.

Figure 1 Projections of the CO_2 Concentration Under Several Scenario[3]



One obvious choice of drastically reducing greenhouse gases emission, including carbon dioxide emission, is to increase the penetration of renewable energy such as wind and solar energy as soon as possible. For example, Germany has decided to phase out the use of nuclear power by 2017 after the tsumami and the subsequent nuclear plant explosion in Fukushima, Japan in 2011. Table 1 shows some targets of the use of renewable energy penetration of Germany.

While it is an admirable goal to substantially increase renewable power to replace fossil fuel and nuclear based power generation, it was reported by the Institute for Energy Research in January 2013 that "Germany's Green Energy Destabilizing the Power Grid"[4]. The Institute for Energy Research has identified the intermittent nature of wind and solar power as the major factor for causing power instability. It has been suggested that 30% might be an upper limit for renewable power generation in a power grid[5], unless new technologies become available to handle the intermittency of renewable power generation.

Table 1 Targeted Percentage of Renewable Energy for Electricity Generation in Germany

Year	Germany - Targets
2012	15% (capacity)
2020	35% (target)
2030	50% (target)
2050	80% (target)

In this article, the need for a change of control paradigm in power system is first put forward. Then an emerging Smart Grid technology called Electric Springs (ES) is described. Its features for voltage and frequency stability, reduction of energy storage and turning a range of electric loads into a new generation of adaptive or smart loads will be described. This article is an update of a previous conference paper reported in [6].

2 NEED FOR CHANGE OF CONTROL PARADIGM

In existing power systems with negligible renewable power, the power flow control is unidirectional and centralized. Power is generated at the power stations and transmitted to the load centres. Power balance of supply and demand can be easily maintained. The existing control paradigm is for the *power generation to follow the power demand*.

The increasing use of distributed power generation such as wind farms and solar power systems means that power generation is become more distributed than centralized. The intermittent and variable nature of wind and solar power makes it difficult to achieve instantaneous balance of power supply and demand, which is the essential condition for power system stability. When the percentage of the two renewable power penetration increases to a high level, e.g. 30% or beyond, it is necessary to change the control paradigm to having *power demand following power generation*. This implies that future loads (or at least a significant of future loads) much be adaptive to the availability of the large-scale renewable energy generation.

3 ELECTRIC SPRINGS AND THEIR CHARACTERISTICS

3.1 HOOKE'S LAW IN THE MECHANICAL DOMAIN

Electric spring is an electric version of a mechanical active suspension system. The Hooke's law published in 1660 provides the relationships of the force and displacement as follows:

$$\mathbf{F} = -k\mathbf{x} \qquad (1)$$

where F is the force vector, k is the spring constant and x is the displacement vector. The potential energy (PE) stored in a mechanical spring is:

$$PE = \frac{1}{2}kx^2 \qquad (2)$$

The array of many individual mechanical springs under a bed's mattress is a highly robust support system, because the overall system is highly stable even if some individual springs fail. Such concept can be adopted in taming the intermittent nature of wind and solar power generation in future power grid[6].

3.2 HOOKE'S LAW IN THE ELECTRIC DOMAIN – ELECTRIC SPRING

An ES can be used to (i) provide electric voltage and frequency stability support, (ii) store electric energy and (iii) stabilize system operation. When implemented with power electronics, it can be regarded as an active suspension system for the power grid.

Analogous to (1), the basic physical relationship of the electric spring is:

$$q = -Cv_a \qquad (3)$$

where q is the electric charge stored in a capacitor with capacitance C, va is the electric potential difference across the capacitor and ic is the current flowing into the capacitor.

The energy storage capability of the ES can be seen from the potential electric energy stored in the capacitor:

$$PE = \frac{1}{2}Cv_a^2 \qquad (4)$$

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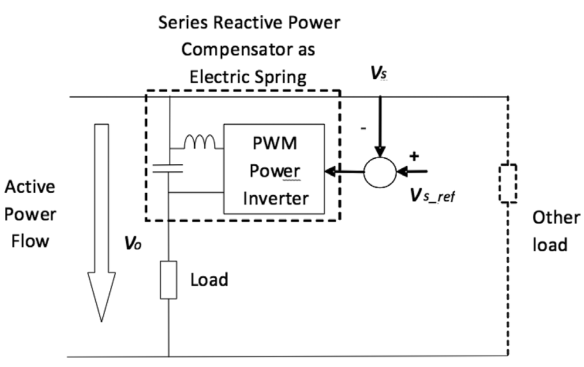
SIEMENS

so the capacitor C serves as the energy storage element for the electric spring.

4 ELECTRIC SPRINGS AND THEIR POTENTIAL APPLICATIONS IN FUTURE POWER GRID

Electric spring technology was reported in 2010 as a means of dynamic demand side management[6]. The basic principle is to include an input control loop in a grid-connected power inverter (Figure 2) to regulate the mains voltage and frequency, and simultaneously enable variation of some of the loads to follow the intermittent nature of the renewable power generation. In the first version [6][7], the ES is connected in series with a non-critical load which can tolerate a certain range of mains voltage fluctuation (Figure 2). The first version of ES essentially uses the grid-connected power inverter as a reactive power compensator which can regulate the mains voltage in the presence of mains voltage fluctuation caused by the intermittent nature of renewable power generation.

Figure 2 An Electric Spring Setup Based on an Input-voltage Control Loop



The second version of ES incorporates an active energy source (i.e. battery) with the power inverter. The full details of the steady-state analysis are reported in [8]. This version provides both active and reactive power compensation and therefore is advantageous for voltage and frequency stability in power grid. Recently, version three of ES has been suggested for incorporation into bidirectional ac-dc grid-connected power inverters[9].

4.1 VOLTAGE REGULATION IN POWER GRID WITH INTERMITTENT POWER GENERATION

In a typical power grid (e.g. a microgrid) with both traditional and renewable power generation (Figure 3), the intermittent power generation is a factor that can cause instability. Figure 4 shows the measured mains voltage of this setup without and with the ES activated. The nominal main voltage is set at 220V. Before the ES is activated, the intermittent power causes voltage fluctuation in the first period from 0s to 720s. The wind profile is repeated in the second period from 720s to 1440s with the ES activated. The ES is successful in stabilizing the mains voltage in the presence of intermittent power injection. The dynamic variation of the ES voltage is also recorded in Figure 4. Thus electric spring action acts as an active voltage suspension system for the mains voltage.

Figure 3 A Typical Experimental Setup of A Microgrid with Traditional and Renewable Power Generation[7]

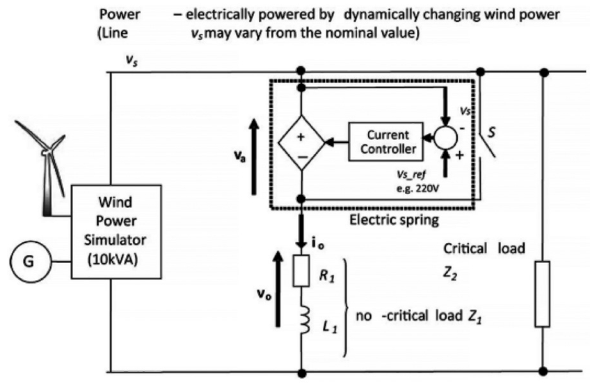


Figure 4 Experimental Results of Mains Voltage in the Setup With and Without the ES[7]

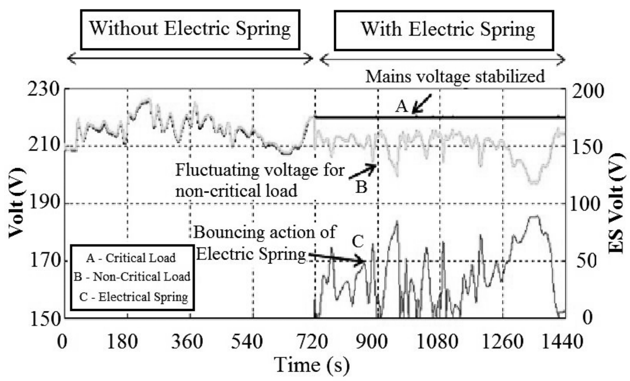
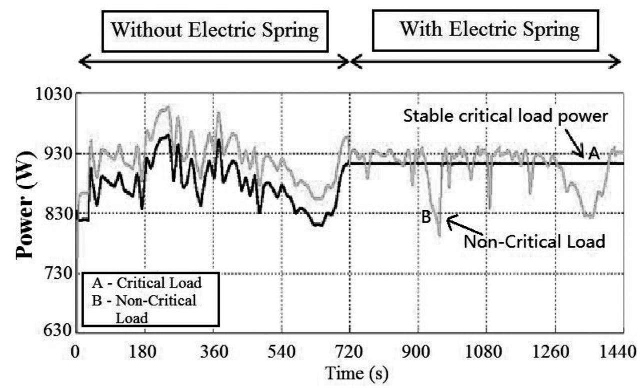


Figure 5 Power Consumption of Critical and Non-critical Loads.



4.2 LOAD DEMAND FOLLOWING POWER GENERATION

An important feature of the ES is its automatic function to shape the non-critical load power to follow the profile of the power generation. Take the setup in Figure 3 as an example, the measured non-critical load power and critical load power are shown in Figure 5 with and without the ES. Before the ES is activated, the mains voltage fluctuates because of the intermittent power, so both critical and non-critical load power consumptions also fluctuate. Once the ES is enabled, the mains voltage is stable and so the power consumption of the passive critical load is also stable. The output voltage of the ES now fluctuates, leading to the fluctuating power of the passive non-critical load in the setup. Therefore, the ES can be used as a new demand-side management technique. It can be used together with supply-side management such as the risk-limiting dispatch principle[11] to achieve the new control paradigm where the load demand follows the power generation.

4.3 REDUCTION OF ENERGY STORAGE

Even though the ES allows the non-critical load power consumption to follow the time-varying profile of the power generation, it does not have unlimited capacity to do so. Therefore energy storage is still considered to be an essential part of future power grid. Figure 6 shows the schematic of a power grid with a bidirectional ac-dc power converter and an energy storage. Mathematical proof has been reported in [11] that the use of ES can ensure a reduction of energy storage because the ES allows the power consumption of the non-critical load to follow the power generation and therefore reducing the power imbalance of the power supply and demand. Figure 7 shows the measured total power, non-critical load power and battery power with and without ES. Before the ES is activated, the battery can act as an energy buffer to absorb or deliver energy so as to keep the mains voltage stable and therefore keep the non-critical load power constant. So the battery bears the full responsibility in balancing the difference of power supply and demand before the ES is used.

After the ES is activated, it enables the non-critical load power to follow the power generation profile, thus reducing the power imbalance. Consequently, the charging and discharging power profile of the battery is significantly reduced. This feature of the ES is very important because the cost of battery is almost exponentially proportional to the battery capacity. The reduction of battery capacity implies that existing battery technology of medium and small capacities can play a realistic and practical role in maintaining power balance in power grid.

Figure 6 Schematic of a Power Grid

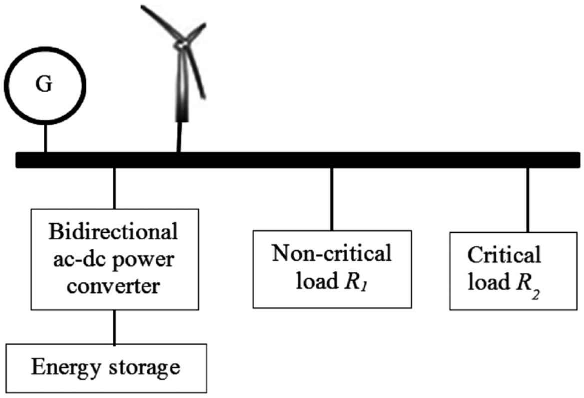
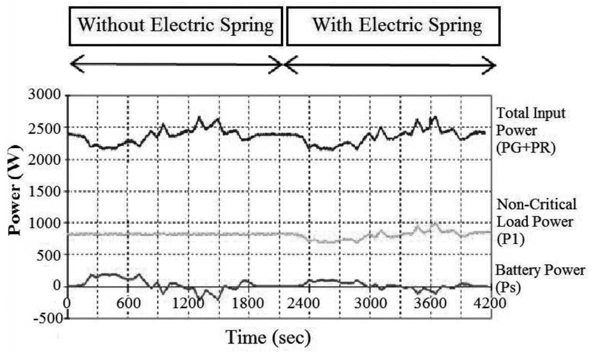


Figure 7 Measured Total Power (A), Non-critical Load Power (B) and Battery Power (C) With and Without ES[11]



4.4 USE OF DISTRIBUTED ES WITH DROOP CONTROL

Normally, the mains voltage value varies within a certain tolerance and is not identical at every point along the distribution line. Figure 8 shows a typical voltage variation along a distribution line. To enable the distribution of ES over the distribution network, it is essential that each ES can be installed to support its location-dependent mains voltage. The droop control concept has been proposed in [12] to allow coordinated operation of multiple ESs. The droop control has the advantage of requiring local information only. Therefore, a large group of ESs can be installed in a distributed manner to provide stability support for the power grid.

The droop control has been demonstrated in [13] for a distribution line with three ESs. Figure 9 shows the measured reactive power compensation behaviors of three ESs distributed in the same power line with and without the droop control [13]. Without the droop control, the three ESs work against one another. With the droop control, they work in a cooperative manner. This important feature enables a large group of small ESs to work collectively without any requirements for communication among the ESs.

Figure 8 Gradual Reduction of Mains Voltage Along a Distribution Line

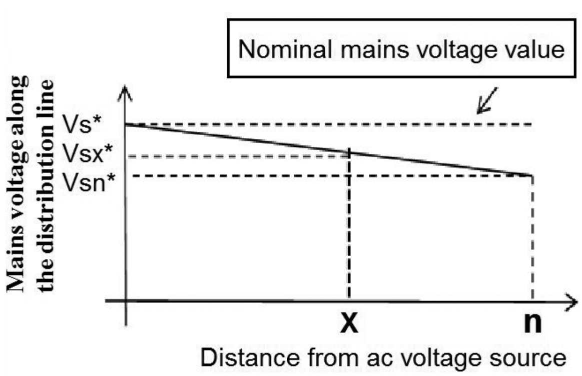
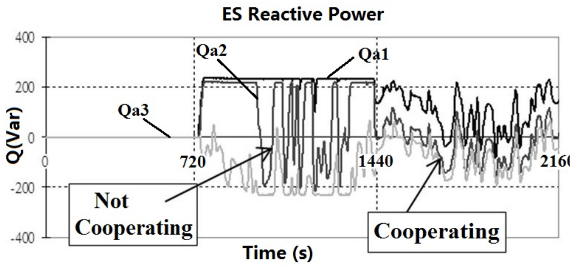


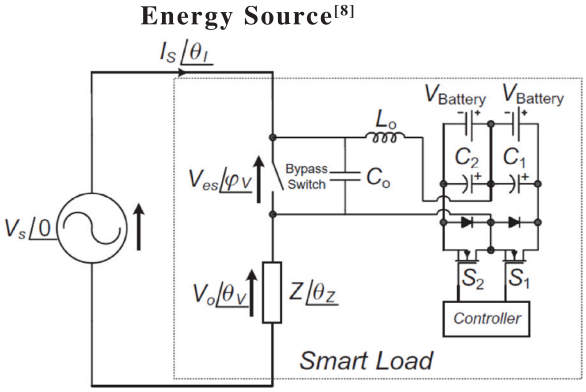
Figure 9 Measured Average Value of Reactive Power Generated by The 3 Electric Springs (Qa1, Qa2 and Qa3)[13].



4.5 USE OF ES WITH ACTIVE AND REACTIVE POWER COMPENSATION

The functions of the ES can be substantially expanded if an active power source is incorporated into the power inverter [8] as shown in Figure 10. The ES can provide both active and reactive power compensation with eight possible operating modes [8]. The capability of the ES to provide both active and reactive power compensation offers a new opportunity for the use of widely distributed ES to play a part in the voltage and frequency stability for the power grid, as well as power quality improvement for the electric loads. More research is needed to explore this potential for stability studies of power systems with large-scale renewable energy penetration.

Figure 10 An Electric Spring With an Active Energy Source[8]



4.6 RECENT PROGRESS OF ELECTRIC SPRINGS

- In a recent study[14] which compares ESs and STATCOM, it is shown that a group of distributed ES can achieve much better voltage control in the distribution network than STATCOM using only a fraction of the total reactive power required by the latter. This new discovery highlights the needs for new technology for the emerging power grid with more distributed and intermittent renewable energy source.

- A power system simulation study on the simultaneously reduction of voltage and frequency stability of power grid based on the use of ES will be reported in [15]. It is found that the ES technology is effective in reducing both frequency and voltage stability in power systems.

- A three-phase power circuit based on the version-2 of ES has been developed. Besides the voltage and frequency stability support, it has the additional function of reducing power imbalance in 3-phase power supply[16].

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5. CONCLUSION & DISCUSSION

The intermittent nature of renewable power generation has been identified as a key factor that may hinder large-scale penetration of renewable energy into the power grid. As the research stage, the electric spring technology has been proven as a viable solution to overcome the intermittency of renewable energy.

ES can turn many non-critical loads to become a new generation of smart loads that are adaptive to the availability of power generation. It has the potential to allow high penetration of wind and solar power in future power grid, and achieve the new control paradigm of power demand following power generation.

With the evidence of climate changes (such as fast melting of the ice cap in Antarctica and rising CO_2 concentration and acidity of oceans) becomes more and more obvious, the warning from the Secretary-General of the United Nations that "Time is not on our side" should not be taken lightly. More efforts and resources should be devoted to the realization of new technology that can drastically increase renewable power generation.

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Paper No. 9

APPLICATION OF
COMPUTERIZED POWER SYSTEM ANALYSIS

Speakers: **Ir Michael M.F. Waye, Director**
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APPLICATION OF
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ABSTRACT

Enjoying the benefit of low cost high computation power computers, Computerized Power System Analysis is becoming very popular and within reach of many engineers. With computer modeling, basic analysis including accurate short circuit analysis meeting IEC 60909, IEE wiring Regulation sizing, protection coordination and advanced application studies including transient behavior of motor starting are possible.

The authors wish to share the experience of application of the software model with some worked examples. In this paper, it can be seen that motor contribution can be a critical factor in the short circuit study when many motors are involved. The discrimination of protection relays although can be done manually, could not be readily revised to reflect the final system configuration and the actual relay settings on site. The equipment selection can be optimized before equipment procurement if the exact short circuit capacity is available. Phenomenon of motor starting can be investigated on the current, speed and load torque. It is anticipated computer modelling will bring the electrical design to next level of accuracy and safety. The arc flash study to protect the worker working on live equipment could be the next requirement in the short circuit calculation.

1. INTRODUCTION

Power System Analysis is one of the important courses that most electrical engineers have taken in their university education. Although the basic principles are not too difficult to be understood, the application of power analysis in the industry is not thorough due to various reasons.

For a lot of smaller projects, the freedom to choose different solutions is very limited. Standard solutions tend to be the quickest and possibly the cheapest. Some larger projects have many project development stages involving changes in architectural plans, structural design and mechanical design. Electrical design being the last in the design process could not have enough time to be optimized so as to accommodate power reconfiguration.

When trying to perform a power system analysis using manual calculation or by spreadsheet calculation, a lot of simplification will need to be included in order to ensure the process can be completed within the time frame allowed. Full analysis following the exact British / IEC Standards "BS EN / IEC 60909 – Short circuit currents in three-phase a.c. systems", might not be a viable approach.

Therefore one can explain the reasons why Computerized Power System Analysis were the privileges for system engineers in major corporations such as utility companies and major suppliers, who can utilize well established computer hardware and software for the analysis.

As personal computer (PC) becomes part of the essential equipment for engineering business, Computerized Power System Analysis is no longer a luxury in the commercial sector. This paper intends to share some of the experiences in the application of PC based software and the possible outlook at the software tools.

2. FUNDAMENTALS OF THE POWER SYSTEM ANALYSIS

Without getting into the details of a university course, the main purpose for a power system analysis can be summarized in the following basic safety requirements:

- Load flow
- Equipment selection to meet the short circuit capacity
- Short circuit analysis
- Protection coordination

IEC 60909 provided a very detailed framework and calculation methodology for the detailed calculation of different short circuit currents. The types of faults are categorized as Three Phase Short Circuit, Line-to-line Short Circuit, Line-to-line Short Circuit with Earth Connection, and Line-to-earth Short Circuit with the Figures 1a to 1d in the standard and as listed below[1]:

Figure 1a Three-phase Short Circuit

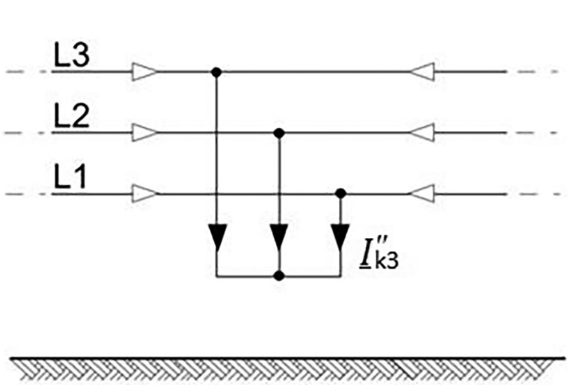


Figure 1b Line-to-line Short Circuit

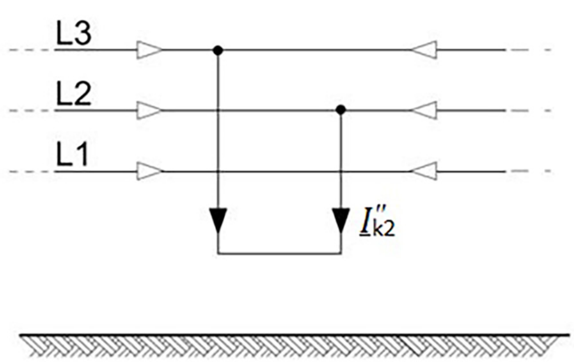


Figure 1c Line-to-line Short Circuit with Earth Connection

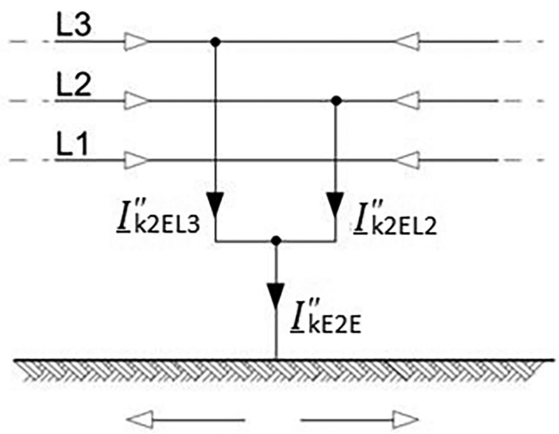
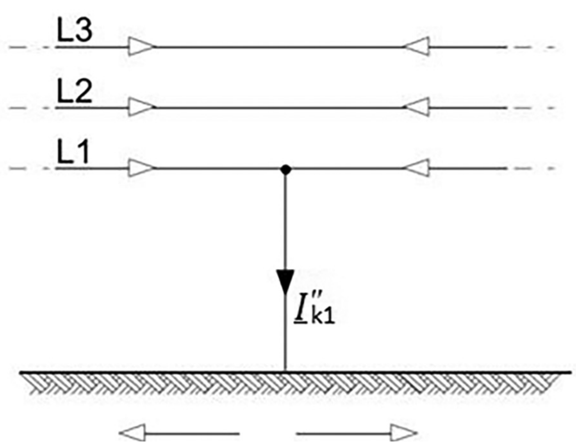


Figure 1d Line-to-earth Short Circuit



The standard then goes into different scenarios to define the exact equation for short circuit calculation with various network components. For most readers, the common cases when highest initial short circuit current is the three phase short circuit (I''_{k3}). The standard also covers cases where the current of line-to-line short circuit with earth connection (I''_{kE2E}) is higher than the three phase short circuit current, and becomes the critical scenarios to be considered.

The standard consists of the following parts:

- Part 0 – Calculation of currents
- Part 1 – Factors for the calculation of short-circuit currents according to IEC 60909-0
- Part 2 – Data of electrical equipment for short-circuit current calculations
- Part 3 – Currents during two separate simultaneous line-to-earth short circuits and partial short-circuit currents flowing through earth
- Part 4 – Examples for the calculation of short-circuit currents

3. SIMPLIFIED APPROACHES FOR POWER SYSTEM ANALYSIS

When manual calculation is performed, it is not easy to follow closely with the procedure required in IEC 60909. Simplified methods are therefore used.

Common practices used including the following assumptions:

- Three phase short circuit is the most concerned fault level needed to be considered.
- Motor contribution to the short circuit is negligible.
- Standardized fault level is assigned to each tier of power distribution.

The above assumptions together with other approximations could work in a lot of cases for short circuit estimation. Where there are uncertainties due to the project development or system parameters, more conservative assumptions will be added in order to ensure a simple analysis can be accomplished manually.

For protection discrimination, plotting protective device curves on graphic paper can still be used for manual calculation. With the assistance from Excel spreadsheet, it is also possible to plot IDMT relay protection characteristics (Standard Inverse, Very Inverse, Extremely Inverse) derived from the equations from IEC 60255 as listed in below Table 1.

Table 1 Formula for IDMT relays

Relay Characteristic	Equation (IEC 60255)
Standard Inverse (SI)	$t = TMS \times \frac{0.14}{I_t^{0.02} - 1}$
Very Inverse (VI)	$t = TMS \times \frac{13.5}{I_t - 1}$
Extremely Inverse (EI)	$t = TMS \times \frac{80}{I_t^2 - 1}$

For some protection devices not governed by a formula, the tripping characteristics can be coordinated manually by putting the values onto the spreadsheet to create the curves for visual coordination. Therefore basic coordination study can be performed by a spreadsheet program as shown in the Figure 2.

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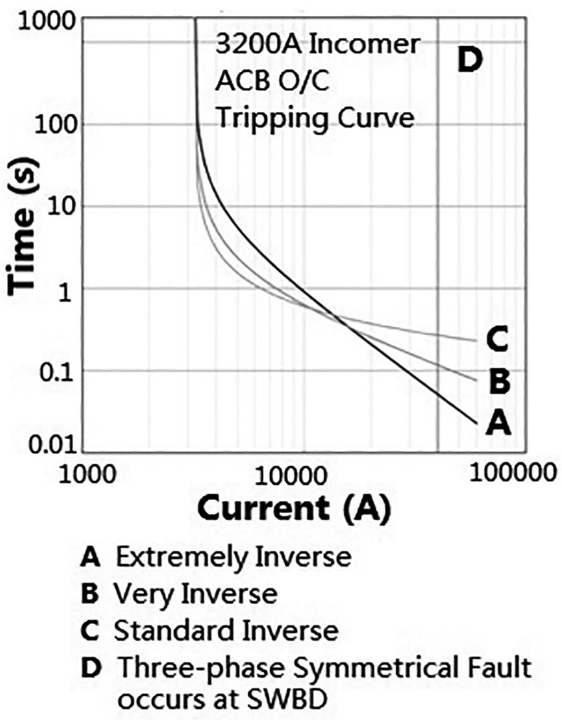
Figure 2 Fault Tripping Characteristics of the 3200A During Three-phase Symmetrical Fault



There are also some free computer software packages available to provide basic calculation of short circuit and protection coordination.

4. POWER SYSTEM NOWADAYS

Although the fundamental theories of power system analysis have not been changed over time, there are many requirements on the power system evolved in the industry during the past decades. These changes created a lot of opportunities and demand to use more sophisticated tools for the analysis.

The changes in power system are driven by more demanding business environment which then drive the end users and engineers to follow. Other changes in power system are driven by prices of the basic power network components. All these created a new set of challenges to our engineers.

Due to the transformer selection and standardization of design, 1,500kVA transformer has been used in Hong Kong for many years. With the increases electricity demand from end users, it is possible to have 2,000kVA transformer to be applied in a project, provided the power companies' policies accept. According to an article in the Journal of the Hong Kong Institution of Engineers[2], higher capacity transformers are available by the utility company. The higher current capacity available at the incoming circuit breaker provided many opportunities to have cascading circuit breaker configurations which require good protection discrimination study.

CLP Power noticed that there is a very high load density development in some of the buildings such as data centre. The "Code of Practice for Power Utility Substation Design for High Load Density Development"[3] was issued to address the increase of load density for buildings for normal and redundant power demand over 50MVA.

To optimize the capacity of power system, some cities in China required the system demand matching closely with the installed capacity. In some cities in China, the local power supply company can impose very high tariff to a consumer if their monthly maximum demand is largely below their installed capacity. As the spare between demand and installed capacity becoming less, overcurrent coordination is becoming critical to keep the system integrity so that any incident will not affect other unrelated circuits. Closer review of the protection coordination study is therefore necessary.

For projects in China, the selection of transformer sizes can be determined by the consumer and therefore the available fault current could be more than 40kA when larger transformer with standard impedance is chosen and with solid neutral to earth system. Power system analysis is becoming essential to obtain a reliable and safe network without putting unnecessary high interrupting capacity equipment to the system.

Motor circuits and transient behavior of motors were not a big issue when the requirements of emergency fans for smoke extraction and pressurization were not too stringent. As the standards of smoke extraction and pressurization are becoming more and more rigorous, motor circuit behaviour to power system will need to be further investigated in details. Motor circuits can produce high motor starting transient to the power system and also higher short circuit current during a fault.

There are power systems that are specially designed for a particular production environment such as data centre. The power system development can be optimized / customized when all the system parameters are confirmed and finalized. There are opportunities to revisit the entire power system to customize the components for best cost benefit to the project if a quick and efficient tool is available.

Engineers in Hong Kong are used to this multicultural and international city that projects can be performed in other parts of the world. There are places that could have different requirements for the power system. Although still not very common in Asian countries, it is possible that some utility companies might require the consumer side to provide parallel transformer scheme. In New York City, the local power company required the consumer HV network to be arranged in parallel in some configurations[4].

5. COMPUTERIZED POWER SYSTEM ANALYSIS SOFTWARE PRODUCTS

There are many Computerized Power System Analysis Software products available presently. With the surge of Apps in smart phone, it could be anticipated more software products will be available and possibly a power system analysis Apps might be available soon. Without going into a detailed survey of all existing products, which could be changing over time, some available software product features are listed in Table 2 for the readers to appreciate the general capability and trend.

With the globalization of engineering market, software package usually comes with different power system analysis standards. Commonly available short circuit analysis included IEC short circuit study to IEC 60909 and American National Standards Institute (ANSI) C37 standards. The software package usually comes with library to provide standard network and protection devices components following the associated standards. Where there is no library component available, it is also possible to create a new item in the library for the analysis. Many major electrical vendors have got the data files required to be included in these software packages. Licensing of the software package can be hardware lock or software key depending on the quantity of licenses purchased and the software vendor policy.

Good computer software packages are usually expensive as it involves a lot of development effort from the software provider. There are however some freeware packages available from different institution / companies, which are created for different reasons. Typically, they are written for specific requirements and therefore their user interfaces are not very friendly.

Table 2 Typical Power System Analysis Software Product Features

Description	SKM[5]	EDSA[6]	ETAP[7]	DIgSILENT[8]
Demand Load	X	X	X	X
Protection Coordination	X	X	X	X
IEC Fault Analysis	X	X	X	X
IEE Wiring Regulation Sizing	X		X	X
Harmonic analysis	X	X	X	X
Transient motor starting	X		X	X

Typically, a software package will have a template for drawing the single line diagram of the power system. Each of the entity in the single line diagram corresponds to equipment either referred in the library or created for the project. The single line diagram, once completed can be used as a single line system schematic diagram tender drawing for the project.

After the single line is completed, the system parameters can be adjusted, such as the length of cable, the type of transformer, the type of protection devices. Therefore it is very handy to revise the power distribution system to reflect the latest design.

Different computer simulation can then be run on the power distribution system represented by the single line diagram. IEC 60909 short circuit analysis for three phase fault, single line-to-earth, line-to-line, and line-to-line with earth are available with the computer simulation for review.

Bus Name	--------------Initial Symmetrical Amps-----------			
Contribution Name	3 Phase	SLG	LLG	LL
BUS-0002	**39,040**	**35,921**	**37,948**	**33,810**

Using the same single line diagram, time current coordination curves can be done at each circuit. The protection discrimination can be considered separately for each circuit according to the requirements.

6. COMPUTERIZED POWER SYSTEM ANALYSIS – MOTOR CONTRIBUTION

In order to show the experience in the application of a software product, it is best illustrated by worked examples. These examples, although done through a particular software product, are expected to be applicable to most software packages

Example 1 is trying to illustrate the effect of motor to the power system analysis. According to IEC 60909, the effect of motor can be included in the calculation of the power system analysis with the following formula.

$$Z_M = \frac{1}{I_{LR}/I_{rM}} \cdot \frac{U_{rM}}{\sqrt{3}I_{rM}} = \frac{1}{I_{LR}/I_{rM}} \cdot \frac{U_{rM}^2}{S_{rM}}$$

U_{rM} is the rated voltage of the motor;

I_{rM} is the rated current of the motor;

S_{rM} is the rated apparent power of the motor ($S_{rM} = P_{rM} / h_{rM} \cos\varphi_{rM}$);

I_{LR}/I_{rM} is the ration of the locked-rotor current to the rated current of the motor

The application of formula will also be needed to check the reactance of all other components as referred in IEC 60909. Manual calculation would be too complicated when these procedures are followed. In many small commercial projects, the motor contribution to the system is not significant. Therefore some engineers could use simplified formula or ignore the effect of motors during initial short circuit current for the simplified calculation. In the Example 1, it is a situation that the motor contribution can be more important than we thought. It is shown that the calculation without motor contribution can confirm the main bus-0011 is 38.4kA that met the 40kA fault level. As the motor contribution is included, the main bus-0002 is increased to 46kA which is exceeding the 40kA fault level.

As a project is getting larger, the possibility of grouping many motors to a single transformer is higher. The calculation of short circuit with motor contribution should be included. When many motors act as sources at the short circuit studies, manual calculation would result in a major engineering effort. Manual calculation would almost be impossible when the configuration of power supply system is changing continually according to the project development. Benefit of using computerized system analysis is very obvious for major projects.

7. COMPUTERIZED POWER SYSTEM ANALYSIS – DISCRIMINATION STUDIES

Example 2 considered a network with multiple protection devices. The protection devices for the main and submain switchboards are provided with overcurrent relays. As the main protection relay is set to match the utility company and provides proper discrimination, there will be very little room for the main protection relay curve to be adjusted to the right hand side (higher current). The branch feeder protection is a relay protection set to match the branch circuit current setting and marked the lowest current limit of the protection. The feeder protection relay has to be coordinated between the upstream main protection relay and the downstream branch feeder protection relay. From the curves, the area between these two curves is limited and therefore the means to provide best coordination is restricted.

In manual calculation, very tedious calculations and curve plotting are required to insert the protection of the submain system between the two protection devices. With a computerized program, the submain system can be dragged within the area to different settings of the relay. The associated settings will then be shown on the graphic that allows the engineer to select. Hours of engineering calculation can be simplified to a drag drop revision.

As the protection devices are provided in the library of the program, the available settings, e.g. current setting at 50%, 100%, 150% ... etc. such as the one shown in Table 3 have already been included in the device parameters and shown on the graphic display. The available setting of a relay can be very complicated. As the settings available from software permitted inputting the catalogue actual values, computerized software can provide a good platform for engineer to confirm the real setting done on site, rather than just by manually plotting onto a chart.

Table 3 Protection Relay Settings

Type	Setting Range	Step
I>	0.2…4.0 x IN	0.01 (0.2…0.5 X IN) 0.02 (0.5…1.0 X IN) 0.05 (1.0…2.0 X IN) 0.1 (2.0…4.0 X IN)
tI>	0.03 – 260 s (definite time) 0.05 – 10 (inverse time)	0.02 (0.03…1.0s) 0.05 (1.0…2.0s) 0.1 (2.0…5.0s) 0.2 (5.0…8.5s) 0.5 (8.5…10.0s) 1.0 (10…20s) 2.0 (20…50s) 5.0 (50…100s) 10.0 (100…260s) 0.01 (0.05…0.5) 0.02 (0.5…1.0) 0.05 (1.0…2.0) 0.1 (2.0…5.0) 0.2 (5.0…10.0) 0.5 (10.0…20.0)
I>>	0.5…40 x IN	0.02 (0.5…0.98 X IN) 0.05 (1.0…2.0 X IN) 0.1 (2.0…4.0 X IN) 0.2 (4.0…10.0 X IN) 0.5 (10.0…20.0 X IN) 1.0 (20.0…40.0 X IN)
tl>>	0.03…10 x	0.02 (0.03…0.5s) 0.05 (0.5…2.0s) 0.1 (2.0…5.0s) 0.2 (5.0…10s)

8. COMPUTERIZED POWER SYSTEM ANALYSIS – EQUIPMENT SELECTION

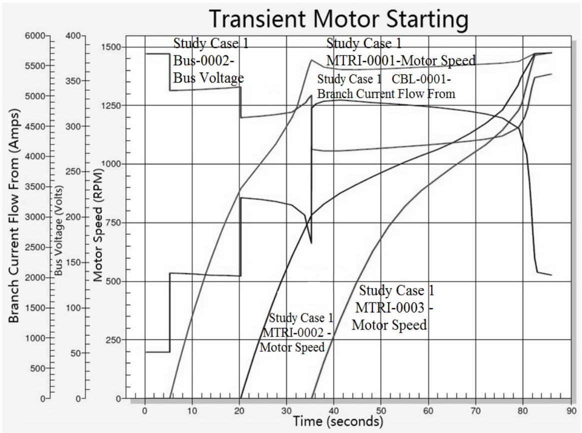
Example 3 showed the standard equipment selection based on a design standard with different tier of distribution equipment allocated with different rating of short circuit capacity. Standardized short circuit rating of 50kA is selected for the design to permit possible system changes and further project development.

As a computer program can allow accurate calculation of system as a project is finalized, it is possible to provide a customization equipment selection based on the final system implementation. When the power system is finalized, there are various submain equipment can be optimized and tailored to the available fault level in the system. The Example 3 is showing that 42kA and 35kA rated equipment can be adopted at the finalization of the design. With the short circuit rating of the equipment matching the available system fault level, the cost of equipment can be trimmed down and the spatial requirements can be further optimized.

9. COMPUTERIZED POWER SYSTEM ANALYSIS – MOTOR STARTING

For smaller projects, the total power of motor fed from a single transformer is limited. However in larger projects, motor transient behaviour will be important.

Figure 3 Example of Transient Motor Starting



The effect of motor starting can be simulated with the motor starting program. The type of starter, motor starting torque and current characteristics are input into the software where the starting current of the system can be appreciated. This is possible that the total motor starting time can beyond the protection device settings and/or the thermal characteristics of the cable / motor. When there are multiple large motors in a network, software simulation is the preferred choice for the motor starting study. An example of Transient Motor Starting is shown in Figure 3.

10. COMPUTERIZED POWER SYSTEM ANALYSIS – COMPREHENSIVE STUDIES

Example 4 showed a comprehensive network study using computerized system analysis. The system is a single utility supply with motor and resistive loads. The simulation provides all the essential information immediately available to the engineer. This information can assist the engineer to make appropriate adjustment of network configuration.

- Short circuit current
- Contribution of short circuit from the utility or from the motor
- Load flow in the system
- Voltage drop of the system at various points
- Protection device coordination curves and protection device settings.
- Equipment selection table and verification of overcurrent and short circuit scenarios.

11. WAY FORWARD FOR COMPUTERIZED SYSTEM ANALYSIS

With the assistance of personal computer, a lot of essential data are available to the design engineers previously not readily available. There are possibilities to provide more information beyond the data that were used before.

Short circuit fault at electrical equipment used to be unpredictable and created a lot of injury to people, in particular the operating engineers and technicians working on live equipment. In United States, National Fire Protection Association standard NFPA 70E Annex D[9] provided the calculation of arc flash and systematically analyzed the energy associated with a fault that created the arc flash. The required Personal Protective Equipment (PPE) is then introduced to match incident energy of arc flash to protect the worker. The requirements are also incorporated into their electrical safety code NFPA 70 clause 110.16 Arc Flash Hazard Warning[10] to provide mandatory requirements for States that follow NFPA standards. The NFPA 70 is similar to the Electricity (Wiring) Regulation in Hong Kong. Arc energy reduction methods are listed in the NFPA 70 clause 240.87. (B) including the minimization of arc flash clearing time[11]. To comply with the arc flash requirements, computer analysis can also provide the arc flash study for the compliance of NFPA 70E. Appropriate arc flash protection results shall be marked at the equipment to ensure adequate warning is provided to the operation and maintenance personnel. A sample of warning label is provided in Figure 4.

Figure 4 Sample of Arc Flash Warning Label

The Institution of Engineering and Technology issued the Arc Flash Protection briefing in August 2012 to promote the health and safety issues related to arc flash due to high energy electrical sources. The incident energy level and the basic PPE details are provided as summarized in the following Table 4[12].

IEC 61482-1-2:2007 provided the classification required for "Live Working – Protective Clothing against the thermal hazards of an electric arc" for Class 1 and 2[13]

- Class 1 tests at an arc current of 4kA and arc duration of 500ms
- Class 2 tests at an arc current of 7kA and arc duration of 500ms

Table 4 Example Incident Energy and PPE Type Requirement

Incident Energy Level (cal/cm2)	PPE Type	PPE Details (basic examples)
0 - 1.2	0	1 layer untreated cotton (covering all body), polycarbonate safety spectacles, lightweight cotton gloves.
1.21 - 4	1	Cotton undergarments, 1-layer flame retardant (FR) work wear, helmet, polycarbonate safety spectacles, lightweight FR gloves.
4.1 - 8	2	As above but with 2-layer FR outer work wear that has wrist closures, and a full face polycarbonate visor. A FR single-layer balaclava may also be worn to protect the face.
8.1 - 25	3	3-layer FR outer work wear with cotton under garments and FR shirt, a full-face hood or visor with safety spectacles underneath, chrome leather gauntlets.
25.1 - 40	4	Typically 4-layer FR outer work wear (as illustration), FR and electrically insulated footwear and suitable FR material spats to close off the ankle area, FR gloves or chrome leather gauntlets, a hood constructed from a triple layer of FR material with a sewn-in polycarbonate face shield with a minimum of 2 panels of suitable thickness with one coated with a gold film for UV protection.

It is the corresponding standard to NFPA which is established for arc flash protection. With the trend to create a safer and better work environment, it is anticipated arc flash requirements will be required for system design and calculation would be best provided by computerized system analysis.

12. CONCLUSION

Power system analysis does not involved very difficult calculations. However, it can be very time consuming and complicated when the project parameters are changing. As very accurate information is required such as motor contribution to the system short circuit level, manual calculation would be very ineffective. By putting the system analysis through computer simulation, there are many benefits including equipment optimization, accurate protection discrimination and on site implementation and setting to work.

It is anticipated more computerized simulations are needed as the industry demand higher accuracy discrimination, precise equipment selection and larger system capacity. Additional features such as arc flash study would be required when protection of worker working on live equipment is enhanced. When all information is input into the computer system, many essential electrical data are available at the same time for overall network optimization.

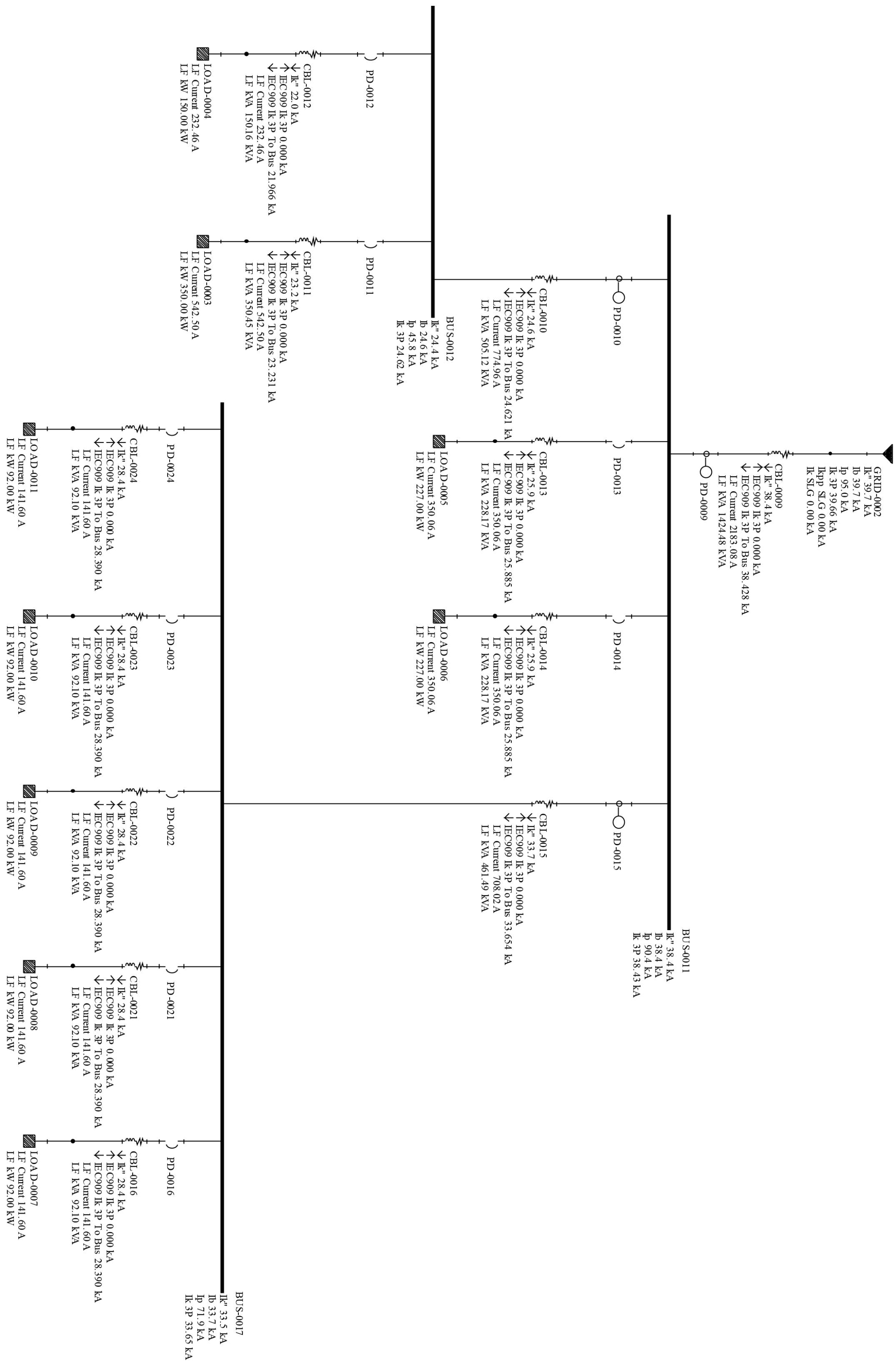
Arc flash study which is available in computerized power system analysis could be one of the important studies that will be performed by these software packages. As a safe working environment for electrical workers is very important, software simulation will be more and more important in future.

When many engineers are using computerized program for power system analysis, the high cost of computer software packages will be trimmed down and all engineers could have their own license in their computers.

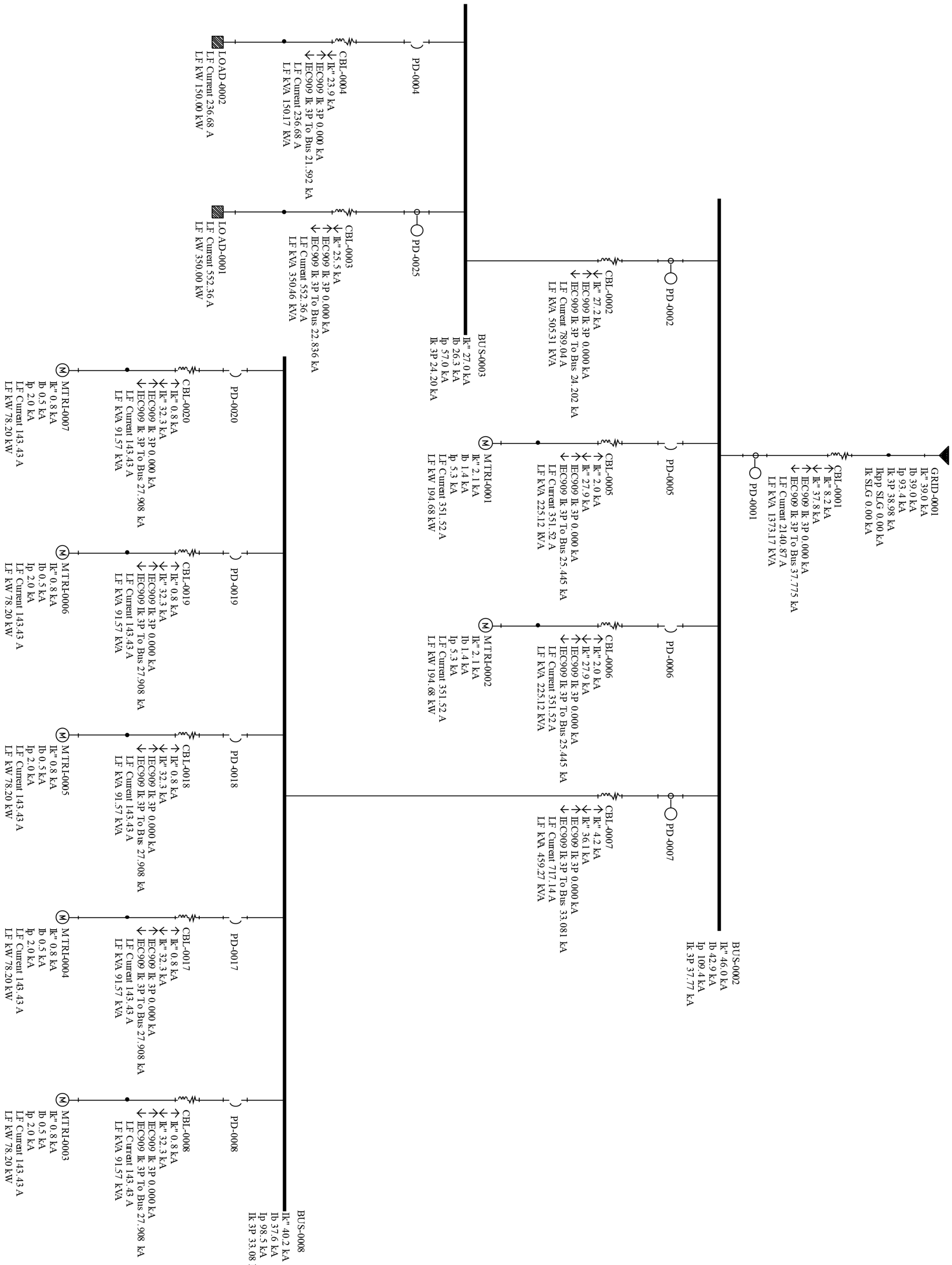
13. EXAMPLES

EXAMPLE 1 MOTOR CONTRIBUTION TO SHORT CIRCUIT CURRENT

I. SIMULATION OF SHORT CIRCUIT CURRENT WITHOUT MOTOR CONTRIBUTION



II. SIMULATION OF SHORT CIRCUIT CURRENT INCLUDING MOTOR CONTRIBUTION



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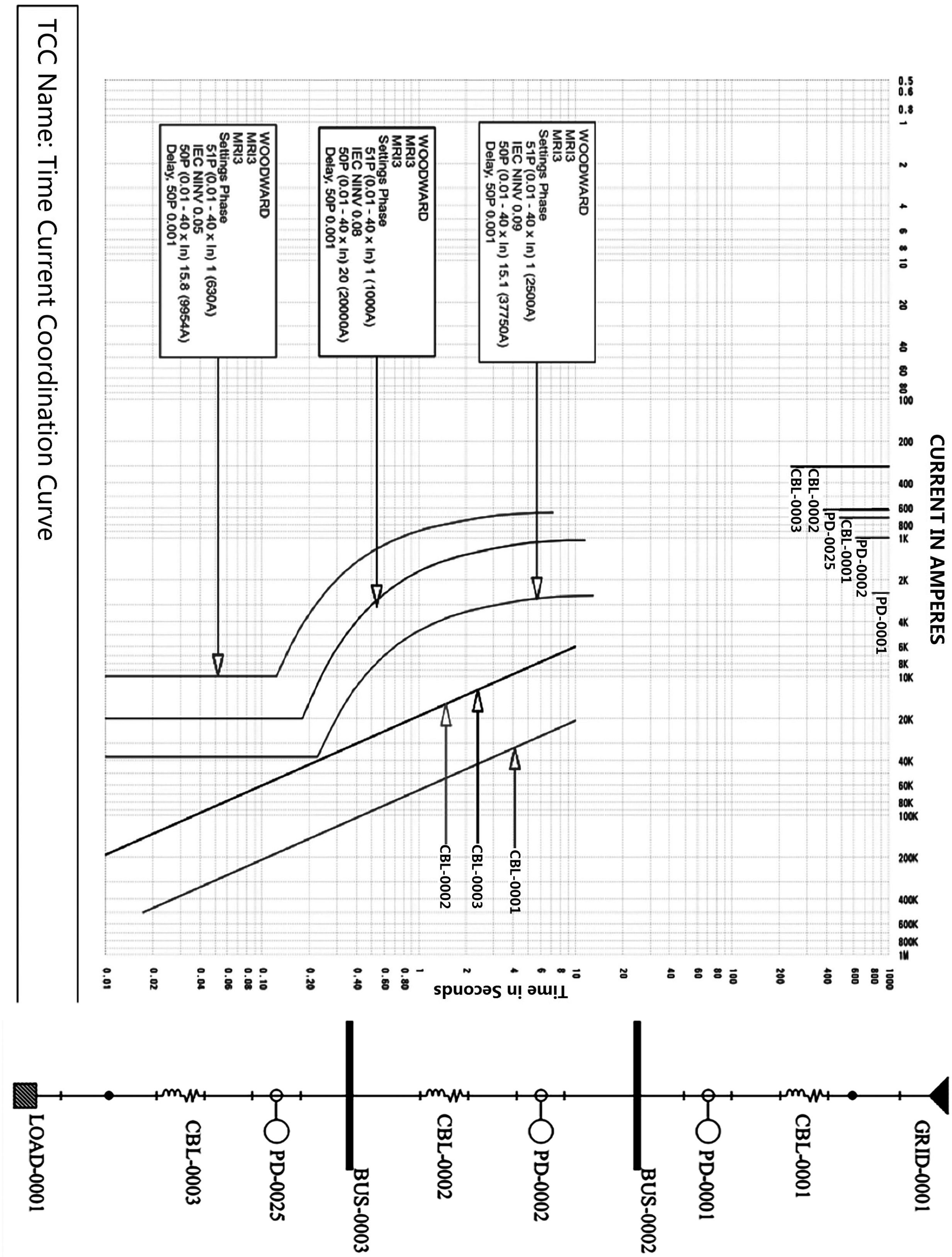
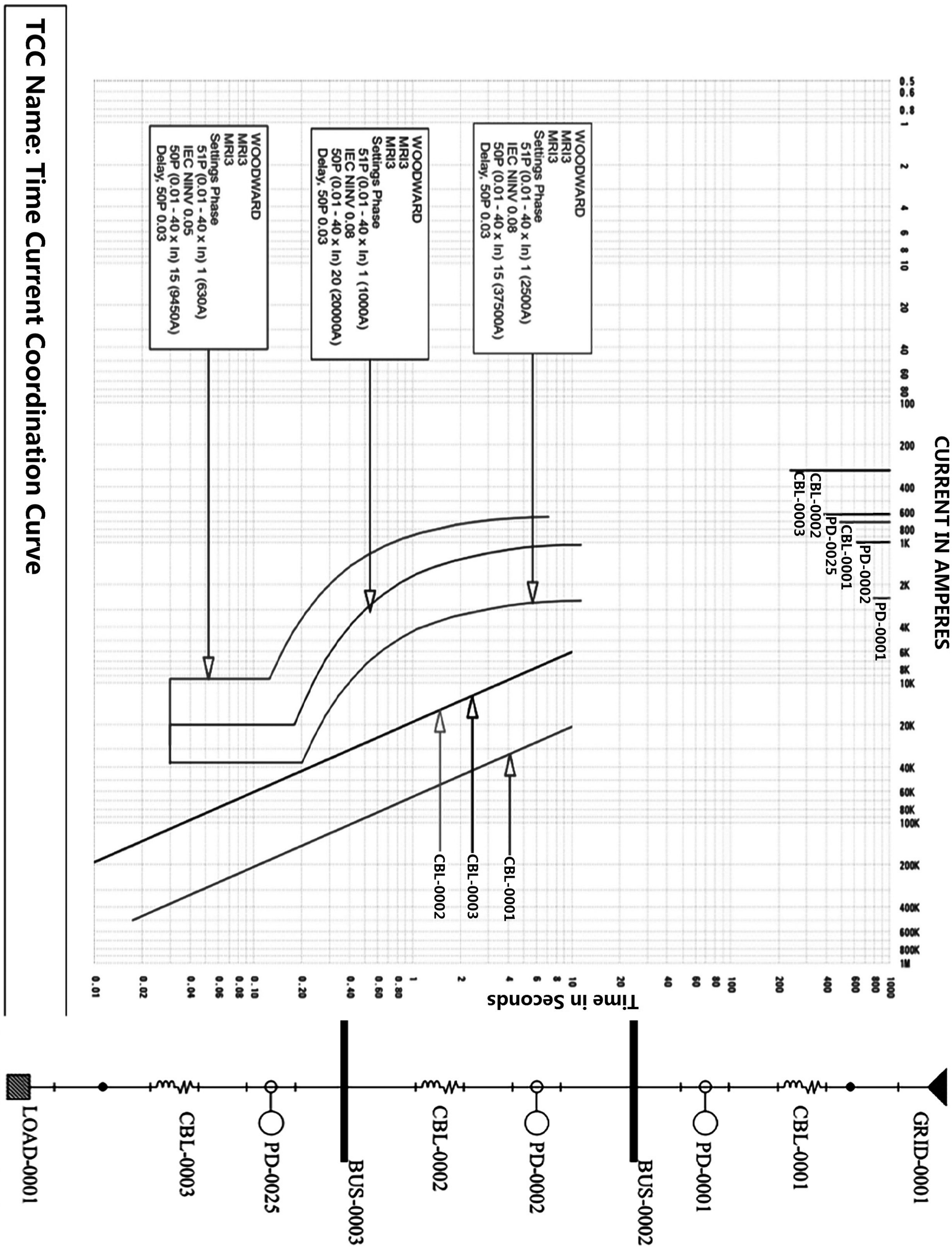
EXAMPLE 2 DISCRIMINATION STUDY

I. DISCRIMINATION STUDY WITH TIME CURRENT COORDINATION CURVE WITH IDEAL RELAY SETTING



II. DISCRIMINATION STUDY WITH TIME CURRENT COORDINATION CURVE WITH ACTUAL RELAY SETTING



EXAMPLE 3 EQUIPMENT SELECTION

I. EQUIPMENT SELECTION RESULTS AS OBTAINED FROM THE SHORT CIRCUIT STUDY

Equipment Evaluation Report - All Buses

Bus	Manufacturer	Status	Type	Bus Voltage	Calc Isc kA	Dev Isc kA	Series Rating kA	Isc Rating%
BUS-0011	GE	Pass	LV Switchboard	380	41.72 (*N1)	50.00		83.45
BUS-0012	GE	Pass	LV Panelboard	380	24.83	50.00		49.67
BUS-0017	GE	Pass	LV Switchboard	380	33.95	50.00		67.89
(*N1) System X/R higher than Test X/R, Calc INT kA modified based on low voltage factor.								

II. EQUIPMENT SELECTION OPTIMIZED BASED ON THE SHORT CIRCUIT STUDY

Equipment Evaluation Report - All Buses

Bus	Manufacturer	Status	Type	Bus Voltage	Calc Isc kA	Dev Isc kA	Series Rating kA	Isc Rating%
BUS-0011	GE	Pass	LV Switchboard	380	41.72 (*N1)	50.00		83.45
BUS-0012	GE	Pass	LV Panelboard	380	24.83	35.00		70.96
BUS-0017	GE	Pass	LV Switchboard	380	33.95	42.00		80.82
(*N1) System X/R higher than Test X/R, Calc INT kA modified based on low voltage factor.								

EXAMPLE 4 COMPREHENSIVE STUDIES

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