THE HONG KONG
INSTITUTION OF ENGINEERS
ELECTRICAL DIVISION

The 39th Annual Symposium
Thursday
21st October 2021

POWERING THE NEW NORMALS

On-site Event at
Ballroom
Sheraton Hotel
Nathan Road
Kowloon
Hong Kong
&
Online Event

SYMPOSIUM PROGRAMME

08.30 Registration

09:00 Welcome Address
- Ir Y.H. Leung
  Chairman, Electrical Division, The HKIE

09.05 Opening Address
- Ir Professor P.L. Yuen
  Immediate Past President, The HKIE

09.10 Keynote Speech
- Ir Professor C.C. Chan
  Past President, The HKIE
  Academician, Chinese Academy of Engineering
  Fellow, Royal Academy of Engineering, UK

1. Power Supply Reliability

09.40 High-Voltage Battery Energy Storage System in Hong Kong International Airport
- Sr Amen Y.K. Tong, General Manager
- Ir James P.M. Ng, Senior Manager
- Mr Wister K.C. Yu, Manager
- Ir Stephen S.K. Lam, Engineer
- Mr Bob H.M. Ng, Engineer
- Mr Tiger K. Y. Lau, Engineer
  Technical Services Infrastructure Department
  Airport Authority Hong Kong

10.00 Critical Power Supply for Healthcare Facilities
- Mr Markus Hirschbold
  Future Offer Director for Mission Critical Facilities
  EcoStruxure Power
- Ir Ian Y. L. Lee, Solution Director
- Mr Kevin S. H. Hung, Power Systems Architect
- Ms Susan S. Chow, Engineering Trainee
  Schneider Electric

10.20 Dynamic Uninterrupted Power Supply
- Mr Macro Nijenhuis, General Manager
- Mr Edwin S.L. Ng, Regional Sales Manager
  Rolls-Royce Solutions Asia Pte. Ltd.
- Mr William W.C. Lee, Service Manager
  Rolls-Royce Solutions Hong Kong Ltd.

10.40 Discussion

11.05 Break

2. ***<u>Condition Monitoring & Wiring Regulations</u>***

11.35 Embracing the New Normal in Condition Monitoring for Medium Voltage System
- Er Seng Kok Ang, General Manager
- Er Yongyi Fu, Deputy Director
- Mr Xingzhou Yu, Senior Principal Engineer
- Er Kem Wah Lo, Principal Engineer
- Er Dr Kai Xian Lai, Principal Engineer
  Asset Sensing & Analytics, SP PowerGrid, Singapore

11:55 New Edition of Code of Practice: Powering New Technology and Enhancing Electrical Safety
- Ir K.K. Sit, Senior E&M Engineer
- Ir Johnson C.T. Sze, E&M Engineer
  Electricity Legislation Division
  Electrical and Mechanical Services Department
  The Government of the HKSAR

12.15 Discussion

12.30 Break

3. ***<u>IoT & Smart Building</u>***

14:00 Blockchain and Post-Quantum Cryptography for Smart Grid & Smart Home Cyber Security
- Dr Chunhui Wu, Associate Professor
  School of Internet Finance and Information Engineering
  Guangdong University of Finance
- Ir Stanley K.W. Leung
  General Manager
  GDEPRI Power Control Systems & Equipment (HK) Ltd.

14.20 Energizing the New Normal through Digital Electrification Empowerment
- Mr Keith T.M. Wong, Head of Digital Business
  Smart Infrastructure Division
  Siemens Ltd. Hong Kong
- Mr C.Y. So, Business Manager
  KEIYIP Engineering Co., Ltd. Hong Kong

14.40 Smart Building Technologies for Enhancing Operational and Energy Efficiency
- Ir Dave C.H. Chan
  Chief Executive
  Information, Communications and Building Technologies
  ATAL Technologies Ltd.

15.00 Discussion

15.30 Break

4. ***Transportation & Parking System***

16.00 Smart Operations & Maintenance of MTR Rolling Stock
- Ir K.H. Lee, General Manager – Rolling Stock Workshop
- Mr Thomas L. H. Leung, Maintenance Engineer
  Rolling Stock Maintenance Department
  MTR Corporation Limited

16.20 Smart Mobility – Application of Automated Car Parking System in Hong Kong
- Ir Antonio C.M. Chan, Deputy Managing Director
- Ms Carmen Y.S. Wong, General Manager
- Ir Jo K.S. Chiu, Manager
  REC Engineering Company Limited

16.40 Discussion

16.45 Summing Up
- Ir W.S. Tam
  Symposium Chairman
  Electrical Division, The HKIE

Closing Address
- Ir Eric Y.H. Pang, JP
  Director
  Electrical and Mechanical Services Department
  The Government of the HKSAR

Acknowledgement

The Electrical Division of The Hong Kong Institution of Engineers would like to express its sincere appreciation and gratitude to the following persons and organizations for their contributions to the Symposium.

Authors/Speakers

Ir Professor C.C. Chan
Ir Eric Y.H. Pang, JP
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Ir James P.M. Ng
Mr Wister K.C. Yu
Ir Stephen S.K. Lam
Mr Bob H.M. Ng
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Ir K.H. Lee
Mr Thomas L.H. Leung
Ir Antonio C.M. Chan
Ms Carmen Y.S. Wong
Ir Jo K.S. Chiu

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Paper No. 1

HIGH-VOLTAGE BATTERY ENERGY STORAGE SYSTEM IN HONG KONG INTERNATIONAL AIRPORT

Authors/Speakers: Sr Amen Y. K. Tong, General Manager
Ir James P. M. Ng, Senior Manager
Mr Wister K. C. Yu, Manager
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ABSTRACT

Hong Kong International Airport (HKIA), as one of the world's leading airports, embraces continuous development to become a smart airport in the world. With the various developments of the Airport City, additional essential supply for airport operation is required. We adopt new technologies and innovative method on the consideration of different means to expand our 11kV emergency power capacity. Lithium-ion battery technology allows energy storage capability with high level of energy density and provides additional advantages through its unique characteristics. In this paper, we introduce a 4MVA High-voltage Battery Energy Storage System to expand the 11kV emergency power capacity in HKIA, to re-use the energy generated during generator's routine test, and to shave power demand peak precisely by the adoption of load predictive control model through big data for achieving a sustainable and smart airport.

1. INTRODUCTION

The emergency power for Terminal 1 (T1) of HKIA is provided by six numbers of 11kV 5MVA generators in Generator House 1 (GH1), as shown in Figure 1 below, with the overall system capacity of 25MVA under N-1 mode of operation. Along with the increase in the electrical loading due to various developments in T1, it is anticipated that an extra 4MVA demand of emergency power is required in the coming future.

Fig. 1 - 11kV Diesel Generators in Generator House 1 in HKIA

To cater for the additional emergency power, installation of an additional generator in the existing GH1 seems to be the most direct method. However, as shown in Figure 2 below, this straightforward approach is not technically feasible due to the limited space inside GH1. Without the need of considerable building construction works, we apply new technologies and install a 4MVA Battery Energy Storage System (BESS) to supplement the existing 11kV emergency generators installed in GH1. As the BESS is of outdoor type, the need of expanding GH1 can be eliminated. The overall emergency power capacity will be enhanced from 25MVA to 29MVA so as to meet the required power demand.

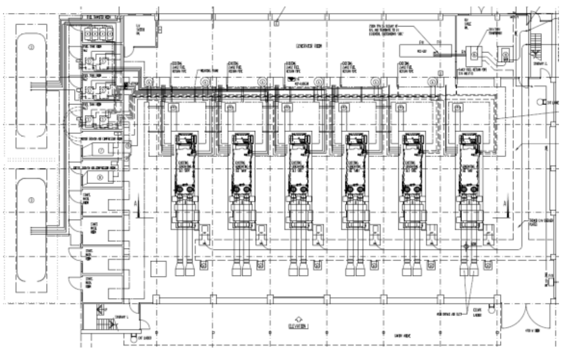

Fig. 2 - Layout of Generator House 1

Besides the enhancement of emergency power capacity, BESS can provide various advantages. Firstly, it can serve as the temporary power supply of Sea Water Pump House 1 (SWPH-1) to ride-through multiple voltage dips during extreme weather conditions like severe typhoon. This can further secure the operation of Chiller System at T1. Secondly, during routine generator load test, BESS can reuse the generated energy to charge its batteries in order to reduce carbon footprint for sustainable development. Thirdly, by discharging the stored energy to airport's 11kV power grid during peak demand period, the power demand peak will be shaved so that the maximum demand charge in the electricity tariff will be reduced. Furthermore, the modular design of BESS can provide additional flexibility for expansion to satisfy the future increasing demand. All these additional advantages are achieved by the unique characteristics of BESS technology.

This paper first introduces the technology of BESS. It then provides detailed review on battery type selection between Lithium Iron Phosphate and Lithium Nickel Manganese Cobalt Oxide. Finally, it presents the details of our highly customised High-voltage Battery Energy Storage System under various operation modes including emergency backup supply, green loader and power peak shaving to achieve different objectives and benefits for our sustainable and smart airport.

2. WHAT IS BATTERY ENERGY STORAGE SYSTEM?

BESS is a type of energy storage system that uses a group of batteries to store electrical energy. On grid-side, battery storage is the fastest responding source of power on grids, and is used to stabilize grids. On customer-side, battery storage is used to stabilize the network by compensating fluctuations caused by intermittent renewable energy sources, and to level out peaks in electricity use during peak demand period so as to avoid an extra maximum demand charge in electricity tariff. As shown in Figure 3 below, BESS is comprised mainly of batteries, Battery Management System (BMS), Power Conversion System (PCS) and Power Management System (PMS). The air-conditioning system and fire suppression systems are designed to provide suitable working environment and protection for batteries and PCS. The battery is a critical BESS component and its technology is rapidly developing. The details of each BESS sub-system are discussed below.

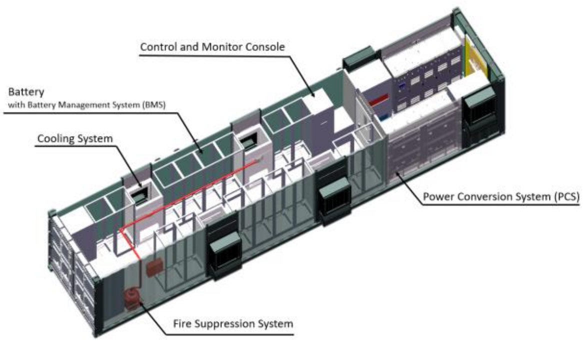

Fig. 3 - 3D Layout of BESS Container

2.1 Battery

Among various types of rechargeable batteries such as lead acid, nickel cadmium, sodium sulphur, lithium-ion (Li-ion), vanadium redox and zinc bromine, Li-ion battery possesses the greatest potential for future development and optimization due to its small size and low weight with the highest energy density and storage efficiency [1] [2]. Therefore, BESS shall be equipped with Li-ion battery in order to optimize its energy density, design lifespan and operating performance. Along with the continuous development of Li-ion battery in the world, there are many kinds of Li-ion batteries. Each kind of Li-ion batteries has its unique characteristics and some battery types will gain advantages in particular applications. In consideration of battery chemistry for Li-ion battery, we have to prioritize different factors, namely safety, energy density, charge cycle and cost. In this project, a comprehensive study on battery selection was conducted and is discussed in Section 4. Figure 4 below presents a 3D model of battery racks and modules installed in BESS.

Fig. 4 - 3D Model of Battery Racks and Modules

2.2 Battery Management System (BMS)

The battery system is designed with battery modules and BMS. Every battery cell, battery module and battery string are monitored by different level of BMS. Multi-level BMS shall be deployed for system monitoring and control. In total, there shall be at least three levels of BMS, namely module-level BMS, rack-level BMS and system-level BMS. Module-level BMS shall monitor the status of each battery cell by measuring attributes such as cell voltage, cell current, cell temperature, module voltage and module current, and perform cell balancing function. Rack-level BMS shall have full function of measuring overall voltages and currents for all cells in the racks, manage all module-level BMS units, measure rack voltage, rack current, and perform cell balancing function and protection functions by switching the DC contactor which are controlled and opened by BMS if fault condition is detected. System-level BMS can manage rack-level BMS units and communicate with PCS. If either charging or discharging limit of the rack is exceeded, warning signals shall be generated. The BMS shall monitor sensors and shut down the racks for fault conditions. In case of any fault condition such as over-temperature, the BMS shall de-rate or shut down the invertor and isolate the faulty component. Figure 5 below displays a 3D model of BMS control box installed in BESS.

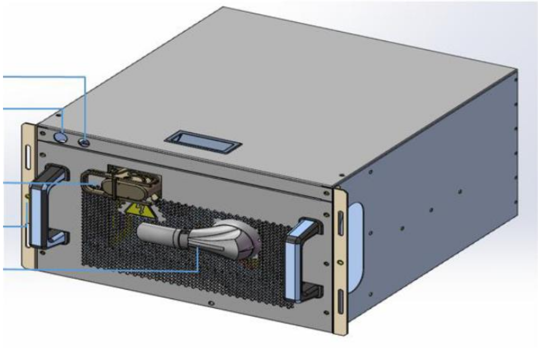

Fig. 5 - 3D Model of BMS Control Box

2.3 Power Conversion System (PCS)

PCS is an equipment that converts AC power to DC power in charging mode and converts DC power to AC power in discharging mode between batteries and the power grid. Also, it shall be capable of supplying active and reactive power to the power grid. PCS shall synchronize with the grid for charging and discharging and all PCS units shall also synchronize with each other before connecting to any live bus. Besides grid-connecting operation, PCS shall be able to perform off-grid operation, which means supplying loads without any external grid connected. Figure 6 below shows a 3D model of PCS installed in BESS.

Fig. 6 - 3D Model of PCS

Moreover, PCS shall provide a proper protection on AC and DC modes of operation including DC over-current, over-voltage, under-voltage and ground fault protection for both battery and PCS, AC over-voltage, under-voltage, over-current, over-frequency and under-frequency protection for both system and PCS, and synchronizing check protection when connecting to power grid. When the BESS is supplying power to the power grid, PCS shall be capable of detecting loss of main within a short period of time and disconnecting the BESS from the power grid to prevent islanding.

2.4 Power Management System (PMS)

PMS obtains measurement data from BMS, PCS and the power meters. These operational data and status data of BESS shall be used to control the PCS and operate the system. When BESS encounters system problem or malfunction, PMS shall detect the failures and send alarms to the operators through the system interfaces. The new control and monitoring devices are arranged and installed into one panel. This panel is responsible for monitoring the battery cell and PCS, as well as the charging and discharging control of PCS. The functions of peak shaving and valley filling are also enabled by PMS. It is also able to receive the predicted cooling load from existing systems and to make short-term re-scheduling for peak shaving on request. The details of such peak shaving strategy is discussed in Section 6.

2.5 HVAC System

Heating, ventilation and air conditioning (HVAC) System shall control the temperature and humidity inside the BESS containers to always achieve the optimal storage, standby and operation temperatures and humidity of the batteries, PCS and all BESS associated systems.

2.6 Fire Suppression System

Gaseous fire extinguishing total flooding systems using Novec 1230 shall be provided for the BESS containers to prevent and reduce fire hazards. BESS containers are also equipped with automatic fire detection system. When the fire detection circuit detects the fault and sends out signals, the energy storage container system (including air conditioning) will be linked to stop, and no manual operation is needed. In case of fire, the safety performance can be more effectively guaranteed.

3. SYSTEM CONFIGURATION OF BESS IN HKIA

Fig. 7 - Site Photo of BESS in Generator House 1

In HKIA, the BESS is capable of providing 4MW power for at least 30 minutes. As discussed earlier, container-type design is adopted so as to not only eliminate the need of expanding GH1 but also provide flexibility and mobility for operational requirement. All the three BESS containers are installed on trailers outside GH1, as indicated in Figure 7. Three sets 400V/11kV step-up transformers are installed outside GH1 together with three LV distribution pillar boxes for connecting and disconnecting power connectors to BESS containers. Nine 11 kV switchgear cabinets are built on G/F inside GH1 and three of them are used as feeder panels for BESS.

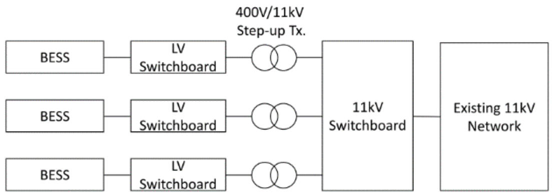

Fig. 8 - Electrical Block Diagram of BESS System

Figure 8 above indicates electrical block diagram of BESS system. The rated power and capacity of each BESS container are 1.34MVA and 0.933MWh respectively. It is a 40-feet container containing eight battery strings, BMS, two 666.7kW PCS, auxiliary transformer cabinet, power distribution system, PMS, fire suppression system, lighting system, HVAC system and video monitoring system. Figure 9 below displays a sectional view of a BESS container. Each container is connected to a LV distribution pillar box through four numbers of power connectors which allow higher flexibility and mobility of BESS by fast connection and disconnection of cables between BESS and the distribution pillar box. A 400V/11kV transformer is then connected to the pillar box for stepping up the voltage to match with our 11kV network.

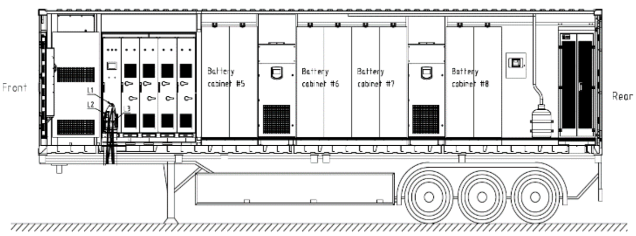

Fig. 9 - Sectional View of a BESS Container

4. BATTERY SELECTION

Nowadays, there are many kinds of Li-ion battery, for example, ternary lithium battery, lithium titanate battery and lithium iron phosphate battery.

Ternary lithium (NMC) battery uses lithium nickel cobalt manganese ($LiNiCoMnO_2$) as the anode material. Lithium titanate (LTO) battery uses lithium titanate (Li_2TiO_3) as the anode material. Lithium iron phosphate (LFP) battery uses lithium Iron Phosphate ($LiFePO_4$) as the cathode material. Among them, lithium titanate battery has the highest cost with the fewest suppliers and market applications. It is however good at fast charging and discharging. It can be fast charged and deliver a high discharge current of 10C. This unique advantage and high cost are not beneficial in the application of BESS.

LFP and NMC battery are the most common types of battery and are widely used in the BESS market. The main differences between LFP battery and NMC battery are energy density and safety performance. The energy density of LFP battery is much lower than NMC battery. The energy density of LFP battery is usually between 90-120 Wh/kg, while that of NMC battery can be 150 - 220 Wh/kg. Hence a large number of NMC batteries have been put into production globally for the application of electric vehicle due to its high energy density [3]. Japan and South Korea insist this technical direction and have become major suppliers of NMC battery in the world.

Despite the high energy density of NMC battery, we concern more on the safety performance of such kind of battery. The secret of NMC lies in combining nickel and manganese. Nickel is known for its high specific energy but poor stability. Manganese has the benefit of low internal resistance but offers a low specific energy. Combining the metals enhances the strengths of each other. There are many Ni-Mn-Co ternary system batteries in the market, such as 523, 111, 811 systems [4]. By blending different portions of Ni, Mn and Co, the characteristics of each system will be different. In the large-scale BESS market, people always aim to increase the energy density to reduce the size of BESS and save space. However, there is a natural constraint between high energy density and safety or stability. To obtain a battery with high energy density, it is inevitable to increase the proportion of Ni and Co in the ternary material. This comes with the potential safety hazard caused by Ni's active characteristics and the high cost due to the lack of Co resources in the world. Regarding the safety hazard of NMC battery, high charge/voltage will even promote thermal runaway of the battery [5].

Lithium iron phosphate battery possesses P-O bonds which are stable and difficult to decompose. Even at high temperature or overcharge, it will not collapse and generate heat or form strong oxidizing substances like lithium cobalt, so it has good safety performance. LFP is more tolerant of fully charge conditions and is less stressed than other Li-ion batteries at high voltage for a prolonged period of time. LFP battery offers good electrochemical performance with low resistance. The key benefits are high current rating, long cycle life, good thermal stability, enhanced safety and tolerance of abuse.

Except safety, the charge cycle of LFP battery can reach 2000 cycles or even more depending on depth of discharge and working temperature, while that of NMC battery is around 1000-2000 cycles. From the cost perspective, NMC battery is usually high in cost owing to the shortage of the scarce metal, cobalt, on earth. Meanwhile, LFP battery does not contain any rare materials and most of its raw materials and metals are abundant in the market. As a result, the cost of LFP battery is lower than that of NMC battery.

Among all the consideration factors (i.e. safety, energy density, charge cycle and cost), we put safety as the top priority. Research [6] showed that NMC battery can reach 731ºC while LFP goes up to 259ºC in the event of thermal runaway. The thermal runaway tests confirmed that LFP battery exhibited a good stability under thermal abuse, while NMC battery presented a poor temperature tolerance at high temperatures. LFP battery certainly has a better safety performance than NMC battery. LFP battery also has a longer cycling life and lower cost. Therefore, LFP battery was chosen to be used in our BESS.

5. FUNCTIONS

The BESS is located in the GH1 of HKIA, working together with the existing 11kV generators. The functions of BESS are mainly used as emergency backup supply, green loader, and power peak shaving for the electrical load of HKIA.

The details of each function are illustrated below.

5.1 Emergency Backup Supply

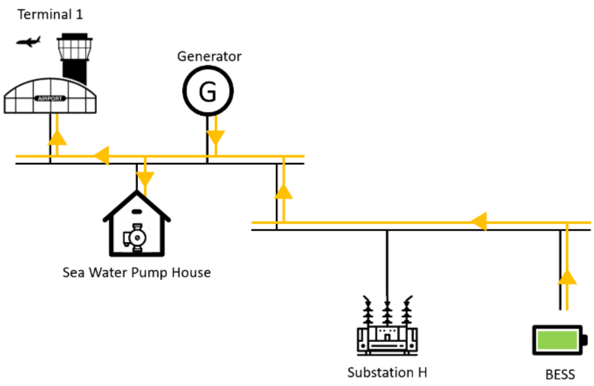

Fig. 10 - Power Flow under Emergency Backup Operation

The major function of BESS is the emergency backup supply. When power outage occurs, the BESS shall supply emergency power and follow the emergency backup supply sequence as described below:

1) When utility power supply to either one of four HV substations (i.e. PA, PB, PC and PH) is interrupted, six 11kV generators in GH1 will automatically start;

2) The first 11kV generator will be connected to a dead bus and the other five 11kV generators will be synchronized and connected in parallel sequentially;

3) Once at least three 11kV generators are in parallel operation successfully, outgoing feeders to the affected HV substations will be closed and the 11kV generators will start to supply emergency power to the essential loads.

4) After all 11kV generators are in parallel operation, the BESS shall be triggered to start under some pre-set criteria (i.e. status of circuit breakers and generators, load percentage of generator, feeder currents, and other associated signals) and then synchronize with the 11kV generators to supply emergency power to the airport.

Besides the emergency backup supply to T1, the BESS can also supply power to SWPH-1 temporarily so as to ride-through multiple voltage dips during extreme weather conditions like severe typhoon. This can enhance the reliability of the chiller system of HKIA. Figure 10 demonstrates the power flow under emergency backup operation.

5.2 Green Loader

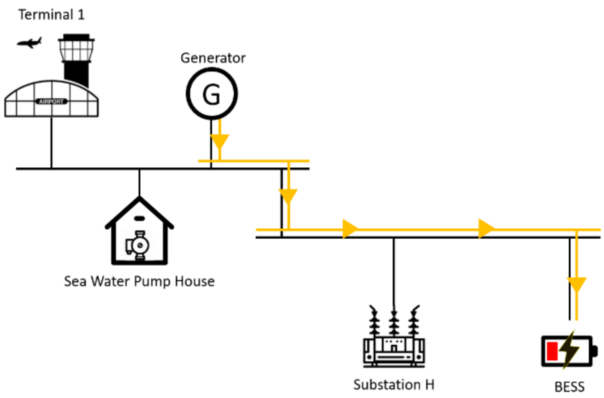

Fig. 11 - Power Flow under Green Loader Operation

During routine load test of existing generators, the generated energy is dissipated as heat in the 11kV load bank. This is a regular test conducted monthly as per the preventive maintenance schedule.

As the BESS is connected to the 11kV generators, it can act as a load bank to absorb the power generated by the generators during the routine load test. The generated energy will be used to charge the battery in BESS for other purposes like emergency backup supply and power peak shaving. The implementation of this green loader operation leads to reuse of energy and reduction of carbon footprint. Figure 11 indicates the power flow under green loader operation.

5.3 Power Peak Shaving

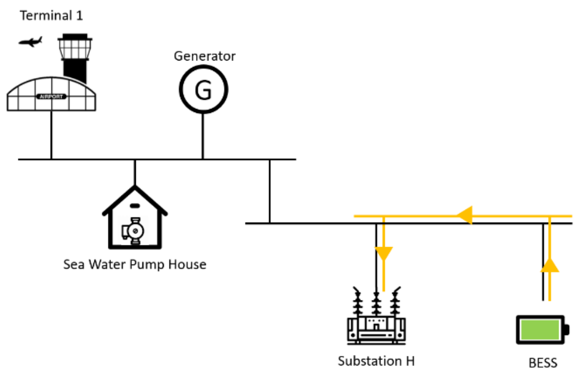

Fig. 12 - Power Flow under Peak Shaving Operation

BESS can synchronize with the utility power network and supply power to existing 11kV Substation H for power peak shaving. Figure 12 above displays the power flow under peak shaving operation. The BESS is charged during non-peak demand period and discharges to airport's 11kV power grid during peak demand period. As presented in Figure 13 below, the power peak supplied by the utilities will be reduced as the energy is supplied by the BESS instead. As there is a maximum demand charge in the electrical tariff, the total electricity charges will be reduced due to the shaved power peak. Research [7] also technically revealed that BESS could effectively shave peak load to obtain economic benefits.

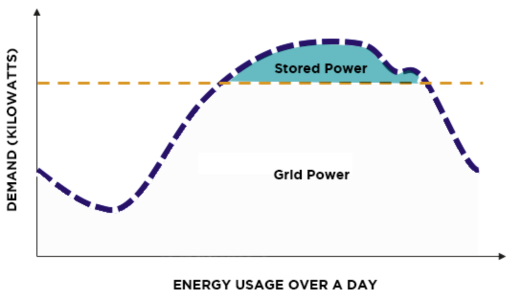

Fig. 13 - Power Peak Shaved by Stored Energy of BESS

6. PEAK SHAVING STRATEGY

Identifying the power peak precisely is a key to improving the effectiveness of the peak shaving operation. We have to predict when the power peak will appear in the electrical network so as to start the peak shaving operation of the BESS. In our BESS, there are two peak shaving strategies, namely normal scheduling and Weather Forecast for Air-conditioning Control System (Weather FACTS) response.

6.1 Normal Scheduling

For the sake of determining the optimal operation time of BESS, it is necessary to study and analyze the historical data of the load profile of HKIA. Figure 14 indicates the load profile of HKIA. In the load profile, we can obtain much useful information such as upward, downward, flat and fluctuating trends. In general, the load profile shows an upward trend in spring, a fluctuating trend in summer, a downward trend in autumn, and a flat trend in winter. The next step is to determine the optimal time of peak shaving in a day. This can also be deduced from the historical data. Normally, it is observed that the power peak appears from 2 pm to 6 pm depending on the seasons. Besides, during peak travel periods around some festivals or holidays like Christmas, Lunar New Year and Easter, the power peak would also appear. By the utilization of this big data, we can strategically schedule the operation of BESS to shave the power peak in the most appropriate days and weeks in a month, and hours in a day.

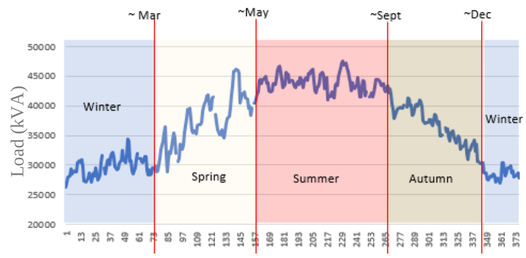

Fig. 14 - Historical Data of Load Profile of HKIA

6.2 Weather FACTS Response

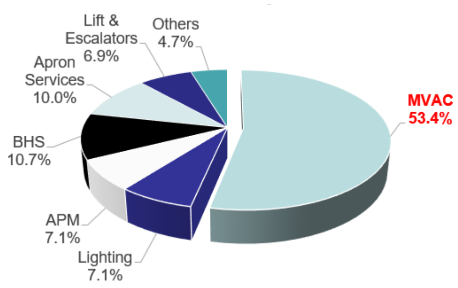

Fig. 15 - Distribution of Electricity Demand in Terminal 1

Another data that shall be analysed is the distribution of electricity demand in the airport. As indicated in Figure 15 above, over 50% demand is contributed by MVAC system. When analysing the historical data of the load profile, it is found that the power peak is closely related to the environmental temperature, especially in summer. As the output of MVAC system is adjusted according to the environmental temperature, this echoes with our findings in load distribution of the airport.

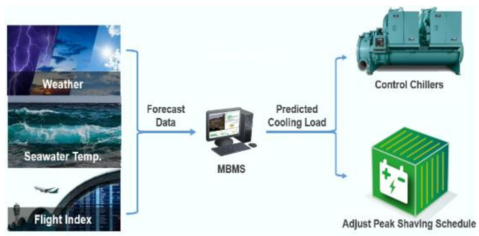

Fig. 16 - Graphical Illustration for the Operation of FACTS

As the power peak is weather-dependent, we decide to deploy the Weather FACTS to interface with BESS for peak shaving operation. Figure 16 above demonstrates the graphical illustration for the operation of Weather FACTS. Weather FACTS will utilize big data such as weather, seawater temperature and flight index to predict the cooling load of a day (i.e. coming 24 hours). The predicted cooling load will be sent to chiller system for control and to BESS for adjusting the normal schedule of peak shaving. According to the predicted curve of cooling load sent from Weather FACTS, the PMS of BESS will analyze the data and decide when it should discharge power to the airport's power grid, how much power it should generate, and how long the whole peak shaving process should be. Consequently, a new daily schedule of peak shaving can be formulated. This strategy offers a more flexible and resilient response to cope with climate changes or fast-changing weather. By interfacing with Weather FACTS, BESS can undoubtedly enhance the effectiveness of peak shaving operation.

7. CONCLUSION

The market of BESS has been growing rapidly around the world in these years [8]. The application of BESS covers from customer-side to grid-side including shaving power peak, filling power valley, spinning reserve, voltage compensation, frequency control, absorbing intermittent power generated by renewable power sources, battery charging station for electric vehicles and even mobile power bank for emergency usage. This wide range of applications, together with the strong market growth, has led to further studies and development of BESS, including battery and PCS technologies. We believe that BESS will play an important role in enabling diversification of energy sources for the next phase of the electrical, renewable energy, and electric vehicle industry.

The practical knowledge and experience gained in this project will definitively acquire professional knowhow in the operation of other innovative battery systems in future and manage the fast-growing electrical market with substantial growth in the quantities of electric vehicles and associated high power chargers in our grids. We welcome and are interested in all kinds of new ideas and innovation for BESS in future. Along with the continuous development of AI technology and other smart systems to be implemented in the airport, we will further create innovative applications with BESS to suit the smart operation of HKIA.

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Paper No. 2

CRITICAL POWER SUPPLY FOR HEALTHCARE FACILITIES

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ABSTRACT
COVID-19 changed the lives of people forever. Greater demand on the quality and quantity of healthcare facilities introduced new challenges to engineers such as Resilience, People-centricity, Hyper-efficiency and Sustainability. This paper examines what changes we are facing and how we could respond to fulfill those requirements. Examples of interesting technologies and successfully implemented cases are also shared.

1. INTRODUCTION

With COVID-19 and its variants being highly transmissible, the constantly escalating number of confirmed cases is overwhelming in medical systems everywhere; and consequently, the quality of care for all patients has been severely diminished. This results in "Critical Power Supply" for healthcare segment a more significant topic that needs to be addressed.

With reliable power supply being a necessity to properly maintain and support a country's medical system and its healthcare facilities, more resources and funding are being injected into Research & Development to improve the reliability and safety of power supply. Severe outcomes for electrical failures and outages at hospitals are top priority to avoid at any cost.

Airborne infection isolation room (AIIR), more commonly known as negative pressure isolation room, is required for keeping those patients contracted with suspected airborne infectious disease isolated; and rigorous standard on the design and implementation are required. With COVID-19 being an airborne infectious disease, demand of AIIR has rocketed. The air pressure inside AIIR should be lower (negative) than the air pressure outside the room to avoid contaminated matters and airborne viruses flowing out to other areas through physical entrances and the heating, ventilation, and air conditioning (HVAC) system. Therefore, uninterrupted power supply is essential in maintaining the pressurized air; and in the event that power failure occurs, emergency power is required for this priority load.

In addition to COVID-19 treatments, vaccine is one of the key measures to prevent severe illness, hospitalization and death associated with contracting the virus. Some varieties of COVID-19 vaccine differ from traditional vaccines in that storage in ultra-cold temperature of -70°C is mandatory. On that account, special vaccine storage units with temperature monitoring are required for proper storage. As a result, stable power supply is necessary.

In Hong Kong, Hospital Authority Supporting Services Centre (HASSC) is an integrated facility with a built-in Data Centre for storage and retrieval of public hospitals' medical records such as patients' diagnostics and testing results. It would be gravely inconvenient if power failures lead to inaccessibility of records.

Above shows how essential power supply is. This could also be echoed with The Hongkong Electric Co. Ltd. upgrading 160 of its substations with anti-flooding system, aiming to avoid water flooding in their substations, each with a cost in construction and implementation of about HK$40,000. The system is composed of two metal sensors with different lengths for detecting rise in water level. When water level reaches the longer sensor, the water pump will be automatically turned on with a pumping rate of 19.8 m^3/hour. If the water level reaches the shorter sensor, it signifies that the system is unable to extract out water fast enough and warning signal will be given by the system to notify responsible staff from System Control Centre in order to prevent electrical failure. Similar system could be implemented for healthcare facilities for detecting water or other fluid to avoid damaging medical appliances as well as maintaining the stability of power.

2. FOUR CHALLENGES

Healthcare facilities are facing great challenges and modernized designs are necessary to meet the need of resilience, people-centricity, hyper-efficiency and sustainability.

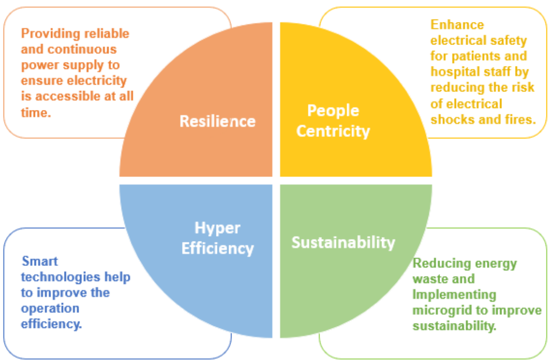

Fig. 1 - Four Challenges that Healthcare System is Facing

2.1 Resilience

2.1.1 Power availability

There is no time for downtime in healthcare facilities. Power availability is crucial for medical equipment such as ventilators, oxygen suppliers, etc. to continue operating in the isolation wards, intensive care units and operating theatres. Especially during operation, power and data availability makes the difference between life and death.

Electrical shocks and fires are the main risk of lives and causes of damage. According to the FM Global Insurance Report 2011, fire is the leading source of accident expenses. Within the risk of fire, 22% are caused by electricity. Therefore, creating a safe and secure environment for patients and staff is important for maintaining the operation of hospital systems.

By providing reliable power supply, IoT-based infrastructure, and continuous thermal monitoring, the goal of all-time electricity supply can be achieved. Patients' safety and well-being related to clinical and health data monitoring can be guaranteed without any downtime or data loss.

2.1.2 Telemedicine / remote control

The COVID-19 pandemic has demonstrated that due to hygiene concern, social distancing and quarantine policies, the need for remote operation is not only growing but will soon become necessary. Remote access is achieved by connecting to the cloud, which can reduce the dependency of on-site IT resources, boost flexibility and obtain access continuity to reduce the impact of external incidents, as well as to improve resilience and operation efficiency.

2.1.3 Cybersecurity

Cybersecurity has become more prominent in the healthcare sector, prompting increased concern during the current pandemic. A cyberattack shut down critical systems at Brno University Hospital, a major COVID-19 testing facility in the Czech Republic. It was one of the first and most visible cases of healthcare cybercrime during the pandemic [1].

As a result, healthcare cybersecurity has become a priority. It is important for healthcare system to enhance cybersecurity to properly secure its infrastructure.

2.2 People - Centricity

Hospitals are supposed to be designed to be responsive to people's needs. People satisfaction is the key for driving the well-being of hospital patients and staff. Satisfied patients may experience better outcomes, resulting in the reduction of readmission rates; and as a consequence, hospitals' performance will be improved as well.

In terms of patient satisfaction, IoT can also enhance the well-being of patients and staff through good lighting control, fresh clean air, comfortable temperature, and proper noise monitoring.

Additionally, other convenience services improved by IoT are appointments, queueing, and payment processes through hospital apps. The Hospital Authority (HA) of Hong Kong has launched "HA Go" Apps for public hospital health management. It allows patients to review and request appointments, access to medical records at anytime and anywhere. The "Rehab" function allows patients to manage their health by doing rehab exercise treatment customized by their therapists. Electronic payments help to avoid physical queueing and contact, which can relief the stress of COVID-19 regulation and reduce the risk of outbreak.

All culminate into healthcare facilities that are more people centric.

2.3 Hyper Efficiency

Energy expenses are significant for large and critical infrastructure such as healthcare facilities. The cost of operation and maintenance accounts for 75-80 % of the entire lifetime of a healthcare building.

For that reason, identifying energy conservation measures and energy reduction opportunities are important to reduce overall operating and maintenance cost and simplify regulatory compliance.

With the help of IoT technologies, power consumption would be continuously monitored, and the real-time data can be gathered for analytic purposes. By assisting facility management teams and advisors in sustaining operations, the clinical teams can provide exceptional care every day so in turn operational efficiency can be improved as well. Lastly, financial health is also improved.

2.4 Sustainability

Healthcare system is a substantial component of the global economy, accounting for an average of 9% of GDP in Organization for Economic Cooperation and Development (OECD) nations [2]. This spending is expected to climb in the coming years as a result of ageing populations, rapid medical development, and an increase in the frequency of lifestyle-related diseases.

According to the Potsdam Institute for Climate Impact Research in Germany [2], carbon dioxide emissions from healthcare facilities account for 5% of the world's major economic nations' carbon footprint, which is more than the emissions from aviation and shipping.

The first step in reducing carbon emissions and improving sustainability is to reduce energy waste. Measuring and continuous monitoring the energy usage is necessary for identifying and reviewing the most energy demanding equipment. From there, action for energy efficiency and energy saving can be achieved. New technologies in development will aid in managing energy use along with more energy-efficient and environmentally friendly products and equipment.

Another important step toward greater sustainability is the use of renewable energy. Renewable-based microgrid can be implemented in healthcare facilities to lower carbon footprint and make healthcare systems both more resilient and sustainable.

3. HOW TECHNOLOGY HELPS

Regarding the mentioned four major challenges that healthcare sector is facing, the market has always been timely in responding to such changes. Electrical suppliers and manufacturers have been developing new products and systems to meet the growing expectations on power reliability and monitoring.

3.1 Resilience

The resilience and reliability of stable and uninterrupted power supply (UPS) is vital for hospital to maintain the operation of medical equipment. Operators should make good use of electrical devices, such as protection relays, smart circuit breakers and uninterrupted power supply to minimize downtime and disruptions caused by the fault of the system. Because in healthcare, there is no time for downtime.

A best-in-class protection relay as shown in Figure 2, can reduce risks, improve reliability with advanced connectivity. While electrical devices are switching, dangerous arc-flash may exist, and built-in protection function is able to detect arc-flash and respond by disconnecting the circuit breaker within milliseconds. As a result, the arc-flash energy can be controlled and reduced to avoid unexpected risk or downtime. In addition, with a withdrawable design, the protection relay can be disconnected and/or swapped to shorten the maintenance time. Once the relay is connected again, communication, data and settings will be restored in a short period of time to minimize the effects on hospital operations.

Also shown in Figure 2, circuit breaker is another indispensable component of the electrical system for protecting the circuit from damage caused by overload or short circuit. To enhance the resilience of the electrical system in hospital, electrical suppliers provide plug and play features for the circuit breaker in order to simplify installation and shorten maintenance time. Furthermore, circuit breaker is equipped with micrologic control unit for measurement of current, voltage, frequency, power and power quality, which allows the end user to carry out comprehensive energy management to optimize continuity of service. The operator could programme alarms for remote indication and be alerted with fault in advance, so that the performance of electrical equipment can be recorded and monitored. To maintain the operation of medical equipment, power supply should be uninterruptable.

Next, in Figure 2, UPS is a necessary electrical equipment. To respond to the growing demand on electrical resilience, the market developed new UPS with compact design and modular architecture. The footprint is highly reduced by deployment of Lithium-ion battery (LiB). According to the white paper published by Avelar [3], with the same rated power capacity of 1 MW, the footprint of traditional valve-regulated lead-acid (VRLA) battery is 5.4m^2 and that of LiB is only 2.2m^2, reduced by 59%.

With the UPS, the electrical supply can be maintained when there is loss in utility incoming power supply to reduce the effects on critical equipment.

Fig. 2 - Protection Relays, Air Circuit Breakers, UPS (From left to right)

In healthcare, recovery should be conducted in a safe and comfortable environment. Patients and healthcare professionals should be ensured that the buildings are safe and reliable so high-level protection of the electrical system must be implemented.

As mentioned earlier, fires cause huge economic loss, in which 22% of them are caused by electricity. Continuous thermal monitoring of major electrical system component is the most efficient solution that allows users and operators to minimize risk for equipment damage, help to prevent power system failures and optimize maintenance costs.

Nowadays, thermal monitoring units are designed to be super compact and easy to install. Some of them are even self-powered by network current and do not require batteries. This real-time thermal data is transmitted via wireless communication protocol such as Zigbee, which can be easily monitored and visualized on smartphones and/or tablets. Traditional infrared scanning can possibly be replaced by implementing these wireless thermal monitoring sensors.

On top of thermal monitoring of the busbar in switchgear, inside a switchboard, there are numerous cables which may emit hazardous smoke before a fire occurs. There are smart sensors in the market which are able to analyze gas and particles in the switchboard and alert before any smoke or insulator browning occurs, as shown in Figure 3.

Fig. 3 - Wireless Thermal Sensor, Wireless Smoke Detector for Electrical Installation (From left to right)

By adopting these smart monitoring devices, actions can be taken before fire occurs, thereby minimizing the damage and effects on electrical system to provide a safe and comfortable environment for the healthcare users and workers.

3.2 People - Centricity

Along with keeping the users safe, occupant experience and well-being also should be maintained at a high level. With various living space sensors (Figure 4), temperature, humidity, CO_2 concentration and occupancy, many parameters can be detected and recorded which allow users to remain in the best thermal comfort with fresh air.

Fig. 4 - Living Space Sensors

By deploying smart living space sensors with controllers, occupant engagement app can be used for great convenience. The patient or the room users in a hospital can simply personalize lighting, temperature, and even blinds from a smartphone and/or tablet, as shown in Figure 5.

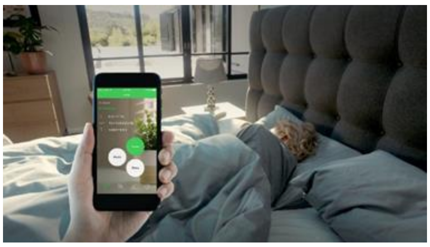

Fig. 5 - Occupant Engagement App

3.3 Hyper - Efficiency

Hospital aims at delivering extraordinary care continuously every day. With growing demand on healthcare services, the market came up with smart solution to boost operational efficiency. Because in healthcare, operational excellence is the only option.

In a hospital, there are countless different systems, as shown in Figure 6, that need to interoperate and share data to ensure patient satisfaction, comfort, and safety while maintaining an energy efficient building. By adopting smart analytic platform, real-time data are collected through sensors and being gathered and analyzed. The facility management (FM) team can set up alarm notifications when readings on sensors exceed the expected threshold values. With continuous monitoring and alarming functions, proactive maintenance is performed instead of reactive maintenance, while faults can be corrected and solved before the break down of the equipment. As a result, equipment performance and efficiency can be optimized, and the FM team can be more flexible in arranging manpower for maintenance and reduce the cost and budget on maintenance work.

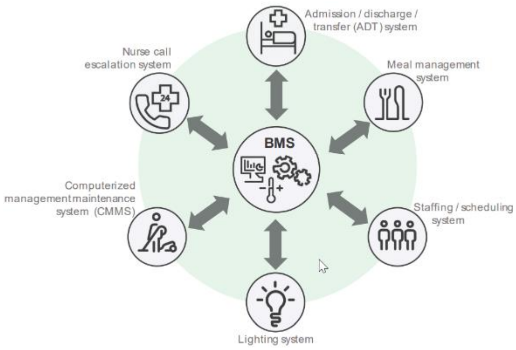

Fig. 6 - BMS System

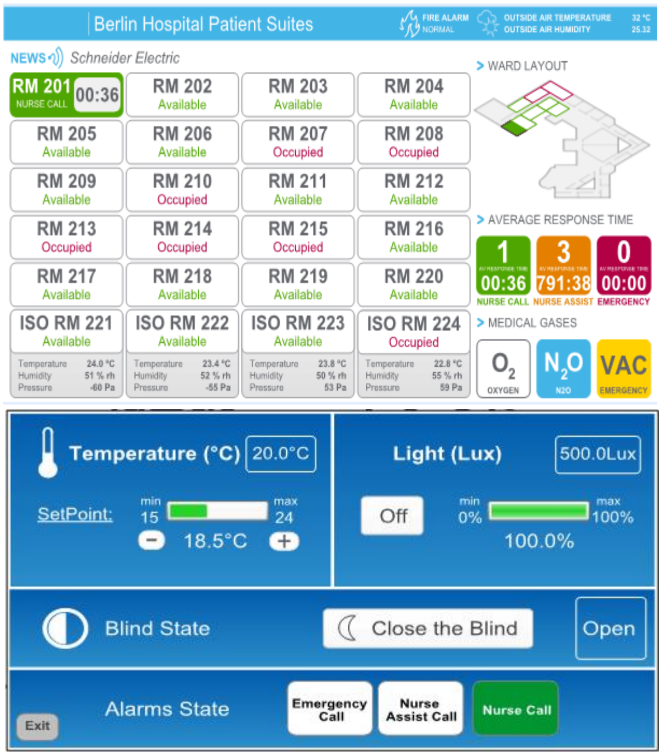

Fig. 7 - Healthcare System Control Dashboard

3.4 Sustainability

In healthcare, uninterruptable power supply for medical equipment is not the only important matter. At the same time, the world has been paying more attention on sustainability. Because in healthcare, sustainable care relies on sustainable solutions.

To meet and achieve sustainability, the Hospital Authority has been implementing different renewable energy throughout hospitals in Hong Kong. For example, in the North Lantau Hospital and Tseung Kwan O Hospital [4], photovoltaic (PV) system and hot water system are installed to provide renewable energy and bring environmental benefits.

With the growing installation and development of renewable energy in hospital, microgrid is needed to monitor the working condition and healthiness of the equipment.

According to Alliance to Save Energy, a microgrid system serves as a local energy grid which is typically connected to the main power grid and can also disconnect and operate independently [5]. With the installed PVs, energy from the Sun can be converted to electrical energy and transmitted to the microgrid.

With the deployment of microgrid, renewable energy resources can be highly utilized to help reduce carbon emission and contribute to the organization's sustainability goals.

3.4.1 Three-layer system

To make the above-mentioned hardware and software interoperable, a three-layer system is required to act as the foundational technology backbone.

As mentioned in a paper published in the HKIE Electrical Division Annual Symposium 2020 [6], a three-layer architecture includes connected product, edge control and apps, analytics & services. This system allows interconnectivity of every component and make data sharable among them. It can assist developers, facility manager and engineering staff in building applications including monitoring, visualization and control.

4. FUTURE PATH

Hong Kong is facing an ageing problem and a shortage of professionals in the healthcare system. By 2041, to maintain the current level of healthcare service levels, hospitals will require an additional 6,200 medical professionals [7]. The need for the advancement of technologies become more and more crucial. The next decade is likely to see new technologies being created and released into the market, including Artificial Intelligence (AI), Robotics, 3D printing, wearable technology, Virtual Reality (VR), Nanotechnology, etc.

Table 1 shows how some of the mentioned technologies are applied to help improve our healthcare system.

In the next few years, healthcare system will rely on technologies to a larger extent. To ensure that all technologies are functional under any situation, we are responsible to design them to reach and overcome the four challenges – resilience, people centricity, hyper efficiency, and sustainability. For all technologies, power supply must be functioning 24/7, with no downtime. For example, wireless tele surgery (WTS) allows remote surgeries with the help of a robot. WTS uses 5G and core network to connect robot and remote surgeon. It requires a stable power supply for operation. If the power system shut down accidentally, there will be serious consequences.

In this New Normal condition that we are facing globally, we should prepare the path for future technologies through a safe power system.

Fig. 8 - Three-Layer Architecture of Healthcare System

Technology	Description
Artificial Intelligence (AI)  Fig. 9 - Medical Data produced by AI	Artificial intelligence (AI) is a type of digital technology that mimics human intelligence. AI systems can evaluate medical data, create treatment plans, and manufacture medications far faster than humans can. It has the potential to minimize worker effort and professional requirements.
Robotics  Fig. 10 - Da Vinci Surgical System	In the fields of science, engineering, and technology, robotics refers to the creation of machines known as robots that perform or imitate human actions. There are several types of robots can that apply to the healthcare aspect, for example, surgical robots and disinfectant robots. It can replace repeated tasks like room services to lower the workload of medical personnel. Robots can also replace some complicated tasks like surgeries to alleviate the need for professionals.
3D-printing  Fig. 11 - 3D-print of a Heart	3D printing is a technique of creating 3D solid products from a digital file. Bio tissues, prosthetic limbs, medicines, and blood vessels etc. may now be printed. As the demand for the above products and materials will increase due to the ageing problem, 3D printing can provide stable supplies to a hospital.
Wearable Technology  Fig. 12 - Healthcare Tracker	Wearable technology refers to electronic technology that can collect health data from a person with wearable devices like smartwatches and healthcare trackers. A patient can monitor their health status in real-time by using healthcare trackers. They can contact medical personnel immediately once the device detected abnormal status. Hospitals can also receive notice. Therefore, hospital can prepare for emergency patients to reduce the time for arranging medical services.
Virtual Reality (VR)  Fig. 13 - Surgical practice done by VR	Virtual Reality (VR) is a digital environment with realistic-looking images and objects that gives the user the feeling of being completely immersed in their surroundings. VR is being utilized to teach future surgeons and provide more practices to them. More practical work can boost their performances during surgeries, which increase the quality of surgeons. VR also benefits patients when providing physiotherapy. Virtual scenario can give assistance to patients.
Nanotechnology  Fig. 14 - Nanomedicine	Nanotechnology can be used to make nanomedicine, to be able to target certain cells or tissues more effectively. As ageing problem will rise, nanomedicine can ameliorate the precision of drugs, medical treatments, and surgeries to tackle senile diseases.

Table 1 - Introduction of New Technologies

5. CONCLUSION

According to the press release of Chinese University Hong Kong Medical Centre [8], in partnership with Hong Kong Telecom (HKT), CUHKMC will be the first, private, smart hospital in Hong Kong which is fully equipped with 5G. Innovative medical applications such as remote consultation, training and operation driven by the advanced 5G technology would bring breakthroughs for the development of smart hospitals and accelerate the digital transformation of the entire healthcare industry. 5G technology could further facilitate the use of Internet of Medical Things (IoMT) and robotics to better serve all patients by allowing faster data flow, which helps to increase efficiency of handling patient information.

It is estimated that the Hospital Authority of Hong Kong will face issues due to the growing and ageing population with an increasing number of patients with chronic diseases, resulting in growth in demand and costs as well as shortage of key manpower resources. Healthcare automation could be the panacea in the coming decades. The development of smart hospital for public is aiming to achieve digital innovations in meeting future sustainability challenges.

Unintentionally, COVID-19 has become the catalyst for the progression and promotion of smart hospitals. Recently, Tseung Kwan O Hospital has successfully carried out surgical operation by using HoloLens. In gist, this technology allows the Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) scan to be accessed from the cloud so 3D model can be created and viewed by the surgeon. It results in locating tumors more accurately and during the surgical removal of lipoma, which normally has more difficulty due to the close distance between the tumor and blood vessel, and hence a higher chance of success.

Due to the pandemic, face-to-face operation is discouraged and replaced by automation to reduce the transmission rate by maintaining social and physical distancing. This new normal is accelerating the adoption of new technologies.

With further advancement of automation, the trend of STEM (Science, Technology, Engineering and Mathematics) education will become even more important. Both public and private sectors are encouraging and providing motivation to younger generation in STEM education by offering scholarships and internships so the younger generation can take part in contributing and improving technologies and foster the mindset of innovation.

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Paper No. 3

DYNAMIC UNINTERRUPTED POWER SUPPLY

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ABSTRACT
If a building contains a critical electrical load, a UPS system should form part of its electrical topology. Positioned between the incoming raw mains and the critical load, it will ensure an uninterrupted, high-quality power supply; business continuity is not compromised due to electrical equipment downtime. Although Dynamic UPS or static UPS solutions can help to secure and protect critical load and equipment from mains perturbations and outages, Dynamic UPS provide a competitive alternative compared to static UPS systems. This paper attempts to present these technologies in a straightforward manner. The design and operation of D-UPS in this paper are based on the dynamic UPS - mtu Kinetic PowerPack®.

1. INTRODUCTION

Dynamic UPS (D-UPS) systems provide output voltage by transforming kinetic energy stored in a rotating accumulator into electrical energy and vice versa, unlike static UPS systems that use power electronic devices with huge number of batteries that provides the back-up power supply. Through this technology, a D-UPS provides an "infinite" back-up power supply, coupled with diesel engine simultaneously, ensuring reliable and environmentally friendly uninterruptible electrical power and power conditioning. Without the need for batteries, D-UPS systems offer the highest power density (kW/m²) in the industry with a high system efficiency in conditioning mode, low total cost of ownership, small footprint, scalable solutions, and a compact design. Last but not the least, it is green.

2. OPERATION PRINCIPLE

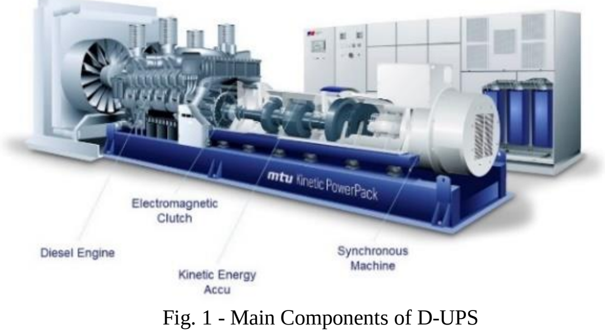

Fig. 1 - Main Components of D-UPS

The main components of D-UPS are including: (1) Diesel Engine, (2) Electromagnetic Clutch, (3) Kinetic Energy Accumulator with single excitation and a synchronous machine (4) Power Panel containing controlled breakers and a choke and (5) Control Panel containing a PLC and the dedicated electronic devices to control and monitor the system operation.

The D-UPS can be operated in conditioning mode and independent mode to secure the critical loads.

2.1 Operation in Conditioning Mode

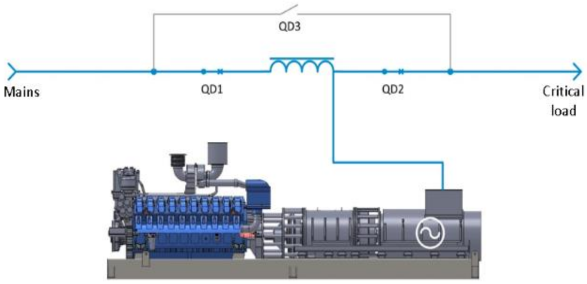

Fig. 2 - Single Line Diagram of D-UPS in Conditioning Mode

When mains supply is available, the input (QD1) and output (QD2) breakers are closed, the automatic by-pass (QD3) is open and the main supplies power to the critical load through the dynamic UPS. The synchronous machine acts as a synchronous condenser. The clutch is open and diesel engine is not running. The shaft of the stato-alternator rotates at 1500rpm (50Hz) when running in conditioning mode, which usually represents 99.9% of the operating time. The D-UPS unit supplies the critical loads with benefits of eliminating microcuts, regulating of output voltage, improvement of the power factor, filtering of transient phenomena and allowing rapid clearing of short circuits on downstream feeders.

2.2 Transition to/from Independent Mode

As soon as a failure in the mains supply is detected, the input breaker (QD1) opens. Instantaneously, the load is supplied by the synchronous machine which draws energy from the accumulator. The main shaft speed is regulated by modulating the inductive coupling between inner and outer rotor.

The supply to the critical loads is maintained without any disturbance to the voltage.

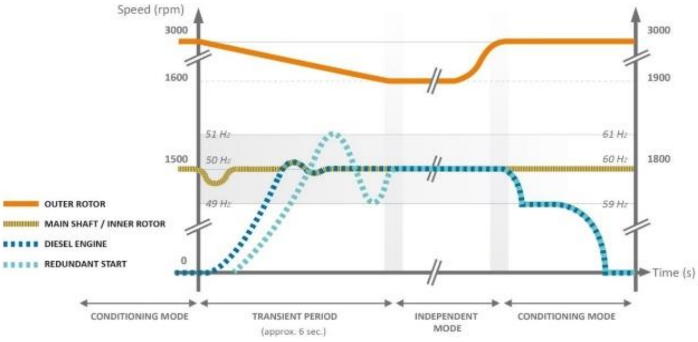

Fig. 3 - Transition of D-UPS to/from Independent Mode

Concurrently, the input breaker opens and the electric starters crank up the diesel engine. Approximately one second later, the electromagnetic clutch closes, thus establishing a mechanical link between the diesel engine and the stato-alternator. The diesel engine accelerates to its rated power output and takes over the transition, producing uninterrupted electrical power via the alternator while charging back the kinetic energy in the accumulator. The changeover from ‘conditioning mode’ to ‘independent mode’ is completed without any interruption.

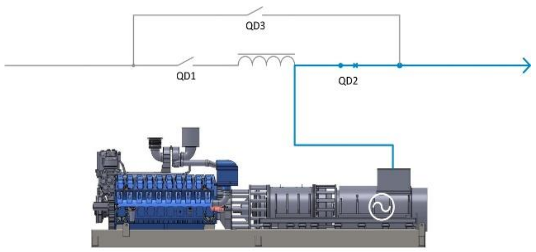

Fig. 4 - Single Line Diagram of D-UPS in Independent Mode

Once the mains power supply returns to normal, the D-UPS system will transit back to “conditioning mode” operation, provided that the accumulator is fully charged to speed. The diesel engine runs at idle speed in order to cool down before stopping.

3. KEY FEATURES

3.1 Voltage Regulation

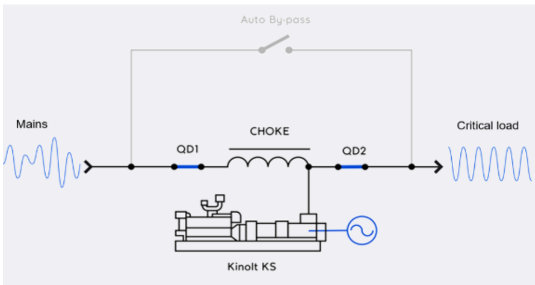

Fig. 5 - Input and Output Voltage Waveform of D-UPS in Conditioning Mode

In conditioning mode, the combination of choke coil and low impedance alternator acts as a dynamic filter. The D-UPS have the advantages in elimination of power line noise and voltage transients, and protection against frequency variations. Due to the input voltage and output voltage are independent at the choke, the input voltage may vary up to 30% for 1 second or up to 10% for unlimited time while the output voltage remains constant at +/- 1%. The system works as a voltage stabilizer. If the main voltage deviates outside the acceptable input voltage deviation curve, the D-UPS will transfer automatically to independent mode.

3.2 Power Factor Improvement

In conditioning mode, circuit breakers QD1 and DQ2 are closed whereas switch QD3 is open. Therefore the D-UPS is coupled in parallel on the main through a choke (reactance X). The stato-alternator excitation is controlled continuously to maintain permanently the rated voltage at the downstream busbar.

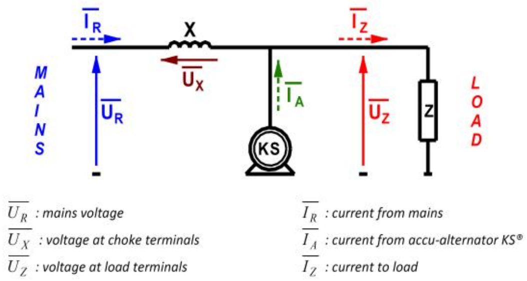

Fig. 6 - Equivalent Circuit Diagram of D-UPS in Conditioning Mode

Since the electromagnetic clutch is in open position and the diesel engine stopped, the synchronous machine cannot deliver any active power. Therefore, the active power absorbed by the load is delivered by mains only. However, the synchronous machine can deliver the reactive power requested by the load. Consequently, the power factor measured at mains terminals is improved significantly and reaches a value close to unity. Basically, the automatic improvement of the power factor measured at mains terminals results from the combination “voltage control – existence of the reactance”.

Electrical quantities can be evaluated by drawing a vector diagram which meets the following conditions:

$\overline{U_R} = \overline{U_X} + \overline{U_Z}$ (mains voltage is equal to the sum of voltages at load and choke terminals)

$\overline{I_R} = \overline{I_Z} - \overline{I_A}$ (current from mains is equal to current to the load minus current from accu-alternator)

$\overline{U_X} \perp \overline{I_R}$ (a 90° phase shift exists between voltage at choke terminals and current through the choke, that is current from mains)

$\left|\overline{U_X}\right| = X \cdot \left|\overline{I_R}\right|$ (magnitude of voltage at choke terminals is equal to magnitude of current through the choke, multiplied by the reactance of the choke)

$\left|\overline{U_Z}\right| = U_{nom}$ (magnitude of voltage at load terminals is equal to rated voltage)

The following diagrams show situations where the main voltage is at 90%, 95% and 105% of rated voltage, respectively. The considered load is the rated one, with a power factor equal to 0.8. Voltage and current vectors are drawn using value as unit length. Voltages are represented by continuous lines while currents are represented by dotted lines. Beside each vector diagram, the single-line diagram is plotted with active power flow (in blue) and reactive power flow (in green). Arrow width is proportional to the amount of (active or reactive) power flow.

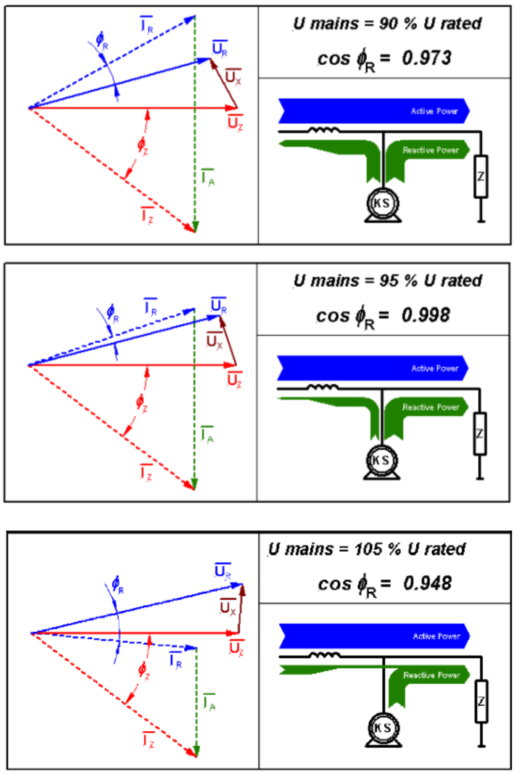

Fig. 7 - Vector Diagrams of Power Flow in D-UPS Unit

3.3 Harmonics Filter

The impedance of the choke expressed in pu (per unit with nominal voltage and power in *mtu Kinetic PowerPack* as reference) is about 30%, whereas the accumulator is characterized by its subtransient reactance close to 5% and its zero-sequence reactance about 2%. The combination of stato-alternator and the choke leads to a string reduction of harmonics (both voltage harmonic from mains and current harmonics due to a non-linear load). Therefore, even when running in normal mode coupled to mains, the D-UPS system influences significantly and positively the "power quality".

3.3.1 Mitigation of voltage harmonics from mains

In D-UPS system, the critical load is supplied with a constant amplitude and nearly not distorted voltage. Indeed, voltage harmonics present on main are reduced according to the "inductive series divider" made up of choke reactance and of the stato-alternator equivalent reactance Xe.

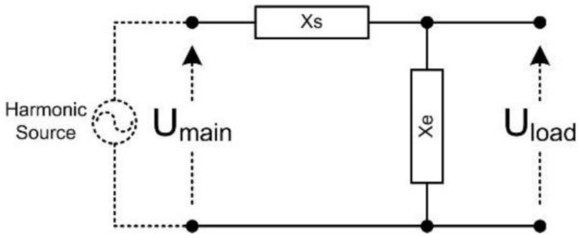

Fig. 8 - Equivalent Circuit Diagram of Voltage Harmonics in D-UPS

The equivalent reactance Xe corresponds to the stato-alternator subtransient reactance. The voltage divider can then be expressed by the following formula:

$$\frac{U_{load}(n)}{U_{main}(n)} = \frac{X"d}{X"d + Xs}$$

X"d – the accu-alternator subtransient reactance at fundamental frequency (50 or 60 Hz)

Xs – the choke impedance at fundamental frequency (50 or 60 Hz)

Where *n* represents the rank of the voltage harmonics

The improvement of the voltage quality allows a better operation for the load as well as an increased lifespan. The following example (Figure 9) was record on a site exposed to important voltage harmonics mainly resulting from large non-linear present upstream of the installation. The blue curve shown mains voltage, measured between phase and neutral, upstream of the *mtu Kinetic PowerPack*. The red curve shows the voltage measured at the load terminals, downstream of the *mtu Kinetic PowerPack*.

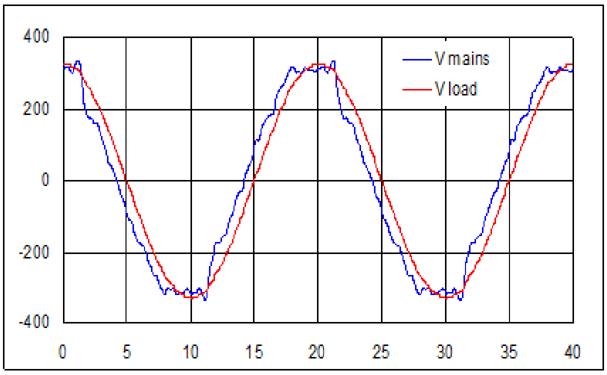

Fig. 9 - Voltage Waveforms in D-UPS Unit

3.3.2 Mitigation of current harmonics due to the load

The D-UPS system reduces significantly the current harmonics generated by the load and rejected to the mains. Indeed rejection of current harmonics due to the load is reduced according to the "inductive shunt divider" made up of the choke reactance and of the stato-alternator subtransient reactance. The current divider can be expressed by the following formula:

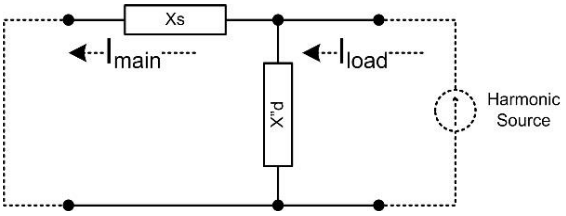

Fig. 10 - Equivalent Circuit Diagram of Current Harmonics in D-UPS

$$\frac{I_{main}(n)}{I_{load}(n)} = \frac{X"d}{X"d + Xs}$$

Where *n* represents the rank of the current harmonic

This filtering diminishes the requested apparent power, reduces the harmonics consequences and even avoids penalties provided by regulations for excessive harmonics rejection. The following example (Figure 11) was recorded on a site where the load current is highly distorted (see red curve). The blue curve shows the current measured upstream of the *mtu Kinetic PowerPack* system: that current, supplied by the mains, is clearly more sinusoidal.

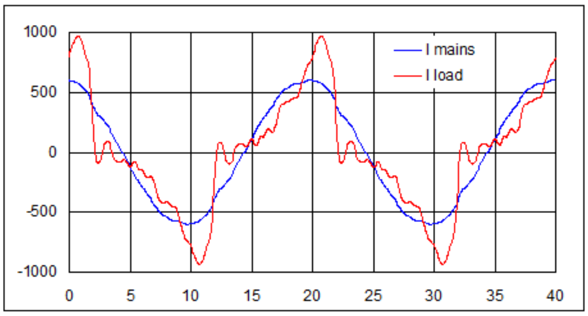

Fig. 11 - Current Waveforms in D-UPS Unit

3.4 Fault Clearing Capabilities

The D-UPS system have great fault clearing capabilities, based on *mtu Kinetic PowerPack*. The input fault clearing capability in utility short circuit is kept low at 3 times of nominal current to provide opportunity for continuity in “conditioning mode” operation without the transfer into “independent mode”; the fault clearing capability in output short circuit is 10 to 20 times of nominal current of D-UPS unit, allowing the protection circuit breakers to open rapidly.

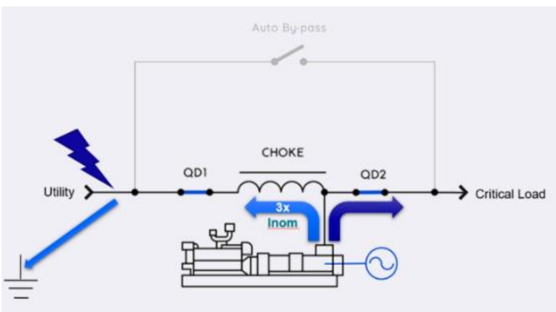

Fig. 12 - Fault located at Utility in D-UPS System

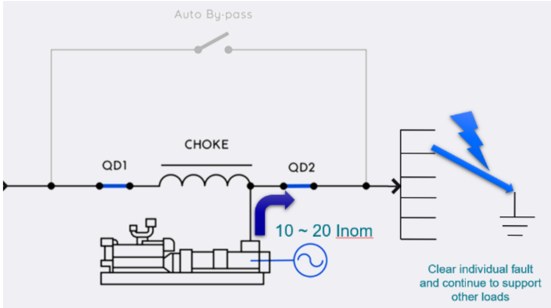

Fig. 13 - Fault located at Load Side in D-UPS

3.5 Additional Features in *mtu Kinetic PowerPack*

3.5.1 KINSTART

Experience gained in the field of generators demonstrates that one of the weak points in their application is the absence of any guarantee that the diesel engine will start. The causes of these starting failures are normally starter motor defects, battery fault, maintenance problems etc. The *mtu Kinetic PowerPack* system solves this weak point with an original solution providing a redundant start-up sequence.

Even if the diesel engine does not start when the input breaker has opened, the clutch will still close and mechanically connect the stato-alternator to the diesel engine. The accumulator will transfer part of the kinetic energy to “kickstart” the diesel engine. This redundant start-up sequence can occur occasionally and has no detrimental effect on the clutch or the diesel engine.

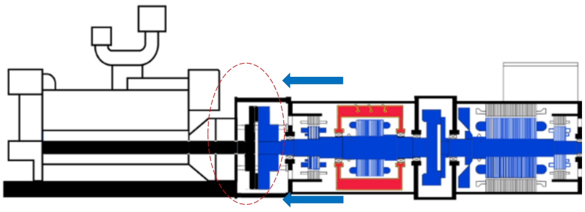

Fig. 14 - Operation of KINSTART in mtu Kinetic PowerPack

3.5.2 Electromagnetic clutch

There is a maintenance free electromagnetic clutch in *mtu Kinetic PowerPack*.

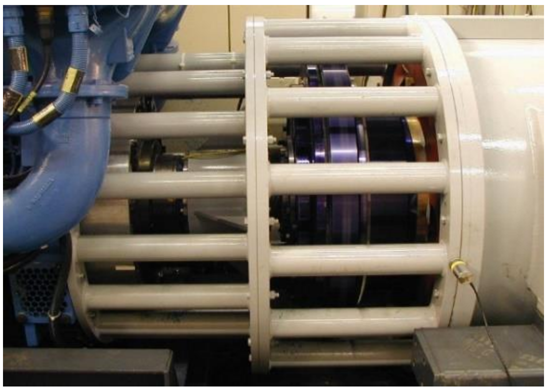

Fig. 15 - Maintenance Free Electromagnetic Clutch in mtu Kinetic PowerPack

4. TOPOLOGIES

The D-UPS can work in both Low Voltage (LV) and Medium Voltage (MV) system. In LV installation, there are high short circuit currents, higher distribution losses and the limited power rating in 5,000kVA at 400V, 100kA. In MV installation, the voltage range is from 3kV up to 36kV and there is high power rating with lower short-circuit current.

Refer to the Data Center Tier Classification System by Uptime Institute, the data center can be divided into four Tiers that match with a particular business function and define criteria for maintenance, power, cooling and fault capabilities. There are different topologies in D-UPS system to meet the Tier requirements.

	Tier I	Tier II	Tier III	Tier IV
Minimum capacity components to support the IT Load	N	N+1	N+1	N (after any failure)
Distribution paths – electrical power backbone	1	1	1 active and 1 alternate	2 simultaneously active
Critical power distribution	1	1	2 simultaneously active	2 simultaneously active
Concurrently Maintainable	No	No	Yes	Yes
Fault Tolerance	No	No	No	Yes
Compartmentalization	No	No	No	Yes
Continuous Cooling	No	No	No	Yes

Fig. 16 - Tier Requirements Table (by Uptime Institute)

4.1 Dynamic UPS, Parallel – Tier I (N)

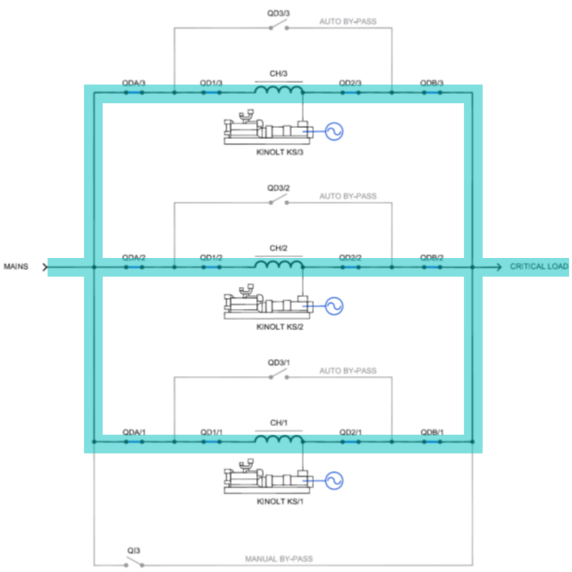

Fig. 17 - D-UPS in Parallel Arrangement (N)

This is the basic site infrastructure of D-UPS system in Tier I design. There is non-redundant capacity and non-redundant distribution path in electrical system. If there is one unit loss, remaining units will be overloaded and the load will be transferred to bypass, thus the load will be supplied by the raw mains directly.

4.2 Dynamic UPS, Parallel – Tier II (N+1)

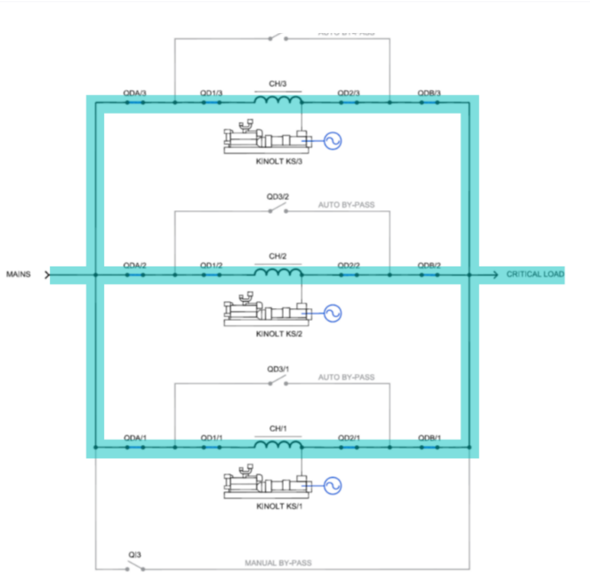

Fig. 18 - D-UPS in Parallel Arrangement (N+1)

In the redundant site infrastructure, there are redundant capacity (N+1) and non-redundant distribution path in the D-UPS system. The planned work on capacity component with no impact to the site operation. If one unit is loss, the breakers QD1 and QD2 of the faulty unit will be opened. The remaining units will keep securing the load.

4.3 Dynamic UPS, Parallel, Dual Bus – Tier III (N+1)

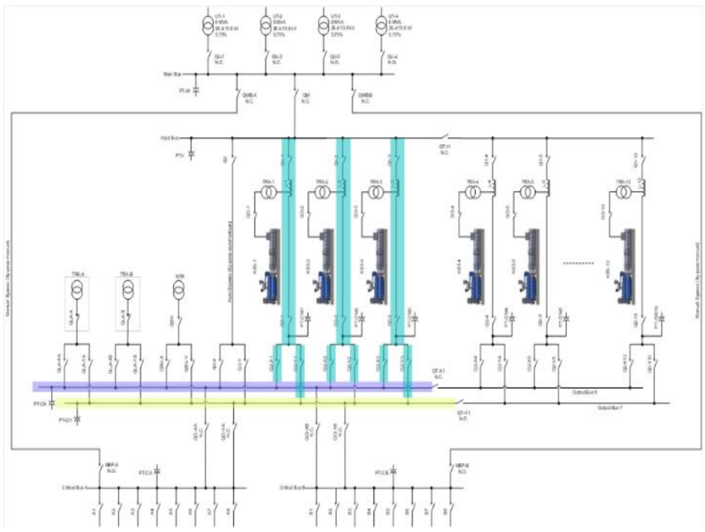

Fig. 19 - D-UPS in Parallel Arrangement with Dual Bus (N+1)

In the concurrently maintainable site infrastructure by D-UPS in parallel dual bus, there are dual output bus and redundant distribution path for IT loads and mechanical load. The site is susceptible to disruption for unplanned activities.

4.4 Dynamic UPS, Distribution Redundant – Tier IV (N+1)

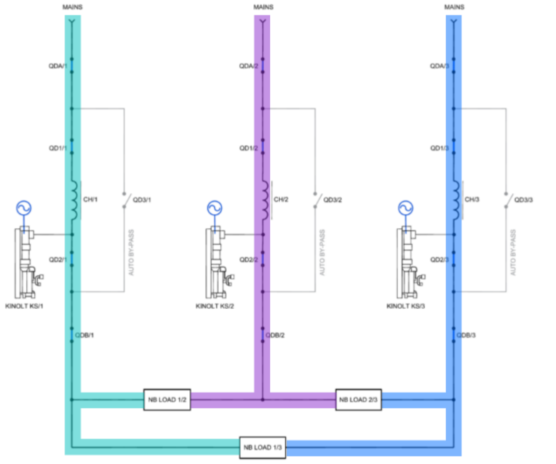

Fig. 20 - D-UPS in Distribution Redundant (N+1)

This is a fault tolerant site infrastructure with D-UPS, and there are redundant capacity, redundant distribution path for IT loads and mechanical load and physically isolated systems. There is no single point of failure in the system and it is scalable: single unit can be added easily.

4.5 Dynamic UPS, 2N Parallel – Tier IV (2N)

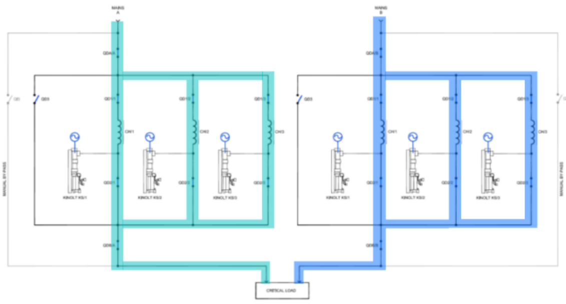

Fig. 21 - D-UPS in Parallel Arrangement (2N)

In the fault tolerant site infrastructure with 2N redundant D-UPS system, the system is physically isolated and there are multiple redundant capacity and distribution path for IT loads and mechanical loads.

5. INSTALLATION

The D-UPS system can be installed in both indoor and outdoor. Compared with static UPS system, batteries, converter of AC/DC/AC, harmonics filter and other ancillary equipment such as air conditioning of both UPS room and battery can be reduced in D-UPS system. For indoor installation of D-UPS system, as the stato-alternator is rotating continuously during operation, there is heat generated within the room and in order to keep the units cool, a mechanical ventilation fan is sized and installed accordingly inside the room.

Fig. 22 - Indoor D-UPS Installation

For outdoor installation, D-UPS system can be designed to house in a container. Remote radiators can be applied on installations in the higher power range. Remote radiators offer the following advantages: 1) Much less heat to be rejected from within the enclosure (vertical internal radiator requires approx. 30% more nominal air flow). 2) Easier implementation of inlet air filtration while respecting air velocity parameters. 3) More compact enclosure footprint. 4) Less overall pressure drop for enclosure ventilation.

Other components of D-UPS system such as fuel daily tank, switchgear and choke also can be containerized. Most of the equipment and auxiliaries are prefabricated and assembled on site, hence the overall site installation period can be reduced.

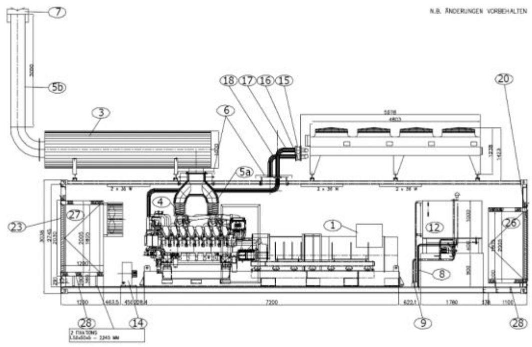

Fig. 23 - D-UPS Installation inside Container

Fig. 24 - Outdoor D-UPS Installation

6. CONCLUSION

UPS systems form part of the value chain for most companies since power quality and availability have direct impact on the continuity of their operations. In some cases, a major discontinuity may even jeopardize survival of the business itself. The UPS needs to provide a clean and stable power supply, free from voltage distortion, frequency variations, electrical noise, harmonics, spikes, brownouts, and surges. If any of these issues occur in the mains supply at a significant level, the critical loads can fail. A trusted robust equipment is all it needs to provide the trusted power security.

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Paper No. 4

EMBRACING THE NEW NORMAL IN CONDITION MONITORING FOR MEDIUM VOLTAGE SYSTEM

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ABSTRACT
The current COVID-19 pandemic has caught the power utilities off-guard. While the grid is trying to maintain network reliability, they would have to adapt to the evolving situation and are obligated to comply with the government measures to contain the pandemic. SP PowerGrid (SPPG) has been practicing condition monitoring (CM), through sourcing better methodology and new technology available in the market to maintain network reliability by averting potential asset failures through early detection. This paper shares how SPPG adapts to the new normal for the condition monitoring on its medium voltage (MV) network's power assets.

1. INTRODUCTION

SP PowerGrid (SPPG) has always focused strongly on condition-based maintenance to prevent possible failure by performing comprehensive measurements to assess the conditions of its power assets.

As of February 1, 2021, SPPG monitors approximately 12,000 electricity transmission and distribution substations with approximately 18,300 transformers in its distribution network. Figure 1 shows SPPG electricity networks from transmission to distribution levels.

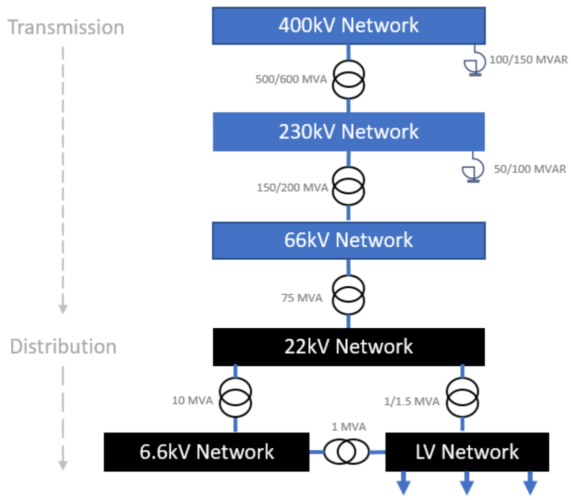


Fig. 1 - SPPG Network

Comprehensive measurements such as transient earth voltage (TEV), thermal and acoustic are proven non-intrusive measurements utilized by SPPG. Check on the power assets for any abnormality is being carried out under in-service condition without the needs of shutting down. Through these measurements performed at a regular condition monitoring (CM) interval cycle, many potential failure cases have been successfully detected and averted.

With the COVID-19 pandemic, new regulations and evolving measures in place to contain the pandemic are being introduced. Closing of businesses for a period of time and the limit on the personnel entering the substations inside the customer premises had affected the daily CM operation work.

Problems identified during this pandemic for improvement:

- How to ensure continuing monitoring for critical stations that are affected by the limitation on the number of persons entering customer premises.
- How to ensure no cross interaction between segregated staff for CM operation.
- How to ensure measurements can be collected, analyzed and interpreted correctly.

SPPG is able to adapt to these changes through its belief in continuously looking for advanced measuring tools and technology to improve the health assessment of the power assets.

2. EVOLUTION OF TECHNOLOGY FOR TEV MEASUREMENT

Partial discharge (PD) measurement is a widely recognized diagnostic technique to identify possible insulation failure. TEV detection is a practical choice for its simplicity to operate as an asset inspection tool for detecting possible PD. The deployment of TEV detection enables SPPG to cover CM scan on the vast number of switchgear and transformers in the MV network.

To conduct the TEV measurement, the TEV probe needs to be in contact with the point of measurement on the switchgear metal surfaces. Officers will record the readings in dBmV. With the readings collected around the switchgear and one at the substation surrounding metalwork, these readings will be used to compare against the criteria value set to determine if there is a need to conduct further investigation.

With the TEV measurements compare against the criteria set, SPPG was able to avert PD cases but there are still some limitations with this kind of measurement. One of the limitations is high noise interference at the switchgear surrounding that prevents correct detection or creates false detection. With this limitation, it would require more effort to conduct further site investigation.

In 2019, SPPG has upgraded the TEV equipment from the older equipment as shown in Figure 2 with a new advanced model shown in Figure 3. As compared to its predecessor, the new model has the ability to record the measurements. This recording ability has helped in reducing the need to make on-site decision for high dBmV values detected, by allowing further analysis and evaluation to be carried out after returning to office.

Fig. 2 - TEV Measurement Equipment

Fig. 3 - Upgraded TEV Measurement Equipment

Another feature of the upgraded model is the ability to display the phase resolved PD (PRPD) pattern and pulse waveforms, allowing the officer to better interpretate the on-site measurements. Such analysis and evaluation can be performed even when the dBmV values may not be seen severe.

The PRPD in Figure 4 and pulse waveforms in Figure 5 are examples of how the information can assist the officers to determine if the abnormality measured from the scanned assets are true PD, noise, or other interference. The analysis outcome for the example in Figure 4 and Figure 5 is of a suspected PD.

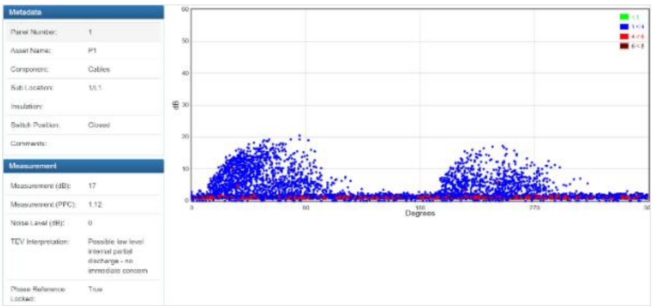


Fig. 4 - PRPD Diagram of TEV Measurement

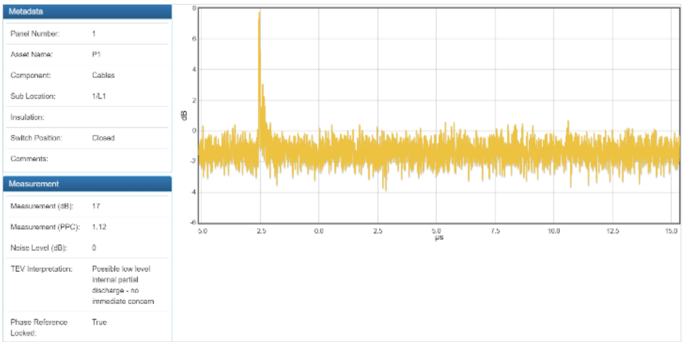


Fig. 5 - Amplitude vs Time Pulse Waveform Chart

3. DIGITALIZATION

Team segregation and work from home were some of the measures implemented during the pandemic, resulted in scattered workforce. With more than 20 teams of officers performed daily CM measurements, data sharing was possible due to SPPG effort in achieving data digitization on removing hard-copy forms.

Since 2016, officers are issued with personal 4G tablet to work with digital forms for different tasks such as site measurements done at site. The data are able to be uploaded real-time to SPPG centralized database, allowing other officers to retrieve with ease without the needs to dig out hard-copy data when needed. Figure 6 shows the officers performing data entry on-site with a tablet.

Fig. 6 - Data Entry with a Tablet On-site

Figure 7 shows an example of data entry through the PowerApps. The apps created is a user-friendly customized form. Data entry can be by selection through either search or choice, instead of typing in manually which may result in wrong data entry.

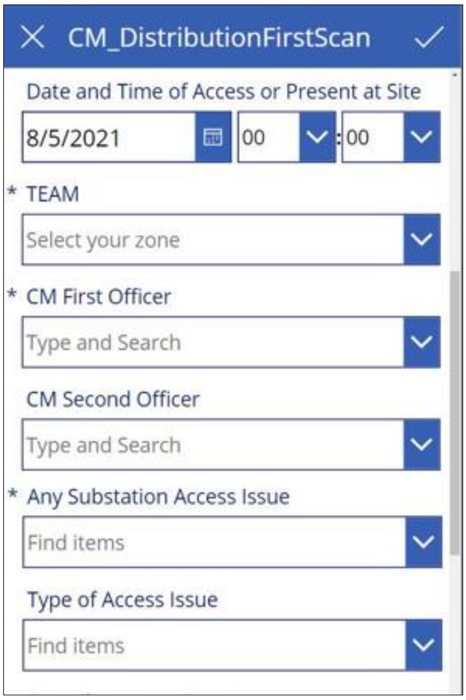


Fig. 7 - Screen of An App

4. AUTOMATION AND ARTIFICIAL INTELLIGENCE

The new TEV equipment is able to record the measurements and to be downloaded for review. However, officers are required to have the skillset to analyze and evaluate the measurements. With the vast amount of measurement data collected by each officer daily, it can be challenging to ensure every data is evaluated correctly with the required skillset.

On a daily basis, the officers scan approximately 80 or more substations, i.e. approximately 400 panels or more. Thus, there are approximately 400 to 1000 numbers of TEV measurements in PRPD and pulse waveform as shown in Figure 4 and Figure 5 to be analyzed.

To deal with the issues of individual analytic skills and work fatigue in analyzing the number of measurements, SPPG has collaborated with Singapore local university, Singapore Institute of Technology (SiT) to come up with an application to automate the analyzing and evaluating process with artificial intelligence (AI) to review these measurements and also improve productivity.

The application works in Microsoft Excel, using Visual Basic for Applications (VBA) scripts to execute. Figure 8 shows the interface in which a number of scanned substations' TEV measurements was loaded for execution. It would then process and analyze each measurement using AI. The result of each substation is presented in the format shown in Figure 9 and helps to classify the result into 3 categories: 0% suspected abnormality, 50% suspected abnormality and 100% suspected abnormality. On average 90% of measurement have no abnormality, reducing the work to the remaining 10% for the officers to focus on.

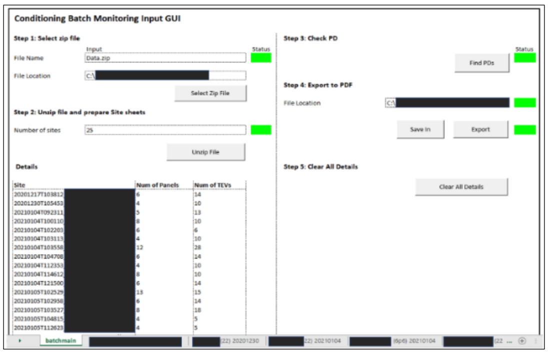
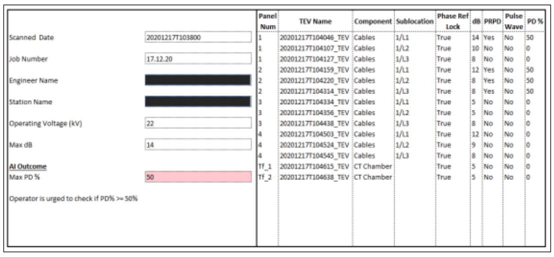


Fig. 8 - Graphical User Interface of the Programme



Scanned Date	20201217T103800
Job Number	17.12.20
Engineer Name	[redacted]
Station Name	[redacted]
Operating Voltage (kV)	22
Max dB	14
AI Outcome	
Max PD %	50
Operator is urged to check if PD% >= 50%	

Panel Num	TEV Name	Component	Sublocation	Phase Ref Lock	dB	PRPD	Pulse Wave	PD %
1	20201217T104046_TEV	Cables	1/L1	True	14	Yes	No	50
1	20201217T104107_TEV	Cables	1/L2	True	10	No	No	0
1	20201217T104127_TEV	Cables	1/L3	True	8	No	No	0
2	20201217T104159_TEV	Cables	1/L1	True	12	Yes	No	50
2	20201217T104220_TEV	Cables	1/L2	True	8	Yes	No	50
2	20201217T104314_TEV	Cables	1/L3	True	8	Yes	No	50
3	20201217T104334_TEV	Cables	1/L1	True	5	No	No	0
3	20201217T104356_TEV	Cables	1/L2	True	5	No	No	0
3	20201217T104438_TEV	Cables	1/L3	True	8	No	No	0
4	20201217T104503_TEV	Cables	1/L1	True	12	No	No	0
4	20201217T104524_TEV	Cables	1/L2	True	9	No	No	0
4	20201217T104545_TEV	Cables	1/L3	True	8	No	No	0
Tf_1	20201217T104615_TEV	CT Chamber		True	5	No	No	0
Tf_2	20201217T104638_TEV	CT Chamber		True	5	No	No	0

Fig. 9 - Summary of the TEV Result of Each Station Analyzed by the Programme

5. ON-GOING DEVELOPMENT

5.1 Installation of Online PD Monitoring System for MV Voltage System

The on-going COVID-19 pandemic has accentuated the need to embrace technology such as online monitoring to overcome physical and resource constraints. SPPG has begun to install permanent online monitoring system to ensure no disruption on monitoring critical substations to ensure their reliability.

In the past, this is not quite feasible due to much higher cost of such monitoring system. With cost of such system becoming more economically affordable, SPPG decided it is time to invest and to start installing them strategically in critical substations. Figure 10 illustrates the online monitoring central management system showing the different regions in Singapore.

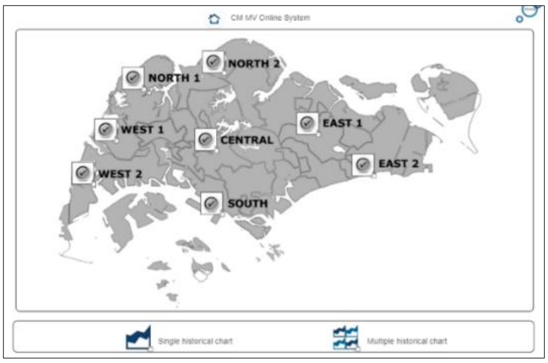


Fig. 10 - Online System

Figure 11 shows the view of one switchboard of the monitored substations. Figure 12 shows the display for one switchgear panel in terms of PD and acoustic measurements. Figure 13 shows the measurement of PD with PRPD and pulse waveforms, the AI classification result as noise. Figure 14 shows the measurement with AI classification result as PD. These information gives the operators the confidence to acknowledge and confirm if the measurement is PD or noise.

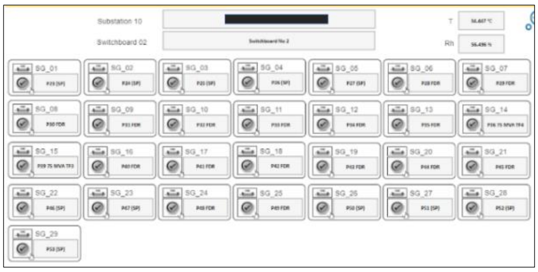


Fig. 11 - A Monitored Substation Switchboard

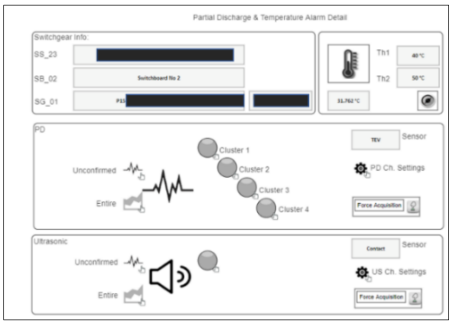


Fig. 12 - Monitoring of a Single Switchgear Panel

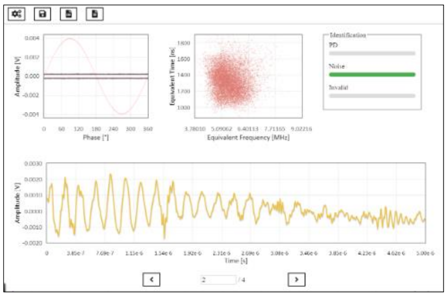


Fig. 13 - PD in terms of PRPD, Pulse Waveform, AI Classification

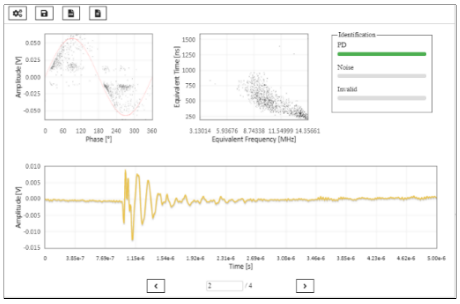


Fig. 14 - PD Measurement with AI Classification

Alarm fatigue is a common problem for online monitoring system. To reduce the false alarms, parameters such as confirmed events and AI classification are considered instead of purely based on threshold levels. The confirmed events are those persistent phenomena, not sporadic to match the phenomenon of a developing PD.

5.2 Replacing the Physical Lock and Keys for Substation Access

To ensure the physical security of SPPG substations, zonal padlocks are used with physical keys to allow access. Officers are assigned to dedicated key press boxes in Figure15 to draw out these keys. With team segregation, this practice creates issues such as limited keys available when officers had to re-assigned to other key press boxes.

Fig. 15 - Key Management System Key Press Box

Starting early 2019, the company started looking into using digital smart lock system to replace existing standard operating procedure (SOP) of using dedicated zonal keys to access the station. With the on-going pandemic, disruption on how officers acquire these keys can be addressed with the implementation of digital smart lock system in Figure 16.

Fig. 16 - Digital Smart Lock System

The smart digital key works with the digital smart lock system using the officer's tablet pairing through Bluetooth to register the key to open the digital locks shown in Figure 17.

Fig. 17 - Pairing of Key to Tablet App through Bluetooth

The process makes use of the facial recognition to tighten the security on protecting the registration process as shown in Figure 18. Registered keys are then allowed for 24 hours access before automatically disabling the usage hence reducing the risk of losing the critical key.

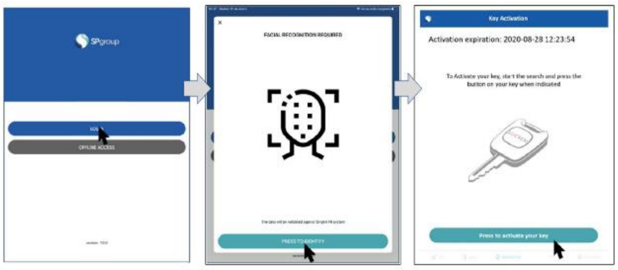


Fig. 18 - Illustration of How the Key is Enabled

With such changes, officers are no longer required to conjugate at dedicated key press box to draw out keys daily. In addition to moving towards a more secure key management, greater productivity is achieved by reducing time wastage in transportation.

6. A MV SWITCHGEAR PD CASE

A PD case which happened during the lockdown period is discussed here. The PD was detected through the CM interval measurement at a gas insulated switchgear (GIS) substation with 10 panels.

Prior to the replacement of the new TEV measurement equipment, a high dBmV reading detected will require to schedule another trip to perform further confirmation using other measurement tools. With the new TEV measurement equipment, the PRPD and waveform data are collected. Suspected abnormality will be flagged by both AI algorithm and officers who review the measurement. The officers can evaluate if the high dBmV detected is of concerns or not, without attending to the site again. This helps to prioritize and eliminate the cases caused by interference. Figure 19 shows the TEV with abnormal PRPD.

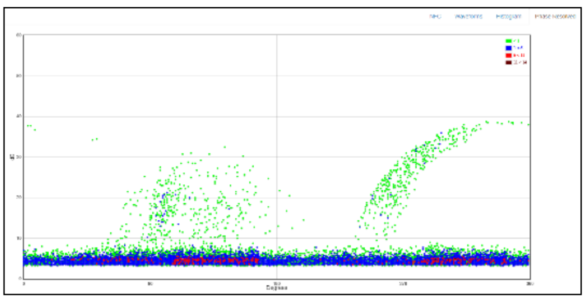


Fig. 19 - Abnormal PRPD from TEV Measurement

In additional to the changes of TEV measurement equipment, an advanced set with high frequency current transformer (HFCT) measurement set shown in Figure 20 is used for on-site PD investigation. HFCT measurement as compared to TEV measurement is less subject to interferences caused by surrounding environment. It can provide detailed information such as time of flight to pinpoint and determine if the source resides in the switchgear or propagates from other source.

Compared to the predecessor, the new measurement set is smaller in size, uses WIFI for communication and adopts power bank to power its operation. This reduces manpower to only two for its operation for conducting on-site investigation. Personal laptop can be connected wirelessly to the advanced set through WIFI, whereby its predecessor had to connect through LAN cable.

Fig. 20 - Advanced PD Set

The advanced set utilized TF map for different sources separation [1][2]. The equivalent time length T and bandwidth W for each acquired signal to form the TF map are calculated as (1) and (2):

$$T^2 = \left(\sum_{i=1}^{N}(t_i - t_0)^2 \cdot {s_i}^2\right) / \left(\sum_{i=1}^{N} {s_i}^2\right) \quad (1)$$
$$W^2 = \left(\sum_{i=1}^{N} {f_i}^2 \cdot |X_i(f_i)|^2\right) / \left(\sum_{i=1}^{N} |X_i(f_i)|^2\right) \quad (2)$$

Where:

- N is the number of samples acquired from the measurement, s_i is the signal magnitude measured at time t_i.
- Time barycenter is $t_0 = \left(\sum_{i=1}^{N} t_i \cdot {s_i}^2\right) / \left(\sum_{i=1}^{N} {s_i}^2\right)$ and $X_i(f_i)$ is the i^{th} component of the signal transformed using Fast Fourier Transform (FFT).

Figure 21 shows the measurements at panel 3 L1 phase which confirmed the signals as a real PD event. Through a series of HFCT measurements, the following investigation can be performed:

(a) Identifying which phase, Fig. 22
(b) Identifying which panel, Fig. 23
(c) Identifying if the signal is local or remote, Fig. 24

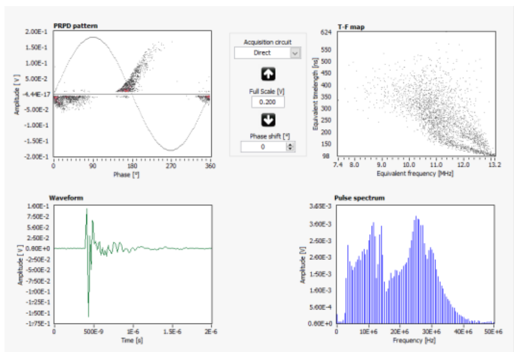


Fig. 21 - Abnormal PRPD from HFCT Measurement

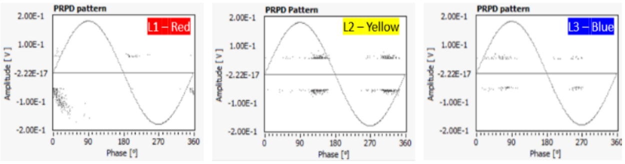


Fig. 22 - Identifying which Phase

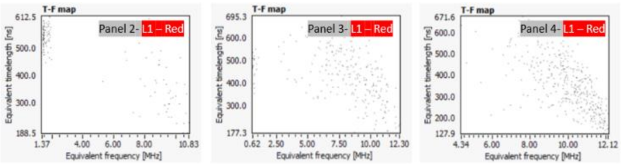


Fig. 23 - Identifying which Panel

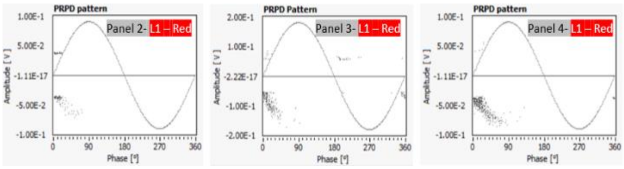


Fig. 24 - Identifying if the Signal is Local or Remote

The measurements and comparisons concluded that the PD signal had originated from within the switchgear. This can be visually proven from the PRPD pattern acquired on L1 phase of panel 2, 3 and 4 with panel 3 detected waveform containing higher frequency content shown in the TF map as compared to the other panels, as illustrated in Figure 23. The measurement findings illustrated as in Figure 25. Reference [3] details more information on the PD localization method.

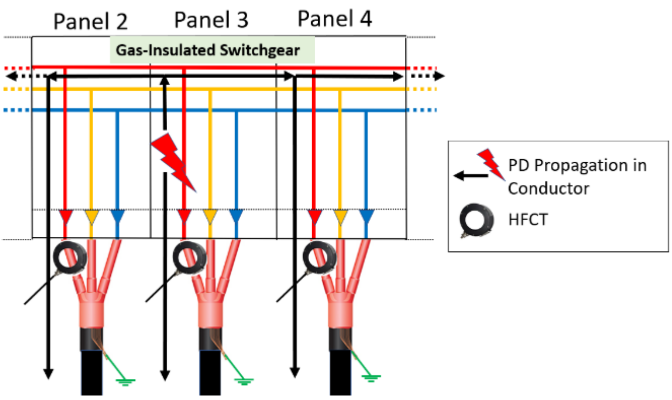


Fig. 25 - Illustration on where the PD was Located

After identifying the panel with PD, the next action is to further narrow down and identify the possible defect component. Switching operation on the panel was performed. The PD source was further located somewhere rear to the circuit breaker (circuit breaker lower supporter, current transformer and termination) as shown in Figure 26.

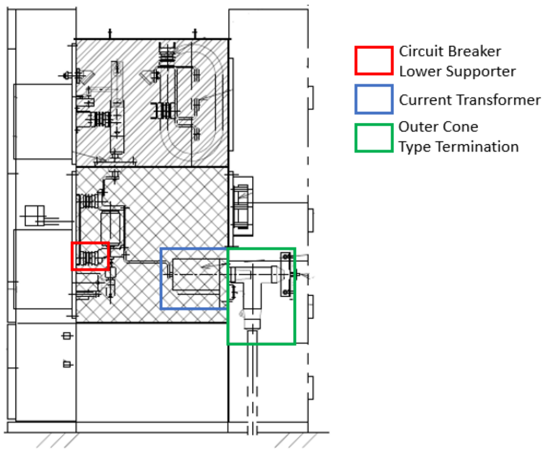


Fig. 26 - Suspected Components with PD Defect

To correctly identify the component, an offline high voltage alternating current (HVAC) test was conducted as shown in Figure 27. The measurement setup complied with IEC 60270 standard.

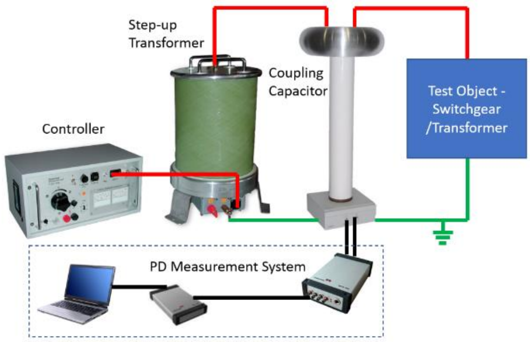


Fig. 27 - Offline HVAC PD Test according to IEC60270

The PD defect was found at the circuit breaker lower supporter shown in Figure 28, and the PD result was Qiec of 367pC at rated voltage shown in Figure 29. Through X-Ray imaging, a void in the solid insulation of the circuit breaker supporter was found as shown in Figure 30.

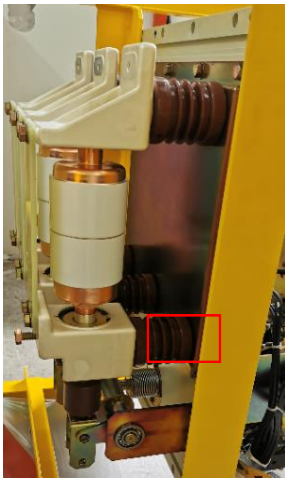


Fig. 28 - VCB Rack Out of the Switchgear Panel

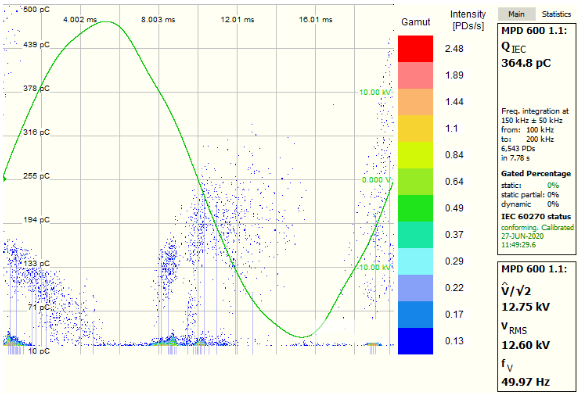


Fig. 29 - PD Result at Rated Voltage

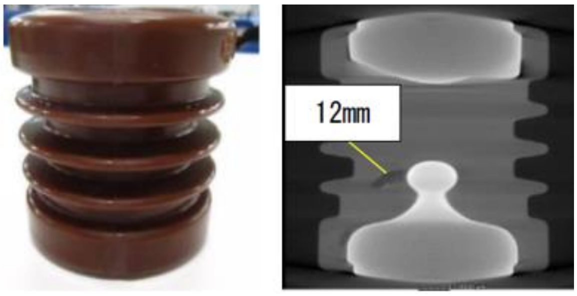


Fig. 30 - VCB Supporter and its X-Ray Image

7. CONCLUSION

The COVID-19 crisis has provided opportunity for power utilities to re-adjust their strategies in order to adapt to the developing situations. To better prepare for the future, the utilities will have to continue to embrace new technologies to meet the changing challenges.

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2. P. Morshuis, G. C. Montanari and L. Fornasari, "Partial discharge diagnostics — Critical steps towards on-line monitoring," 2014 IEEE PES T&D Conference and Exposition, 2014, pp. 1-5, DOI: 10.1109/TDC.2014.6863449.

3. K. X. Lai, N. F. Affandi, B. H. Leck, Y. Fu and S. K. Ang, "Localization with phase resolved partial discharge measured with high frequency current transformer," 2021 IEEE International Conference on the Properties and Applications of Dielectric Materials (ICPADM), 2021, pp. 77-80, DOI: 10.1109/ ICPADM49635.2021.9493908.

Paper No. 5

NEW EDITION OF CODE OF PRACTICE: POWERING NEW TECHNOLOGY AND ENHANCING ELECTRICAL SAFETY

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NEW EDITION OF CODE OF PRACTICE: POWERING NEW TECHNOLOGY AND ENHANCING ELECTRICAL SAFETY

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ABSTRACT

The Electrical and Mechanical Services Department (EMSD) of the Government of the Hong Kong Special Administrative Region (HKSAR) published the 2020 edition of the Code of Practice for the Electricity (Wiring) Regulations (CoP) on 31 December 2020. Major revisions and new codes were introduced to facilitate safe adoption of relevant new technologies on electrical installations, support the Government's new policies and establish the benchmark against relevant international standards.

This paper discussed the new codes for charging facilities of electric vehicles (Code 26S) and installations for modular integrated construction (MiC) (Code 26T), as well as the recommended use of arc fault detection devices (AFDDs) (Code 6B). The new edition of the CoP will be fully implemented on 31 December 2021 to replace the 2015 edition, after a one-year grace period.

1. INTRODUCTION

The Electrical and Mechanical Services Department (EMSD) is committed to enforcing the Electricity Ordinance and its subsidiary regulations with professionalism, reliability, commitment and integrity, as well as raising the trade's professionalism and enhancing the public's electrical safety awareness to ensure electrical safety in Hong Kong. To keep abreast of the latest technology development and safety requirements of electrical installations, the EMSD has published the fifth edition of the Code of Practice for the Electricity (Wiring) Regulations (CoP) in December 2020.

A work group consisting of representatives nominated by key stakeholders of the trade, including trade unions and associations, professional bodies, academic institutions, power companies and government works departments, were formed in 2019 for the review of the CoP. Major revisions include the recommended adoption of arc fault detection devices (AFDDs), requirements on USB outlets, renewable energy power systems, charging facilities for electric vehicles and installations for modular integrated construction (MiC), etc. With the introduction of these new codes and revisions, the EMSD facilitates the trade and the public with specific guidelines and requirements for safe adoption of relevant new technologies on electrical installations, supports the Government's new policies and establishes benchmark against relevant international standards, with the aim of fostering a smarter, greener and safer environment for all.

This paper particularly specifies three prominent up-to-date codes. In Section 2, the charging facilities for electric vehicles (Code 26S) are discussed. Section 3 focuses on installations for MiC (Code 26T). In Section 4, the operation mechanism and installation recommendations in respect of AFDDs (Code 6B) are deliberated.

2. CHARGING FACILITIES FOR ELECTRIC VEHICLES (CODE 26S)

Extensive charging facilities are necessary to accommodate and encourage the use of electric vehicles (EVs). To assist the Government in attaining the long-term target of zero vehicular emission before 2050 and cope with the prospective increasing number of EVs, technical requirements on the installation of charging facilities for EVs have been included in the revision of the CoP (2020 edition).

2.1 Government Initiatives on EVs

Hong Kong strives to achieve carbon neutrality before 2050 as announced by the Chief Executive in the 2020 Policy Address. Promoting zero carbon emission from vehicles is one of the key approaches to endeavour for carbon neutrality. In Hong Kong, the number of EVs has raised significantly with an increase beyond 100 times, from 162 in 2010 to 18 361 in 2020 [1].

Fig. 1 - Growth of EV in Hong Kong

To accommodate the wide adoption of EVs, sufficient charging facilities are vital in establishing a charging network to support the popularisation of EVs. According to the "Hong Kong Roadmap on Popularisation of Electric Vehicles", a target of at least 5,000 public chargers will be provided by 2025 [2].

The new Code 26S is therefore devised with the aim of facilitating the quick and safe deployment of EV charging facilities by the trade, covering the introduction of charging modes, selection and erection of installations, protection requirements as well as provisions for diversity by adoption of load management systems to cope with capacity constraints in existing buildings.

2.2 Classification of Charging Modes

Brief introduction is given in Code 26S to facilitate understanding on the four modes of charging specified in IEC 61851 for electric vehicle conductive charging systems.

- Mode 1: Connection of the EV to the AC supply network utilises a standardised BS 1363 socket outlet and a charging cable without communication function to the on-board charger of the EV.

- Mode 2: An in-cable control box is incorporated into the charging cable assembly. The provision of fixed electrical installation for charging facility is similar to that for Mode 1 except that the final circuit, protective device and socket outlet shall be of a suitable rating to cater for the higher level of charging current not exceeding 32A.

- Mode 3: Connection of the EV to the AC supply network utilises a dedicated EV supply equipment (EVSE) where the control pilot function extends to control equipment in the EVSE, permanently connected to the AC supply network. Subject to the power rating of the on-board charger of an EV, Mode 3 charging can deliver a higher charging current (e.g. 220V/32A, 380V/32A and 380V/63A).

- Mode 4: Connection of the EV to the AC supply network utilises an off-board charger where the control pilot function extends to equipment permanently connected to the AC supply. In this charging mode, either single-phase or three-phase AC is converted to DC within the EV charging equipment. The resulting DC is supplied to the EV via a charging cable that is tethered to the EV charging equipment.

Control pilot functions provided by the EV supply equipment are mandatory in Modes 2, 3 and 4, which typically include the functions for continuous continuity checking of the protective conductor, verification that the EV is properly connected to the EV supply equipment, functional switching of the power supply to the EV, as well as control on maximum allowable current [3].

2.3 Selection and Erection of Installations

The EV charging installation should be selected and erected to ensure safe operation and ease of maintenance at all times. The EV charging installation should be designed and installed in accordance with IEC 61851 or equivalent.

In addition, if the EV charging installation is designed for outdoor use, the equipment shall be selected with a degree of protection of at least IP44 in accordance with IEC 60529 to protect against water splashes (AD4) and the ingress of very small objects (AE3) respectively.

One socket outlet or connector shall supply only one EV. The socket outlets or connectors shall comply with the following standards or equivalent:

- In Mode 1 charging – BS 1363;

- In Mode 2 charging – IEC 60309, with the socket outlet or connector interlocked and classified to prevent the socket contacts being live when accessible;

- In Mode 3 charging – IEC 62196.

In Mode 3 and 4 charging, an electrical or mechanical system shall be provided to prevent from plugging/ unplugging the plug unless the socket-outlet or the vehicle connector has been switched off from the supply.

2.4 Load Management System

To cope with the practical constraint of limited power supply capacity for the addition of EV charging facilities in existing buildings, diversity may be allowed for a dedicated distribution circuit supplying multiple electric vehicle charging points if a load control system is available. Examples of load control systems for EVSEs are illustrated below.

2.4.1 Time-shared load management

Time-shared load management adopts the strategy to control the charging at various charging points based on time allocation [4]. It usually includes a system controller that preassigned the sequence and duration of charging. Charging is provided to an EV for a prescribed time period, and then charging is reallocated to the next EV according to the assigned schedule. In general, a system controller works independently with the EVSEs, and communication between the controller and EVSEs is not included.

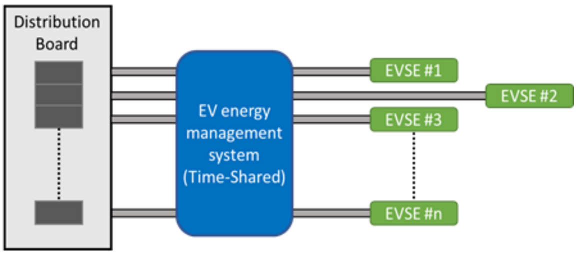

Fig. 2 - Time Shared Load Management

2.4.2 Static load management

In static load management, charging control is based on even power allocation to each EVSE, dividing the available charging capacity amongst the EVSEs connected [4]. For example, in a simple arrangement with two EVSEs, when only one EV is charging, it receives 100% of the available capacity, and when two EVs are charging, each of the EV receives 50% of the available capacity.

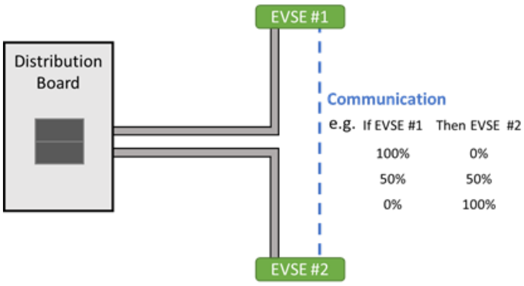

Fig. 3 - Static Load Management

2.4.3 Dynamic load management

The control of charging by dynamic load management is based on the capacity available and the requested demand from each EVSE [4][5]. Dynamic load management delivers power based on the actual demand at each EVSE, which is considered more flexible in terms of sharing configuration. The load management system and the EVSE monitor the near real-time power consumption of an EVSE, then distribute a portion of the power supply available to each EVSE according to the actual usage.

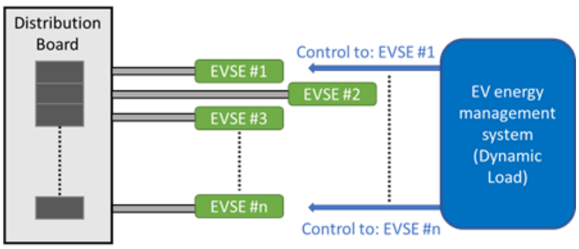

Fig. 4 - Dynamic Load Management

2.5 Selection of Residual Current Device (RCD)

Particular attention should also be paid to the type of RCD selected in EV charging facilities. As these types of equipment are often subject to DC current or AC current with DC components, the use of RCD Type AC is not suitable. Except for circuits using the protective measure of electrical separation, each charging point shall be protected by its own RCD of at least Type A.

For each charging point incorporating a socket outlet or connector complying with the IEC 62196 series, protective measures against DC fault current shall be taken, except where provided by the EV charging equipment. The appropriate measure, for each of these connection points, shall be of RCD Type B; or RCD Type A together with appropriate equipment that provides disconnection of the supply in case of DC fault current above 6mA. Figure 5 illustrates the requirement and its typical symbol of RCD to be provided for EV charging points of different modes / connectors [6].

Fig. 5 - RCD Requirement for EVSE

Other protection requirements are also incorporated in Code 26S, including protection against impact damage and devices for isolation and switching, etc., which will ensure electrical safety of the installation.

3. INSTALLATIONS FOR MODULAR INTEGRATED CONSTRUCTION (CODE 26T)

Hong Kong has long been recognised internationally for its formidable strength in infrastructure development. A huge portfolio of infrastructure comprising housing and land-supply programmes, hospital development plans and other livelihood projects are in the pipeline. However, there are some considerable concerns which must be addressed, particularly the shortage of labour and an ageing workforce, as well as the high construction cost faced by the entire construction industry.

To help relieve this situation, the Government has been promoting the adoption of MiC as an innovative construction method, which utilises the concept of "factory assembly followed by on-site installation" with a view to achieving lower project costs, better quality control, shorter construction time, faster capital return, better site safety, and better environmental sustainability with less wastage.

3.1 Guidance Note on Fixed Electrical Installations with Modular Integrated Construction Method

Given electrical installations are indispensable to modern buildings and infrastructure, the EMSD has issued the Guidance Note on Fixed Electrical Installations with Modular Integrated Construction Method in June 2019 [7], to provide specific guidance for project owners, developers, consultants, authorised persons, and registered electrical contractors/workers on how the adoption of MiC method on fixed electrical installations could be achieved under the current provisions of the Electricity Ordinance.

In view of the maturing technology and expanding application, the EMSD has reviewed the Guidance Note on Fixed Electrical Installations with Modular Integrated Construction Method with the trade during the revision of the CoP, and has adopted the latest trade practice to form the new Code 26T, providing specific requirements on fixed electrical installations designed and constructed using the MiC method.

3.2 Certification of Electrical Work by Registered Electrical Workers

Given that electrical installations are prefabricated and pre-installed on modules in MiC factories probably outside Hong Kong, they would form parts of the fixed electrical installations upon permanent installation on site as part of a premises or building. As such, the design and construction of these electrical installations should conform to the requirements of the Electricity Ordinance. Specific guidance is provided on the certification of electrical work by registered electrical workers and contractors.

When a registered electrical contractor is employed to carry out the design of a fixed electrical installation, including the wiring installation with MiC method, a registered electrical worker employed by this registered electrical contractor shall certify the design of the fixed electrical installation and this registered electrical contractor shall endorse the certificate (i.e. Part 1 of Work Completion Certificate) to confirm that the fixed electrical installation has been designed in accordance with the Electricity Ordinance.

When the same or another registered electrical contractor is employed for carrying out electrical installation work at the premises, the fixed electrical installation shall, after completion (including any work completed after repair, alteration or addition) and before it is energised for use, be inspected, tested and certified by a registered electrical worker of this registered electrical contractor and this registered electrical contractor shall endorse the certificate (i.e. Part 2 of Work Completion Certificate) to confirm that the fixed electrical installation complies with the requirements of the Electricity Ordinance and is in safe working order.

3.3 Factory Acceptance Test Before Delivery

If part of the electrical installations is constructed and installed in modules at the off-site workshops (e.g. factories outside Hong Kong), these parts of the electrical installations could be regarded as a MiC electrical assembly and should be inspected and tested to the satisfaction of the registered electrical contractor before delivery to site for permanent module fixing. In addition, this registered electrical contractor shall also ensure the MiC electrical assembly being constructed and installed at the off-site workshop with suitable materials and good workmanship.

3.4 Quality Control and Supervision System by Registered Electrical Contractor and MiC Factory

This registered electrical contractor is recommended also to establish or agree with the factory to implement a quality control and supervision system (including the factory test requirements) to ensure the MiC electrical assembly being constructed and installed at the off-site workshop with good workmanship and quality. Such arrangement is similar to the typical factory acceptance test for major electrical plant equipment (e.g. main switchboards and power transformers) and the tests have long been adopted in the trade and proven to be effective in ensuring built quality off-site, as well as compliance with relevant technical and safety standards before acceptance of equipment for delivery to site. The existing Code 21B on testing of low voltage installations, which has stipulated the necessary test items and requirements for low voltage fixed electrical installations, further serves as a practical reference for test items to be included in the factory test for MiC electrical assemblies.

While the pandemic has normalised remote work with ample technological solutions already in place, we encourage the trade, particularly the registered electrical contractors for MiC projects, to adopt innovations and IoT technologies which allow effective off-site monitoring of manufacturing processes at MiC factories, as well as managing and witnessing factory tests without the hassles of sending registered electrical workers often across borders to MiC factories for supervision.

3.5 Selection and Erection of Wiring Installations

To facilitate the adoption of MiC for wiring installations, Code 26T also provides examples of wiring installations in buildings/developments with the MiC method for general reference. Wiring installations by MiC can be generally, but not exhaustively, classified into or a mix of the following types:

3.5.1 Entire module without electrical inter-connection with other modules

The wiring installation and associated electrical installations such as distribution board, switches, socket outlets, fuse spurs, lighting connection units, etc. of a module are installed at a factory. There is no electrical inter-connection with other modules. After the entire module is installed on-site, the power supply will be connected to the distribution board of that module.

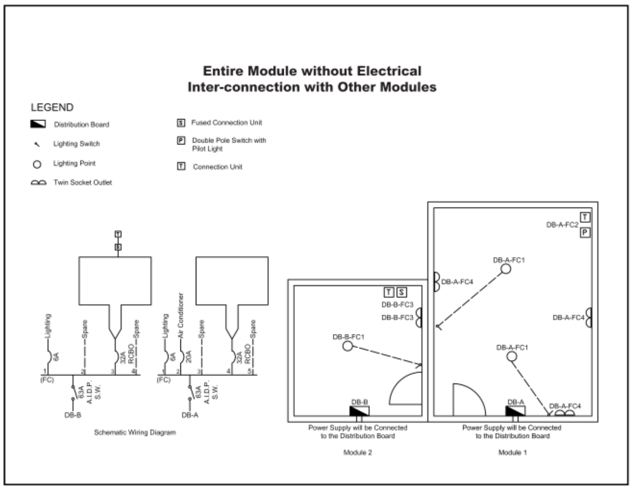

Fig. 6 - Typical Diagram of the Entire Module without Electrical Inter-connection with Other Modules

3.5.2 Cable connection between the modules at the termination box or through "looping-in" wiring system

The wiring installation and associated electrical installation such as distribution board, switches, socket outlets, fuse spurs, lighting connection units, etc. of a module are installed at a factory. After the entire module is installed on-site, the power supply will be connected to the distribution board of a module that has already been installed at the factory, whilst cable connections between the modules will be carried out on-site at the termination boxes or through "looping-in" wiring system to the equipment terminals of a module so as to complete the circuits.

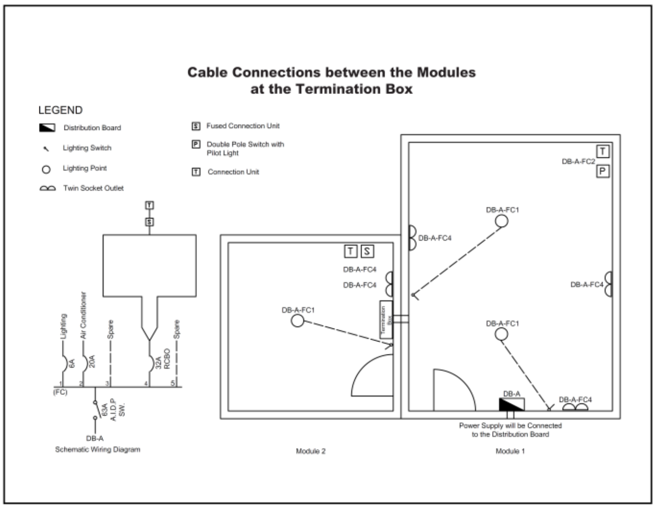

Fig. 7 - Typical Diagram of Cable Connections between the Modules at the Termination Box

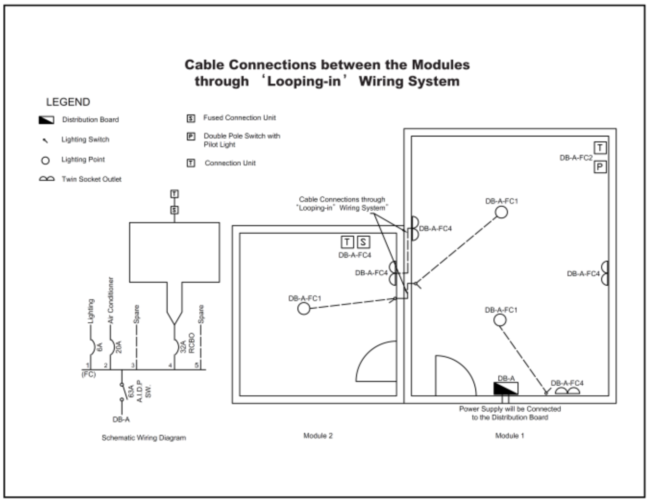

Fig. 8 - Typical Diagram of Cable Connections between the Modules through "Looping-in" Wiring System

3.5.3 Cable connections between the modules through cable couplers of prefabricated wiring system

The prefabricated wiring system and associated electrical installations such as distribution board, switches, socket outlets, fuse spurs, lighting connection units, etc. of a module are installed at a factory. After the entire module is installed on-site, the power supply will be connected to the distribution board of a module that has already been installed at the factory, whilst cable connections between the modules will be carried out on-site via cable couplers so as to complete the circuits.

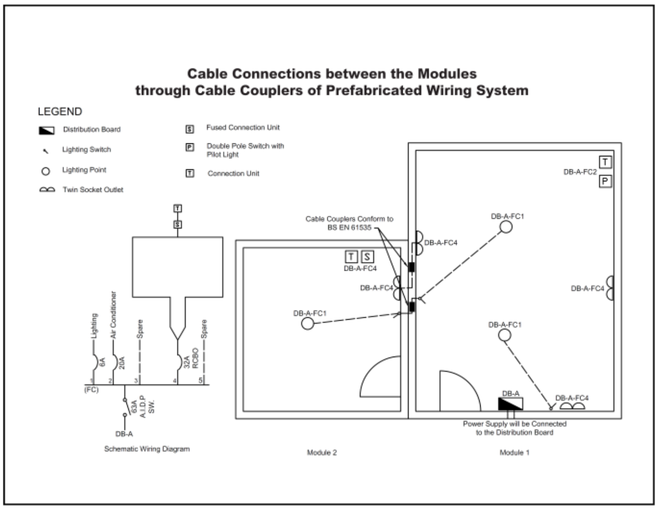

Fig. 9 - Typical Diagram of Cable Connections between the Modules through Cable Couplers of Prefabricated Wiring System

Simplified diagrams are also provided in Code 26T and are shown in Figures 6 to 9 above, to illustrate the configuration and connection methods of such examples.

3.6 Prefabricated Wiring Systems for MiC

Modular and prefabricated electrical equipment have been readily available for major equipment typically used in low voltage distribution systems in buildings (e.g. switchboards and busbar trunking).

Until recently, panelised electrical modules and prefabricated cable containments, etc., are also seen to be adopted at sub-main level in some projects, and these require on-site cable laying and installations.

Nevertheless, to achieve the full benefit of MiC for electrical installations, prefabricated wiring systems are an established alternative to conventional fixed wiring methods, as adopting such systems can minimise wiring work on sub-main and final circuits that are often labour intensive on-site and allow permanent connection of cables in a quick “plug-and-play” approach.

To facilitate the trade in adopting prefabricated wiring systems, Code 26T specifies BS 8488 as the accepted standard for prefabricated wiring [8].

BS 8488 covers the key aspects of prefabricated wiring systems rated up to 500V and 100A a.c., including specifications and safety requirements on construction, earthing, protection and associated tests, as well as a guide to use with typical examples at its annex as shown in Figure 10.

Lighting systems, typical features of most buildings and infrastructures, can easily adopt prefabricated wiring systems, which allow rapid connection on-site with minimal effort, and can be used in suspended floors and

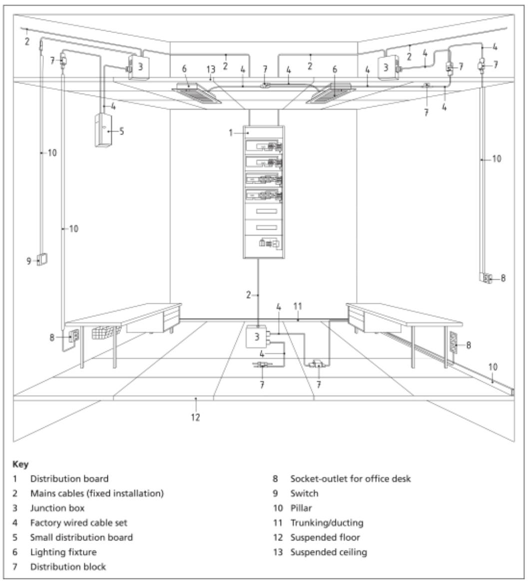

Fig. 10 - Diagrammatic Presentation of a Typical Prefabricated Wiring System

ceilings often found in commercial buildings, schools, hospitals and infrastructures.

Cable couplers conforming to IEC 61535 or equivalent, should be used in prefabricated wiring system. IEC 61535 specifies cable couplers of two-wire and up to five-wire including earth if provided, having a typical current rating from 10A to 100A and connecting capacity from 1.5mm^2 to 10 mm^2 [9]. These cable couplers shall be distinctively labelled to facilitate electrical circuit checking.

As prefabricated wiring systems are intended for permanent connection in fixed electrical installations of the buildings/developments, their installation including the connection and disconnection of cable couplers, shall be carried out by registered electrical workers or skilled persons under the instruction of registered electrical workers.

4. ARC FAULT DETECTION DEVICES (CODE 6B)

Arc fault detection devices (AFDDs) are intended to reduce the risk of fire caused by electric arcing faults. Protective devices like circuit breakers, residual current devices (RCDs) and fuses are not designed with early detection feature for arc fault. To further enhance electricity safety in Hong Kong while keeping abreast of the technological development, the use of AFDDs has been introduced in the CoP (2020 edition) to provide additional protection for arc faults.

4.1 History of AFDDs

The United States (US) is one of the first countries applying AFDDs [10], which are known as Arc Fault

Circuit Interrupters (AFCIs). In the US, AFDDs have been deployed successfully since 2002, with the 1999 National Electrical Code (NEC) requiring AFDDs installation on bedroom branch circuits [11]. In 2008, the International Electrotechnical Commission (IEC) initiated the standardisation work for AFDDs. Since 2013, AFDDs have been covered by IEC 62606 - “General requirements for arc fault detection devices” [12]. In 2014, IEC 60364 - “Electrical installations for buildings” Part 4 - 42 gives recommendations on the application of AFDDs in residential and commercial buildings [13]. Recently, the IET Wiring Regulations, BS 7671:2018 includes the recommendation and installation arrangement of AFDDs, with a view to providing extra measures for protection against fire with an arc fault origin.

4.2 Basics of Arc Fault

An arc fault is defined as a dangerous unintentional arc [12]. It creates high intensity of heat which may ignite the surrounding materials. Instantaneous outbreak of arc fault is rare as it usually takes time to develop, and it may originate from a number of causes, such as damaged wires, crushed cables, loose terminations and deterioration of insulation.

In general, there are two types of arcing fault, i.e. series arc fault and parallel arc fault. A series arc fault occurs between two parts of the same conductor. When a conductor is damaged or with loose connections, it leads to localised heating. As the temperature of insulation increases, it may carbonise the insulating materials. As carbon is a conductive material, the current passing though it generates arcs [13]. Then each arc amplifies the carbonisation of insulation, and may eventually ignite the insulation if this is not detected in time [13] [14]. In case of series arc fault, its fault current is typically too low to initiate the operation of protective devices such as circuit breakers or fuses, and only AFDDs are able to isolate the series arc fault.

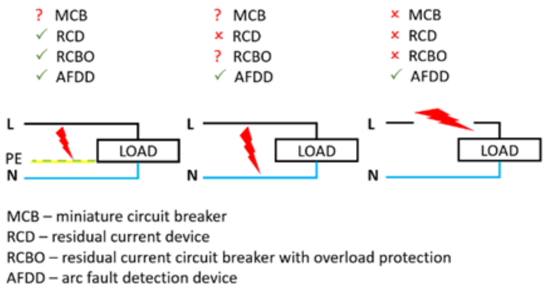

Fig. 11 - Characteristics of Different Protective Devices under Arc Faults

A parallel arc fault occurs between two different conductors. Right after the insulation between two conductors are damaged, a significant current is able to flow between the two conductors. While flowing through the insulation materials, these leakage currents optimise their paths through generating arcs. Gradually, the cycle on carbonisation of insulation materials takes place and may cause ignition [13]. In case of parallel arc fault, the impedance of the fault can be large due to damaged insulation, then the parallel arc fault current may trigger the operation of protection devices.

4.3 Operation Theory of AFDDs

An AFDD is an electromagnetic switching device with electronic components to constantly monitor and analyse patterns in electrical current and voltage. It utilises electronic technology in analysing the waveforms of an arc to distinguish what is known as dangerous arcing fault and normal arcing in normal circumstance. Although different manufacturers of AFDDs may make use of different detection algorithms for arc analytics, their efficacy should be the same [15]. AFDDs should be able to detect parallel arcs and series arc. Once an arcing fault is sensed by an AFDD, it disconnects automatically to protect the installation from damage, such as arcing and thermal impacts.

4.4 Recommended Application of AFDDs

Given the established standards and improved reliability, AFDDs complying with IEC 62606 or equivalent are recommended as a means of providing additional protection against fire caused by arc faults in final circuits. AFDDs shall be placed at the origin of the circuit, if used.

Examples where AFDDs can be used:

a) premises with sleeping accommodation (e.g. dwellings, hotels and guest houses);

b) premises for manufacturing or storing readily combustible substances or substances liable to spontaneous combustion;

c) premises where combustible materials are used as the main construction materials (e.g. wooden buildings); and

d) premises with endangering or irreplaceable goods.

In light of the introduction of AFDDs installation in the CoP, the EMSD is liaising with the Architectural Services Department and the Housing Authority to support trial projects on the adoption of AFDDs. The EMSD is also exploring to introduce the use of AFDDs in venues (e.g. museums) during alteration or addition works in existing installations. With the Government’s leadership in the application of AFDDs, it is foreseen that with a wider adoption of AFDDs, electricity safety will be further enhanced in Hong Kong.

5. CONCLUSION

The new codes and revisions discussed in this paper, alongside with other major revisions of the 2020 edition of the CoP, demonstrate our on-going commitment and partnership with the trade in respect of electrical safety, as well as our proactive role in not only providing practical guidance to facilitate the adoption of new technologies and applications, but also fostering the transition of our community towards a smarter and more sustainable future. The new edition of the CoP will be fully implemented on 31 December 2021 to replace the 2015 edition, after a one-year grace period.

ACKNOWLEDGEMENT

Sincere thanks are extended to members of the working group for the review of the CoP (member organisations include the Electrical Division of the HKIE) in offering their expertise advice and support in the revision and development of the CoP.

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Paper No. 6

BLOCKCHAIN AND POST-QUANTUM CRYPTOGRAPHY FOR SMART GRID & SMART HOME CYBER SECURITY

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BLOCKCHAIN AND POST-QUANTUM CRYPTOGRAPHY FOR SMART GRID & SMART HOME CYBER SECURITY

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ABSTRACT
The electricity industry is now under the revolution of the existing electrical grids to smart grids, which support more efficient and effective power management, better reliability, reduced production costs, and more environmentally friendly energy generation. This evolution not only brings enormous benefits but also causes great risks.

This paper focuses on the security issues of smart grid and smart home, including the most representative threats in this environment. We also review contemporary literatures to present promising security countermeasures for each scenario. Moreover, we talk about the applications of blockchain.

1. INTRODUCTION

Blockchain is a decentralized distributed ledger which has attractive features such as immutability, unforgeable, traceability, smart contact, and consensus mechanism etc. It has many applications in smart grid cyber security. However, recent works mainly focus on the electricity trading subsystem, the wide applications still need a lot of effort from both industry and academy.

In addition, NIST (National Institute of Standards and Technology, USA) had started the post-quantum standardization programme since 2016 and announced 7 candidates in the 3rd round in 2020. Their adaptation in smart grid needs desperate investigation. We shall introduce some of our recent works, and conclude this talk with discussions of future challenges.

2. SMART GRID AND SMART HOME'S ARCHITECTURE

A multi-layered conceptual model of the smart grid's architecture [1] is shown in Figure 1. Smart homes at the lower layer are in continuous two-way communication with the (Advanced Metering Infrastructure) AMI-Head End at the top layer, via the AMI-network entities of the second layer.

Figure 2 illustrates a smart home's internal environment (via Energy Management System or EMS) and the way it interfaces to the external environment (via Energy Service Interface or ESI) [1]. The ESI and EMS are in continuous two-way communication ensuring that the internal environment is acting in accordance with the external environment's requirements and capabilities. The integration of the energy-aware smart home to the smart grid successfully meets some of the smart grid's major goals, such as demand response programmes, load shedding programmes, effective feedback, peak shaving capabilities, and energy exchanges.

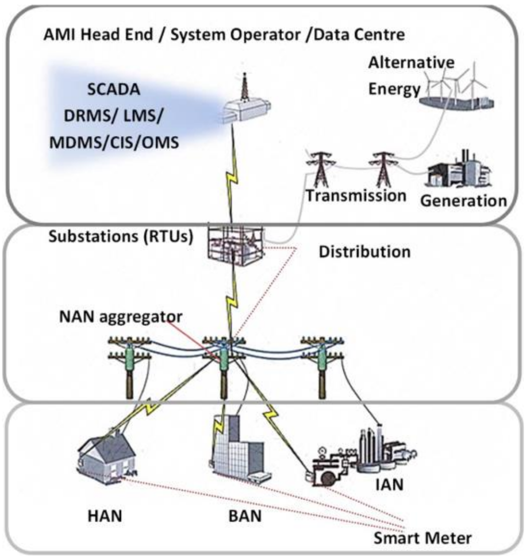

Fig. 1 - A Multi-layered Conceptual Model of the Smart Grid's Architecture

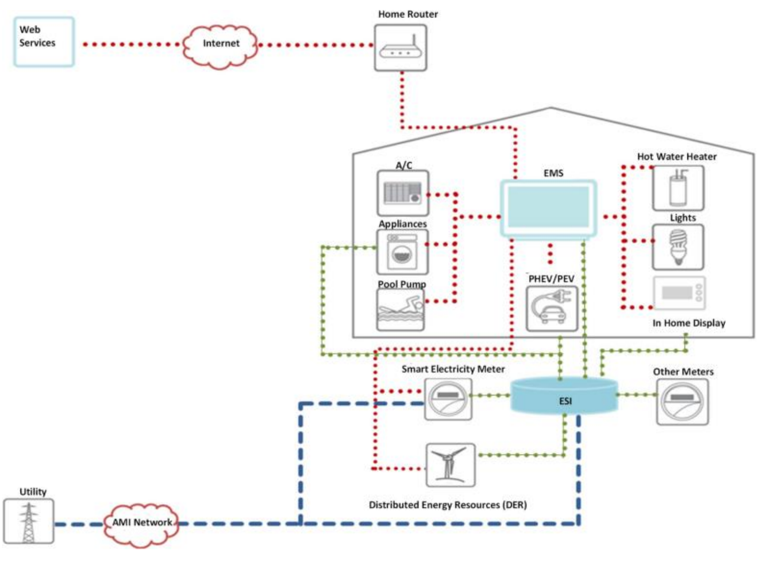

Fig. 2 - An Overview of a Smart Home's Architecture, Internal and External Environments

3. SECURITY ISSUES AND COUNTERMEASURES

As the connectivity amongst the different entities of the smart grid and/or the smart home increases, the challenges also increase. Though the security goals in smart grid are also considered generally in cyber security, such as confidentiality, integrity, availability, authenticity, authorization, and non-repudiation, but they have different specific requirements here.

The existing techniques to meet these goals are summarized as follows. Note that cryptography is most widely used.

a) Confidentiality and Privacy

- Symmetric/Asymmetric algorithms
- Anonymization: Direct anonymous authentication, group/ring signature
- Trusted aggregators
- Homomorphic encryption
- Perturbation models
- Verifiable computation models - Zero Knowledge Proof Systems
- Data obfuscation techniques

b) Integrity

- Cryptographic hash functions
- Digital watermarking against false data injection attacks
- Adaptive cumulative sum algorithm against bad data injection attacks
- Phasor measurement units (PMUs) against un-observable attacks
- Load profiling algorithm against device im-personation attacks
- Timestamps / Sequence numbers / Session keys / Nonce against replay attacks

c) Authenticity

- Keyed cryptographic hash functions (e.g. hash-based message authentication code or HMAC)
- Digital signatures
- Physical Unclonable Functions (PUF)

d) Non-repudiation

- Mutual inspection strategy
- Unique keys for customer-AMI communication
- AMI transaction logging

e) Availability

- Alternate frequency channels (physical layer)
- Anomaly-based / Specification-based Intrusion Detection (IDS) (higher layer)

f) Authorization

- Attribute-based encryption
- Attribute certificates
- Attribute-based access control system based on eXtensible Access Control Markup Language (XACML)

4. NEW TECHNIQUES

4.1 Blockchain Techniques

Blockchain changes the way we share information, it is considered as a disruptive new technology to overcome the IoT security issues, e.g. data reliability. Security and privacy become a primary concern in smart grid. Vulnerabilities in communication systems can have consequences more severe than what we are accustomed to face in ordinary information systems, causing the entire infrastructure to severe harms, economies to collapse, societies to fall apart and even people to lose their lives.

Blockchain can, but not limited to, improve smart grid in the following aspects [2]:

a) Decentralization and scalability - The decentralized P2P network will remove central points of failures and bottlenecks, it will also help prevent scenarios where a few powerful companies control the processing and storage of the information of a huge number of people.

b) Identity - Every single device can be identified by using blockchain. Data provided and fed into the system is immutable and traceable. Additionally, blockchain can provide trusted distributed authentication and authorization of devices in smart grid.

c) Autonomy **-** Devices are capable of interacting with each other without involvements.

d) Reliability **-** IoT information can remain immutable and distributed over time in blockchain. Moreover, data can be traced and accounted.

e) Security - Device message exchanges as transactions, validated by smart contracts, hence securing communications between devices.

f) Market of service - Blockchain can accelerate the creation of an IoT ecosystem of services and data marketplaces. Microservices can be easily deployed and micro-payments can be safely made in a trustless environment.

g) Secure code deployment - Taking advantage of blockchain secure-immutable storage, code can be safely and securely pushed into devices.

There are several successful projects using blockchain in smart grid. For example, LO3 Energy is an energy microgrid. It has been demonstrated in Brooklyn (USA), southern Germany and South Australia. The project builds a community energy marketplace that allows devices at the grid edge to securely and directly transact energy sales among microgrid participants. However, the applications of blockchain in smart grid mainly focus on microgrid, the entire system needs further adjustments to implement the blockchain technology.

Incorporating blockchain into smart grid is not trivial, some main challenges are as follows [2]:

a) Storage capacity and scalability - In smart grid, devices can generate gigabytes (GBs) of data in real time. There are ways the limitation could be alleviated. Firstly, since only a limited part of IoT data is useful for extracting knowledge and generating actions, techniques to filter, normalize and compress IoT data can be applied. Secondly, the cloud and fog computing architecture can extend the storage capacity and scalability. Last but not least, the consensus protocol can be adapted to increase the bandwidth.

b) Security - Many experts see blockchain as a key technology to provide the much-needed security improvements in IoT. However, one of the main challenges in the integration is the reliability of data generated by the IoT. When corrupted data has been recorded in blockchain, redactions should be performed. We give such a solution in Section 5. The IoT and blockchain integration can also have repercussions on the IoT communications. Secure communication protocols such as Transport Layer Security (TLS) or Datagram Transport Layer Security (DTLS) used in IoT requires heavy key management infrastructure. In blockchain network each IoT device has its own GUID (Global Unique Identifier) and asymmetric key pair installed once connected to the network. This would simplify the current security protocols.

c) Anonymity and data privacy - The consumers in smart grid want to be anonymous and their real-time energy consumption data should be kept private. These problems have already been discussed in blockchain, and suitable cryptographic tools are needed to be integrated.

d) Smart contracts - Smart contracts would provide a secure and reliable processing engine for smart grid, recording and managing all the interactions. In the meantime, smart contracts should leverage their distributed nature to enable the processing capabilities provided in other paradigms, such as big data and cloud/fog computing.

e) Legal issues - The ability to store arbitrary messages in blockchain has already been abused. Improper content (gossip, pictures, etc.) may affect the life of people forever if it is not removed from the blockchain. Technically, we can make redactions using the method in Section 5. However, laws are lacked to regulate the revision process.

4.2 Post-Quantum Cryptography

Quantum computers would completely break many commonly used public-key cryptosystems, and it will certainly threaten the smart grid due to its critical nature. National Institute of Standards and Technology (NIST) had started the post-quantum standardization programme since 2016 and announced 7 candidates in the 3rd round in 2020, including 3 public-key encryptions / key encapsulation mechanisms (KEMs) and 2 digital signatures based on lattice, 1 public-key encryption based on code, and 1 digital signature based on multivariate. However, further research need to be done to gain more confidence in their security and to improve their performance. The large key size is the main challenge in their adaptation in smart grid, and adjust the smart grid architecture with the support of fog and cloud computing may be a solution to storage limitation.

5. OUR WORKS

Immutability is a basic property in blockchain. However, it is often desired to allow editing a transaction or a block in a controlled way. Chameleon hash function, with enhanced collision-resistance property, has recently found to be an important tool to construct redactable blockchain. This means that the traditional key-exposure free (double-trapdoor) constructions are unsuitable for the applications here. Although single-trapdoor key-exposure free chameleon hash functions naturally satisfy enhanced collision-resistance, they are very rare, and none is based on quantum-resistant assumptions.

We propose two single-trapdoor key-exposure free chameleon hash functions based on lattice, without/with lattice trapdoors respectively, and show their applications in redactable blockchain [3]. Our constructions do not need heavy cryptographic tools, such as encryption and Non-Interactive Zero-Knowledge Proof (NIZK), therefore are more compact and computation-ally efficient than schemes following Ateniese et al.'s generic transformation framework of Public Key Encryption (PKE) + NIZK [4]. We introduce two mechanisms also in order to prevent the misuse of redaction functionality in blockchain. We present a fully distributed key management mechanism for the first scheme and solve the redaction-misuse problem which remains in blockchains using Ateniese et al.'s generic framework. We also suggest the voting strategy when applying our second scheme. Finally, we show how to efficiently integrate our chameleon hash with any blockchain technologies, with only minor changes to the current blockchains in use, refer to Figure 3. For extend interests, our proposed chameleon hash functions are also suitable for constructing quantum-resistant chameleon signatures and off-line / on-line signatures.

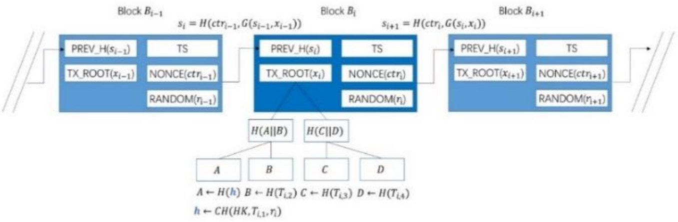

Fig. 3 - Using Chameleon Hash to Construct Redactable Blockcain with Transaction-level Rewrites

6. CONCLUSION

While immutability is a crucial property of blockchain, it is often desirable to redact its content in some specific conditions, such as removing improper or sensitive information from the blockchain, or updating a smart contract et al. It is even legally obliged for the blockchain to be editable. For example, "the right to be forgotten" is a key right of people imposed by the EU in the General Data Protection Regulation (GDPR). Under this regulation, it is illegal to use immutable blockchain where personal data are recorded. Various other legal regulations can be found in the U.S. Security and Exchange Commission's (SEC) Regulation S-P and Gramm-Leach-Bliley Act. Of course, the redaction should be under strict constraints.

With the wide application of blockchain in IoT and smart grid, the confliction between absolute immutable and redactable is even even worse. Our work provides a technique possibility to redact blockchain in a controlled way.

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Paper No. 7

ENERGIZING THE NEW NORMAL THROUGH DIGITAL ELECTRIFICATION EMPOWERMENT

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ENERGIZING THE NEW NORMAL THROUGH DIGITAL ELECTRIFICATION EMPOWERMENT

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ABSTRACT

The world has changed. The disease caused by the novel coronavirus (COVID-19) is undoubtedly changing the world. Even for those who feel able to predict the passing of the storm, counting on a quick return to business as usual is not a viable option. For the survival companies in all sectors, it will be vital to combine effective scenario planning with examination of how technology developments and behavior changes could affect their business in short, medium, and long term. These also happen in energy and utilities sectors, the experience of COVID-19 will certainly accelerate momentum towards new ways of working, automation, and digitalization.

In this paper, we deal with the revolution of energy sector, transforms from the traditional electrical devices to Digital / Cloud computing century. It covers the technology development of low voltage components, adaptability of industrial internet of Things (iIoT) technologies, applications of cloud computation, the communication and cybersecurity standards. We aim to provide the objective and adaptable implementations for the power industry, ultimately recommendations of actionable asset management.

1. INTRODUCTION

In various research, digitalization, the use of digital technologies, is ensuring a reliable and efficient power supply through the optimization and analysis of energy data. Despite remarkable efforts have been made in the digital transformation of power industry, the revolution is still yet to come. The catalyst of change is unfortunately COVID-19. The industry players start planning for a new sense of vulnerability, such as applying the built-in resiliency during the crisis and reducing the dependence on human resources. The policy makers and public also change and focus on the impact of lockdowns on reduced traffic, pollution, and CO_2 emission. These also turn to the discussions about other threats, such as climate change. Decarbonization, decentralization and digitalization become the hottest 3D topics nowadays. Other than technological transformation, the evolvement consists of business continuity, sustainability in supply chains, operations, standardizations, cyber-security measures and local adaptation, which are the critical factors, contributing to the revolution.

2. ENERGY REVOLUTION

The transition of global energy systems can be characterized in four phases. It starts from energy generation, power capacity, flexibility for matching the supply and demand, and data revolution to enhance the efficiency of overall system operation. With the Paris Agreement, introduced at the UN climate conference in December 2015, the global leaders have agreed on keeping global temperature increase well below 2 ºC to purse efforts to limit to 1.5 ºC. 194 parties have signed the agreement and most of the governments around the world set ambitious goals to reduce greenhouse emissions, targeting to achieve carbon neutrality by 2050. Timetables to achieve climate goals are being presented, decarbonization have to embed into all phases.

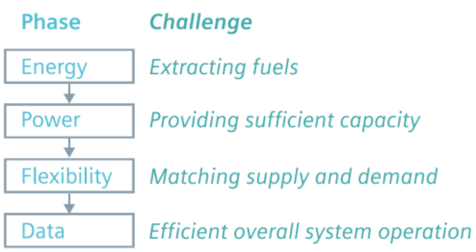

Fig. 1 - Four Phases of Energy Revolution

The answers from power industry are decarbonization, decentralization and digitalization. Many of these starting points lie in a new dimension between smart electricity grids, buildings, and prosumers – energy consumers that generate electricity themselves.

Historically, the energy generation was from fuel extraction and centralized. Among the sources of fuels, coal mines and oil fields are carbon-intensive, even for the natural gas and combined-cycle generation which has significantly improved the generation efficiency. The low carbon renewable resources, which are highly dynamic and generating small amount of power capacity, compare to the traditional generations, would be one of substances in revolutions, whilst the arising of Electric Vehicles (EV) is also contributing to the change. Last but not least, the rising impact of COVID-19 has changed the traditional pattern of usage. The increase of people working from home tapers off the energy use in commercial buildings. It also results the transfer of electricity cost and responsibility from work to home, potentially increasing costs for many consumers. Thus, there is the neediness of more customer-centric solutions, feed-in-tariff, Distributed Energy Resources (DER). All in all, it is forced to adjust and solve the problems.

From the policy makers and utilities, safeguarding and stabilizing operations are always with the priority. Digitalization would be the key element of the new energy system. It provides the visibility and control over energy use, enables the emergence of renewable energy resources, and the opportunities for replacing and renovating the aging equipment to secure the power supply reliability.

3. TECHNOLOGY DEVELOPMENT

In the age of digitalization, the investors often start from the generation and transmission assets which the cost of investment against asset value ratio are more easily justified. There are the introductions of combined cycle generation turbine which can offer over 60% of energy efficiency, and environmentally friendly SF_6 - gas free and IoT HV Switchgear which reduce the greenhouse gas consumption and improve installation efficiency in recent years.

The implementation of Smart Grid has been starting in different level. From the substation level, there is continuous installation of digital substations, including latest IEC 61850 digital protection relays and smart remote terminal units for additional data mining adjacent to traditional control and automation. The introduction of Integrated Substation Condition Monitoring (ISCM), including partial discharge monitoring, circuit breakers monitoring, transformer monitoring and substation room monitoring not only providing accurate timely information and assets status, but also the reliable data to enable the additional value creation. The Reliability Centered Asset Management (RCAM), Condition-Importance diagram and Health Index (HI) development further unleash the potential for data value. These are the enablers for predictive asset planning, enhanced operation and comprehensive resources and asset management planning tools in enterprise level.

From Supervisory Control and Data Acquisition (SCADA) level, there is also the discussion of seamless data integration between Grid Control software and Grid Simulation tool, based on Common Information Model (CIM) data sharing. It is highly believed that Digital Twin will definitely improve the grid efficiency and operation planning in the foreseeable future.

Aside from those technologies, it is unfortunately true that the development for power distribution equipment is lagging. The modern low voltage breakers were invented in 1950s. In 1970s, the industry developed the first Electronic Tripping Unit, which often named as ETU and Micrologic nowadays, as a revolution from traditional plug setting to electronic age. Between 1990s to 2000s, with the technology improvement and arising of remote control, the ETUs for the Air Circuit Breakers (ACBs) and Molded Case Circuit Breakers (MCCBs) had been upgraded with modular communication and remote diagnostic possible. After this invention, the development seemed slowing down.

Certainly, there is still mechanical improvement. Starting from 2000s, for the ACB perspective, the operation cycle and breaking capacity were much improved which represented as higher quality and longer life cycle even with reducing frame size. The communication topology had been also upgraded to ring communication to avoid loss of communication due to single point of failure. For the MCCB, recently, it supports the nominal current up to 1,600A, which offers a more cost-effective option for the market players. The implementation of plug-in and draw-out units provides the easier and faster change of the MCCB in case of faults occur. It is obvious that most of these developments are with the commercial considerations, e.g., space requirement, life cycle costing, alternative cost effectiveness etc. Although the introduction of digital technology might further improve the life cycle and operation effectiveness, the cost of sensing and processing devices is contributing significantly comparing to the asset value of the power distribution equipment, i.e. less attractive to the investors. It is difficult to overcome until the RCAM concept is introduced. Not only the cost of asset has to be considered, the cost of installation, replacement, Customer Minutes Loss (CML), catastrophic failure and also cost of safety event, together with the importance of supply reliability, are the crucial factors for decision makers, facility managers, and critical infrastructure considerations.

In parallel with economic considerations, the low voltage breakers also improve the functionalities and precise measurement accuracy for meeting the requirements of power quality measurement and protection advancement. In addition to the conventional voltage and current measurement, the embedded power meters meet the IEC 61557-12 and IEC 60364-8-1 standards which define metering accuracy, Power Monitoring Functionality (PMF) levels and the minimum requirements fulfilling energy efficiency according to ISO 50001.

Power Monitoring Functionality:
PMF I: Energy Efficiency
PMF II: Basic Power Metering
PMF III: Advanced Power Metering

Fig. 2 - Power Monitoring Functionality

Functionalities		PMF Type		
Electical quantities to measure	**symbol**	**PMF I**	**PMF II**	**PMF III**
Power (Power Demand)	P		■	■
Reactive Power	Q		■	■
Apparent Power	S		■	■
Active Energy	E_a	■	■	■
Reactive Energy	E_r		■	■
Apparent Energy	E_{ap}			■
Frequency	f		■	■
Current	I		■	■
Current (neutral)	I_N		■	■
Voltage	U and/or V		■	■
Power Factor	PF		■	■
Voltage Harmonics	THD_U and/or THD_V and/or $THD\text{-}R_u$ and/or $THD\text{-}R_V$			■
Current Harmonics	THD_i and/or $TDH\text{-}R_i$			■

Table 1 - Types of Power Monitoring Functionality

The latest generation of ETUs, similar to the digital protection relays, on top of traditional L – Overcurrent, S – Short Circuit, I – Instantaneous Fault, and G – Ground Fault protections, supports various protection functions, such as Reverse Power, Unbalance Voltage/ Currents and Frequency protections to meet the requirement of renewable integrations, and circuit breakers monitoring through the measurement of operation timing, counter and contact wear monitoring. These features are to be handled via different application processors and protection processors to minimize the risk of malfunction due to single component failure. Also thanks for the pioneer of HI and RCAM development in transmission switchgears, rather than suspect, the measured parameters form the solid base to deduce the specific health indicator and estimated remaining lifetime for the low voltage breakers, thus the operating capability and maintenance time could be set at optimal.

Fig. 3 - Health Indicator

Another innovation is about the upgradability. The users can activate the ETU's different PMFs, and protection functions as needed via the license and firmware enablement. The future proof design allows low investment cost at the project initial phase, whilst the users can progressively upgrade to enjoy the advance technology later.

4. DIGITALIZE ELECTRIFICATION

Throughout the digitalization journey, it is essential to walk through "Connect & Monitor", then "Analyze & Predict" and "Transform & Optimize" eventually. The three-layers approach is usually adopted in the industry.

The first layer is the Data Acquisition layer, consists of sensors, intelligent electronics devices such as protection relays, and IoT gateways. The low voltage switchboard often acts as the "Smart Assemblies" for the digital devices' installation. The term of "Smart Assemblies" has been used recently, however, without a common understanding. The only relevant guideline available would be the GB7251.8-2005 "Low Voltage Switchgear and Controlgear Assemblies – General Technology Requirement for Intelligent Assemblies".

It is advised to include the following as the minimum while digital breakers are mostly fitting into the requirement:

- Communication via Standard Protocol
- Remote Configuration
- Remote Measurement
- Remote Control
- Communication Monitoring, Information Log, power management
- Real Time Control
- Shield and Isolated Communication Cable
- Electrical Interlocking

The second layer is Data Management and Visualization layer. The functions for this layer are database management, data visualization – providing the human machine interface to operations and alarm management. Some of the system providers might also offer mobile application to enhance the user experience. The common applications are Power Management System (PMS) and Building Management System (BMS), also known as Industrial Control System (ICS). Nowadays, some of the data concentrators and industrial servers, in parallel with the local data management function, also act as the IoT gateway for cloud connectivity to support Fleet Management application.

The IoT gateway is generally classified into two different types - vendor specific and open communication options. The vendor specific gateway usually offers plug-and-play advantage to the users. The configuration is considered as minimal, the vendor's devices can be simply connected to the gateway then to the vendor specific cloud platform. The User Interface (UI) is also pre-defined, with limited capability for customization and project specific development. The users can enjoy the benefits of the one-stop solution from data management, visualization, to alarm management and any additional vendor developed applications without hiring of experienced software nor communication engineers. However, the connectivity of 3rd party's devices is limited, users might take extensive efforts for the connections and configurations, work around might be also required. The data ownership is also a topic of concern, another fallback would be the limitation of customized development. The users have to heavily rely on the vendor development and pay for the cost of development which might without reasonable control.

Another option would be the open communication gateway. This type of gateway offers several open communication options, such as IEC 61850, Modbus TCP/IP, and Profibus for downstream connections, does not limit to any vendor devices. For the upstream communication, it supports Message Queuing Telemetry Transport (MQTT) and Open Process Communication Unified Architecture (OPC UA) Pub/Sub which also known as IEC 62541, the standard of IoT connectivity. In contrary to the advantage of plug-and-play, software configuration between devices and platforms, and UI customization are necessary. The users have to mobilize the suitable resources and/or contract with any external vendors for such a development. The users retain the data ownership and is free in the selection of platform services provider. It is also possible to localize the development into the on-premises data server.

The third layer is the Application and Services layer. This is about Asset Utilization, Risk Simulation, Artificial Intelligent, Trend Prediction, Data Analytic and On-demand Services. These seamless integration forms the Energy Internet, in which most of the users are interested, as it shows all the benefits of digitalization such as optimal asset management, enhanced energy efficiency and resources management. It is the transformation of domain knowhow from Operation Technology (OT) to Information Technology (IT) knowhow and has to establish trustful computing and information exchange.

5. CYBERSECURITY

The arising for iIoT and digitalize electrification have blurred the boundary between the OT and IT, further leads to the attention of cyber security over the traditional system, especially it comes to large scale deployment. Operation reliability and data security are the key discussion topics, considering the growing threat of cyber-attacks around the world. The best recipe for success is the combination of well-defined and professionally implemented standards and requirements, combining with usability - centered workflows. Putting cybersecurity into practice, there are few standards available nowadays, which describe the Information Security (ISO/ IEC27001), Engineering Process & Technical Solution (IEC 62443) and Technical Features (IEC 62351) respectively.

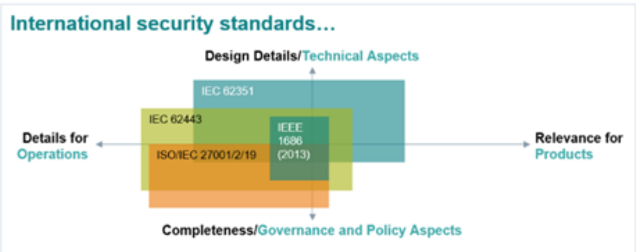

Fig. 4 - International Security Standards

The standards consider the fact that cybersecurity involves more than just technically secure products but is instead an entire process that has to be put into practice. The 3 Ps (people, processes, and products) are essential and form the basis of a comprehensive security concept for digitalize electrification.

5.1 Patch Management and Security Updates

Most of the products are based on components of various vendors, examples are Microsoft, SQL, Oracle etc. It is essential to establish, document and implement a security patch management programme for tracking, evaluating, testing, and installing applicable cyber-security software patches. Reference to the NERC CIP Standard and BDEW White Paper, which is about the timely information about security vulnerabilities and availability of patches or workarounds, these include, a) Monitor and classification, b) Check for relevance and final classification, c) Implementation and Test and d) Release. The responsible entity shall document the assessment of security patches and updates for applicability within thirty (30) calendar dates if availability of the patches or upgrades. The patches and workarounds have to be tested before use them with products. Workarounds are possibly available in order to mitigate the risk as long as no fix is available or feasible. The responsible entity shall also document the implementation of security patches. In any case where the patch is not installed, it shall document the compensating measure(s) applied to mitigate risk exposure.

5.2 Secured Process, Application and Technical Implementation

The IEC standards provide governance and requirement of cybersecurity to support the digitalized operations. It would be an ideal case to certify the entire solution and processes, including products, systems, communi-cations as well as the operations, however it is hard to achieve in reality. It is often that the vendors will only obtain the certifications for their own range of products and systems. However, the selection of equipment is always compositing several brands, based on different technical and commercial considerations. Thus, the certification specific project selection is nearly impossible. To overcome this difficulty, it is essential to study the details then to dictate the suitable requirement and governance to strengthen the defense-in-depth. Other than the certification, it is more common to outline cybersecurity requirements, include:

- System security requirements and security levels
- Role-based access control
- Encrypted & Secured communications
- Vulnerability Disclosure & Incident Management
- Application Whitelisting
- Patch Management/ Signed Firmware
- Error Detection
- Event and Security Logging

- OT PKI/ Digital Certificates

These serve as the framework references after a variety of current security standards, ranging from general guidelines for the organization in question, secure product development processes to the systematic treatment of weak points, the creation of a secure system architecture, the provision of access control systems, protection against malware, creation of data backups, and the use of secure remote access methods and confidentiality standards. Essentially all users and devices that participate in communications must be authenticated, their scope of actions limited to an authorized set of access rights and essentially all data communications must be encrypted. Those principles apply to any kind of IT/OT infrastructure, the same applies to the Internet of Things. The use of X.509 public / private key infrastructure digital certificates enable the establishment of trusted relationships. It supports the identity management, access control, data encryption, and protection in all directions, and enhances security for IoT connectivity devices.

6. IMPLEMENTATION AND CHALLENGES

The implementation of Smart Assemblies becomes an inevitable trend. New products in future will be deeply integrated with iIoT features such as monitoring, communications, self-diagnostic and edge computing. In the USA, Europe and China, there are some relevant standards that can be referred, such as GB7251.8, ISA, IEC, NIST, etc. Some special industrial has their own standard development organizations, such as petroleum, chemical, water & wastewater, electric sectors. The framework of the digitalization can make reference from the standards above. In general, there are three phases, i) Assess, ii) Develop and implement and iii) Maintain. The detailed steps are as below:

a) Setup the scope, the architecture, network diagram, inventory list, expected functions, test and commissioning (T&C) plan and maintenance guideline of the Smart Assemblies which should be designed in advance. It is essential to define the cyber security measures, considerations, and workarounds in the initial phase, prior to the procurement and implementation starts.

b) For the existing assemblies, throughout the study, it can be integrated into ICS by adding hardware such as sensor, data processors, network devices, backup power supply, etc. in same protocol. Protocol converter is also needed if necessary.

c) The Smart Assemblies requires ICS to operate OT equipment, in parallel, establish the connectivity of those iIoT devices for monitoring via On-Premises/ Public systems.

d) Testing and commissioning after installation completed to verify if the system conforms to the design. The availability and integrity are the necessary elements for choosing the operation systems and components.

e) For more advanced requirements, devices and software for AI features, real-time response and cyber security are considerable.

f) Technically, for upgrade of existing equipment the first consideration is connecting them to the network. The hardware and software mentioned above can be added onto the equipment and achieve this. However, the cost maybe high due to power down and manpower cost of site work and T&C.

g) The asset owners need to set up management framework. Training of personnel is required for the knowledge of basic OT operation and cyber security procedures.

h) Maintenance, monitoring and management of changes. Review and audit periodically if necessary.

Unfortunately, in most cases, the digitalization of electrical equipment involves several stakeholders while the most important one is the asset owner who provides leadership commitment, scope, support, and funding based on business rationale. The implement-ation is a process of joint effort to engage management for a commitment.

Recently the Hong Kong public works are responsive to the trend. The electrical assemblies in new or replacement projects are only required to gather up real time energy data. There are only limited demands on smart breakers and asset condition monitoring. A common pitfall is to initiate without a high-level rationale. The asset owners or the representatives are not clear about the mission and goal, hence the service providers are unable to provide suitable plan. The return on investment is thus difficult to quantify so the asset owner is uncertain about the investment amount.

One of sharing is about a factory in Vietnam owned by a Hong Kong enterprise. The management team, resident engineer and operator were failed to align on the implementation of Smart Assemblies. As a result, it was unable to reach any consensus before supplying the ordinary switchboard on site. The management finally decided to implement the smart features after the arrival and resulted in much higher cost to the original due to site constrains and modifications eventually. Another example is about a Macau casino, while this was an old imported existing system. The asset owner was willing to make replacement. However, the operation teams failed to provide sufficient documentation, hence, detailed examination of the assets was not allowed. The policies and records were absent, so risk assessment cannot be done, and potential impact of site modification was difficult to be estimated. Even the components were commercial off-the-shelf and software was too old and proprietary for updating or patching.

There is also a common misalignment between IT and OT operations. The IT policies are difficult to fully integrate into the OT systems, whilst OT operators are lacking IT understandings to against the cyber-attacks and intrusions might happen. Most E&M operators are afraid of mythic terms of cybersecurity and many operators are using default password for remote accessible devices. Professionalism is required.

Another challenge would be the software platform implementation. To allow fast track delivery and implementation, the users usually opt for a plug-and-play option in the initial trial. In many cases, the out-of-the-box features cannot satisfy the user requirements, extra scopes and features, specific outlooks and customized UIs are generally required after several stakeholder meetings. There are also typical concerns about the data ownership and network security, even though there are several cybersecurity measures such as VPN and data encryptions in place. To limit the risk exposure, the information technology officer will demand for a on-premises solution. The scope of "trial" is changed, and it becomes a software development project, contrary to advantages of low setup cost and timely delivery.

A semi custom-made solution is developed to overcome these constraints. Empowered by software application center, the regional office develops a custom solution, based on the standard corporate UIs, typical reporting formats, and analytic features on any open cloud services platforms such as Amazon AWS, Google Cloud, MS Azure, Ali Cloud, etc. Subjected to the capability of the regional office, the developers could implement the additional features as "add-ons". A typical example is "*SiePower*", which is an open software application for any third-parties' devices, the basic features include:

- Geographical Information Display
- Power Monitoring
- Energy reporting
- Real Time Status Display
- Thermal Monitoring
- Asset Health Reporting

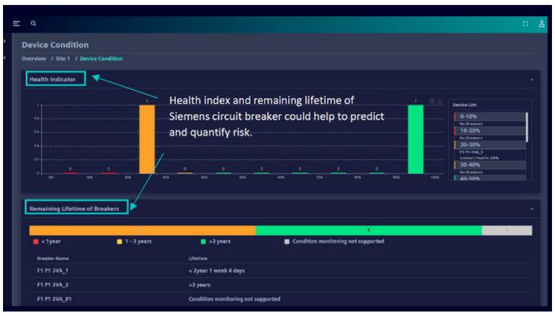

Fig. 5 - SiePower - Circuit Breaker Health Indicating

It is flexible to build on additional "add-ons" such as Building Information Model (BIM), switch-room monitoring, and digital database for manuals and maintenance recording. Application Programmer Interfaces (APIs) allow accessing to the core transaction and the solution can be also localized after trial completion.

7. THE FUTURE – "ENERGY INTERNET"

Without any doubts, energy data add value to industries. The rise of IoT is irreversible, and the revolution is faster than ever. Digitalize electrification boosts the industry development and "Energy Internet" applications. This makes our adaptation to the New Normal and building of the sustainable environment possible. It removes the boundary of the real world, transforms it into the world of software and virtual and information, and offers the scalability for future expansion of quantity structures.

7.1 Control and Increase Share of Renewables

One of the "Energy Internet" applications nowadays would be the DER integration. The adoption of digitalize electrification – iIoT, and it is open standards for the communication and data structure layers, are the fundamental elements for the connectivity and seamless integration. The nearly real-time and bi-directional information exchange of the Microgrid components, including but not limited to the SCADA Center, DERs, energy storage systems and micro-to-macro weather forecast systems enhance the accuracy of the generation - offsetting and balancing, load storage control and automated control, result in the benefits of better energy efficiency, grid reliability, improve resilience to the fluctuations with sustainable energy resources.

7.2 Induce Measures by Consumption Transparency

It is the enabler of effective and active energy management system. The establishment of a systematic data acquisition approach, enables the facility management to identify cost saving opportunities, verifies the continual improvement of energy efficient data storage, and establish Energy starting Bases (EnB) and Energy Performance indicators (EnP). It also provides the transparency for better use of energy and better use of space for the development smart office/ building solutions, to detect idle time and prevent unnecessary energy wastage, and to provide the people centric and comfort user experience, ultimately increase the utilization and productivity.

7.3 Prevent Asset Malfunction and Failure

Throughout the development of Smart Breakers and the centralized RCAM solution, monitoring the conditions of assets and predict maintenance of power distribution are possible. Based on the information exchange, the present and future network stability can be simulated by

Electrical Planning Software, e.g. SIMARIS Tools and Power System Simulator (PSS) software, and the operator can decide several actions or pre-cautions to optimize power supply contingency planning, continuously improve and optimize the maintenance strategies, and develop predictive maintenance to minimize the consequence of asset failures so as to increase power supply reliability.

7.4 Artificial Intelligent

The information is linked and shared across various systems via CIM. Utilizing the big data analytic capabilities of the industrial Energy Internet platforms, can further increase the value along with self-learning algorithms. Rather than rule-based algorithm, the Supervised Learning and/or Deep Learning are more commonly used in the centralized platform. Examples are AI chiller plant optimization, motor analytics for efficient plant operations and electric vehicles charging management systems. The Energy Cloud can correlate the acquired data with other sources such as human polling, key performance indices, historical data, weather data, age of the assets, etc, then to provide suitable recommendations to actions.

8. CONCLUSION

Digital Electrification is not an isolated technical topic, but a solid base for accruing the energy and asset data to develop management applications about the residual lifetime, asset performance, and commercial Enterprise Resource Planning (ERP) systems. The efficiency of operational maintenance of the power assets can be significantly improved. It is necessary for the relevant stakeholders, including the Government, developers and asset owners, and critical infrastructure owners and operators adapt to the future-proof equipment with iIoT technology in the considerations of the soar of electricity demand and maintaining the sustainable future. Investments into new assets can be made at the right and probably later point in time, considering their actual heath status and their strategic relevance.

Unplanned downtimes can be avoided, with a positive effect on supply availability and asset productivity. Decisions can be made more consciously, better, and faster and it is the solution to energize our New Normal.

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Paper No. 8

SMART BUILDING TECHNOLOGIES FOR ENHANCING OPERATIONAL AND ENERGY EFFICIENCY

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SMART BUILDING TECHNOLOGIES FOR ENHANCING OPERATIONAL AND ENERGY EFFICIENCY

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ABSTRACT

Innovative technologies are in demand at all aspects of buildings – from energy saving, facility management, tenant comfort to health and safety.

This paper presents a holistic view of how to adopt advanced technologies in buildings for optimised building performance by leveraging IoT technologies and big data analytics. Practical experiences on the deployment of smart building technologies will be discussed in detail from the perspectives of big data collection, IoT infrastructure, analytics & applications, and visualisation.

1. INTRODUCTION

The explosive growth in technological advances is leading us into a new era of building management. The digitisation transformation of building control has been happening at a rapid pace. Today's smart buildings have begun leveraging IoT technologies to connect various systems, sensors, and devices to a cloud-based smart building platform. Building operational data generated from various building systems and sensors at one building can be more than billions per year.

By integrating data, analytics techniques, machine learning (ML) and artificial intelligence (AI), smart applications for different purposes can be built upon the platform which proactively enhance operation efficiency and optimise energy consumption for HVAC systems. The analytics architecture applying in the smart building platform is a framework of three layers including data collection, analytics & applications, and visualisation.

In line with the Smart City vision of the HKSAR Government, making use of innovation and technology in the built environment is the key to achieving smart buildings across Hong Kong. Smart buildings go way beyond saving energy and sustainability. Businesses that adopt technologies are leveraging data in new ways to achieve a new level of efficiency. The success in smart buildings brought by innovative technologies is not temporary but rather represents a continuing effort to lead the way in developing smart cities. Smart buildings are a key component of urban evolution towards a truly intelligent world.

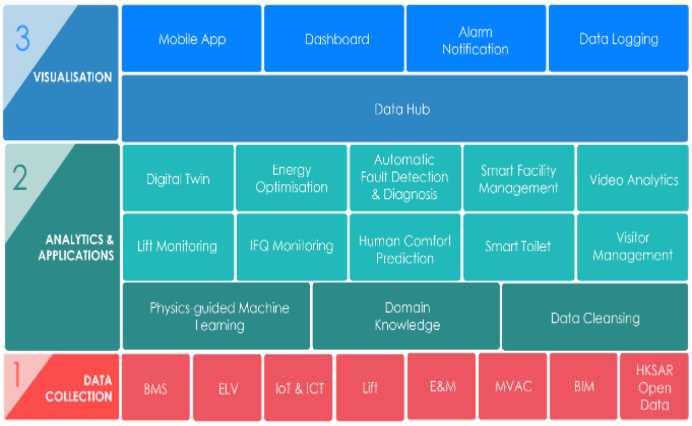

Fig. 1 - System Architecture of Smart Building Platform

2. DATA COLLECTION

2.1 IoT Connectivity

Data is changing and reflecting building performance constantly. Examples of big data within a built environment include data from HVAC systems, lighting, and security systems, as well as many other building services. Such data is normally not available in existing buildings where the building management system (BMS) provision is very primitive. However, collection of big data is becoming easier as technology advances. With wireless IoT sensors, installation works can be done without fixed infrastructure and therefore, implementation and maintenance cost can be minimised. Real-time operation, environmental and energy data can be easily obtained through different IoT sensors and connected devices via an IoT network. An IoT connectivity known as LPWAN (low-power wide-area networks) is designed to allow long range communications at a low bit rate among devices relying on the star network topology and modulation technique. LPWAN technology works well in the built environment where IoT sensors can transmit small data inside / outside premises. Big data collected from wireless IoT sensors can be sent to a cloud platform through the IoT network in real-time for further processing and analysis. Several LPWAN network technologies, namely NarrowBand Internet of Things (NB-IoT), Long Range Wide Area Network (LoRaWAN), and Sigfox, have established in the market with their unique characteristics as summarised in Table 1.

	Sigfox	NB-IoT	LoRaWAN
Private network	No	No	Yes
Modulation	BPSK	QPSK	CSS
Bandwidth	100Hz	200 kHz	250 kHz and 125 kHz
Data rate (maximum)	100bps	200kbps	50kbps
Message per day	140	Unlimited	Unlimited
Range	10 km (urban), 40 km (rural)	1 km (urban), 10 km (rural)	5 km (urban), 20 km (rural)
SIM card required	No	Yes	No

Table 1 - LPWAN technologies: Sigfox, NB-IoT and LoRa

The major decision factors in choosing the appropriate LPWAN technology (Sigfox, NB-IoT, or LoRa) are highlighted as below –

2.1.1 Deployment model

Both NB-IoT and Sigfox operate on private shared network. NB-IoT's communication protocol is based on the LTE protocol and the network is built upon LTE infrastructures. Sigfox owns its patented technologies and provides proprietary equipment for its users to build IoT networks. Unlike NB-IoT and Sigfox, a significant benefit of adopting LoRa is its ability of allowing users building local / private network on premises, meaning building owners can set up and manage their own networks. According to LoRa Alliance, LoRaWAN networks exist in over 160 countries, mostly as local installations.

2.1.2 Network coverage

The SigFox network covers an average range of about 30 - 40km in rural areas and 3 - 10km in metropolitan areas due to the nature of cities comprising a mix of buildings obstructions and noise. LoRa has a lower average range of <20 km. It offers three different classes of end-point devices to address the different needs reflected in the wide range of applications including Class A – Lowest power, bi-directional end-devices; Class B – Bi-directional end-devices with deterministic downlink latency; Class C – Lowest latency, bi-directional end-devices. NB-IoT has the lowest range of <10 km. Its applications tend to take place in the locations where cellular networks are out of reach. (e.g., deep-indoor environments). The coverage of NB-IoT is limited to LTE base stations.

2.1.3 Scalability

All Sigfox, NB-IoT and LoRaWAN are designed to support a massive number of devices for future network expansion and various IoT applications. To determine the scalability, one of the significant indicators is the number of daily messages or devices that a single base station can handle. NB-IoT is highly scalable which allows a network of up to 100K end devices per cell. LoRaWAN and Sigfox offer moderate scalability of up to 50K end devices per cell.

There is no one-size-fits-all LPWAN solution to addressing every need and issue. Each of these technologies comes with a set of unique characteristics which provide the capabilities for different applications according to circumstances.

3. ANALYTICS & APPLICATIONS

Advanced analytics accompanied by efficient data cleansing eliminates inaccurate, incomplete, inconsistent, and repetitive data in avoidance of misleading conclusions. Abnormal and noisy data is eliminated to ensure data quality. Subsequently, the processed data can be put in use for the development of a various scopes of analytic applications. In this session, some examples of smart building application are discussed

3.1 Automated Fault Detection and Diagnostics (AFDD)

Due to sensor issues, equipment deterioration, improper system control and settings, the HVAC systems often fail to operate at the efficient performance, leading to the unnecessary energy use. As such, there is a need for building owners to adopt big data analytics for monitoring-based commissioning to continuously examine building system performance, identify system and control faults, as well as improve the overall energy performance. Automated Fault Detection & Diagnosis (AFDD) leverages big data analytics to provide automated end-to-end diagnosis for discovering faults, investigating root problems, and recommending best-suited solutions, ultimately achieving optimal system performance. AFDD is a data-driven and model-based algorithm comprising five layers of monitoring, including data quality, fault detection and diagnostics, energy performance, control stability and thermal comfort.

Fig. 2 - Five Layers of AFDD Monitoring

Each of the layer is analysed using big data analytics. Big data analytics aims at deriving conclusions and correlations from a huge amount of data. Data quality can be detected for any missing data in avoidance of incomplete model training. Unnoticed faults are commonly found in the AC system. These unnoticed faults, such as insufficient charge of refrigerant in chillers, VAV box damper stuck, sensor biases etc., are not easy to be identified as the existence of these faults will not lead to the breakdown of the overall system operation. It only affects thermal comfort, system control as well as energy performance. However, if there is no action to rectify these unnoticed faults, energy performance will not be optimised. For energy performance, equipment performance model can be developed using advanced modelling techniques to describe actual operating performance. The developed model is considered as the baseline model to compare the future model for performance deterioration detection. In order to analyse system stability, it is important to obtain the high frequency data in buildings. Without the high frequency data, it is difficult to evaluate system stability. Fourier transformation can be performed to covert time-series function to frequency domain function for detailed analysis [1]. This provides a standard tool to analyse stability of the AC system operation, detect any abnormal operation, as well as identify the influential factors affecting the system operation. According to ASHRAE standard 55 (2017), the thermal comfort can be evaluated based on six parameters, including air temperature, mean radiant temperature, air speed, humidity, metabolic rate, and clothing level. In practice, only the air temperature sensor is installed in the indoor environment. In this case, the thermal comfort level is defined as the temperature error between the room temperature set point and the actual temperature.

$$temp.\ error = T_{actual} - T_{set\ point}$$

It is worth noting that the air temperature sensor biases can significantly affect the accuracy of the thermal comfort evaluation. More importantly, the air-side system control (e.g., VAV system / Fan Coil System) heavily relies on the measured air temperature to control either supply air temperature or flow rate. When there are obvious sensor biases in measuring the actual air temperature, it will result in poor thermal control and thereby lead to either over-cooled or insufficient cooling. Together with the thermo-physical relationships among the flow rates and temperatures of water in a piping system, the Bayesian method was employed to develop a model for detection and evaluation of biases of water flow and temperature sensors in a central chiller plant [2].

3.2 Dynamic Optimisation

Analytics works best when large amounts of data are available. This characteristic is particularly suitable for energy management in HVAC systems where large sets of operating data are accessible. Big data analytics applies in optimising energy use of HVAC systems with a dynamic optimisation algorithm built upon the basis of physics-guided machine learning (PGML). Chiller is one of the heat exchanger devices in HVAC equipment and operates according to physics principles including conservation of energy and the second law of thermodynamics. These physics laws are adopted in the machine learning algorithms to make it into a hybrid approach for ensuring modelling accuracy. Moreover, the dynamic algorithm takes the factors affecting the energy use of chillers into account, including cooling load (Qe), chilled water supply temperature (Tchws), condensing water supply temperature (Tcdws), chilled water flow rate (Frchw) and condensing water flow rate (Frcdw). For example, an increase in chiller lift leads to an increase of energy consumption of chillers. This hybrid blend of physics and ML approach reveals the actual performance of individual HVAC equipment, holistically optimising overall performance of HVAC systems under different cooling loads in real-time. Figure 3 shows the PGML chiller model that represents the actual performance of chiller. With the PGML chiller model, it can provide an accurate performance prediction under different operating conditions. If there is no physical principle guiding the machine learning in developing chiller models, the predictability will be limited or even invalid outside the range of available data. Dynamic Optimisation adopts an algorithm to determine the optimal control setting in real-time, based on the latest cooling load and the weather conditions. A key feature of the algorithm is that in determining the optimal control setting, it can evaluate all possible combinations of equipment and control settings to ensure the minimum energy use of chiller plant at all time. Once the optimal control setting is found, it is sent back to the BMS for immediate implementation so as to continuously minimise the energy consumption of the whole chiller plant.

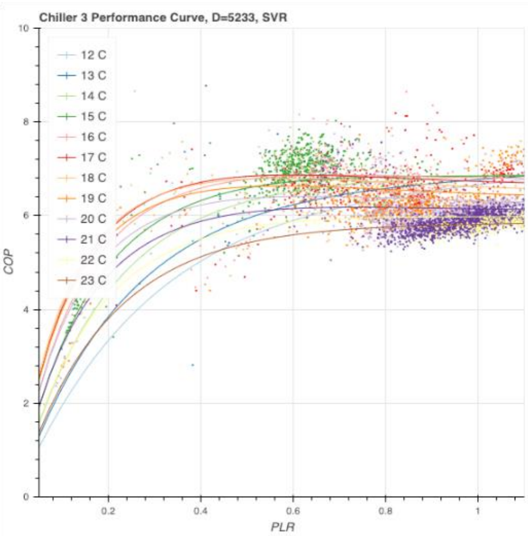

Fig. 3 - Only Applying Machine Learning for Chiller Model Development

The cost varies depending on the age of buildings. Payback on investment is typically between two and five years. The abovementioned energy analytics platform has been adopted by multiple prestigious Grade-A properties which are rated as BEAM Plus Platinum and LEED Platinum. Subscribed buildings have achieved significant energy savings. After one-year implementation, yearly energy saving ranged from 7% to 15%, improving COP from 3.58 to 3.86. Actual energy savings were calculated in accordance with ASHRAE Guideline 14-2014 - Measurement of Energy, Demand, and Water Savings.

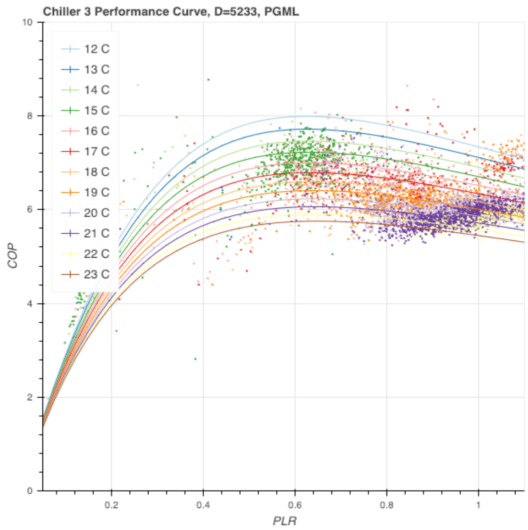

Fig. 4 - Physics-guided Machine Learning for Chiller Model Development (with Predictability outside the Range of Available Data)

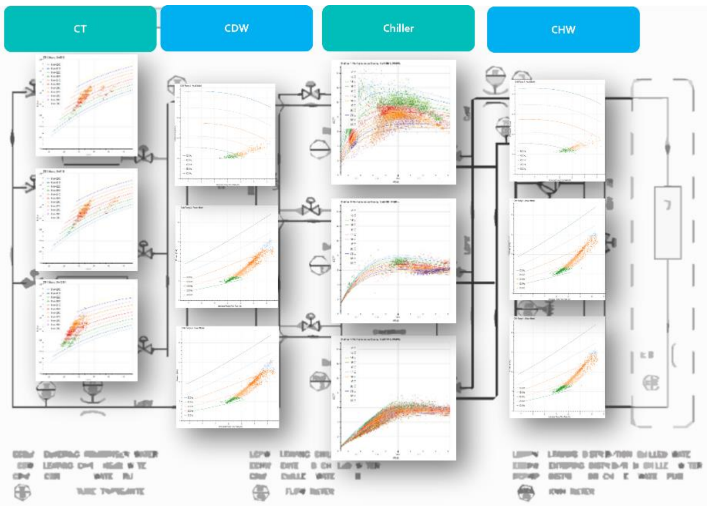

Fig. 5 - Core Structure of Dynamic Optimisation

3.3 Indoor Environmental Quality (IEQ) Analytics

Incorporating big data analytics into measuring IEQ helps achieve healthier workplaces. This approach can identify critical factors in the physical environment that impacts building occupant comfort and satisfaction. The key factors that have the greatest impact on office workers' health and comfort include air quality (i.e., CO_2, PM2.5, PM10, PM1.0, formaldehydes), thermal quality (i.e., air temperature, relative humidity), lighting quality (i.e., light / daylight level), acoustic quality (i.e., ambient noise level), and spatial quality (i.e., occupancy level). The recorded data can be used to train an ML algorithm for automatically classifying the level of tenant comfort and satisfaction, necessary adjustments of redefining user comfort thresholds can therefore be made based on real-time analytics. The captured data shown in the cloud-based analytics dashboard continuously provides actionable insight for easy identification of issues and opportunities for optimising tenant comfort.

3.4 Smart Washroom

Incorporating IoT technologies at washrooms can empower facilities managers making evidence-based decisions to maintain high level of hygiene and cleanliness in prevention of spreading coronavirus and different kinds of disease. Real-time foot traffic data can be monitored for better management of washroom usage by diverting toilet users to vacant washrooms, shortening queue times and increasing overall efficiency.

Reliable level detection assesses accurate level data from containers of the washroom consumables which enables enhanced facility management for timely replenishment and effective inventory management. Automatic fall detection can alert facility management personnel of emergencies to ensure user safety. Any odour (i.e., ammonia) or smoke (smoke particles) build-up can be promptly detected for quick improvement of indoor air quality. Control settings of toilet facilities (i.e., ventilation system, air-conditioner, air-filtering, and lighting etc.) can be adjusted according to the changing conditions in washrooms, creating the best possible ambience at minimum power consumption. The app installed at users' mobile devices can display real-time information of cubicle and urinal vacancies, remaining level of consumables and IEQ data (i.e., CO_2, PM2.5, temperature, humidity). The app can be equipped with instant feedback tools for users to provide responses immediately, enhancing customer engagement and retention. Smart washrooms also bring improvements in efficiency and productivity, achieving optimal user experience and customer satisfaction.

Fig. 6 - IoT Sensors installed at Washrooms

Fig. 7 - Smart Washroom's Interface for Facility Management

Fig. 8 - Smart Washroom's Interface for Washroom Users

3.5 Video Anayltics

With AI-based video analytics, large volumes of unstructured video data collected from multiple targeted locations can be transformed into intelligence and actionable insights. It covers a wide range of applications beyond crime prevention and accident management. By leveraging video analytics technologies, customer demographics and their shopping behaviours can be captured for further analysis in real-time. The function of crowd detection monitors occupancy levels within a given space, triggering alarms when allowed number of people is exceeded. The advanced people tracking function, which utilises facial recognition technology can, not only detect movement of people in both indoor and outdoor environments, but also instantly identify and verify authorised personnel by facial attributes. The left object detection feature identifies the presence of unattended static objects. Real-time notifications and alarms are generated for security staff to provide responsive actions. Video analytics is ideal for places with high traffic and population density to ensure crowd security, engage shoppers and enhance operation efficiency.

3.6 Indoor Positioning Analytics

Indoor positioning system locates objects, tracks motion patterns, and measures time spent in each predetermined zone via mobile devices (i.e., tags and beacons) using IoT technologies. Real-time locating system (RTLS) provides instant visibility on operational processes and handling capacity which helps improve overall performance for reduced search time, more efficient work order tracking, and optimised utilisation rate. RTLS is applicable to the healthcare sector, the system collects location data through tags and base stations for asset / personnel tracking and safety management. RTLS helps improve operational efficiency and medical services.

4. DATA VISUALISATION

Advanced visualisation integrated with big data analytics enables users to interact with the relevant data, allowing them to see a summary of big pictures and intricate details at the same time. A picture is worth a thousand words while a visual is worth thousands of datasets. With machine learning, discovering hidden patterns in data helps users instantly gain deeper insights of energy-saving opportunities.

Fig. 9 - Data Visualisation

4.1 Digital Twin

Before going into details, it is important not to confuse Building Information Modelling (BIM) with Digital Twin Technology. BIM is designed to enable real-time collaboration and visualisation during design and construction, not operation and maintenance. On the contrary, the intent of digital twin is to manage buildings' daily operation. Every data collected by sensors and devices is fed to the digital twin for information modelling to create a live digital model of a physical building. Replacing design data / assumptions, the operational model updates and responds in real-time to reflect the actual performance of each building system. Facility managers can gain insights on the current state of the building performance and make evidence-based decisions in adjusting the control settings to optimise building performance.

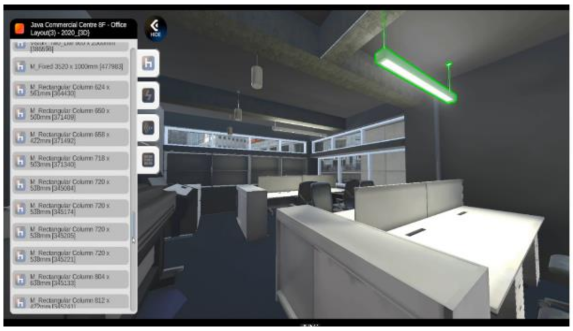

Fig. 10 - Digital Twin

4.2 Virtual Reality and Augmented Reality

Maintaining hidden and hard-to-access system components has always been a challenge for facility management. Incorporating the data from BIM and digital twin, the three-dimensional renderings of facilities create realistic scenarios of internal design with detailed information for each piece of equipment, providing immediate access to all the user manuals, training materials, and maintenance history.

5. CONCLUSION

The architecture of applying big data analytics in buildings can be broadly categorised into three components. IoT network is the fundamental element that enables efficient data collection from numerous sources. The unique characteristics of each LPWAN technology (NB-IoT, LoRaWAN, and Sigfox) provide the suitable IoT connectivity based on individual requirements. By applying big data analytics techniques, data can be analysed and adopted in the areas of energy saving, facility management, security, and health & safety, streamlining operation and building performance. The results of data analytics can be easily interpreted through interactive visualisation in real-time for identifying patterns and exploring business insights. Advanced technologies are reshaping the ways we operate in the built environment. We should be prepared ourselves and leverage big data analytics to enhance building performance.

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Paper No. 9

SMART OPERATIONS & MAINTENANCE OF MTR ROLLING STOCK

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SMART OPERATIONS & MAINTENANCE OF MTR ROLLING STOCK

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ABSTRACT

Mass Transit Railway (MTR), serving as a backbone of Hong Kong Transport Operation to our community, has been launching a series of transformation process, in which Rolling Stock Maintenance Department of MTR Corporation has recently put forward a number of pilot projects through emerging technologies and innovations to drive new ways of maintenance of our railway assets in a sustainable and efficient manners. With key foci on robotics and automation, data digitalization and process optimization, many applications and initiatives are now in place and being rolled out to improve staff working environment, work quality, effectiveness and efficiency of rolling stock maintenance & overhaul through Artificial Intelligence (AI) maintenance planning, robotic routine inspection / maintenance processes, real-time equipment health monitoring and digitalization of maintenance and overhaul data and process.

This paper describes MTR's experience of transforming traditional ways of rolling stock maintenance by exploitation of various state-of-the-art technologies to overwhelm new challenges.

1. INTRODUCTION

Hong Kong railway network has extended over recent decades and rolling stock fleet has been increasing over the years which comprises over 10 train types and 2,300 train cars. The volume and complexity of rolling stock maintenance activities ranging from backend maintenance planning, depot operations, routine inspection / maintenance and overhaul are significantly increased alongside from the network expansion to cope with fast-changing operational needs and meet higher expectation of safety, train reliability and operational efficiency.

Emerging AI technologies are introduced to transform the ways of maintenance and operations planning. The preparation of depot's daily train dispatch plan is no longer straight-forward task to duty engineers because they need to thoroughly assess / consider increasing number of operational rules, restrictions and requirement in more complex train timetable and maintenance plans. Human intelligence not only takes longer time to comprehend different operational rules but also has difficulty to optimize the train dispatch plan that has impact to far-future mileage-based train utilization, i.e. actual running mileage / allowable running mileage between overhaul. Hence, a pilot Smart Train Planning (STP) system powered by AI algorithm is developed in MTR to make fast decision for Rolling Stock Fleet Maintenance Management towards (1) the best optimal depot's daily train dispatch plan that complies all operational rules and restrictions and (2) optimizing train utilization between overhaul by regulating train to certain mileages accurately.

Delivery of routine maintenance and overhaul of rolling stock assets require considerable resources to conduct a vast volume of inspections, measurements and removal and re-installation of major equipment for overhaul. Some repetitive and heavy duty maintenance tasks such as cleaning and handling of bulky and weighty rolling stock equipment have high potentials to be automated to free up skillful staff to perform more complex tasks and shorten cycle time of overhaul. Several robotic systems and latest Automated Guide Vehicle (AGV) equipped with autonomous control capabilities have been recently introduced in our depots / workshops to automate some maintenance tasks in order to improve safety, deliver consistently high quality and increase productivity.

While delivering world-class train service is our prime objective, MTR Rolling Stock has also launched a number of projects collaboratively with different vendors with an aim at further enhancing our train reliability by online monitoring of equipment condition and using big data analytic in order to make our maintenance smarter and in a more proactive and predictive manner. In the era of big data and rapid advancement of image recognition capability, MTR has introduced state-of-the-art data analytic tools and equipment to store and analyze large volume of operational and condition data of rolling stock equipment such as bearing temperature, train vibration and video analytic of roof-mounted pantograph collected from several newly built monitoring systems. Compared to traditional Condition Based Maintenance (CBM) which only consider small volume of measurement data, "big data" collected from increasing quantities of monitoring systems and expanding railway networks significantly increase the sensitivity and accuracy of diagnosis and predict train equipment abnormality. This is crucial to achieve breakthrough in asset reliability in a more complex railway network.

2. SMART TRAIN PLANNING (STP)

Overhaul of trains can be planned far before actual overhaul mileage limit to stagger the schedule of train overhaul in order to eliminate the risk of having trains overdue for scheduled maintenance / equipment overhaul and maintain train availability for service.

Nevertheless, it demands tremendous effort in manually monitoring and regulating train deployment throughout the period and undoubtedly scheduling for completion of necessary equipment overhaul is usually advanced to prevent from overdue, i.e. unable to fully optimize maintenance resources. To achieve high operational efficiency without compromising high train availability, a mileage control mechanism was developed in MTR rolling stock maintenance department. In the mechanism, the maintenance planning team regularly prepared train list to suggest depot engineers to consider assignment of dedicated long and short running paths to target trainsets when they prepared daily train dispatch plan in order to enhance the utilization of overhaul mileage limit of trains before planned overhaul date. Higher utilization means less quantity of heavy overhaul and lower maintenance cost for the same planned train mileage over the fleet.

Nevertheless, there was a challenge that the mileage utilization rate could not be maintained at its high level consistently due to more complicated service requirements and constraints arising from various types of maintenance needs which at the end hindered the effectiveness of the preparation of daily train dispatch in accordance with the laid down plan simply by human intelligence.

A pilot IT system, named as Smart Train Planning (STP), was therefore proposed to automate the preparation and optimization of daily train dispatch plan by AI algorithm in order to achieve high train availability and operational excellence in a more complex operational environment.

STP is an AI based platform which has the advantage of low infrastructure cost and strong data computing and analytic power. STP comprises mileage prediction model and train assignment model (Figure 1). With the application of big data platform and AI algorithm, data mining of a massive set of train operational data including train number, train type, timetable data, train path mileage data, maintenance jobs, depot track occupation data is conducted to keep track of train specific information which is useful for development of machine-learning mileage prediction model. The model is used to make long range forecast of mileages of all trains based on daily operational data fed from existing train service data storage system.

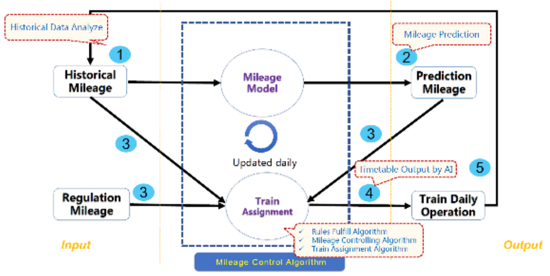

Fig. 1 - System Architecture of STP

Train assignment model is another machine-learning model in STP which is developed to prepare daily train dispatch plan. With the use of AI algorithm, the model controls mileage of each train to achieve high mileage utilization rate before overhaul by selecting the running path in the daily train timetable that has the most appropriate length for each train with consideration of the difference between forecast of accumulated mileage fed by mileage forecast model and regulation mileage which targets high mileage utilization rate (Figure 2). Beside mileage control, rules and regulations algorithm for depot operations are also embedded in this model to prioritize and set operational restrictions in the output of daily train dispatch plan. There are currently more than 27 operation rules and limitations such as planned preventive maintenance activities, wheel turning and modifications of train after morning peak, avoidance of conflict of location of train stabling in the depot and outbound direction of the selected running path, limitation of wake-up time at some stabling locations in the depot to avoid tripping of depot power system.

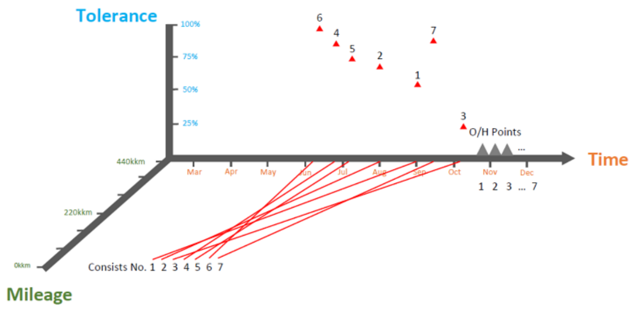

Fig. 2a – As-is Mileage Utilization Rate

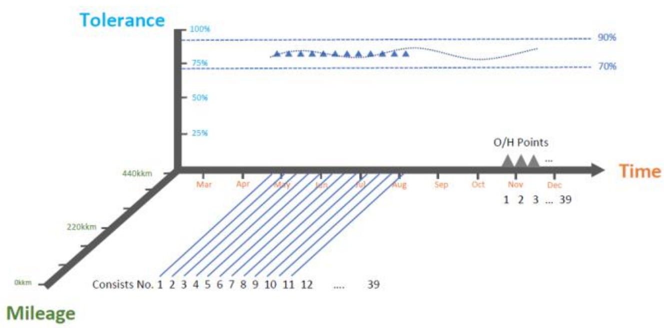

Fig. 2b – Target Mileage Utilization Rate using STP

Fig. 2c – Mileage Pulling of a Train that Lags Behind Mileage Target using STP

STP targets to increase mileage utilization rate from the figure of 50% to 80% in coming 3 years with due consideration of train availability for each operating line, shorten the time and reduce effort of depot engineer to prepare daily train dispatch plan. The increase of mileage utilization rate from 50% to 80% represents additional 8 weeks of service of each train between overhaul and reduction of maintenance cost. More than that, STP also improves the quality of train dispatch plan by comprehensively learn and consider increasing number of factors and restrictions and give consistent and standardized output without human intervention. More restrictions can be applied more easily in the daily train dispatch plan to address concerns from the passengers, public and operating staff. For example, assignment of train type that has higher capacity to dedicated train path that runs along busiest section in a railway line at peak hour can be achieved with considering the need of maintenance schedule and mileage control.

The STP pilot has been already in use at our Kowloon Bay Depot (KBD) which is responsible for maintenance and deployment of Kwun Tong Line trains and some Tseung Kwan O Line trains. It is also being rolled out to other depots in urban line of MTR as some trains are exchanged for use within these 4 depots. STP should enable wider scope of long-range mileage control of total 128 nos of trains managed by these 4 depots through assignment of more options of running paths in the timetable of 4 railway lines to achieve more savings and higher train availability. These tasks cannot be implemented by even daily manual working without the use of AI technology. Moreover, the use of STP will also be extended to Tuen Ma Line which is the longest route in MTR and consists of 2 depots, 1 stabling siding and total ultimately up to 65 trains serving east-west corridor. With the opportunity of STP Project, the yard sheet in each depot is also digitalized and linked with STP database to replace the traditional display method to avoid duplicated manual update of yard sheet information and ensure display of consistent information (Figure 3).

Fig. 3a – Yard Sheet in STP

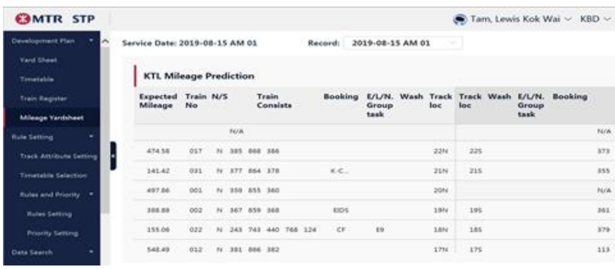

Fig. 3b – Milage Prediction Result shown in STP

3. ROBOTIC AND AUTOMATION

Full automation of the complete maintenance process is not bound to be lean. Improper application of robotic automation may also have adverse impact on productivity due to extra waste such as space and time. Therefore, a holistic review had held to prudently look into the complete maintenance process from planning to execution in details with tools such as Value Stream Mapping (VSM) to identify appropriate cases of robotic application that can reduce process time / efficiency and shorten cycle time to meet increased maintenance demands, enhance quality of critical tasks as well as improve workplace safety whereas balancing the cost of capital investment and extra space requirement.

Air-Conditioning Unit (ACU) Robotic Cleaning System (Figure 4a), one of several pilot robotic projects, was newly developed and installed in MTR Pat Heung Depot to conduct deep cleaning of trainborne ACUs serving 2 train types running at Tuen Ma Line, namely SP and TML-C trains. Deep cleaning of ACU in overhaul is crucial because accumulation of dirt in ACU heat exchangers (i.e. condenser coil and evaporator coil) will affect ACU's cooling performance, energy efficiency and reliability due to triggering of high and low pressure protection if not completely cleaned at overhaul opportunity. ACU Robotic Cleaning System consists of two robotic arms which are programmed to automatically move along preset paths and spray pressurized hot water to clean saloon ACUs of two types of passenger trains in Tuen Ma Line. The parameters of paths including route designs and cleaning sequence, running speeds and spraying time at different points along the route, water spray temperature and pressure, the points of detergent application along the routes are carefully considered according to our maintenance know-how and on-site verification in order to configure the most optimal cleaning cycle for each type of ACU. Compared to traditional way of working which deep cleaning was carried out solely by maintenance staff manually with hand-held pressurized water spray, the consistency and quality of deep cleaning of ACU is greatly enhanced as robotic arm has higher repeatability and accuracy to run the designed cleaning cycles (Figure 4b). Moreover, robotic arms have high flexibility to change cleaning cycles to cater for two types of ACUs which have different designs. The cycle time and manhour of deep-cleaning of 1 no. of ACU are also reduced by 12.5% and 50% respectively. This increases the facility capacity to meet increased new demand of 300 nos. of ACU deep cleaning per year due to opening of Tuen Ma Line and increase of train mileage. The maintenance staff is also benefited from workplace improvement brought by the new robotic cleaning system as they can spend less time on repetitive and tedious cleaning tasks and get rid of irritating detergents and long-time working in dirty and humid cleaning bay especially in hot summer. With the use of the robotic system, high-skilled maintenance staff can be withdrawn from cleaning tasks and deployed to carry out more skill-demanding tasks to facilitate shortening cycle time of maintenance to meet increased demand.

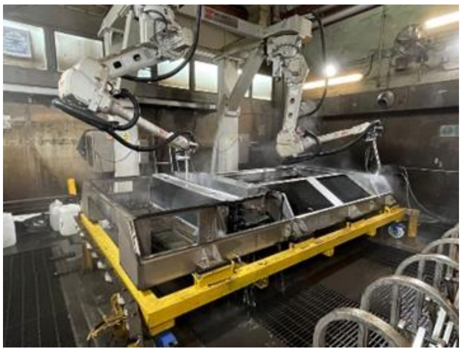

Fig. 4a – Photo of ACU Robotic Cleaning System

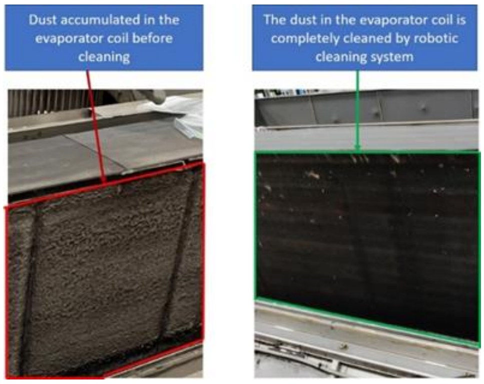

Fig. 4b – Photos showing Before and After Deep Cleaning of ACU Evaporator Coil by Robotic System

In the VSM of rolling stock maintenance process, manual handling and transportation have also accounted for large proportion of resources among the seven deadly "TIMWOOD" wastes defined in lean manufacturing. Moreover, time was wasted for waiting materials to proceed some maintenance activities due to fully occupied lifting appliance and forklift trunks. Although re-layout of maintenance workshop was conducted to reduce the time and path for transportation, there were limitations that relocation of some major plants and facilities was not technically and financially viable because complex civil and building service utilities modification such as drainage was needed. Addition of lifting appliance such as overhead crane faced the same headache as re-layout.

With the advancement of light detection and ranging (LIDAR) technology and simultaneous localization and mapping (SLAM) algorithm, AGV technologies have become smarter in recent years. Compared to traditional AGV that MTR did trial previously, SLAM-based AGV no longer needs physical infrastructure such as pole reflectors, magnetic strips on the floor, wiring and sensors fixed on the ground to perform localization and navigation. The smart SLAM-based AGV system has short set-up time as no infrastructure is needed. It also has high flexibility to add more or change transportation routes easily by simple software programming. Moreover, SLAM-based AGV is intelligent to adjust routes and bypass obstacle autonomously when it detects obstacle in the original planned route, which works differently when compared with the fixed path feature of traditional AGV. MTR assessed that the unique feature of SLAM-based AGV specifically suited the dynamically changing and compact environment of rolling stock depots and therefore kicked off another pilot project to introduce 3 nos of SLAM-based AGV in 3 workshops for automatic handling and transportation of rolling stock equipment and maintenance material (Figures 5a and 5b).

Two types of AGV were used for different applications, e.g towing and lifting, 2 nos. of hook-type SLAM-based AGV with towing payload of 500kg were introduced and they had the advantage of high flexibility to transport goods carried by various types of trollies by simply parking in front of the trolley, followed by coupling and moving, vice versa. Hook-type AGVs have been used to transport train equipment such as brake caliper sub-components, bogie dampers, linear fans, and maintenance materials. Besides hook-type AGV, 1 no of lift-type SLAM-based AGV with payload of 500kg was also introduced and it had the advantage of space saving because it was designed to park underneath the goods followed by lift and move. Although this lift-type AGV was originally designed for lifting standard ISO standard pallet and a maintenance staff needed to load or unload the goods to a standard rack for AGV to handle, our engineers specifically designed a mobile workbench which had large legroom for lift-type AGV to run underneath followed by lift up and move. The mobile workbench was also designed to contain the train's equipment, workpiece and tools from end to end of the maintenance process so that the maintenance staff no longer need to load or unload the goods to a standard rack for handling by AGV. The lift-type AGV has been used to transport a tray of dampers, traction motor stators and rotors, gear couplings and maintenance material (Figures 5c and 5d).

The SLAM-based AGV pilot project started in January 2021 and the average monthly running mileage is 30km per AGV, representing around 60 trips per AGV per month. This figure has gradually increased over recent months as more application cases are being developed. It is observed that waste time for transportation by high-skilled staff and waiting time for material handling equipment can be reduced with the use of AGV.

Fig. 5a – Hook-type SLAM-based AGV (Left)
Fig. 5b - Lift-type SLAM-based AGV (Right)

Fig. 5c – System Architecture of AGV System

Fig. 5d – Area of AGV Application in Pat Heung Depot

Robotics and automation are also deployed for enhancement of quality on new components through endurance testing. An intelligent relay testing system (Figure 6) at MTR Kowloon Bay Depot is under development with an aim at carrying out endurance test of various kinds of relays automatically with a capacity of up to 400 nos. of trainborne plug-in relay per shift using flexible and speedy robotic arm, image recognition by high definition 3D camera and accurate relay testers. Another robotic system named as Underframe Inspection Robot is installed at MTR Pat Heung Depot (Figure 6b). Equipped with high definition 3D camera, the system performs multi-angle shooting of train underframe with automated robotic arms to scan the underframe of trains with high efficiency using image recognition and AI to check for abnormalities under trains such as wear and tear of mechanical parts and foreign objects. If abnormalities are found, the system provides alert for subsequent follow-up.


Fig. 6a – The Intelligent Relay Testing System (Left)
Fig. 6b - Underframe Inspection Robot (Right)

The application of robotic systems on frequent deep cleaning with strong disinfectants have helped MTR and passengers fight against COVID-19 which has led to more demanding hygiene requirement. Vapourized Hydrogen Peroxide Robot (Figure 7a) has been used to sterilize saloon of rolling stocks regularly and on-demand when passenger's vomit case happened in saloon. Automatic air filter cleaning machines (Figure 7b) have also been installed in various depots to clean washable ACU's filter of rolling stocks. In the MTR fleet, there are more than 4600 nos. of ACU of rolling stocks in which large proportion of ACUs adopt washable filters. This type of automation helps free up highly-skilled staff to conduct more valuable task instead of monotonous and repetitive tasks to reduce waste.

Fig. 7a – Vapourized Hydrogen Peroxide Robot

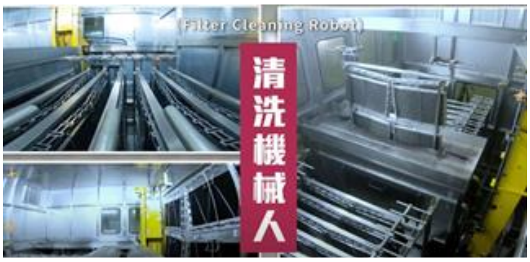

Fig. 7b – Automatic Air Filter Cleaning Machines

Moving ahead, there is a number of robotic projects under development and will be rolled out by stages so as to enhance our maintenance efficiency on one hand and at the same time to better provide working environment for staff and deliver customer service to our community.

4. BIG DATA AND REAL-TIME EQUIPMENT HEALTH MONITORING

The concept of Maintenance 4.0 is vigorously advocated in maintenance, repair and overhaul (MRO) activities of different industries in recent years. Although there is no clear definition of Maintenance 4.0, it generally regarded as an application of Industry 4.0 in MRO to make use of cutting edge smart manufacturing technologies to collect and analyze vast volume of data from interconnected sensors in real-time health monitoring system of asset followed by analyze to drive further intelligent actions with the objective of maximizing asset on time with assurance of quality by eliminating unplanned reactive maintenance and reducing waste with lean principles. MTR Data Studio was set up in 2019 to collect and analyse big data collected from operations which include data from various rolling stock real-time health monitoring systems, paving the way to implement Maintenance 4.0 in rolling stock assets.

MTR previously introduced real-time temperature monitoring system of axle bearings of some types of rolling stocks in various railway lines in which temperature data of sensors were transmitted to depots via active Radio Frequency Identification (RFID). Moreover, the temperature of main transformers and traction motor bearings of some train types in MTR East Rail Line is also being monitored in the same ways. The RFID temperature monitoring systems (Figures 8a and 8b) enabled early detection of premature failure of axle bearing, traction motor bearing and the armature shaft and traction power system.

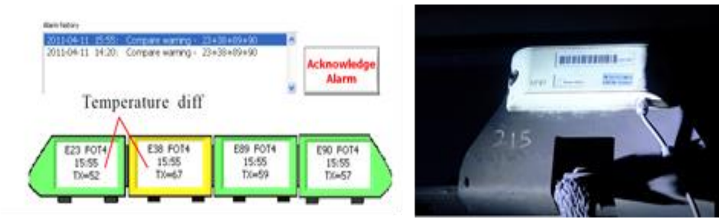

Fig. 8a – RFID Real-time Temperature Monitoring System of Train Equipment

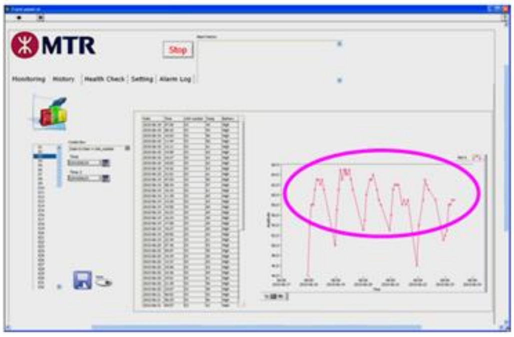

Fig. 8b – RFID Real-time Temperature Monitoring System Displayed in Control Centre Equipment

Moving toward Maintenance 4.0 from 3.0, MTR not only adopts real-time monitoring and traditional CBM techniques to monitor the actual condition of rolling stock asset to decide maintenance need and give alert but also starts storage and analysis of data with cutting edge machine-learning data science software to find hidden pattern and predict the failure in advance. Accurate prediction of failure and asset deterioration condition allows MTR to swiftly and holistically carry out a set of maintenance activities such as part ordering, maintenance window scheduling, man-power planning early before outbreak of failure. This greatly reduces unplanned down and increases efficiency of maintenance. MTR Data Studio has more than 30 tools to perform data analysis. Various graphs and index show results of data analysis in dashboards for maintenance staff to visually check (Figure 9a). Train's axle bearing temperature data is one of the scope of analysis by MTR Data Studio. Previously, a brake issue of a Light Rail Vehicle (LRV) was identified successfully by data analysis of axle bearing temperature and the LRV was withdrawn from mainline service timely without affecting passengers (Figure 9b).

Fig. 9a – Dashboard in MTR Data Studio

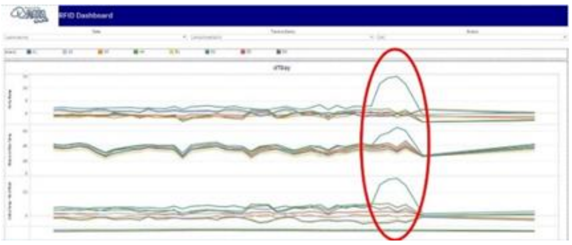

Fig. 9b – Failure Identified Analysis of Axle Bearing Temperature in MTR Data Studio

Another system named as Smart Train Roof and Pantograph Monitoring System (Figure 10) was installed and under trial at Tuen Ma Line, which automatically captures a complete image of the train pantograph and train roof and uses image recognition technology to identify potential anomalies and alert maintenance staff to prevent further escalation. The system is capable of capturing images of equipment of each train running at speeds of up to 135 km/h. Defect such as carbon strip damage, missing pantograph horn, disorientation, deformation of pantograph and train roof equipment, missing screws and external objects, etc. could be recognized by software image processing technique. The system is designed to identify each passing train by image processing technique without the use of RFID. With the use of big data technology, a database was established by the system to match each pantograph to the train consist for trend analysis.

Fig. 10a – Cameras Installed at a location of Tuen Ma Line Mainline

Fig. 10b – Image sent to Data Studio from Smart Train Roof and Pantograph Monitoring System

The development of health monitoring system of R-train, the newest train in East Rail Line is under study (Figure 11). In this project, it is targeted to transmit all data recorded by on-board Train Management System (TMS) of all R-trains to database on real-time basis via cellular network. With the vast volume of operation data, it is expected that machine learning data analytic tools give prediction of R-train equipment health condition such that maintenance staff can carry out predictive maintenance in planned downtime efficiently. Moreover, it is prospected that the knowledge learnt from "big data" can be used to build up digital twin of R-train which is very useful to know how the condition of R-train changes in a variety of conditions such as increase of passenger load, increase of average train speed, lowering the target temperature of trainborne ACU, lengthening the target life of some trainborne equipment, etc. This eventually helps optimization of R-train configuration in response to dynamically changing operation environment and provides comprehensive analysis for deciding the most appropriate asset management strategy.

Fig. 11 – Diagrammatic Dashboard of Health Monitoring System of R-train

5. CONCLUSION

Rolling Stock Maintenance of MTR has evolved into new technologies at various aspects with an aim at further enhancing maintenance efficiency and at the same to provide better customer service. It transforms into new ways of working initially through pilot projects and now subsequently expanding into different applications.

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Paper No. 10

SMART MOBILITY - APPLICATION OF AUTOMATED CAR PARKING SYSTEM IN HONG KONG

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ABSTRACT
The Automated Parking System (APS) is one of the approaches to increase the parking spaces with limited piece of land. Along with well-developed mechanical tridimensional parking lifting system technologies, fully automated intelligent parking system is being introduced in Hong Kong.

Integrating intelligent parking technologies and E&M system is a trend in local market. EMSD (Electrical and Mechanical Services Department) and TD (Transport Department) have been initiating some pilot projects in the past few years. This paper will introduce different types of APS and share the project implementation experience in Hong Kong.

1. INTRODUCTION

"Smart Mobility" has been a hot issue in Hong Kong in recent years. One of the key features of Smart Mobility is to alleviate the problem of insufficient public parking spaces through the application of technology. Aligning with the HKSAR Government's Smart City Blueprint 2.0 for Hong Kong, the Automatic Parking System (APS) is able to address the issue of land shortage and limited supply of parking spaces to offer a new solution to enhance long-term sustainability for Hong Kong.

APS is a mechanical system designed to increase the supply of car park spaces in limited land resources. APS provides parking for cars on multiple levels stacked vertically to maximize the number of parking spaces while minimizing land usage. APS utilizes a mechanical system to transfer vehicles to and from the parking spaces in order to eliminate much of the spaces wasted in multi-story parking building. While comparing to the traditional car park, APS is able to increase 30% to 160% parking spaces under the same area subject to the system configuration.

EMSD introduced the first pilot project on APS at its Headquarters in 2018 and published the "Guidelines for Implementing Mechanized Vehicle Parking Systems" (MVPS) to provide the requirements for implementation and regulatory measures from design, installation, operation, and maintenance of MVPSs.

Another project in Tsuen Wan initiated by the TD consists of not less than 75 nos. automated parking spaces. In addition, there are 6 more locations selected for the public car park in Tai Po, Tseung Kwan O, San Po Kong, Sham Shui Po, Chai Wan and Sheung Wan to be constructed in the coming few years.

The application of APS also brings advantages on reducing the land costs and time for new buildings and existing premises. APS has shown an enhancement in road safety and environmental performance as well.

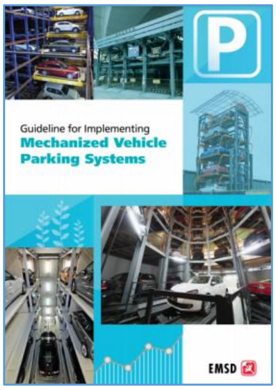

Fig. 1 - Guideline for Implementing Mechanical Vehicle Parking Systems

2. AUTOMATIC PARKING SYSTEM (APS) AT A GLANCE

2.1 Background

APS has different types of designs to suit various types of buildings and car parks. There are generally 6 standard types of Automated Car Parking System, including:

a) Simple Lifting (PJS);
b) Vertical Circulation (PCX);
c) Puzzle Type (PSH);
d) Tower Type (PCS);
e) Vertical Lifting Horizontal Sliding (VLHS); and,
f) Automated Guided Vehicle (AGV).

2.2 Different Types of APS

In Hong Kong, it is common to see Double-Deck Car Park which is one of the Simple Lifting (PJS) type. Double-Deck Car Park is easy to install with a simple structure design in the existing building. The Double-Deck Car Park has two parking spaces, only double layers can be installed. The vehicle at the lower level must be driven away before accessing the upper level. It is used to raise cars that do not pass through any floor, and the height of travel does not exceed 3.5m. The user or designer shall refer to the EMSD Guide to Safety on Double-Deck Car Park.

Fig. 2 - Double-Deck Car Park (PJS)

Vertical Circulation (PCX) type APS can be designed within the building or designed separately. Ferris-wheel-like operation only requires a small footprint. A robust structural design is needed to cater for the unbalanced situation; however, a longer time is required to retrieve the vehicle. Also, higher power consumption is required for this PCX.

Fig. 3 - Vertical Circulation Type (PCX)

For Puzzle Type (PSH) APS, vehicles will be maneuvered vertically and horizontally to fill up the system. PSH is able to build up to 8 layers. It can be easily configured and customized to any premises and open ground carparks as a fully automatic independent system. PSH has a simple design that is more desirable to suit most architectural layouts, especially for the peak hour pattern of general commercial and institutional buildings.

Fig. 4 - Puzzle Type (PSH)

For Tower Type (PCS) APS, vehicles will be maneuvered via a vertical shaft in the centre and then parked horizontally at different levels. The design is very compact to save space which can be built underground. However, it takes a longer time to retrieve the vehicles.

Fig. 5 - Tower Type (PCS)

For Vertical Lifting Horizontal Sliding (VLHS) type APS, the running speed is fast. VLHS is the type that moves the vehicle with shuttle and shifter, parks and retrieves the vehicle via platform’s transfer cabins.

VLHS provides high efficiency of space usage and only requires one-third of the conventional parking space. The high speed eliminates traffic jam even in rush hours. VLHS is user-friendly and users can retrieve the vehicle easily which saves time and effort. The wide varieties of storage modes and transfer vehicles are suitable for all kinds of vehicles to park. Thus, VLHS is widely adapted to different type of buildings such as airport, railway stations, stadiums, office buildings and etc., which is one of the most commonly adopted APS in the world.

Fig. 6 - Vertical Lifting Horizontal Sliding (VLHS)

Automated Guided Vehicle (AGV) - Users can park their vehicles in the designated transfer cabins and then the AGV will proceed with the parking automatically. AGV helps users reduce time looking for vacant parking spaces and eliminate accidents in the car park. Design parameter of floor requirement is needed to consider on a finished floor surface (hardness, smoothness, inclination etc.) in the early design stage to minimize the rework to the floor.

Fig. 7 - Automated Guided Vehicle with Pallet (AGV)

A comparision table on different types of APS is shown in Table 1.

2.3 General Requirements for Adoption of APS

2.3.1 Statutory requirements

Before the installation and operation of different APS, statutory requirements are necessary for implementation of these projects in Hong Kong. APS is a mechanical plant with a power-operated mechanism for transferring a vehicle to the designated parking space. Thus, APS is regarded as a "lift" installation and subject to the regulatory control of the Lifts and Escalators Ordinance (the LEO), Cap. 618. Only Registered Lift Contractors are allowed to install, repair and maintain, alter or demolish APS.

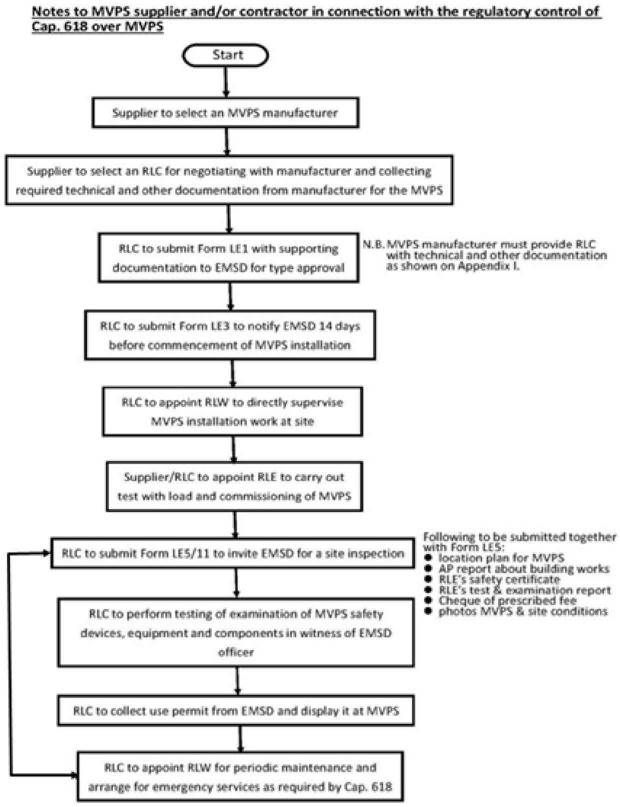

Fig. 8 - Regulatory Control of Cap. 618

2.3.2 Type approval

Type approval is meant to assess a particular type of products on the fulfilment of regulatory, technical and safety requirements for its general implementation and applications. EMSD will review the system design, principles in relation to sizing of components, control logics, safeguards, assurance of quality, the sufficiency of instructions concerning safety, installation, commissioning and testing, examination, repair and maintenance, emergency operation, availability of technical support and spare parts, etc. for the APS.

According to the "Guideline for Implementing Mechanized Vehicle Parking Systems", APS is required to meet the mechanical safety and fire services requirements. For example, audio and visual alert, overload protection and safety mechanism shall be installed. The light intensity, motorized gate, etc. have a standard for APS. In respect to the open-ground MVPS, the fire service requirements have to be fulfilled and complied with the Code of Practice for Minimum Fire Service Installations and Equipment.

Advice and requirements by Fire Service Department shall be included in the type approval application. EMSD relays on the fire safety-related submissions to FSD for review and provision of comments and advice collectively on fire and mechanical safety on the MVPS type approval application.

Type	Pros	Cons	Typical	Average Retrieval Time
PJS	- Simple - low cost	- Not smart, need to move away lower car to retrieve the upper car	- Standalone installation	Minimal
PCX	- Small footprint	- Mechanically unstable when in operation - Higher energy consumption - Cannot support EV	- Small scale (<14 spaces)	3 mins
PSH	- Simple - Suitable for existing carparks - High retrieval efficiency - Easy installation/ maintenance - Low headroom requirement	- Smaller parking area (harder to park the car esp. reverse parking)	- All scale - residential/ commercial area with peak hour pattern	1 min
PCS	- Simple - Small footprint - High spatial utilization efficiency	- For underground design, need to fulfill many statutory requirements	- Medium scale (50 spaces)	2 mins
VLHS	- High efficiency and redundancy (especially for multi-entrances design)	- For underground design, need to fulfill many statutory requirements	- Large scale (100-500 spaces)	2 mins
AGV	- High convenience	- Expensive (initial/maintenance cost) - Need special requirements on finished floor surface (hardness, smoothness, inclination)		2 - 4 mins

Table 1 - Comparison of Different Types of APS

2.3.3 Operation & maintenance

Use Permit is issued after the testing and examination of MVPS safety devices, equipment, and components. Under the Lift and Escalator Ordinance (Cap 618), periodic maintenance works is required for APS. Only registered lift contractors are allowed to carry out the periodic maintenance works and any alter of APS to ensure the MVPS or any of its associated equipment or machinery in a safe working order, including any inspection, cleaning, oiling, adjusting, repair, replace-ment and alteration of MVPS.

For the provision of the maintenance services, the following aspects shall be included:

As per the Code of Practice for Lift Works and Escalator Works under Lifts and Escalators Ordinance (Cap. 618), the periodic maintenance, periodic examination and test shall be carried out and keep the APS and its associated equipment or machinery in a safe working order. Such periodic maintenance, examination and test to be carried by Registered Lift Engineer and Registered Lift Worker will be:

- Monthly maintenance
- Yearly maintenance (including renewal of use permit)
- 5-year maintenance (including full load test)

Proper record and logbook of the operation and maintenance activities will be taken as record as required.

APS is a standalone system to increase the parking spaces. Hence, integration with car park management system is recommended for maintaining the system efficiency and safety.

2.3.4 Other accessories and system design

a) Online pre-booking system – it can improve the driving experience and enhance the external traffic flow. The user can check the vacant parking space information in the online booking system. It saves the time of searching and queuing for parking.

b) Car parking management system – it is not only used for access control, but also for assign of the designated parking space and transfer cabin. With the aid of car size and weight measurement system at the entrance of carpark, the cars exceeding the limit are diverted to non-APS parking spaces. It can reduce the loads on the APS with the car size and weight measurement system. It also improves the operation efficiency.

c) Transfer cabin – it is equipped with sensing and protection devices and CCTVs. The kiosk outside at the transfer cabin for user's declaration of parking. Dual confirmation can ensure no kids or pets leaving in the car and driver press the confirmation button to complete the parking process.

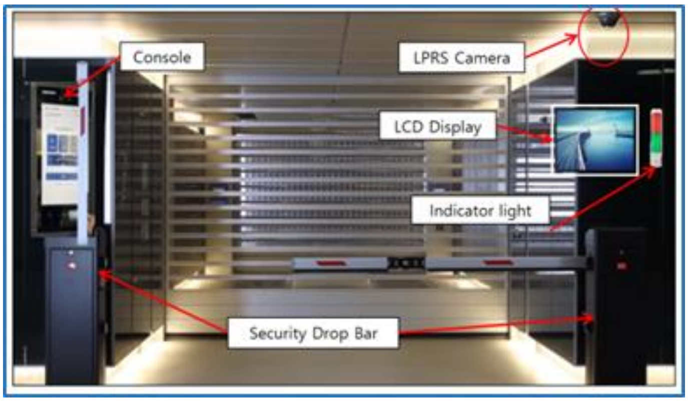

Fig. 8a - Example of Kiosk and Monitoring Devices Outside at the Transfer Cabin

Fig. 8b - Example of Transfer Cabin Inside Equipped with Sensing and Protection Devices and CCTVs

d) Man-Machine separation - it will certainly enhance the safety of driver and passenger.

During the operation of APS, safety and performance can be secured and maintained with the integration of APS and car park management system.

2.4 Case Sharing

The pilot APS project at EMSD was completed in 2019, which is a puzzle type at open ground. In this project, 3 layers and 13 nos. of parking spaces were designed for originally 1-layer ground carpark. This project has increased the total number of car parking spaces by 160% (from 5 nos. to 13 nos.). The car size and weight limit of this APS suit most of the types of private cars in the market (5,200L x 2,000W x 2,000H, 2,500 kg). The power requirement is 3-phase / 20A, which suits general carparks in Hong Kong. In general, users can park and retrieve vehicles within 2 minutes. The APS helps reduce parking time and increase the no. of the parking lot on the same land usage.

Fig. 9 - APS Project at EMSD Headquarters

The steps of implementation:

- Under the Lift and Escalator Ordinance (Cap. 618), type approval for a 3-layer puzzle stacking system is required prior to general application.
- The design of the puzzle stacking system shall comply with BS EN 14010:2003+A1:2009, or equivalent international safety standards.
- Registered Structural Engineer is required to design, calculate and review the structural study of the APS.
- Fire safety installations are required to be approved by Fire Service Department.
- Testing and Commissioning - the tests are divided into structural, mechanical and electrical. After the construction works, electrical test, dynamic test, safety test and etc. are scheduled and thoroughly examined by Registered Lift Engineer.
- Use Permit for the APS shall be applied after the acceptance of examination tests and relevant supplementary document.

After the completion of this pilot project, EMSD has taken this experience as a reference to compile the “Guidelines for Implementing Mechanized Vehicle Parking Systems” to provide the requirements for implementation and regulatory measures from design, installation, operation, and maintenance of MVPSs.

3. CONCLUSION

APS is the promising solution for alleviating the problem of insufficient public parking spaces to enhance the city’s sustainability. Recent projects in Hong Kong show the efficiency and success in the implementation of this system. The installation of APS shows us the major benefits which suit Hong Kong the most.

- Increasing the parking capacity within same limited area.
- Reducing construction costs and time.
- Enhancing better security for vehicles and personal property.
- Promoting pedestrian safety.
- Reducing harmful car emissions.
- More manageable and friendly for disabled drivers.

To align with the HKSAR Government's Smart City Blueprint 2.0 for Hong Kong, APS is highly recommended to be installed and adopted to enhance sustainability.

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