THE HONG KONG
INSTITUTION OF ENGINEERS
ELECTRICAL DIVISION

The 37th Annual Symposium
Thursday
24th October 2019

INNOVATION FOR ENGINEERING ADVANCEMENT

at

Ballroom
Sheraton Hotel
Nathan Road
Kowloon
Hong Kong

SYMPOSIUM PROGRAMME

08.30 Registration and Coffee

09.00 Welcome Address
- Ir Tony K.T. Yeung
  Chairman, Electrical Division, The HKIE

09.05 Opening Address
- Ir Ringo S.M. Yu
  President, The HKIE

09.10 Keynote Speech
- Mr K.K. Ling
  Director
  Jockey Club Design Institute for Social Innovation
  Hong Kong Polytechnic University

1. Smart Air Transportation

09.40 Realizing Smart Airport Vision using Digital Twin
- Ir Kelvin K.W. Wong, Deputy General Manager
- Mr Stanley K.C. To, Senior Manager, Technical Systems
- Mr Tiger K.Y. Lau, Assistant Engineer, Electrical & Mechanical
  Technical Services Department
  Airport Authority Hong Kong

10.00 Multi-illuminator Passive Radar (MIPAR) Technology
- Dr Feng Cheng
  Deputy Professor
  Electronic Information School
  Wuhan University
- Ir Stanley K.W. Leung
  General Manager
  GDEPRI Power Control Systems & Equipment (HK) Ltd.

10.20 Discussion

10.50 Coffee Break

2. Environmentally Friendly Power Supply

11.20 Environmentally Friendly F-gas Free and IoT HV Switchgear
- Dr. Mark Kuschel, Chief Technology Officer
  High Voltage Gas-insulated Switchgear
  Siemens AG Germany
- Ir Alex S.H. Chan, Senior Manager
  Gas & Power Division
  Siemens HK & Macao

11.40 Review of Electric Vehicle Charging Facilities
- Dr Lawrence C.K. Poon
  General Manager
  Automotive Platforms & Application Systems R&D Centre
  Hong Kong Productivity Council

12.00 Discussion

12.30 Lunch

14.00 Special Talk on Innovation
- Mr Vivek Mahbubani
  Stand-up Comedian

3. Building Services Management

14.20 Retro-commissioning of Building Services Installation
- Ir Victor W.T. Leung
  Director
  Victor Leung & Associates Limited

14.40 IoT Enabled Smart Building Operation and Maintenance
- Ir C.K. Lee, Chief Engineer
- Ir Steve H.Y. Chan, Senior Engineer
- Ir Grace K.M. Yip, Engineer
- Ir Francis P.H. Yuen, Engineer
- Mr T.C. Chan, Assistant Engineer
- Ms P.Y. Cheung, Assistant Engineer
  Electrical & Mechanical Services Department
  The Government of the HKSAR

15.00 Discussion

15.20 Coffee Break

4. Emerging Technological Applications

15.50 Bring the World into 5G Era
- Mr Philip H.F. Yick
  Solution Director
  Huawei International Co. Ltd.

16.10 Dynamic Optimisation of Peak Demand Charge using Machine Learning Algorithms
- Ir Dave C.H. Chan, Director
- Mr Kenneth K.Y. Lee, Technical Manager
- Dr Pan P. Lee, Senior R&D Engineer
  Information, Communications and Building Technologies
  ATAL Building Services Engineering Ltd.

16.30 Discussion

16.45 Summing Up
- Ir T.K. Chiang
  Symposium Chairman
  Electrical Division, The HKIE

Closing Address
- Ir Professor H.C. Man
  Dean
  Faculty of Engineering
  Hong Kong Polytechnic University

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

Mr K.K. Ling
Ir Prof. H.C. Man
Ir Kelvin K.W. Wong
Mr Stanley K.C. To
Mr Tiger K.Y. Lau
Dr Feng Cheng
Ir Stanley K.W. Leung
Dr Mark Kuschel
Ir Alex S.H. Chan
Dr Lawrence C.K. Poon
Mr Vivek Mahbubani
Ir Victor W.T. Leung
Ir C.K. Lee
Ir Steve H.Y. Chan
Ir Grace K.M. Yip
Ir Francis P.H. Yuen
Mr T.C. Chan
Ms P.Y. Cheung
Mr Philip H.F. Yick
Ir Dave C.H. Chan
Mr Kenneth K.Y. Lee
Dr Pan P. Lee

Sponsors

Siemens Ltd.
CLP Power Hong Kong Ltd.
The Hongkong Electric Co., Ltd.
The Jardine Engineering Corporation Ltd.
Junefair Engineering Co. Ltd.
Elibo Engineering Ltd.
Keystone Electric Wire & Cable Co. Ltd.
Netsphere Solution Ltd.
MTR Corporation Ltd.
Kum Shing Group
C&K Instrument (HK) Ltd.
Greenland Engineering Co., Ltd.
Schneider Electric (Hong Kong) Limited
Mitsubishi Electric (Hong Kong) Ltd.
TE Connectivity Hong Kong Ltd.
Gammon E&M Limited
Metrix Engineering Co. Ltd.
Chat Horn Engineering Ltd.
FSE Engineering Group Ltd.
S.G.H. Electric Wire & Cable Co. Ltd.
Hong Kong Electrical Contractors' Association Ltd.

37TH ANNUAL SYMPOSIUM ORGANIZING COMMITTEE

Symposium Chairman:	**Ir T.K. Chiang**
Members:	**Ir Tony K.T. Yeung**
	Ir W.S. Tam
	Ir Y.H. Leung
	Ir Dr Edward W.C. Lo
	Ir Andrew K.W. Yan
	Ir Steve K.K. Chan
	Ir C.L. Wong
	Ir Kit N.K. Chan
	Ir Alex T.H. Fu
	Ir Hugo C.Y. Chan
	Ir Joseph C.W. Leung
	Ir Simon H.C. Tsui
	Ir Jason K.H. Chan
	Ir Raymond K.M. Sze
	Ms Yani Y.Y. Ko
Hon. Secretary and Treasurer:	**Ir Y.K. Chu**

Paper No. 1

REALIZING SMART AIRPORT VISION USING DIGITAL TWIN

Authors/Speakers: Ir Kelvin K.W. Wong, Deputy General Manager
Mr Stanley K.C. To, Senior Manager, Technical Systems
Mr Tiger K.Y. Lau, Assistant Engineer, Electrical & Mechanical
Technical Services Department
Airport Authority Hong Kong

REALIZING SMART AIRPORT VISION USING DIGITAL TWIN

Ir Kelvin K.W. Wong, Deputy General Manager
Mr Stanley K.C. To, Senior Manager, Technical Systems
Mr Tiger K.Y. Lau, Assistant Engineer, Electrical & Mechanical
Technical Services Department
Airport Authority Hong Kong

ABSTRACT

Hong Kong International Airport is integrating five new enabling technologies into airport engineering and management process to realize the Smart Airport Vision, including Advanced Biometrics, Robotics, Digital Twin, Mobile Technology and Big Data Intelligence. These technologies aim at automating passenger's process, and improving operation and maintenance efficiency. Digital Twin, among them is a key enabling technology to provide a virtual model in which data from different sources will be integrated and made available instantly, visualized in a human-centric interface and analysed to make predictions in an explainable way. In this paper, we will give an introduction of a Digital Twin platform with various IoT integrations to gain insights into airport operational processes in order to prolong the lifespan of airport facilities through predictive maintenance and on-going optimization, and to use the airport operational data in research and development for a sustainable future smart airport.

1. INTRODUCTION

Hong Kong International Airport (HKIA) rolled out its Smart Airport Vision in 2016. Our primary objective is to apply innovation and technology to create a more enjoyable and memorable experience for our passengers and more efficient operating environment for the airport. For passenger experience, we want to achieve seamless travel, personalised attentive services, new retail experience with fun and memories, and behind the scene: efficient operations and predictability. This vision is also common goals of many international airports and is likely achievable in 10 years or less.

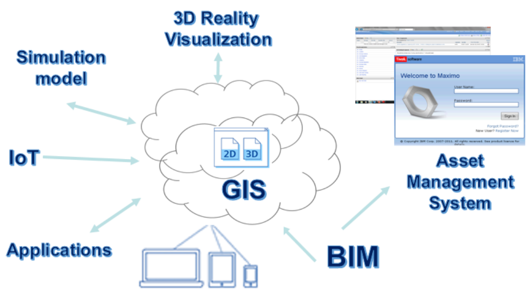

Fig. 1 - Architecture of HKIA's Digital Twin platform

Digital Twin platform is one of the key elements of building a smart airport. Figure 1 shows the architecture of our Digital Twin platform. The process of building the platform can be divided into two parts. First, from the very beginning, we have been working with multiple partners to develop a broad 3D model for the current airport as a whole to ensure a shared platform for subsequent expansion. Second, we then develop detailed 3D models and other applications based on business demand so that it can be rolled out to use as soon as possible.

This paper first introduces the concept of Digital Twin. It then provides detailed discussion on the modelling methods, including Building Information Modelling (BIM) and Geographic Information System (GIS). Finally, it presents a Digital Twin platform with various IoT integrations to highlight some important developments in pursuing our Smart Airport vision.

2. WHAT IS DIGITAL TWIN?

The vision of the Digital Twin is to facilitate holistic airport management and predictive decision making. Its application will cover design, construction, operation and maintenance for the complete asset life cycle.

There are different definitions of the term "Digital Twin" [1]. For Hong Kong International Airport, we define "Digital Twin" as a virtual model of our Airport, in which data from different sources can be integrated, made available instantly, visualized in a human-centric interface, and analysed to make predictions in an explainable way. Instant Availability, Human-centric Visualization and Explainable Predictability form the three key pillars of our Digital Twin platform.

2.1 Instant Availability

Fig. 2 - Digital Twin platform

The first goal of our Digital Twin is to provide instant availability of a complete, single source of truth of the entire airport at anywhere and anytime. From one single platform in Figure 2, users can get access to the most up-to-date and complete digital model of the entire airport infrastructure and facilities. When new works are added or existing works are modified, each of these changes will be made in a timely manner to the Digital Twin model, and then shared with other applications using the same model so that the 3D model and applications will always be kept up-to-date. The same model will also provide a unified and holistic view for the entire airport.

From the single Digital Twin platform, users will also get access to their needed key data about past, present and future in a location-based context in addition to infrastructure and facility information. Besides the availability of all key data from a single platform, we also aim to provide users with an intuitive interface and "3 clicks or less" navigation system from the main screen to ensure "Instant" availability of their most needed information.

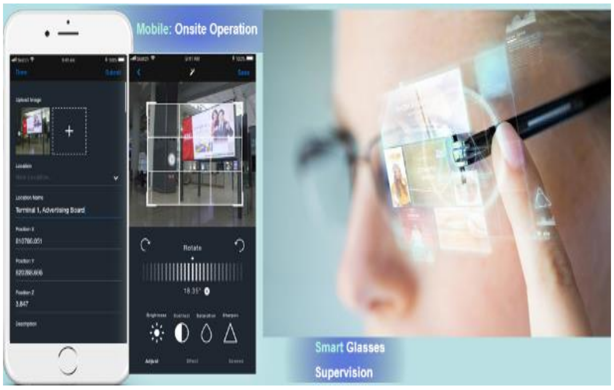

Fig. 3 - Mobile device accessibility

As shown in Figure 3, the Digital Twin will also be accessible from mobile devices to ensure airport staff will get their needed data instantly. This is especially important for front line staff who interact with passengers or airport facilities on a day-to-day basis and have to respond immediately to any change in circumstances. The use of smart glasses is being developed so that it can free up both hands for other tasks during work.

2.2 Human-centric Visualization

The second goal is to provide human-centric visualization for users to interact with and intuitively realize the underlying information or data. We aim to present complex data output in the form of photorealistic animations over 3D models wherever practical.

Fig.4 - Flooding simulation

As shown in Figure 4, users can easily visualise and understand the extent and possible impact of flooding during a selected typhoon scenario. This can help us to plan the contingency arrangement to protect safety and critical infrastructure at the airport [2].

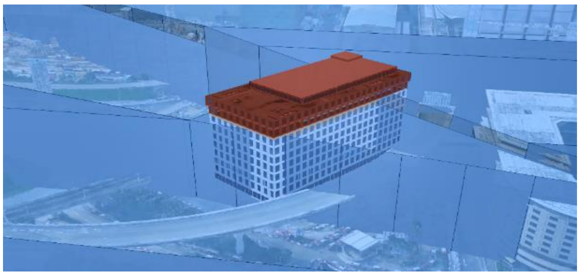

Fig. 5 - Airport height restriction checking

The Digital Twin model also aims to provide insight at a glance to maximize operation efficiency. Figure 5 shows an example of utilizing Digital Twin model to assess the impact of new development on airport height restriction. With the 3D model, vertical dimensions are easier to be visualised and height encroachments are quickly revealed. This can save time, enhance efficiency, avoid unnecessary human errors and enable clash-free design.

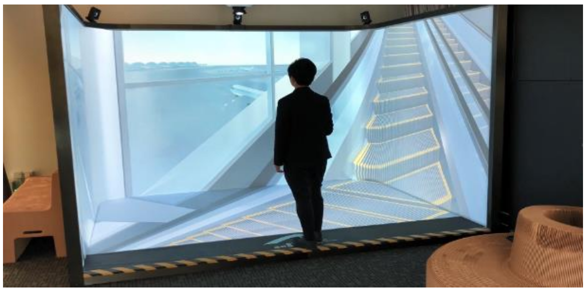

Fig. 6 - 4D Immersive Cave for 1st person experience

The Digital Twin must be adaptable to new and emerging human machine interfaces. We built an Immersive Cave shown in Figure 6 to provide users with first-person immersive experience. Without the need for VR glasses, the cave environment aligns the participants along common viewing platform and facilitates communication and discussion.

For a new project like Sky Bridge, the Digital Twin will provide users a virtual reality to experience the future designs to facilitate efficient design review. This is especially important because of our increasing use of Modular Integrated Construction and other off-site construction methods. Due to their longer lead times, early design freeze is critical. With the 3D model, alternative design proposals can be easily and effectively modelled, reviewed and compared in the context of the entire airport [3]. This can minimize the design alternation during the design stage in construction.

Fig. 7 - 4D construction prediction

By expanding 3D to time-based 4D model as shown in Figure 7, we can critically review construction methods and sequences well in-advanced of the actual construction and predict and mitigate potential problems on the new works and whole airport environment, like design clashes and operational impact.

2.3 Explainable Predictability

Fig. 8 - Crowd prediction and control

The third pillar is explainable predictability. With big data analytics, we can integrate the data collected from IoT and other sources, analyse them to make future predictions and present it in the Digital Twin model. For example, in Figure 8, crowd control is a critical airport operation especially during or after major disruptions. The Digital Twin model may provide early alerts and help resource deployment based on its crowd prediction analytics using available historical and real time data.

One point to note is that as we move from rule-based AI to more advanced machine learning, it is important to ensure that explainable AI approach is adopted to provide the users to make informed decisions with understandable basis instead of simple probability.

3. MODELLING METHODS

In Hong Kong International Airport, we are creating digital modelling or representation of our physical airport infrastructure for a 3D based GIS model with BIM integration. This 3D model will contain all spatial, geographic data and building information, including architecture, structure, civil, electrical, mechanical, plumbing services, to provide a solid foundation for our Digital Twin platform. By integrating BIM into GIS model, our Digital Twin platform can be benefited from reduced hardware requirement so that every user can access to the data instantly and easily, fulfilling the first goal of our Digital Twin platform.

Fig. 9 - Completed 3D models

The 3D model is a live modelling of our airport, with the anticipated expansion and upgrading projects. We mandated that all new designs to be done shall be based on BIM. For existing facilities, we are building a broad 3D model for the Terminal 1 building and an enterprise GIS platform. Figure 9 shows the 3D models for the arrivals and departures levels of Terminal 1 building and the coming Sky Bridge.

3.1 Building Information Modelling (BIM)

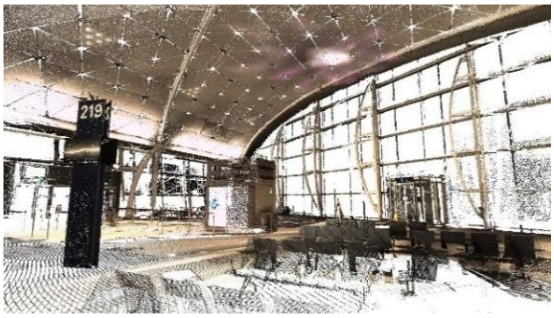

Fig. 10 - Point cloud data collected from laser scanning

To create a 3D model of our existing infrastructure, laser scanning for obtaining point cloud data is used. The laser scanner contains a rotating laser rangefinder which measures the distance between each reachable point in the building and the scanner. By continuously rotating the rangefinder by 360° in x/y+z axes, the laser scanner will become omnidirectional. Point cloud data is then collected at a particular reference point in the building. Figure 10 shows an example of point cloud data collected through laser scanning in Midfield Concourse.

Fig. 11 - Real-time rendered image in BIM software

After repeating the laser scanning many times in and around the building, point cloud container model is formed and then linked into the working model in BIM software as a background reference. Relevant elements will be built in the main model to intelligently interpret the point cloud data. After that, building information will be applied to the model in forms of materials and finishes. Until this stage, the 3D model is basically created. As shown in Figure 11, real-time rendering can help to visualize the model in a photorealistic context.

3.2 Geographic Information System (GIS)

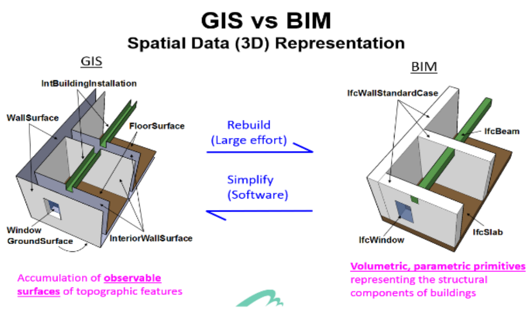

Fig. 12 - Comparison of spatial data representation

Integrating BIM into GIS model can reduce hardware requirement for instant availability of data. As shown in Figure 12, GIS model represents data in observable surfaces while BIM represents data in parametric volumes. For construction planning, design, implementation and monitoring, the high level of details provided by BIM is critical for us to enable tasks like crash analysis for various building services. For Digital Twin platform, the purposes are different. We want to create a Digital Twin platform with Instant Availability, Human-centric Visualization and Explainable Predictability. Driven by these purposes, our platform shall be simplified from the BIM to GIS model through software by combining 2D as-built CAD drawing and the building information from BIM.

3.3 Integration with Other Systems

Fig. 13 - 3D model with asset details

With the BIM model and enterprise GIS platform, construction and facility management will be a lot easier. As shown in Figure 13, this is made possible with integration to our asset management system so in future we could easily retrieve the asset details in a 3D based virtual layout of the airport. This will make facility management more effective and more accurate. We also target to integrate our different operations and maintenance systems into a single environment layered on top of the 3D based Digital Twin of the airport. This allows an agiler response and decision making when handling unforeseen disruptions at the airport.

4. IoT INTEGRATION

When we further layer the IoT devices or smart sensor on top of the 3D Digital Twin model, more possibilities can be implemented to improve system reliability, as well as prolonging the lifespan of airport facilities. This enables predictive maintenance, improves operational effectiveness, enhances the passenger experience, and facilitates research and development, resulting in comprehensive airport facility designs into the new airport development.

4.1 Predictive Maintenance

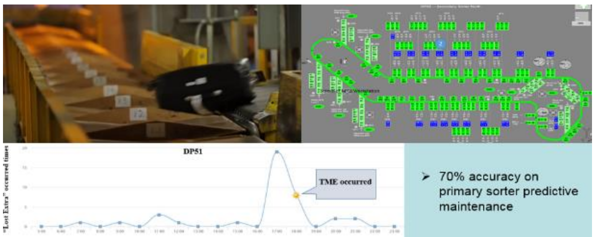

Fig. 14 - Predictive maintenance for baggage handling system

We see that predictive maintenance is a crucial strategy to help us reduce possible downtime of our facilities and equipment especially for our mission critical facilities e.g. baggage handling system. With big data analytics, a combination of industrial IoT and new IoT, including cameras to collect real time data, we can eventually predict most major problems and fix them before they occur [4]. As shown in Figure 14, we completed a Prove of Concept (PoC) with a Hong Kong Start-up firm and successfully predicted a main primary sorter fault by the predictive analytics based on system logs and maintenance history of our baggage system. We are about to expand the scale to a comprehensive predictive maintenance for our baggage handling system.

4.2 Smart CCTV

Fig. 15 - Smart CCTV system with video analytics

Another opportunity is with our new smart CCTV system shown in Figure 15, which will provide valuable visual data for the Digital Twin model. A total of over 4,500 digital camera sets based on 4K resolution are being installed to provide full coverage of the airport. With video analytics, these cameras will not only provide surveillance video but also valuable real-time structural data on people, vehicles and facilities with characteristics for further analysis and predictions [5].

With the smart CCTV system, we have also completed a proof of concept, analysing and identifying emotional attributes. Detected faces are analysed and the emotions are identified via Smart CCTV system. Analysis result of each detected face includes confidence scores for seven kinds of emotion: anger, disgust, fear, happiness, neutral, sadness, and surprise. For example, happiness can be used to assess customer satisfaction. On the other hand, fear and anger can be useful in assessing security risks.

4.3 Robotics

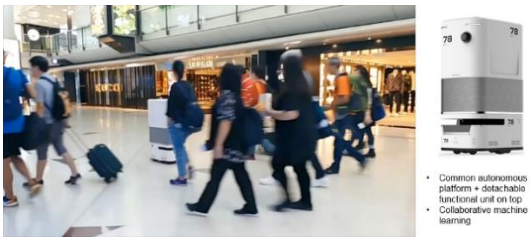

Fig. 16 - Multi-functional patrol robot

We are co-developing a multi-function robot with a Hong Kong technology firm. The patrol robot, shown in Figure 16, can be adapted to many monitoring and sensing use cases. This is the development of an indoor multi-function, Human-assisted AI and collaborative learning robot at terminals. With common autonomous platform, we can modify the functional components at different times for tasks such as patrolling, delivery, message dissemination etc. This demonstrates that IoT sensors do not have to be fixed installations, but instead can be dynamic and mobilized all around the airport and collect data for the Digital Twin model.

4.4 Driverless Vehicles

Fig.17 - Autonomous electric tractor

Another pilot is the autonomous electric tractor to transport baggage or cargo dollies in the dynamic environment from aircraft stands to baggage/cargo reception points. This is the first autonomous electric tractor pilot at major international airport. Our key priority of the pilot is to control costs in particular possible LIDAR sensors so as to ensure commercial viability for mass deployment.

With the Digital Twin, we can also train the autonomous electric tractors in simulated environments, shown in Figure 17, to accelerate the learning process under normal and extreme operating conditions. This may apply to other robotics and automation that we studied to reduce mundane and physically demanding tasks at the airport.

5. CONCLUSIONS

Digital Twin is a recent term named by Gartner as one of the 10 strategic technologies [6]. It refers to building digital model that is operated in a virtual environment. Our vision is that with this Digital Twin, we could easily monitor and manage the airport environment as well as tracking all the events centrally and automatically. More importantly we can do simulation and prediction in digital platform in an efficient and effective way without causing disruptions to real environment.

Also, big data intelligence is the powerhouse of most technology areas because all digital technologies rely on data. Our goal is that data will become one of the most important assets of the authority and we have systems and processes in making best use of such asset. We also encourage more sharing of useful data with the airport community and beyond. The end state is that we can make decisions in an instant data driven approach.

Future air travels will be exciting and fun and perhaps not yet visualised by us at this moment, in such a fast changing technology era. Technology will offer us limitless possibilities and many rewarding opportunities. Everyone is welcome to partner with us and take part in co-creating and innovating process to create a more enjoyable experience for the airport passengers. Together, we can create a smarter airport for Hong Kong.

REFERENCES

1. Erikstad and S. Ove, "Merging Physics, Big Data Analytics and Simulation for the Next-Generation Digital Twins," High-Performance Marine Vehicles, pp. 141–151, 2017.

2. M. Werner, "Impact of grid size in GIS based flood extent mapping using a 1D flow model," Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere, vol. 26, no. 7–8, pp. 517–522, 2001.

3. R. Eadie, et al., "BIM implementation throughout the UK construction project lifecycle: An analysis," Automation in construction, vol. 36, pp. 145–151, 2013.

4. Z. Liu, N. Meyendorf and N. Mrad, "The role of data fusion in predictive maintenance using Digital Twin," AIP Conference Proceedings, vol. 1949, no. 1, pp. 020023, 2018.

5. Y. He, J. Guo and X. Zheng, "From surveillance to Digital Twin: Challenges and recent advances of signal processing for industrial internet of things," IEEE Signal Processing Magazine, vol. 35, no. 5, pp. 120–129, 2018.

6. E. Saddik and Abdulmotaleb, "Digital Twins: The convergence of multimedia technologies," IEEE MultiMedia, vol. 25, no. 2, pp. 87–92, 2018.

Paper No. 2

MULTI-ILLUMINATOR PASSIVE RADAR (MIPAR) TECHNOLOGY

Authors/Speakers: Dr Feng Cheng
Deputy Professor
Electronic Information School, Wuhan University
Ir Stanley K.W. Leung
General Manager
GDEPRI Power Control Systems & Equipment (HK) Ltd.

MULTI-ILLUMINATOR PASSIVE RADAR (MIPAR) TECHNOLOGY

Dr Feng Cheng
Deputy Professor
Electronic Information School, Wuhan University
Ir Stanley K.W. Leung
General Manager
GDEPRI Power Control Systems & Equipment (HK) Ltd.

ABSTRACT

MIPAR consists of an antenna system, a radio receiver system and a signal processing system. It does not radiate electromagnetic signals, but performs the radar function via receiving the radio signals reflected by the target that are originated from third party radiation sources (e.g. public radio, TV broadcasts and cellular stations etc.)

There is a reference antenna for receiving third parties' radio signals directly, and an array of monitoring antennas to receive the radio signals reflected by the targets within the detection zone. The radio receiver system would use its multi-channel receiver to amplify, demodulate as well as perform A/D conversion to the signals received by the antenna system. The signal processing system takes the subsequence output for computing relevant information of the detected targets.

MIPAR is capable to detect and track low attitude flying targets such as drones, airplanes, birds, balloons, parachutes etc. Due to the unnecessity of the radio transmitters in conventional active radars, it carries advantages of radio spectrum reservation, dispense with frequency permission, high electromagnetic compatibility, easy deployment and low costs of operation. It has a high potential to become the core technology for low attitude air-space security, aviation safety or even military applications.

1. INTRODUCTION

The MIPAR itself does not radiate electromagnetic signals, but performs the radar function via receiving the radio signals reflected by the target that are originated from third party radiation sources (e.g. public radio and TV broadcasts, cellular station etc.), see Figure 1.

The MIPAR system consists of three major components, namely the antenna system, the radio receiver system and the signal processing system. There is a reference antenna for receiving the radio signals directly from third party radiation sources, and an array of monitoring antennas is there for receiving the radio signals reflected by the targets within the detection zone. The radio receiver system would use its multi-channel receiver to amplify, demodulate as well as perform A/D conversion to the signals received by the antenna system. Finally, the signal processing system takes the subsequence output for computing relevant information of the detected targets.

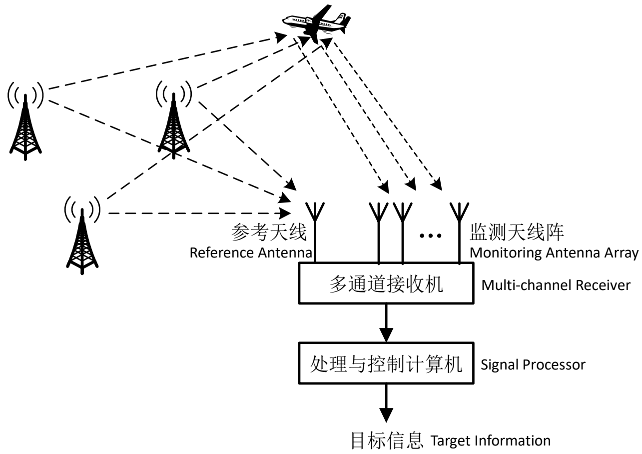

Fig. 1 - MIPAR operation principle

2. CHARACTERISTICS OF MIPAR

Compare to traditional active radar technologies, MIPAR has the following characteristics:

2.1 Environment Protection

As there is no electromagnetic wave radiation, this technology is suitable for installation and operation in radio sensitive areas such as public airport, critical facilities and densely populated areas

2.2 Radio Spectrum Conservation

This technology utilizes passive radio receiving of existing third parties' broadcasting radiation sources, so it does not require radio frequency usage licensing, therefore significantly reduces the overhead of system deployment.

2.3 Low Costs of System Setup

The low cost is mainly due to the fact that the radio transmitting portion is not necessary, that simplifies significantly the system hardware complexity hence would substantially reduce the manufacturing costs after massive production is in place. The license free operation also means low operation and maintenance costs.

2.4 Ready for Networking

The passive nature makes the MIPAR technology exceptionally high in electromagnetic compatibility. In addition to license free operation and low setup costs, this technology is suitable for building large scale network coverage, see Figure 2.

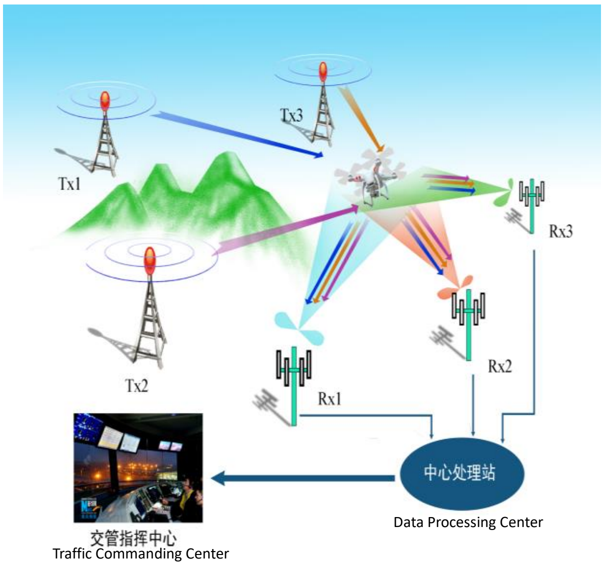

Fig. 2 - MIPAR network topology
(Tx1 - Tx3 third party radiation sources, Rx1 - Rx3 radar stations)

3. TECHNICAL CHALLENGES OF MIPAR

MIPAR is facing the following key technical challenges:

3.1 Understanding and Modeling the Complex Radio Wave Environment

Besides the propagation characteristics of the radio waves received by the monitoring-antenna array, it is also vital to take extra attention to the propagation characteristics of the radio waves received by the reference antenna. Since the transmitting waveform is unknown, it is necessary to obtain the key signal parameters of the external radiation sources, such as modulation information and signal structure, etc. The external radiation sources are actually constructing a kind of man-made multipath propagation environment, whose impact to the performance of the MIPAR will require further analysis and research.

3.2 Station Location Optimization and Performance Evaluation

Radar power coverage gets the priority in the consideration of station location optimization. Since the radiation sources are usually uncontrollable, this complicates evaluation of the MIPAR performance. Different hardware system configurations and signal processing capabilities would affect the practical detection performance of MIPAR. How to optimize the resources allocation of each receiving station is a deep-rooted research topic of networking location optimization.

3.3 Direct Wave and Clutter Suppression

Under a complex radio environment, the direct wave and clutter would take up relatively larger degree of freedom in spatial domain, so the spatial suppression method often causes overloading of the degree of freedom. Also, the performance of time-domain suppression method is limited by the non-ideal factors, such as reference signal purity, carrier frequency offset, sampling frequency offset and channel frequency response, etc. The filter order required for direct wave and clutter suppression is too high, and as a result, the conventional adaptive filtering methods face the problems of poor convergence and high computational complexity.

3.4 Detection and Tracking of Low Attitude, Slow Speed and Small Size Flying Targets

The low attitude, slow speed and small size flying targets share common difficulties for detection and tracking: Due to the low flying attitude, these targets usually fly in low elevation blind zone located in the lobe of conventional radar antenna; Slow speed flying targets are easily filtered out by radar as clutter; The small size and non-metal construction result in smaller radar cross section, high maneuverability, and irregular flight routes, etc.

MIPAR is capable to detect and track low attitude flying targets such as drones, airplanes (see Figure 3), birds, balloons, parachutes etc. It has a high potential to become the core technology for low attitude air-space security, aviation safety or even military applications.

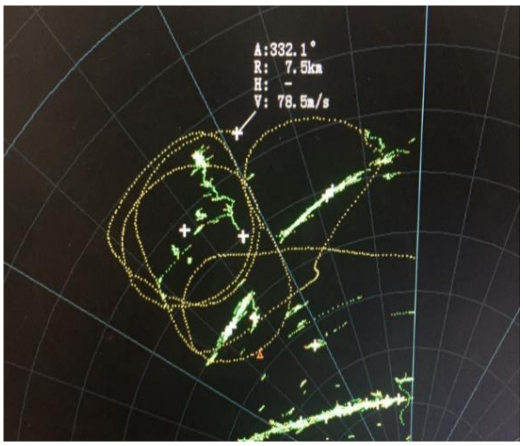

Fig. 3 - Results of general aviation aircraft detection
Funding Project: China National Key R&D Plan (2016YFB0502403)

4. CONCLUSION

MIPAR is capable to detect and track low-altitude flying targets such as drones, general aviation aircrafts as shown in Figure 3, birds, balloons, paragliders, and so on. This technology is suitable for applications where electromagnetic radiation is limited and various types of low altitude targets (including radio silent targets) need to be detected. Compare to traditional active radar technologies, MIPAR has great advantages in EMC, spectrum saving, cost control and networking capability, so it has potential to become the core technology of future low altitude surveillance network. It has broad application prospects in the fields of low-altitude security control, general aviation safety monitoring and civil-military integration.

Paper No. 3

ENVIRONMENTALLY FRIENDLY F-GAS FREE AND IOT HV SWITCHGEAR

Authors/Speakers: Dr. Mark Kuschel, Chief Technology Officer
High Voltage Gas-insulated Switchgear
Siemens AG Germany
Ir Alex S.H. Chan, Senior Manager
Gas & Power Division
Siemens HK & Macao

ENVIRONMENTALLY FRIENDLY F-GAS FREE AND IOT HV SWITCHGEAR

Dr. Mark Kuschel, Chief Technology Officer
High Voltage Gas-insulated Switchgear
Siemens AG Germany
Ir Alex S.H. Chan, Senior Manager
Gas & Power Division
Siemens HK & Macao

ABSTRACT

Two global megatrends are leading to sustainable and fundamental changes in the high-voltage world. These are the trends towards digitalization and towards more environmental protection and resource conservation.

In environmental protection, the aim is to improve product sustainability while maintaining reliability and cost-effectiveness. Sulphur hexafluoride (SF_6), which has outstanding technical properties but has a very high greenhouse potential when emitted into the environment, is today the most frequently used medium for switching and insulation in high-voltage equipment. In this paper, we will explore the current status of SF_6-free GIS development (labelled "Blue" means sustainable without SF_6) which is based on vacuum switching technology combined with clean air insulating gas.

In digitization, the focus is on increasing customer benefit in optimizing operational processes. In addition to the proven reliability, the systems must have additional functionalities for dynamic operation control. This obligation comes from the constant increase of renewable energies and decentralized feed-in on the generation side as well as a rapidly increasing electrification in the areas of transport, industry and buildings on the user side. Integration of intelligent products and connectivity through robust IoT gateway and cloud-based data storage is a common state-of-the-art approach. The different digitalization approaches are presented with the focus of Sensgear® and LPIT (Low-Power Instrument Transformer) using digital process bus.

1. INTRODUCTION

Sustainable development is the key for a prospering global society. The United Nations defined a set of development goals to achieve a better and more sustainable future. One goal is to ensure the access to affordable, reliable and sustainable energy for all. Backbone of a sustainable energy system is the renewable generation of electricity and its sustainable CO_2 neutral transmission and distribution.

Leading, future-oriented, socially responsible transmission and distribution system owners and operators drive the realization of those sustainable power transmission and distribution systems [1]. SF_6 is today's most applied gas for switching and insulation in high-voltage equipment, with excellent technical characteristics, but also strong global warming potential (GWP). The GWP value of SF_6 for 100-year time horizon shown in the fifth assessment report is 23,900 times of CO_2 [2]. Due to this fact, transmission system operators (TSOs) and distribution system operators (DSOs) handle the gas with maximum care. For further improvement of sustainability, new innovative products are required, with the well-known performance and reliability, high health and safety standards and with the lowest possible global warming impact.

Beside sustainability with also more renewable energy share and visible environment, health and safety (EHS) care, further trends, challenges and opportunities are discussed as summarized in Figure 1. Digitalization and IoT in T&D business are a chance and an enabler. They empower the users, no matter if you operate the T&D equipment in a power generation plant, an industrial application or in the grid, to handle these challenges, to improve performance, to lower the costs and risks in a smarter way.

Fig. 1 - Trends, challenges and opportunities for grid operators

2. F - GAS FREE SWITCHGEAR

The alternative gases mixtures available today and their main properties, as well as pros and cons are discussed in detail in different papers e.g. [3, 4]. The decision to utilise clean air (CA) as an insulating gas is grounded upon the following core facts of CA.

For high voltage applications CA consists of 80 % N_2 and 20 % O_2, is free from CO_2 and other substances as well as almost free of moisture (synthetic air). CA has neither global warming potential (GWP = 0) nor ozone depletion potential (ODP = 0). For a typical average

145 kV GIS switchgear with 7 bays and a lifetime of 50 years, a total reduction of around 700 t CO_2-eq. environmental impact can be achieved. In fact, this corresponds approximately to the CO_2 compensation of about 1200 adult beech trees [4].

CA is extremely stable and only with CA are there no toxicological aspects to consider when operating high voltage products. In fact, the operating costs are lower compared to SF_6 [5]. Figure 2 summarises the main pro and cons with regards to the insulation characteristics.

The basis for CA as an insulating gas in the case of switching application is the use of vacuum switching technology for short-circuit current interruption, which has been used successfully for more than 40 years. Above all it is characterized by its constant properties over the entire life cycle, wherein the vacuum interrupter tube is hermetically sealed and excludes any external influence. Furthermore, environmentally damaging decomposition products do not occur in the vacuum. Additional advantages result from the lower burning voltage and energy conversion in the switching path. The shorter arcing time reduces the wear of the contacts, resulting in less material erosion and more nominal and more short-circuit current switching capabilities (more than 30, with SF_6 usually without additional special measures up to 8). Figure 3 summarizes the switching characteristics.

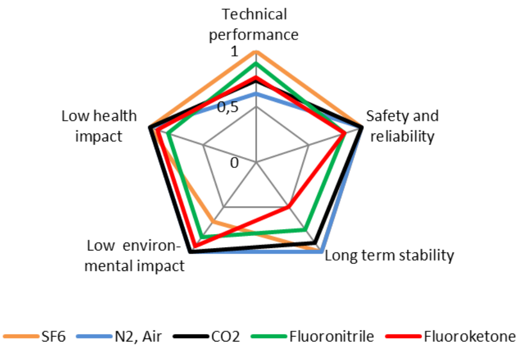

Fig. 2 - Evaluation of the insulation characteristics of SF_6 and alternatives [4]

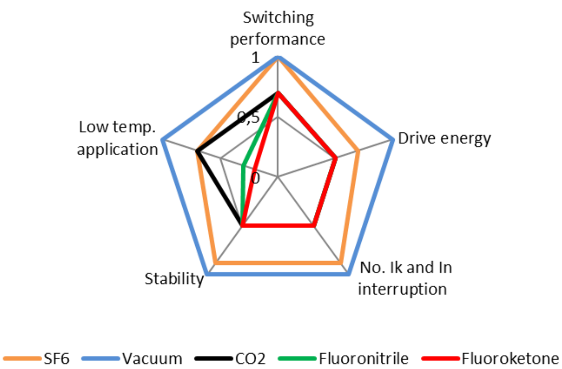

Fig. 3 - Evaluation of switching characteristics of SF_6 and alternatives [4]

Currently live tank CB & GIS up to 145 kV / 40 kA as well as instrument transformers till 420 kV are fully successfully type tested and available on the market. More than 50 bays are in operation and more than 900 bays are in order so far based on clean air insulation and vacuum interrupter technology.

Figure 4 shows impressions of the products in operation or from on-site installation. To summarise, the entire operating experience reveals quick and effective on-site handling, as well as high reliability and positive customer feedback.

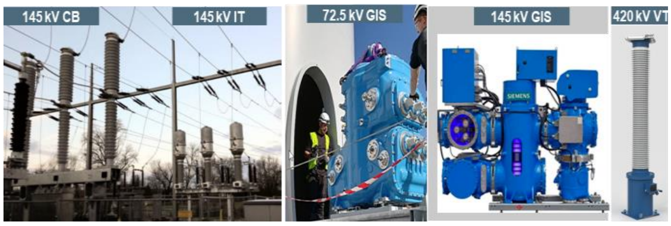

Fig. 4 - Examples of SF_6-free high-voltage (CO_2-neutral) product with vacuum switching technology and clean air insulation; from left to right: pilot application air-insulated cubicle with 3AV1 blue circuit-breaker and SVAS blue combi converter; 8VM1 blue GIS for wind tower application in an on-site installation; 8VN1 blue GIS with double busbar, a cable connection and a LPIT installation, 420 kV Voltage Transformer (VT) type SVA 420

The experience in clean air insulation and vacuum switching technology form the basis for ongoing product developments to extend the blue portfolio of high voltage products.

The development of single vacuum-interrupter units up to 245 kV and 63 kA is ongoing. Prototypes were presented at Cigre Session 2018 in Paris, Figure 5. This vacuum-interrupter will be the base for single-interrupter circuit-breakers and GIS up to 245 kV and up to 420 and 550 kV as a double-interrupter design. Next HV products available will be GIS up to 170 kV/ 50 kA and dead-tank circuit-breakers up to 145 kV/63 kA.

Fig. 5 - Single vacuum-interrupter units up to 245 kV/63 kA in development for HV circuit-breaker and GIS up to 420 kV and 550 kV

3. LOW-POWER INSTRUMENT TRANSFORMER (LPIT)

Due to the configuration of Inductive Current and Voltage Transformer (conventional), compartments for the CT and VT will be involved in the switchgear. No matter how simplifies of the characteristic of the CT and VT, it is still not easy to eliminate the bulky housing. A certain amount of SF_6 will be required consequently. In order to minimize the size of CT/VT housing, a new design is required.

The growing trend for digitalization and communication of measured process data in high voltage substations leads to increased interest of utilities in innovative LPIT-solutions (LPIT, also NCIT for non-conventional IT). Figure 6 shows the underlying technical principle. Basically, a Rogowski coil and a capacitive electrode-based sensor are integrated and sealed for life in a cast resin partition and therefore optimal protected against outer impacts like mechanical shock, vibration, SF_6-decomposition products, rust or overheating. The solution with the LPIT in cast resin is fully SF_6- or oil free, its design contains no active electronic parts. Both sensors can be used for metering and for protection (Rogowski Coil shows no saturation like conventional CT with iron core). Besides the two sensors for measurement of current and voltage, the LPIT cast resin partition is equipped in each phase with an integrated temperature sensor. The temperature is used in the Merging Unit for temperature compensation algorithm.

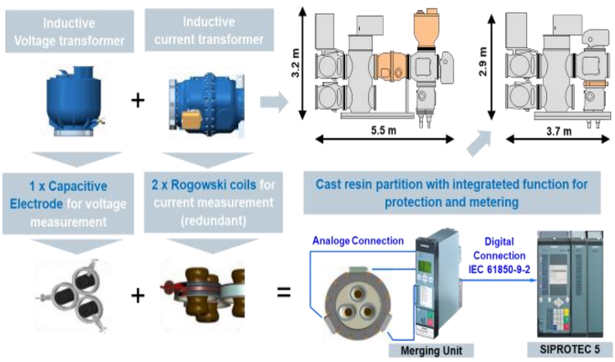

Fig. 6 - Principal concept of LPIT on the 8VN1 example (three-phase SF_6 free 145 kV GIS)

The LPIT-partition is equipped for each GIS phase with one passive box (no power supply, no pre-processing of signals) for the connection of wires with secondary signal from the sensors containing an overvoltage and EMC protection. The sensor-connection boxes are connected to the Merging Unit (MU) by a standard network cables (CAT-7, copper cable, commercially available). The MU realizes the analogue signal sampling from the sensors, their digitalization and measured value evaluation. The digitalized data from the MU are transmitted via a standardized interface with process bus according to IEC 61850-9-2 LE. In fact, the copper hardwiring is in this way replaced by fibre optic cables.

The LPIT including MU has undergone extensive testing and all relevant type tests have been carried out. The functionality of this technical solution was successfully confirmed in various pilot applications. The recognized accuracy in operation of 0.2 and 0.1 is comparable or even better than the accuracy of conventional inductive CT & VT. The development of LPIT and MU not only offers another solution for instrumentation, but also improves the size and weight of the GIS and minimizes the application of SF_6.

Figure 7 shows exemplary site installations and summarize the overall key benefits.

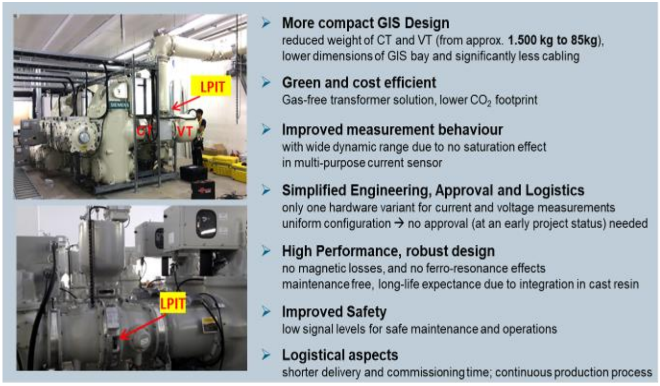

Fig. 7 - Exemplary site installations and benefits of LPIT

4. IOT CONNECTED T&D PRODUCTS

The concept and data features of IoT/digitally connected transmission products is shown in Figure 8. It is found on reliable transmission products, proven sensors, a safe and secure IoT connectivity device, an open cloud platform and applications for operational value [7].

For safety and security reasons, there is only monitoring, and no remote-control functionality is allowed. Data handling and security are essential for a reliable power transmission. State-of-the-art security and encryption technologies are therefore used while transmitting data to the cloud-platform. A unique ID will be assigned to each transmission product for encryption purpose. The transmission is realized via HTTPS with a 256-bit TSL (Transport Security Layer) encryption. The cyber security concept considers various security standards such as NERC-CIP, ISO and IEC 27001. It complies with best in class data handling and management guidelines to ensure data privacy and secure segregation in the cloud. The access to data is reserved for users only, of course users can permit this access to any third party (e.g. the manufacturer of the equipment) to get support or to let e.g. the manufacturer to use the data to optimize their products further. The users and operators can have a comprehensive and quick overview about their assets easily. The Sensformer® and Sensgear® offer an open architecture platform for user to integrate third-party applications easily or other specific user requirements [8].

All Sensformer and Sensgear provide:
GPS Location, Local weather information

additionally product specific:

Sensformer:
Oil Level Alarm, Top Oil Temperature, LV Winding Current

Sensgear GIS and Sensgear Circuit Breaker:
Gas Density, CB Counter, Position, Readiness, Temp. (LCC)

Sensgear Arrester:
Surge Counter, Leakage Current

Sensgear Instrument Transformers:
Gas Density (gas-insulated), Oil Level Alarm (oil-insulated)

Sensgear Arc Suppression Coils:
Oil Level Alarm, Top Oil Temperature,
Zero Sequence Voltage, Coil Setpoint

Fig. 8 - Functional concept and features of Sensformer® and Sensgear®

The main electrical functionalities of a substation are connective and together with data analytics, it will increase the efficiency and sustainability of the assets and operation. The assets will report their operational status and give an indication when abnormalities occur. The consequence: more transparency and flexibility at minimized risks and cost.

The visualization and analytics are presented in software applications, Figure 9. The platform is standardized as an integral part of Sensformer® and Sensgear®. Due to all the connectivity levels are in the same platform, a user's asset fleet can consist of basic Sensformer® units as well as Sensgear® in order to enhance the productivity with advanced intelligence features.

The App offers enhancing asset management. After logging in the M2M (Machine to Machine) application via a secure mobile device, an instant overview about the asset status and real-time data will be presented. The connected assets are visible with a general overview, Figure 9. By clicking to an asset on the application map, more detail of the selected asset will be displayed. Moreover, the app enables for key KPIs (Key Performance Indicators) push messages in case of alarms reported in order to offer precise information to the asset management. It can facilitate the management to make any operation and maintenance decision consciously, Figure 10.

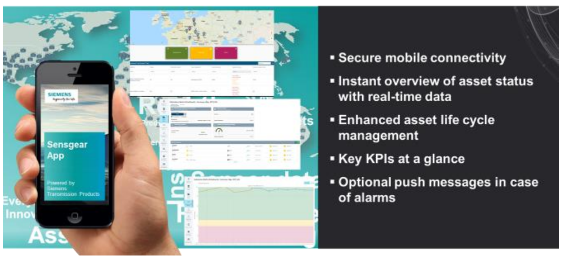

Fig. 9 - Overview about the user interface for Sensformer® & Sensgear® functions

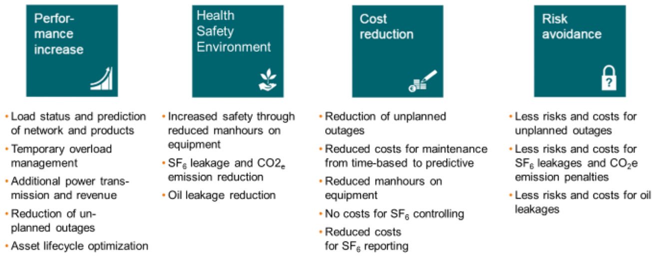

Fig. 10 - Operational values of digitalized products

In regarding to the sensors, they have the well-known reliability since they are already used in today's switchgear products. Intensive development tests were carried out to secure the IoT connectivity and reliability with application in the special environment e.g. vibration and mechanical shocks, transient over-voltages and electromagnetic fields. In particular, the following main tests were carried out without any objections:

- ✓ Electrical tests: EMC (Electromagnetic Compatibility), High Power, High Voltage including GIS disconnector switching
- ✓ Mechanical tests: Shock ±35g; mechanical endurance tests with different AIS and GIS products (M2)
- ✓ Environmental tests: temperature range -60 °C to +70 °C, humidity, material compatibility

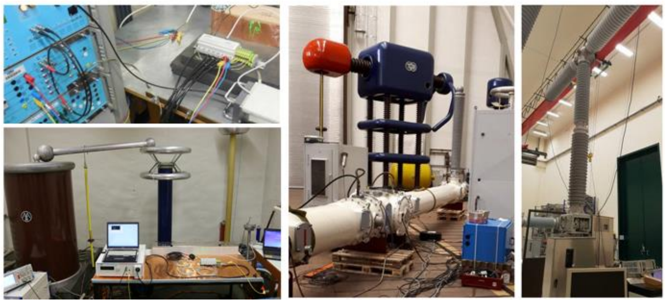

Fig. 11 - Exemplary tests impressions, left EMC, middle GIS disconnector switching and right mechanical endurance

To date, more than 300 SensProducts have been delivered and commissioned worldwide. The operating experience confirms the functionality with positive feedback from different customers. These feedbacks offer a better understanding about the product and offer a base for further development.

By using the measured data via sensors, the system owner can monitor the conditions of the equipment and simulate its future behaviour in real time. This is so-called as digital twin operation. With the digital twin operation, it can create a completely new type of experience and value-add applications: Active overload management to manage temporary overloads without compromising on lifetime. Furthermore, based on the digital twin, more applications with additional advanced sensors can be used on the asset, e.g. bushing, partial discharge or gas monitoring sensors. Health index as well as a health index prediction for the reduction of unplanned downtime of assets [8].

Overall digitally connected products enable operators to optimize performance, quality and speed of operational decisions as well as to become more flexible, act faster and more efficiently. Moreover, Sensgear® and Sensformer® provide an open platform that enables co-creation of customer-centric use cases and applications. Together with the digital twins of the product from development, testing and production, it opens completely new ways for efficient grid operation.

5. CONCLUSIONS

Without doubt, to protect our world in order to let us have a better living environment is the common goal for all of us. With the implementation of the F-gas free switchgear (fluorinated greenhouse gas, a switchgear with vacuum interrupter and clean air insulation gas), the global warming impact to our earth can be minimized significantly.

Together with the application of digitalization, the condition of electrical equipment will become transparent instantaneously. Operators can optimize performance, quality and speed of operational decisions as well as to become more flexible, act faster and more efficiently. In addition, all maintenance work can be well organized and planned according to real-time assessment management, any un-expected system interruption can be avoided. It is not only facilitating the decision making of maintenance work, but also the system stability and reliability can be improved eventually.

A "digitally enabled F-gas free switchgear" will be an essential element to turn the high-voltage T&D world into another generation.

REFERENCES

1. T. Rak, "PG&E phases out SF_6 greenhouse gas", T&D world, January 2019

2. "2.10.2 Direct Global Warming Potentials". Intergovernmental Panel on Climate Change. 2007. Archived from the original on 2 March 2013. Retrieved 22 February 2013.

3. N. Presser, C. Orth, B. Lutz, M. Kuschel, J. Teichmann: "Advanced insulation and switching concepts for next generation high voltage substations", Cigré Session 2016, Paris

4. M. Kuschel, L. Dejun, S. Kosse, U. Prucker, T. Rank, C. Stiehler, S. Wethekam: "Latest development status and operational experience on SF_6 free high-voltage products based on Clean Air insulation and Vacuum Interrupter technology", paper 26, Cigré Chengdu 2019 Symposium, China

5. B. Lutz, M. Kuschel, K. Pohlink, R. Kurte: „Gas handling and assessment of gas quality in gas-insulated switchgear", paper 57, Int. Conf. on Condition Monitoring, Diagnosis and Maintenance (CMDM), September 2019, Romania

6. W. Olszewski, M. Kuschel: "New smart approach for a U/I-measuring system integrated in a GIS cast resin partition – design, manufacturing, qualification & operational experience", ETG Congress 11/2017, Germany

7. M. Kuschel, D. Helbig, T. Hammer, M. Heinecke, P. H. Singh: "Sensformer® and Sensgear® - Intelligent IoT-connected High Voltage T&D Products", paper 81, Int. Conf. on Condition Monitoring, Diagnosis and Maintenance (CMDM), September 2019, Romania

8. Sensformer® and Sensgear®: Product information. https://new.siemens.com/global/en/products/energy/high-voltage/transmission-products/sensgeartm.html

Paper No. 4

REVIEW OF ELECTRIC VEHICLE CHARGING FACILITIES

Author/Speaker: Dr Lawrence C.K. Poon
General Manager
Automotive Platforms & Application System R&D Centre
Hong Kong Productivity Council

REVIEW OF ELECTRIC VEHICLE CHARGING FACILITIES

Dr Lawrence C.K. Poon
General Manager
Automotive Platforms & Application System R&D Centre
Hong Kong Productivity Council

ABSTRACT

Electric Vehicles (EVs) are widely welcomed as the new transportation means over the world. Most of the automakers are planning to produce more EVs in the coming 10-15 years. Some countries have even announced to ban selling of internal combustion engine vehicles within 10-20 years, such as Norway in 2025, France and United Kingdom in 2040. In Hong Kong, there are 11,660 EVs for road use as at end of March 2019, up from less than 100 in end 2010. As EV technology continues to advance and gains more public acceptance, it is expected that the number of EVs will continue to grow and then reach a significant level in the future. It will be challenging to cater to the coming demand with the current EV charging infrastructure. On the other hand, thanks to advances in battery technology, the energy capacity of EV batteries is increasing to offer a longer driving range. However, charging with traditional chargers may result in prolonged charging times, thus reducing the utilization rate of the facilities.

This paper aims to review the development of EV chargers around the world, EV charging standards, charging technology trends, and status of EV charging development in Hong Kong. It is found that in a few countries, industrial platforms are established to harmonize common goals of EV charging network development. This can avoid stakeholders to make investment in direction that may not be fully accepted by the industry. Establishing an industrial platform or association can also encourage data sharing among the members to create more innovative business and services. Meanwhile, governments are keen to promote the use of innovation and technology such as Internet of Things (IoT), interoperable charging network, smart charging and high power charging to facilitate the adoption of EVs.

1. INTRODUCTION

Over the past few years, the stakeholders in the EV charging industry have been more proactively to contribute the expansion of EV charging network to support the rapid growth of EVs in Hong Kong. In 2014, HKPC proposed 6 recommendations on EV charging development strategies, some of the recommendations haven been adopted by the industry while the others are still in early stage. In this year, we have reviewed their implementation progress individually.

2. CHARGING STANDARD

Our Recommendation in 2014
Create a common set of standards for all levels of EV chargers in Hong Kong

"To promote the wider adoption of private EVs, it is recommended that the HKSAR Government consider defining the charging standards for all levels of EV chargers and making these charging standards a part of the type approval processes."

Latest Update
Create a common standard for medium charger and keep multi-standard for quick charger

We observed that the majority of medium chargers installed in recent years are in IEC Type 2 standard, which is adopted by European EVs. This does not create obstacle to the U.S. and Japanese EVs as they can simply use a conversion cable (SAE J1772 to IEC Type 2) to conduct charging thanks to the compatible communication protocol between those two standards. Although early Tesla EVs employ proprietary charging standard, all Tesla EVs sold to HK in recent years are equipped with IEC Type 2 socket.

However, there is yet an internationally harmonized standard for quick charging. The existing standards including Japanese CHAdeMO, European/U.S.'s Combined Charging System (CCS), European IEC Type 2 AC 3 Phase, and Chinese Guobiao (GB) are not compatible with one another. In recent market development, EV charger manufacturers have launched multi-standard products to enhance the versatility of EV chargers. The most common multi-standard quick chargers installed in Hong Kong support CHAdeMO, CCS, and IEC Type 2 AC 3 Phase, while the GB standard quick chargers in Hong Kong are all dedicated chargers.

3. CHARGING INFRASTRUCTURE

Our Recommendation in 2014
Migrate EV charging infrastructure to medium and quick charging

"The HKSAR Government and EV charging operators are recommended to consider migrating existing slow charging Level 1 standard chargers to medium and quick charger to cater for new-generation EVs."

Latest Update

Continuous upgrade of EV chargers

To enhance the charging efficiency of public charging facilities, the Government has been upgrading and increasing more public chargers at government carparks managed by Transport Department and Government Property Agency:

- In 2014, EPD upgraded 100 sets of standard chargers to medium chargers.
- In 2017, EPD upgraded 170 sets of standard chargers to medium chargers.

The two power companies and the commercial sector also progressively upgrade their existing public standard chargers to medium chargers and install multi-standard quick chargers.

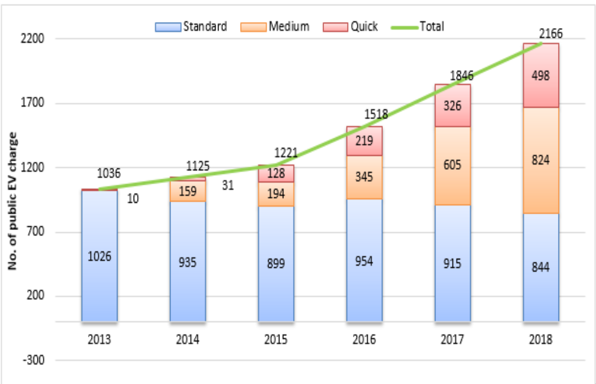

Fig. 1 – Growth of public EV charger in Hong Kong [1]

Figure 1 illustrates the number of public EV charging points in Hong Kong from 2013 to 2018. These public chargers are built by the HKSAR Government, the two power companies, and private sector in carparks of government buildings, public estates, shopping malls, etc. It can be observed that both the numbers of medium chargers and quick chargers are growing and the number of those less practical standard chargers is decreasing gradually.

4. CENTRALIZED DATABASE

Our Recommendation in 2014

Set up a centralized database of EV charging points

"A centralized database of available EVSE (EV supply equipment) can be set up and maintained, either by the Government or a neutral third party, to provide information to EV drivers on EVSE locations and status."

Latest Update

More data is provided towards the provision of real-time information

Through mobile or web application, EV charging service providers provide general information of the charging facilities, e.g. the location, charging standard. Although not for all chargers, it is more common to find newly installed EV chargers having Internet of Things (IoT) capability to provide real-time information such as the status and availability for EV users. Figures 2 and 3 show the EV charging station map of CLP and Hongkong Electric (HK Electric) respectively.

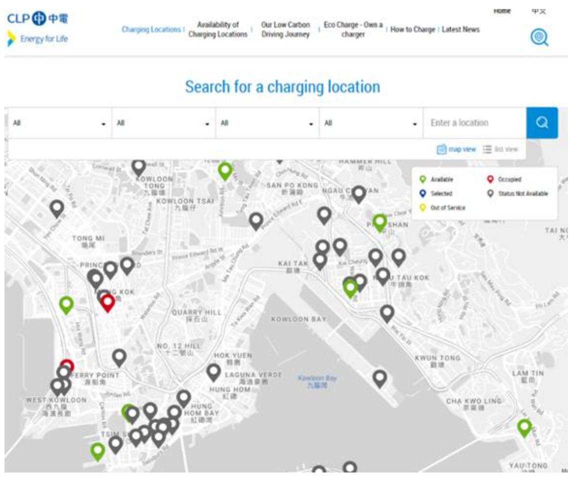

Fig. 2 – Charging Location Map of CLP [2]

Fig. 3 – Charging Location Map of HK Electric [3]

However, there is a lack of common platform for information sharing among the service providers. In other words, EV users can only use dedicated mobile app to find the real-time information of particular service provider.

The Government has established DATA.GOV.HK as the public sector information portal, while the industry has not taken full advantage of this platform for data sharing. Regarding EV charging information, only CLP and HK Electric are involved where the former provides XML format file [4] for location data (including GPS data, address, etc.) of electric vehicle charging stations while the latter provides CSV file [5] that contains carpark name, district, address, level/ floor, parking bay number, service provided and GPS data of the charging stations.

5. BUSINESS MODEL

Our Recommendation in 2014
Develop a viable business model for electricity supply for EV charging services

"This study recommends that EVSE service providers develop a sustainable business model with property developers, property management companies and power companies. If needed, the Government can play a role in helping these players work together in mutually-beneficial arrangements."

Latest Update
EV charging business is growing

In recent years, there are more private companies to provide one-stop EV charging service including installation of charging facilities and provision of charging service in both public and private carparks of housing estates and private premises.

One business model is the "Buy and Own" model, where site host purchases and owns all relevant equipment from the EV charging service provider. The service provider will be responsible to operate or maintain the charging infrastructure. The site host can decide to provide free or paid-charging service. The other model is the "Subscription" model, where the service usually targets on private carparks. EV charger service provider builds the charging infrastructure at its own costs. Tenants of these carparks can use the EV charging services at their private parking spaces by subscripting suitable monthly service plans.

These business models would facilitate the growth of private sector to provide EV charging service sustainably and to take up more responsibility of developing EV charging infrastructure in Hong Kong.

6. POWER LOAD MANAGEMENT SYSTEM

Our Recommendation in 2014
Install power load management systems in existing car parks

"It is recommended that EV charger operators and property management companies investigate the use of intelligent electricity load management systems in order to meet the overall demand for extra EV charger without needing to increase electricity supply loading in existing car parks."

Latest Update
The growing demand of EV chargers will soon boost the importance of load management technology

The provision of sufficient charging facilities is crucial to the adoption and use of EVs. The technology of load management can analyze and regulate the power usage of each EV charger in real-time so that EVs can share the available electric power capacity in the charging station. The technology offers the market a smart, economic and viable solution to build more EV chargers under limited power supply.

In Hong Kong, a few charging service providers, charger manufacturers, or research institutes start to provide load management solutions. Although the technology is still in pilot run or small-scale implementation, it is foreseen that load management technology will soon become important along with the growing demand of EV chargers.

7. DEPLOYMENT OF EV CHARGING SOLUTIONS

Our Recommendation in 2014
Install more EV chargers in private residential buildings and commercial sites with Government support

"The HKSAR Government is recommended to consider augmenting its support for EV charger setup in residential buildings and power supply infrastructure at commercial sites. This support may be achieved through the extension of the Green Transport Fund to cover the setup costs of EV chargers."

Latest Update
Greater acceptance thanks to the collaboration of the Government and private sector

The Government encourages the developers and property management companies to facilitate setting up chargers at existing private residential buildings and install more chargers at commercial buildings. With effect from 2011, concessions on gross floor area for carparks in new buildings have been granted and extended in phases so as to encourage developers to put in place the necessary EV charging infrastructure (including provision of sufficient power supply, cables and ducts) in the buildings concerned. From April 2011 to December 2015, nearly 80% of car parking spaces under newly approved development plans were equipped with infrastructure for EV charging facilities.

The Government continues to collaborate with the property management sector, incorporated owners, owners' committees, the two power companies and charging service providers in organizing seminars for stakeholders to share the latest development and technology of charger installation and successful experience, with a view to encouraging developers and property management companies to provide charging service to install in more housing estates.

The two power companies have launched a one-stop service to give technical support to EV owners who intend to install charging facilities at the parking spaces of residential or commercial buildings. For instance, Hongkong Electric has launched an online tool, "Smart EV Charge Easy Online Advisor." By completing some simple questions, the online advisor could provide a tailor-made preliminary proposal for EV owner/ incorporated owners/management office. CLP offers Eco Charge Electric Vehicle Power Supply Support as a one-stop service to support EV users for EV charger installation.

On the other hand, there are some private companies in the market that provide one-stop EV charging service, where the companies will invest full charging facilities for private carparks at a residential site, and provide charging service via subscription service plan. Such one-stop solution relieves the concerns from incorporated owners, owners' committees.

REFERENCES

1. EPD, Promotion of Electric Vehicles in Hong Kong, 2018. http://www.epd.gov.hk/epd/english/environmentinhk/air/prob_solutions/promotion_ev.html

2. CLP, Charging Location, 2017. https://services.clp.com.hk/ev/en/charginglocations.html

3. Hongkong Electric, Charging Location, 2017.

4. DATA.GOV.HK, CLP Electric Vehicle Charging Station Locations, 2017. https://data.gov.hk/en-data/dataset/clp-team1-electric-vehicle-charging-location

5. DATA.GOV.HK, Hongkong Electric, Details of HK Electric EV Charging Stations, 2017. https://data.gov.hk/en-data/dataset/hkelectric-tnd_cs_ci-hkelectric-ev-location

Paper No. 5

RETRO-COMMISSIONING OF BUILDING SERVICES INSTALLATION

Author/Speaker: Ir Victor W.T. Leung
Director
Victor Leung & Associates Limited

RETRO-COMMISSIONING OF BUILDING SERVICES INSTALLATION

Ir Victor W.T. Leung
Director
Victor Leung & Associates Limited

ABSTRACT

Retro-commissioning is the commissioning of existing installation in operation and the objective is to improve performance and energy efficiency of the installation. Building services (BS) installation after being put into operation may be subject to change of building operation mode or equipment characteristics. These affect the performance and energy efficiency of BS installation. Retro-commissioning of BS installation mainly involves adapting to prevalent situation such as means of adjusting system operation pattern and media distribution, implementation of sensors/actuators. This paper not only covers the concept and field application particularly for air conditioning installation which is the major power consumer in a commercial building, but also other installations such as power distribution and lifts/escalators.

1. INTRODUCTION

Retro-commissioning is a knowledge based systematic process of reviewing an existing building's condition/ performance in order to identify opportunities of improving energy efficiency. It comprises identification of such improvement opportunities and accordingly implement necessary works to realize the identified opportunities. Energy efficiency improvement related to retro-commissioning generally includes adjusting existing operation setup of facilities and/or implementing minor modifications such as:-

- modifying system operation to maximize system operating energy efficiency and suit building functional requirement
- optimizing heat transfer media distribution
- minor hardware modification such as implementing of variable speed drive or replacement with energy efficient lighting fitting
- rectification of equipment or material defect

Information to identify energy efficiency improvement opportunities including such as:-

- inspection of equipment/material
- discussion with operation staff to identify operation profile/problem
- manual/BMS record of operation data
- O&M manual
- equipment manufacturer information

2. AIR CONDITIONING

2.1 Equipment Operating Quantity Optimization

Air conditioning equipment such as compressor/ pump/fan operates at maximum efficiency when delivering optimum output under prevalent condition. Hence, equipment operating efficiency can be increased by operating optimum quantity of equipment so that individual item of equipment delivers optimum output under prevalent condition. With the widespread use of variable speed drives, this method of increasing equipment operating efficiency is even more effective since this enables modulating output from individual item of equipment to proximity of optimum output for prevalent operating condition. Followings are examples of increasing operating efficiency of variable speed pump (Figures 1 & 2) and chiller with this method (Figures 3 & 4).

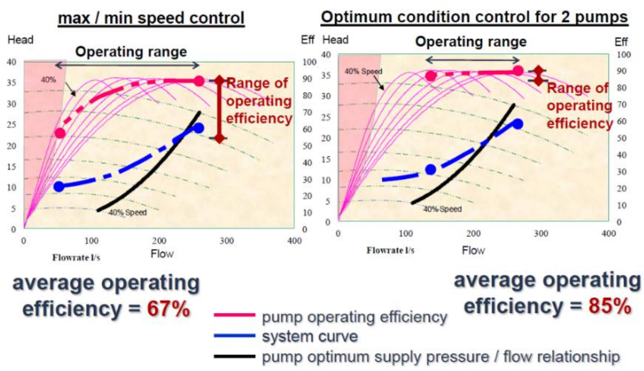

Fig. 1 - VSD pump optimum operating quantity control operating efficiency improvement

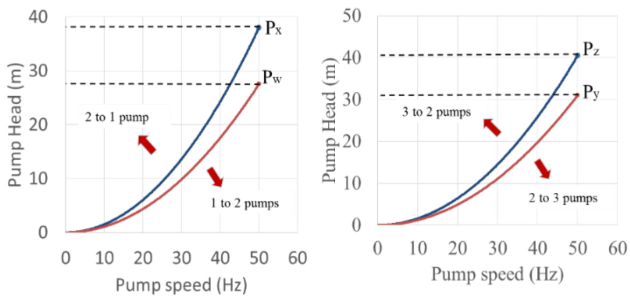

Fig. 2 - VSD pump optimum operating quantity control criteria

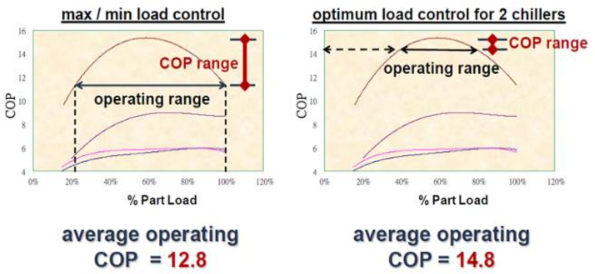

Fig. 3 - Water cooled chiller optimum operating quantity control operating efficiency improvement

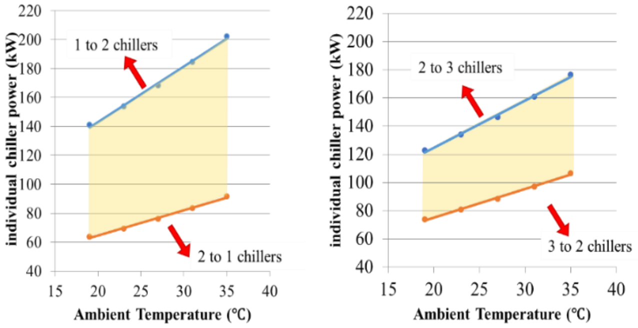

Fig. 4 - Air cooled chiller optimum operating quantity control criteria

2.2 System Operating Parameter Optimization

Chiller compressor head increases with difference between compressor suction/discharge refrigerant saturation temperature. The following contribute to compressor suction/discharge refrigerant saturation temperature difference:-

- outdoor & indoor temperature difference
- air conditioning system heat transfer media supply & return temperature difference
- temperature difference in between contiguous air conditioning system heat transfer media

Out of these contributions to chiller compressor suction /discharge refrigerant saturation temperature difference, Figure 5 indicates that indoor/outdoor temperature difference is only a minor contribution under summer condition, leaving heat transfer media temperature difference being the major contribution. Chiller compressor suction/discharge refrigerant saturation temperature difference can be reduced by methods as follows:-

a) Increasing operating quantity of equipment including heat exchanger/variable speed cooling tower/chiller will increase heat transfer area which will lead to reduction of temperature difference between related heat transfer media, and will also increase heat transfer media flow path which will lead to reduction of power consumption of related fan/pump. However, as described in [2], operating quantity of variable speed cooling tower and chiller should not be excessively increased since this may have adverse effect on chiller/cooling tower operating efficiency.

b) Increase circulation quantity of heat transfer media to reduce heat transfer media supply & return temperature difference, and also to increase heat transfer surface heat transfer coefficient.

c) Perform regular cleaning of heat transfer surface to maximize heat transfer coefficient of heat transfer surface.

Items a) & b) above indicate that heat transfer media temperature difference generally has contrary effect on power consumption of chiller compressor on one hand and that of heat transfer media delivery pump/fan on the other. Hence, in order to maximize air conditioning system overall energy efficiency, it is necessary to optimize heat transfer media operating temperature difference such as examples in the following (Figures 6 & 7).

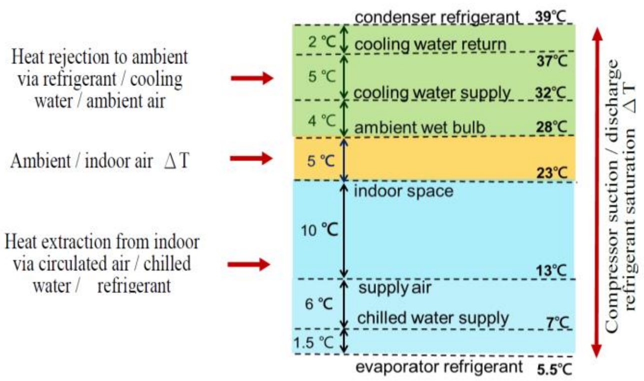

Fig. 5 - Chiller suction/discharge refrigerant saturation temperature difference

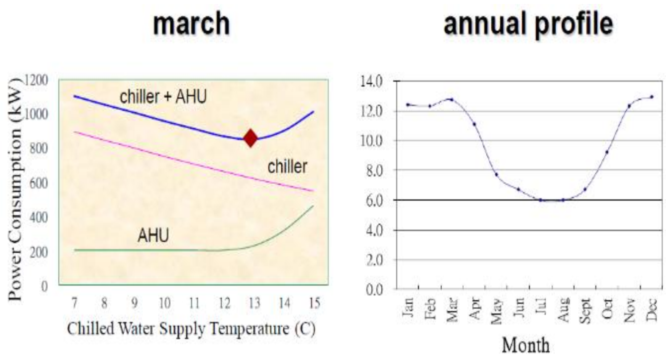

Fig. 6 - Optimum chilled water supply temperature

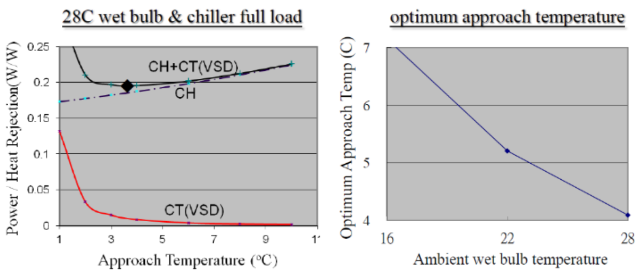

Fig. 7 - Optimum cooling tower approach temperature

2.3 Effective Demand Control

Effective demand control requires both feedback which accurately indicates system demand and sufficient capability to modulate supply in accordance with system demand. These aspects are illustrated with chilled water supply pressure demand control as follows:-

- The objective of chilled water supply pressure demand control is to deliver appropriate supply pressure to maintain chilled water control valves in the distribution system operate within desired range of valve opening position. Hence, control valve opening position provides more direct indication of system supply pressure demand as compared with pump head or distribution circuit index pressure, and can result in more effective demand control (Figure 8).

- Due to pressure dependent characteristics of conventional control valve, opening position of this type of control valve is dependent not only on flow rate but also affected by uneven supply pressure in the chilled water distribution system. This result in generally has widely varying opening positions of conventional control valves in a chilled water distribution system, and this limits the practicality of using conventional control valve opening position as feedback for chilled water supply pressure demand control.

- For dynamic balancing control valve, provided ΔP across valve is above a nominal value of say 20kPa, control valve opening is not affected by uneven supply pressure in chilled water distribution system and has linear relationship with flow rate (Figure 9). Hence, in comparison with conventional control valve, it is more practical to use dynamic balancing control valve opening position as feedback for chilled water supply pressure demand control and result in even more effective demand control (Figure 8).

The above discussion of chilled water supply pressure demand control indicates the general principle that feedback which provides more accurate indication of system demand result in more effective demand control and hence higher operating energy efficiency. Figure 10 is a summary of how demand control effectiveness can be improved by adopting feedback which provides more accurate indication of system demand.

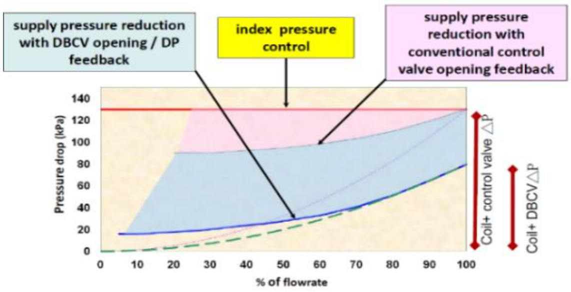

Fig. 8 - Effective demand control of chilled water supply pressure

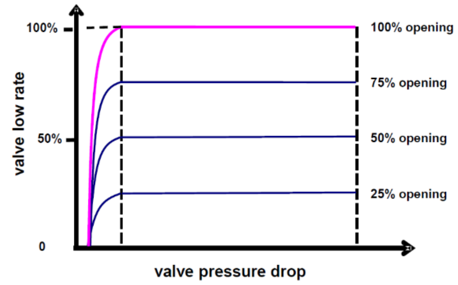

Fig. 9 - Characteristics of dynamic balancing control valve

demand		AHU control valve controllability	AHU heat transfer	chiller condenser heat transfer	CT heat transfer
		Feedback adopted			
demand control effectiveness ↓	constant output	constant speed CHWP	constant CHWS temp	constant speed CWP	constant speed CT
	variable output	CHWP S/R ΔP	CHW mains S/R ΔT	CW S/R ΔT	constant CWS temp
		CHW index S/R ΔP	AHU CHW S/R ΔT	condenser LMTD	CWS / WB ΔT
		control valve opening			

Note : pink – current practice, brown – further improvement

Fig. 10 - Demand control effectiveness vs feedback being adopted

2.4 Yearly and Daily Operation Schedule

As described in [3], adapting air conditioning system operating parameters to prevalent climate conditions will contribute to improvement of system overall operating efficiency. This is similar for air conditioning system equipment operation. For instance, requirements for operating chillers/air handling units prior to commencement of office operation during winter and summer are substantially different. Furthermore, adapting building services operation to building operation schedule will also contribute to improvement of system overall operating efficiency. For instance, chilled water supply temperature can be allowed to be higher during morning start/evening than during daytime, fresh air supply quantity may be allowed to be lower during morning start/lunchtime/evening than that required for full occupancy. Followings are examples of adapting system/equipment operation to climate condition and building operation pattern (Figures 11, 12, 13, & 14).

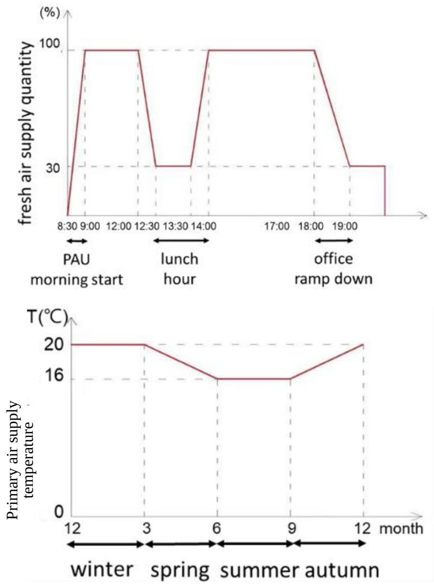

Fig. 11 - Primary air daily supply quantity and annual supply temperature

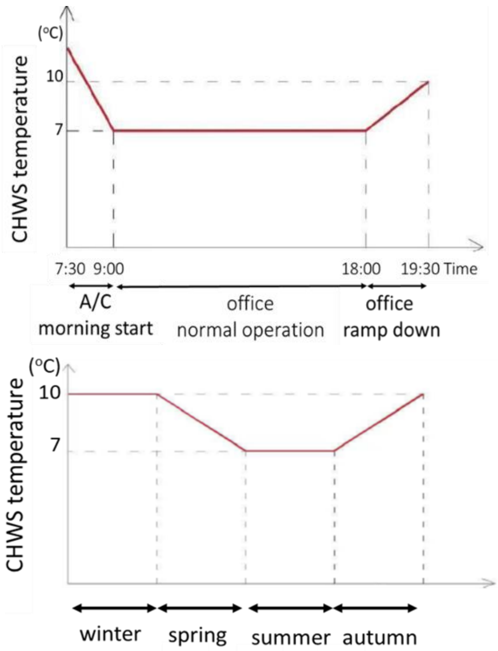

Fig. 12 - Chilled water daily and annual supply temperature

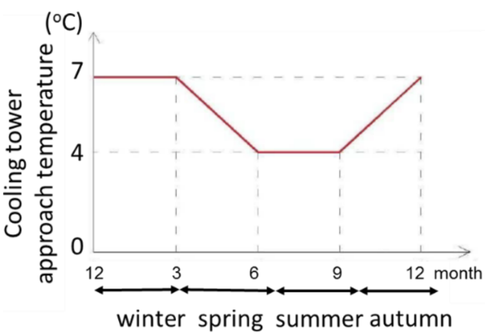

Fig. 13 - Annual chilled water distribution index pressure

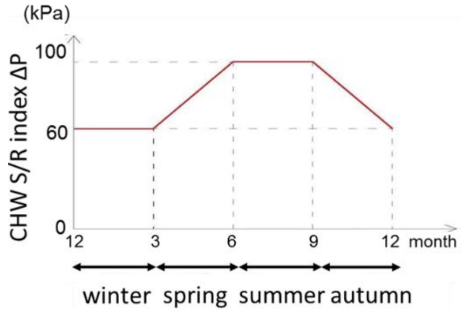

Fig. 14 - Annual chilled water distribution index pressure

2.5 Air/Water Distribution Optimization

This refers to adjusting of air/water distribution to aim at distribution in accordance with maximum demand of individual zone/equipment. This includes air/water heat transfer media and fresh air supply. When there is no demand control in the existing system, this will improve utilization of air/water being distributed. When there is demand control provision in the existing system, this will improve effectiveness of demand control. Examples are as follows:-

- Adopting appropriate type/location of supply/return air terminal contribute to improving effectiveness of air conditioning air circulation in serving occupants (Figures 15/16). This will minimize required air circulation quantity and hence minimize fan power consumption.

- Figure 17 indicates adjustment of cooling water distribution for split units in commercial building with cooling towers on roof. The adjustment was on the basis of existing cooling water supply/return difference on individual floor and estimated piping resistance between roof and individual floor.

- Cooling of fresh air supply for air conditioned space accounts for substantial portion of building cooling load under summer climatic condition. Hence, it is worthwhile to verify if actual fresh air supply quantity matches with design/operation requirement. Figure 18 indicates verification of fresh air supply quantity against design value.

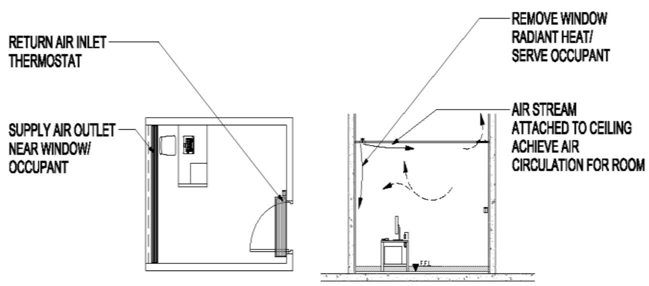

Fig. 15 - Air terminal location in perimeter office

SIEMENS
Ingenuity for life

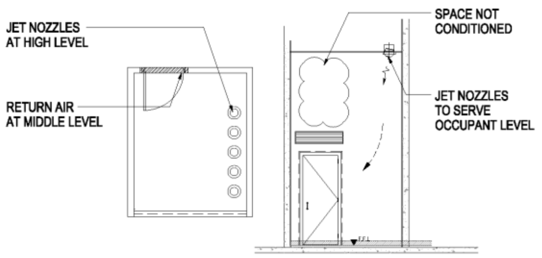

Fig. 16 - Air terminal location in high headroom space

Floor	Existing S/R ΔT (C)	Valve opening	
		Existing	Adjusted
G/F	2	8	8
…	…	…	…
7/F	2.5	8	8
8/F	2.5	8	6
…	…	…	…
15/F	1.5	8	6
16/F	2	8	4
…	…	…	…
23/F	2	8	4

Fig. 17 - Cooling water distribution optimization

Floor	FA inlet (l/s)		FA outlet (l/s)		EA (l/s)
	pitot	hot wire	pitot	hot wire	
17/F	179	262	105	140	52
16/F	197	203	101	121	52
18/F	163	209	109	129	48
Difference between FA fan inlet/supply grille measured air quantity indicates noticeable duct leakage. Measured FA fan inlet flow rate consistent with design FA flow rate of 180l/s					

Fig. 18 - Fresh air supply quantity verification

2.6 Repair and Rectification

The objective of repair/rectification of equipment is to minimize the effect of aging on operating efficiency of respective item of equipment. Examples of means to minimize reduction of air conditioning system operating system due to aging are as follows :-

- Contamination/corrosion of heat transfer surface, including cooling tower/chiller condenser & evaporator/AHU cooling coil, will lead to increase of temperature difference between heat transfer media. Cleaning of heat transfer surface by means of periodic manual cleaning/filtration/ water treatment/automatic cleaning device will help to minimize the adverse effect of this on operating efficiency of air conditioning system.

- Pulley drive belt elongation has adverse effect on efficiency of power transmission from motor to driven equipment, and tightening of loosen belt will minimize this adverse effect.

- Appropriate cleaning/replacement of dirty air filter will avoid unnecessarily high air flow resistance.

- Motor aging will lead to increasing motor winding energy loss as reflected by high motor surface temperature. Motor with excessively high surface temperature should be replaced for reason of operation safety and energy efficiency improvement.

- Inaccurate sensor output will lead to ineffective automatic control and, as a result, adverse impact on indoor comfort and air conditioning system operating energy efficiency. Sensor calibration to verify output accuracy should be regularly carried out, and sensor should be replaced if found to be excessively inaccurate.

3. LIGHTING

Followings are means of improving artificial lighting operating energy efficiency:-

3.1 Lighting Level

Measure existing lighting level and compare with that of design practice (Figure 19). Experience is that lighting level is more likely over provided than vice versa. A common phenomenon is over provision of lighting level for computer based working area which has lower lighting level requirement as compared with paper based working area. Accordingly, lighting level may be reduced to an appropriate value such as by reducing quantity or output of lighting fitting.

Accommodation	Recommended lighting level (lm/m^2)
Office	300(screen based work) / 500(paper-based tasks)
Meeting room / Conference room	300 (normal) / 500 (intensive reading / writing)
Store / pantry	200
Lift lobby	200
Corridor	100

Source : CIBSE Lighting guide

Fig. 19 - Design practice lighting level

3.2 Lighting Efficacy

There has been noticeable development of lighting filament during recent decades with an effort to improve lighting efficacy. Currently, light emitting diode (LED) lighting is widely adopted and has higher lighting efficacy as compared with other types of lighting filament (Figure 20). When replacing existing lighting fittings with more efficient type, quantity/output of the more efficient lighting fitting should be such that lighting level after lighting fitting replacement should not noticeably exceed the desired value. The assessment of necessary quantity/output of the more efficient lighting fittings requires calculation of lighting level after replacement.

Type of lighting filament	Efficacy (lm/W)
Tungsten halogen lamp	12
Incandescent lamp	15
Tubular fluorescent tube (T5/T8)	90
Compact fluorescent lamp (CFL)	60
LED lamp/tube	140

Source : Market product information

Fig. 20 - Lighting filament efficacy

3.3 Lighting Control

This refers to controlling of artificial lighting to suit prevalent operation requirement. Firstly, provide lighting only when there is occupant, such as controlling lighting operation on the basis timer or occupancy sensor feedback. Secondly, adapt artificial lighting output in accordance with window/skylight solar lighting intensity, such as by dimming of light fitting in vicinity of window/skylight on the basis of local lighting level sensor.

4. POWER DISTRIBUTION

4.1 Harmonics

With the extensive use of equipment with non-linear load, such as variable speed drives/computers/electronic ballasts/LED lighting, harmonics in power distribution system has become a common phenomenon. Harmonics in power distribution systems result in increased energy loss/reduce efficiency/reduced performance of the power distribution system and associated driven equipment. Followings are examples of adverse effects of harmonics in a power distribution system:-

a) Cable carrying current
This will increase cable carrying current, particularly for the third harmonic which substantially increases neutral conductor current. In addition, the increased power supply RMS frequency causes AC current to flow on the outer periphery of the cable conductor (skin effect). All these increase energy loss in cable conductor and may even lead to cable carrying current being in excess of cable rated capacity.

b) Motor
This will increase core loss (magnetic field hysteresis loss and eddy current loss) of motors connected to the system. As a result, there will be increased heating of the motor core which reduces both motor operating efficiency and motor service life.

c) Capacitor bank
This may lead to harmonic resonance in capacitor bank when inductive and capacitive reactances are equal to each other and the resulting voltage amplification may damage the capacitor bank and associating equipment.

Hence, even if only from the perspective of energy efficiency, it is worthwhile to monitor harmonics in a power distribution system, particularly if substantial portions of equipment connected to the power distribution system are non-linear load. This allows identification of any excessive harmonics in power distribution and accordingly considers mitigation measures such as harmonic filter to reduce amplitude of harmonics or isolation transformer to reduce its impact on the power distribution system and connected electrical load.

4.2 Power Factor

Low power-factor of loads connected to a power distribution system will lead to increased current in the system and hence increased power distribution energy loss. If there is major load with low power factor being connected to a power distribution system, it would be desirable to implement power factor corrector in vicinity of the major load.

5. LIFT AND ESCALATOR

5.1 Lift

Power consumption of lift may be reduced by the following means:-

- If individual lift responds only to lift calls to floors in proximity of each other, lift travel distance will be reduced. This can be achieved by manual or automatic control of lifts.

- During non-busy hours, such as late morning or late afternoon, portion of lifts may be put on standby to reduce quantity of lifts that respond to lift call and hence reduce lift travel.

- During night time when lift call is envisaged to be quite rare, power supply to portion of lifts may be cut off. This will reduce unnecessary lift power consumption, particularly lift air conditioning.

- Lift counterweight may be adjusted in accordance with observed lift traffic load profile to aim at median of lift traffic load. This will reduce lift motor torque for overcoming lift counterweight being excessively higher than lift traffic load.

5.2 Escalator

Escalator power consumption may be reduced by stopping escalator operation or reducing escalator speed when there is no usage. This can be achieved by control escalator start / stop or operating speed on the basis of motion sensor feedback.

6. MEASUREMENT & VERIFICATION

The objective of "Measurement & verification" (M&V) is to verify the improvement that has been achieved after implementing of measures to improve energy efficiency. This is achieved by comparing energy consumption during baseline period and post-implementation period. The comparison has to be adjusted for impact of difference in operating condition during baseline period and post-implementation period, including such as weather/duration of operation/ increased use of equipment. According to "International Performance Measurement & Verification Protocol", there are four options of M&V methodology:-

a) Option A – partially measured retrofit isolation

Measure only portion of parameters of affected facility expected to change. Examples are to measure instantaneous kW for lighting replacement assuming duration of operation unchanged, and measure kW for addition of variable speed drive to pump with flow/head maintained unchanged by means of automatic control.

b) Option B – retrofit isolation

Measure all parameters of affected facility. Example is to measure kW/flow/head/speed for addition of variable speed drive to pump.

c) Option C – whole facility

Measure all parameters within entire facility. This may have to be adopted when implemented energy saving measure have dominating effect on energy consumption of the entire facility.

d) Option D – calibrated simulation

Measurement not carried out and rely on simulation to compare energy use. This may have to be adopted when there is no baseline period information or when the effect of implemented energy saving measure cannot be isolated.

7. CONCLUSION

This paper has presented various methods to improve operating energy efficiency of existing building services installation. Briefly, these aim to efficiently adapt operation of building services installation to building operation/climate condition by utilizing available information and technology. It is hoped that there will be more devotion to this aspect in order to combat global warming and natural resource depletion.

REFERENCES

1. HKSAR EMSD, 2018, Code of Practice for Energy Efficiency of Building Services Installation

2. CIBSE - The Society of Light and Lighting, 2005, Lighting Guide 7 : Office lighting

3. Sankaran, C. , 1999, Effects of Harmonics on Power Systems, EC&M

Paper No. 6

IOT ENABLED SMART BUILDING OPERATION AND MAINTENANCE

Authors/Speakers: Ir C.K. Lee, Chief Engineer
Ir Steve H.Y. Chan, Senior Engineer
Ir Grace K.M. Yip, Engineer
Ir Francis P.H. Yuen, Engineer
Mr T.C. Chan, Assistant Engineer
Ms P.Y. Cheung, Assistant Engineer
Electrical and Mechanical Services Department
The Government of the HKSAR

IOT ENABLED SMART BUILDING OPERATION AND MAINTENANCE

Ir C.K. Lee, Chief Engineer
Ir Steve H.Y. Chan, Senior Engineer
Ir Grace K.M. Yip, Engineer
Ir Francis P.H. Yuen, Engineer
Mr T.C. Chan, Assistant Engineer
Ms P.Y. Cheung, Assistant Engineer
Electrical and Mechanical Services Department
The Government of the HKSAR

ABSTRACT

With the rapid development of Internet of Things (IoT) technologies, massive and rapid deployment of IoT sensors can be supported with the unique features of low power consumption, low bandwidth and long-distance coverage. To support the building of a smart city and provide value-added services, Electrical and Mechanical Services Department (EMSD) established a physical testing ground for conducting tests on the performance of Low Power Wide Area Network (LPWAN) technologies including LoRa, Sigfox and NB-IoT. Different types of sensors were installed in EMSD Headquarters (HQs) for testing the performance of these sensors in meeting room and carpark space management applications. The use of IoT sensors had been explored for collecting Electrical & Mechanical (E&M) equipment operating status at venues without Building Management System (BMS). This paper will discuss the adoption of IoT technologies in smart building operation and maintenance (O&M) with a view to provide a cost-effective solution for near-to-real time monitoring and the benefits of building a common IoT network infrastructure for sensor connectivity contributing to smart city development.

1. INTRODUCTION

With an aim to transform Hong Kong into a smart city, the government published the Smart City Blueprint in 2017 and actively promotes smart city development to enhance the Government's capability in innovation and the standard of city management. Being a works department responsible for providing quality engineering services to upkeep electrical and mechanical (E&M) facilities and enhance energy efficiency in over 8,000 government buildings and facilities, the Electrical and Mechanical Services Department (EMSD) has been exploring various Innovation and Technology (I&T) solutions in the Operation and Maintenance (O&M) of building facilities, which act as a microcosm of smart city infrastructure.

In the past few years, EMSD has started to digitise the E&M assets in government buildings, venues, and infrastructure systems, striving for a new vision which we call "E&M 2.0". Digitalisation is the key enabling step to building up a Smart City, and IoT offers a means to collect massive volume of data as a very first step in enabling digitalization. This paper will walk through EMSD's journey in utilizing the IoT technology to achieve smart building operation and maintenance and contribute to smart city development.

2. ADOPTION OF LPWAN TECHNOLOGIES

The Internet of Things (IoT) refers to the inter-connection and exchange of data among devices/sensors via the Internet [1]. In the early 2000s, EMSD adopted the first generation of IoT by installing Remote Monitoring Units and used 2G/3G/4G sim card to transmit real time operation data from territory-wide distributed infrastructures such as subway pumps, footbridge lifts and escalators and electrical systems to central computers so that maintenance personnel could be mobilized as soon as any failure alarm was reported. With the increasing practical IoT use cases such as smart home, wearables, smart metering and smart city, EMSD had been exploring the application of LPWAN technologies in E&M facilities since 2016.

LPWAN has become a popular wireless radio communication technology in recent years because of its low power, long range and low cost communication characteristics as compared with WiFi, Zigbee and Bluetooth. It provides long range communication up to 10 - 40 km in rural zones and 1 - 5 km in urban zones [2]. With its low power characteristic, it is a highly efficient technology for transmitting data of low bandwidth with a wide area of coverage as shown in Figure 1.

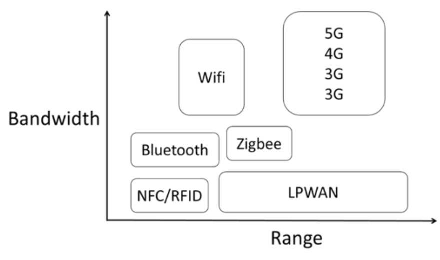

Fig. 1 - Bandwidth versus range of radio communication technologies

In addition, the LPWAN sensors are mostly battery-operated devices which can be massively deployed within a short period of time. Site work for fixed electrical power connection can be minimized to lower the implementation cost and shorten the installation time.

While there are many LPWAN technologies and standards utilising either the licensed or unlicensed frequency band, the three main types of LPWAN in the market are LoRa (short for Long Range), Sigfox and Narrowband-IoT (NB-IoT) (see Figure 2). To evaluate their performance and capabilities in different use cases, the pilot projects for three technologies were conducted in the EMSD HQs which acts as a testing ground for E&M related innovation.

Fig. 2 - Three main LPWAN technologies

3. PILOT PROJECTS AT EMSD HQS

The project objective was to examine the transmission and sensor performance of the three different LPWAN technologies. EMSD firstly commenced the trial on LoRa standard at EMSD HQs in 2018. Eight LoRa gateways were installed to provide the signal coverage for majority indoor areas within the 7-storey building having a gross floor area of 81,000 square metres. For the outdoor coverage, the signal from the rooftop antenna could reach Energised Kowloon East Office (EKEO) which is around 2km away from the HQs.

Unlike LoRa technology which offers enterprise customers the choice of installing their own gateways to build a private network, both Sigfox and NB-IoT are operator-managed public networks requiring subscription for sensor connectivity. Therefore, the trials of Sigfox and NB-IoT technologies involved mainly the supply and installation of sensor devices. Over 250 carpark sensors were installed in the indoor and outdoor area while over 200 other battery-operated sensor devices, such as temperature and humidity sensors, light sensors, air quality sensors, and door sensors, were installed in meeting rooms and other areas throughout the headquarters building. The collected sensor data from different platforms were displayed on dashboards for performance evaluation. Smart facility management applications, such as smart carpark and smart room reservation system and smart toilet management system, were developed to enhance the workplace efficiency in EMSD HQs as well as showcase the benefits of IoT technologies.

3.1 Smart Reservation System for Meeting Rooms and Carparks

In 2019, EMSD launched the new Smart Meeting Room and Carpark Reservation System. Apart from the typical online facility booking feature, the system provides a central management platform with interactive dashboards (see Figure 3) to visualise the meeting room, carpark occupancy status as well as temperature and humidity information collected by the IoT sensors. The facility manager can also check the usage statistic of meeting rooms & carparks and generate reports that provides insight on how to maximize the utilisation of the facilities.

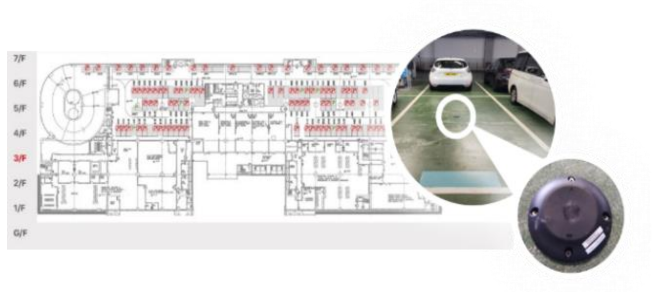

Fig. 3 - Smart carpark reservation system

3.2 Smart Toilet Management System

Smart toilet management system was developed with an objective to deliver a pleasant restroom experience with less manpower. The IoT sensors collect relevant data covering the various aspect of toilet management, including toilet cubicle occupancy, queue detection, detection of remaining consumables such as toilet paper and hand-wash liquid, odour and water leakage detection (see Figure 4). Leveraging on IoT technologies, the smart toilet management system offers a holistic view of the usage patterns so that manpower can be deployed more efficiently to ensure the toilets are always in prime condition for better user experience.

Fig. 4 - Smart toilet management system

4. PILOT TRIALS FOR ENHANCED E&M SYSTEM OPERATION AND MAINTENANCE

Further to the IoT sensor deployment at EMSD HQs for facility management, the trials were extended to other government premises and facilities in Shatin district in early 2019 to exploit the benefits of IoT technologies in facilitating E&M system O&M, especially in unattended venues without BMS system or remote monitoring functionality. The LPWAN technologies offer the opportunities for E&M digitalization in existing buildings without the need to upgrade the existing BMS nor install extensive wiring for additional sensor devices.

4.1 Interfacing with Local E&M Systems

In the market, there are LPWAN devices readily available for interfacing with existing E&M systems through traditional signals protocols such as Modbus, 4 to 20mA current loop, dry contact signals. Figure 5 shows the LoRa RS-485 device installed to collect the operation status of filtration pump system of swimming pool for remote monitoring. In the case of community halls, the hard-wired alarm panels of the local HVAC system were retrofitted for installing dry contract LoRa devices to transmit the common fault signals. Based on the same design approach, the local alarm points of irrigation pump system at sport ground and heat pump system at municipal building could be collected via the LPWAN technology for display on a dashboard such that the maintenance staff can be notified the fault and attend on site in a timely manner.

Fig. 5 - LoRa RS-485 device installed at swimming pool filtration system

4.2 Digitalising Existing E&M Systems

Due to the constraint of existing installation, E&M operation data being useful for O&M is sometimes not available. In the trials of LPWAN technology at Shatin, LoRa current meters were installed to measure the current flow of the three-phase power supply to the chillers as shown in Figure 6. The data could help the maintenance staff to understand the system operation pattern and estimate the power consumption of the chillers. Other use cases include the installation of vibration sensors for capturing the vibration patterns of ventilation fans in public transport interchange and temperature sensors for lift car environment monitoring to provide insights on existing E&M system operation conditions. All these use cases could demonstrate how LPWAN technology could enable smarter building operation and maintenance.

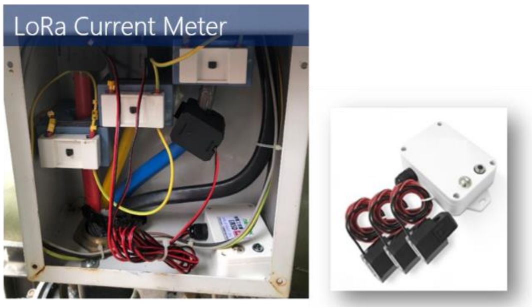

Fig. 6 - LoRa current meter for chiller power supply monitoring

5. COMMON IOT NETWORK AND DATA PLATFORM FOR SMART APPLICATION DEVELOPMENT

With the aforesaid IoT use cases for building operation and maintenance, EMSD identified the need to build a common IoT network infrastructure to provide connectivity to massive amount of sensor devices. A trial commenced in 2019 to build a Government wide IoT Network (GWIN) - a private IoT network infrastructure and data platform, to process and consolidate sensor data to a single point of interface for end-user application development. Considering the respective advantages of various LPWAN technologies as shown in Figure 7 [1], the infrastructure was built based on the LoRa technology with the adoption of MQTT (Message Queuing Telemetry Transport) protocol to integrate data from LPWAN sensors based on Sigfox, NB-IoT, LoRa technologies transparent to end-users (see Figure 8).

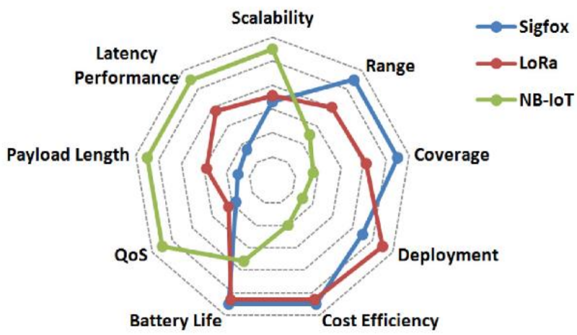

Fig. 7 - Respective advantages of LoRa, Sigfox and NB-IoT

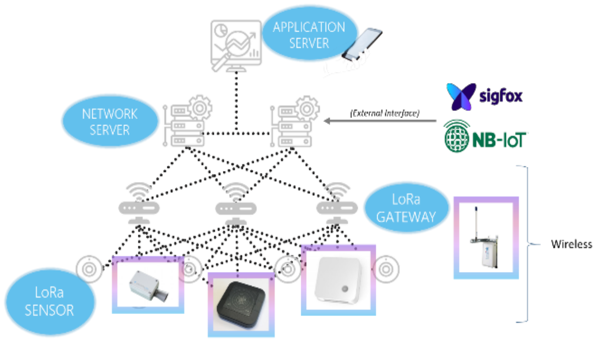

Fig. 8 - EMSD IoT network infrastructure and data platform

34 numbers of LoRa gateways, providing the signal coverage as shown in Figure 9, were installed at the government buildings and facilities in Shatin district providing connectivity to sensors at various venues for trials. The network infrastructure and data platform consolidate not only the sensor data collected from the various venues at Shatin for E&M system O&M, but also the data provided by the sensors installed at EMSD HQs based on the Sigfox and NB-IoT technologies.

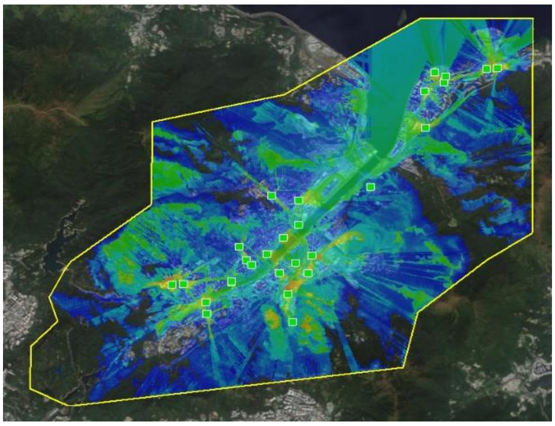

Fig. 9 - Network coverage simulation of LoRa gateways installed in the trial at Shatin district

5.1 Deployment of Smart City Applications

Riding on the common IoT network infrastructure, EMSD had been collaborated with other government departments to explore potential smart city applications adopting LPWAN technologies. One of the successful showcases is the use of LoRa sensors to support Drainage Services Department's (DSD) Smart Drainage project on flood monitoring (see Figure 10).

This battery operated solution, without the need for last mile physical connection, was set up at 15 monitoring spots in just 4 months. Both the installation cost and set-up time were reduced by 90% as compared to conventional wired solution. This fast and scalable deployment enabled DSD to effectively monitor real-time information of water level at various strategic locations before the coming typhoon season, which also helps DSD to better protect the lives and properties of the general public.

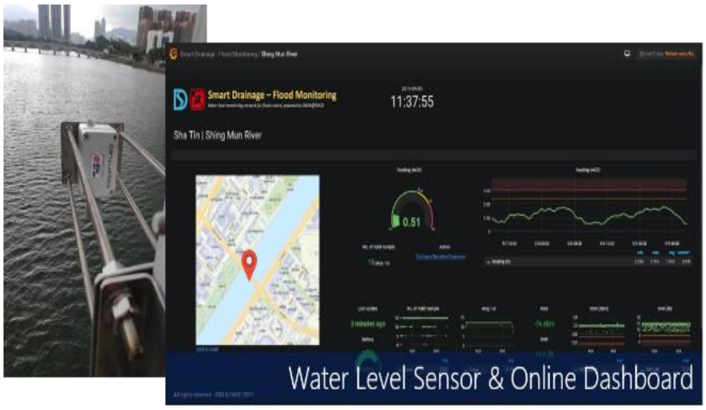

Fig. 10 - Water level sensor deployed at Shatin

5.2 Data Analytics for Predictive Maintenance and Energy Optimization

With the common data platform supporting multiple LPWAN technologies under GWIN, the E&M system operational and maintenance data recorded can be remotely accessible by central service team for data analysis, arranging equipment repairing at early stage so as to enhance system availability and reduce down time. For example, the historical trends of vibration patterns of ventilation fans could be studied and analysed to facilitate predictive maintenance before breakdown occurs. In addition, the LPWAN technologies enable the collection of building operational data for conducting occupant behaviour analysis which can quantify the impact of occupant behaviour on building energy performance [3]. By analysing the historical data, the underlying correlation between indoor and outdoor temperature, occupant behaviour and total building energy consumption can be correlated for the prediction of optimal settings to achieve energy saving and user comfort.

6. CONCLUSION

The emerging LPWAN technologies featuring low power consumption with large coverage area, enable smart building operation and maintenance in terms of fast and cost saving deployment. EMSD, working towards E&M digitalization, had implemented a cost-effective IoT network infrastructure – GWIN to further promulgate the use of LPWAN technologies in collecting useful data for data analytics (e.g. artificial intelligence) and adopting innovative solutions to address various smart city challenges. Looking ahead, EMSD will continue to play a proactive role of a "facilitator" and a "participant" to drive the IoT applications with a view to transforming Hong Kong into a Smart City.

REFERENCES

1. Kais Mekki, Eddy Bajic, Frederic Chaxel, Fernand Meyer. A comparative study of LPWAN technologies for large-scale IoT deployment, 2018.

2. Marco Centenaro, Lorenzo Vangelista, Andrea Zanella, Michele Zorzi. Long-range communications in unlicensed bands: The rising stars in the IoT and smart city scenarios, IEEE Wireless Communications, 2016.

3. C.K. Lee, H.Y. Chan, C.Y. Poon, K.M. Yip, P.H. Yuen. BIM in respect of digitalization, HKIE Electrical Division Symposium 2018.

Paper No. 7

BRING THE WORLD INTO 5G ERA

Author/Speaker: Mr Philip H.F. Yick
Solution Director
Huawei International Co. Ltd

BRING THE WORLD INTO 5G ERA

Mr Philip H.F. Yick
Solution Director
Huawei International Co. Ltd.

ABSTRACT

5G brings a great opportunity to engage with operators and plan "changes or evolutions" in their network. What 5G means, it depends on perception and people's role: "5G will radically improve the life style of people" (focus on the multi-connectivity that 5G enables), "5G enables the initial implementation of the digital transformation" (focus on the optimization and automation of the infrastructure), "5G enables fast services" (focus on the enhanced mobile broadband with higher uplink and downlink data rate), "5G will enable services with better user experiences" (focus on the reduced delay on the architecture design). All these statements are shared in the discussion on how to plan the next step in the "digital transformation".

1. INTRODUCTION

Huawei has been promoting 5G technologies worldwide. With the persistent effort, digital transformation has been put to create a better digital world. In order to achieve a well digital transformation, cloud adoption of networks, operation systems and services are much appreciated for the transformation. With the cloud technology, telecom operator transforms the existing networks into Cloud-native architecture network in which all functions and services application supported by the network are based on cloud data center (DC).

When our world enters a 5G era, a single network infrastructure will be able to support diversified service demands and user requirements. Advantages come with 5G networks include:

- Provides logically independent network slicing on a single network infrastructure to meet diversified service requirements and provides DC-based cloud architecture to support various application scenarios.
- Uses CloudRAN to reconstruct radio access networks (RAN) to provide massive connections of multiple standards and implement on-demand deployment of RAN functions required by 5G.
- Simplifies core network architecture to implement on demand configuration of network functions through control and user plane separation, component-based functions, and unified database management.
- Implements automatic network slicing service generation, maintenance, and termination for various services to reduce operating expenses through agile network O&M.

5G is the beginning of the promotion of digitalization from personal entertainment to society interconnection. In order to cope with the increasing trend of new requirements on communication and mobile services, telecom network ecosystem needs to be modified and expanded to suit for the changes. At this moment, 5G mobile network services can be classified into three categories (see Figure 1), namely enhanced Mobile Broadband (eMBB), Ultra-reliable and Low-Latency Communications (uRLLC), and Massive Machine Type Communications (mMTC).

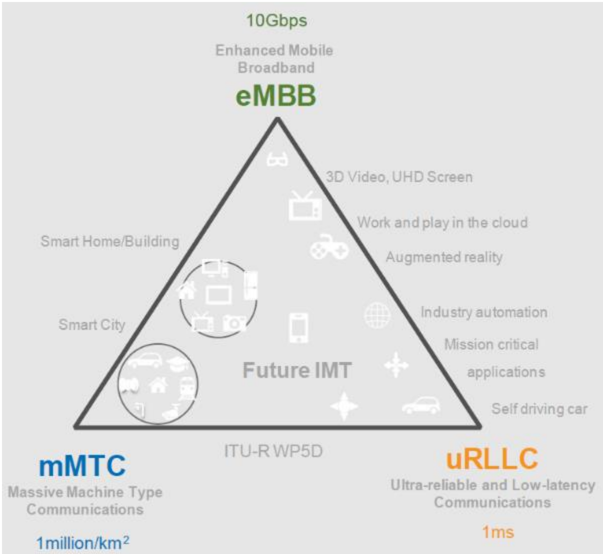

Fig. 1 - Correlation of the three main 5G mobile network services

2. 5G NETWORK ARCHITECTURE

When we enter 5G era, 5G networks are able to provide diversified services through supporting multiple standards, such as 5G, LTE, and Wi-Fi, and coordinate different site types (macro, micro, and pico base stations). 5G is expected to co-exist with LTE and Wi-Fi for an extended period of time incorporating multi-connectivity technologies and the new 5G air interface so as to provide sufficient transmission throughput and mobile continuity.

5G network architecture aims to flexibly and efficiently meet diversified mobile service requirements. With software-defined networking (SDN) and Network Functions Virtualization (NFV) supporting the underlying physical infrastructure, 5G comprehensively cloudifies access, transport, and core networks. The design of the 5G network architecture is based on access sites and three-layer DCs. According to different services requirements, fiber/optic cable availability, network resource allocations, RAN real time and non-real time resources can be deployed on the site or on the access cloud side.

Cloud adoption allows for better support for diversified 5G services, and enables the key technologies of E2E network slicing, on-demand deployment of service anchors, and component-based network functions.

2.1 End-to-End (E2E) Network Slicing

E2E network slicing is a foundation to support diversified 5G services and is a key to 5G network architecture evolution. Based on NFV and SDN, physical infrastructure under 5G network architecture consists of sites and three-layer DCs. Sites support multiple modes (such as 5G, LTE, and Wi-Fi) to implement the RAN real time function. Three-layer cloud DC consists of computing and storage resources. The bottom layer is the central office DC, which is closest in relative proximity to the base station side. The second layer is the local DC, and the upper layer is the regional DC, with each layer of arranged DCs connected through transport networks (see Figure 2).

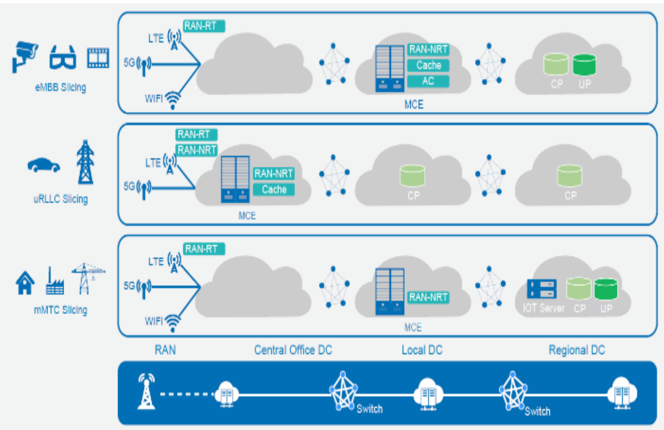

Fig. 2 - Physical infrastructure for E2E network

According to diversified service requirements, networks generate corresponding network topologies and a series of network function sets (network slices) for each corresponding service type using NFV on a unified physical infrastructure. Each network slice is derived from a unified physical network infrastructure, which greatly reduces subsequent operators' network construction costs. Network slices feature a logical arrangement and are separated as individual structures, which not only allows for heavily customizable services functions but also greatly reduces subsequent operator's network construction costs.

2.2 CloudRAN

CloudRAN consists of sites and mobile cloud engines which coordinates multiple services, operating on different standards, in various site types for RAN real time resources that require a number of computing resources. Multi-connectivity is introduced to allow on-demand network deployment for RAN non-real time resources. Networks implement policy control using dynamic policy, semi-static user, and static network data stored in the unified database on the core network side. Component-based control planes and programmable user planes allow for network function orchestration to ensure that networks can select corresponding control-plane or user-plane functions according to different service requirements. The transport network consists of SDN controllers and underlying forwarding nodes. SDN controllers generate a series of specific data forwarding paths based on network topology and service requirements. The enabling plane abstracts and analyzes network capabilities to implement network optimization or open network capabilities in the form of API. The top layer of the network architecture implements E2E automatic slicing and network resource management.

Multi-connectivity is key to high speed and reliability. It plays an important role as an underlying fundamental construct for the deployment of the future network architecture. It helps provide an optimal user experience based on LTE and 5G capabilities such as high bandwidth and rates of high frequency, network coverage and reliable mobility of low frequency, and accessible Wi-Fi resources.

In the traditional architecture integrating base stations as an anchor for data connection, LTE, 5G, and Wi-Fi data is aggregated into a non-real time processing module of a specific standard to be forwarded to each access point. In the CloudRAN architecture, non-real time processing function modules in access points of different modes are integrated into the Mobile Cloud Engine (MCE), which serves as an anchor for data connection. Data flows are transmitted to each access point over the MCE, which prevents alternative transmission and reduces transmission investment by 15%, and latency by 10 ms.

MCE is the logical entity of central control and management for CloudRAN, incorporating RAN non-real time functions, Wi-Fi AC, distributed gateway, service-related application distribution entity (App), and Cache. RAN non-real time functions include a general control plane (cRRC) to facilitate multi-connectivity and new technology deployment, and a centralized resource management module (cRRM) to ensure the efficient coordination of resources in heterogeneous networks.

3. CLOUD NATIVE CORE ARCHITECTURE

3.1 Control and User Plane Separation Simplifies the Core Network

Existing network gateways integrate parts of both user plane and control plane functions. In the 5G era, many services with high requirements for latency require gateways to be relocated by a downward shift towards the local or central office DCs. This requires the number of gateway nodes to increase by 20 to 30 times the original amount.

Gateway control and user plane separation divides complex control logic functions for convergence into control planes, which reduces the costs of distributed gateway deployment, interface load, and number of alternative signaling routes. In addition, the control plane and user plane separation supports scaling of the forwarding and control planes, which further improves network architecture flexibility, facilitates centralized control logic functions, and ensures easy network slicing for diversified industry applications. This segregation technique also decouples the forwarding plane from the control plane, which prevents frequent forwarding plane upgrades caused by control plane evolution. Two tasks must be completed to implement control and user plane separation. First, an implementation of lightweight functions to divide complex control logic functions. Second, the construction of models for the reserved core functions with the definition of a generalized template model complete with object-oriented interface for the forwarding plane to ensure that the forwarding plane is both programmable and scalable.

After the control and user planes are successfully separated, interfaces providing the associative link connections operate through the enhanced GTP protocol. Based on subscriber access types and subscription data, the control plane initiates an orchestration for service objects and atomic actions, and sends the request to the forwarding plane over the enhanced GTP interface. The forwarding plane then responds with a service-based event notification confirming receipt which is directed back to the control plane.

3.2 Flexible Network Components Satisfy Various Service Requirements

In the 5G era, with the 5G network architecture, logical control functions can be abstracted as independent functional components, which can be flexibly combined according to service requirements. Logically decoupled from other components, network function components support neutral interfaces and implement an identical network interface message to provide services for other network function subscribers. Multiple coupling interfaces are transformed to converge into a single interface. A Network function management framework provides network registration, identification, and management. Independent features ensure that the addition of network functions and potential upgrades do not affect existing network services.

Compared to tightly coupled network control functions, the control plane component architecture significantly simplifies the development and deployment of new services through flexible orchestration and plug-and-play deployment, and lays a solid foundation for 5G E2E network slicing.

3.3 Unified Database Management

Rapid fault recovery is required for network data status information (such as user data and policy data shared across data centers) to meet network reliability requirements after the virtualization of functions. The traditional recovery mechanism based on N+1 backup relies on private signaling interaction to implement status information synchronization, which produces system inefficiency and complex interaction of cross-vendor products.

With separated data and control logic, network status information can be centralized in a unified database. All network functions can access metadata models through standard interfaces and locally store dynamic user data. Together with the distributed database synchronization, network status information can implement real-time backup between data centers (see Figure 3). With the help of the service management framework, the unified database simplifies the procedure for network information retrieval functions introduced by the component-based control plane to reduce the required signaling overhead for data synchronization.

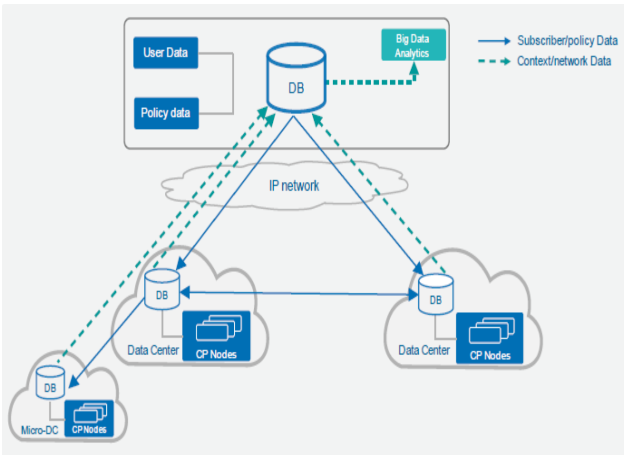

Fig. 3 – Illustration of unified database management

4. CLOUD X: INTERACTIVE APPLICATIONS BROUGHT BY 5G NETWORK

5G network technology promises to disrupt existing markets, enable new business models and alter the competitive landscape for a wide number of industries. The characteristics of 5G - low latency, increased capacity, faster speeds, and potential for a much greater volume of connections - make it particularly suited as a network technology for interactive cloud-based software and services.

The Cloud X concept is a content and service delivery framework comprised of cloud-based GPU-based servers, applications streamed from the cloud, high-speed mobile connectivity and smart hardware. It offers 3 innovative features viz Cloud PC, Cloud Gaming and Cloud AR/VR.

4.1 Cloud PC

Cloud PC helps to prevent data loss and hardware failure as compared with standalone PC. Besides, it reduces the uses of expensive high powered machines to support high-level software. There are also other benefits to placing virtualised desktop solutions in the cloud rather on premises which include scalability, security, reliability and redundancy.

4.2 Cloud Gaming

Cloud gaming allows consumers to access a portfolio of games whenever they want and on different screens/ devices of their choice. All the games' content will be stored in cloud and easily accessible by consumers at any time at anywhere. There are other benefits of 5G for cloud gaming.

- Thin or low-powered client devices can be used to access high-end gaming content. Consumers do not need to buy expensive consoles or gaming PCs to enjoy high-end games content.
- The support of non-specialist hardware including mobile devices means that gamers can play high-end games across different use cases including out of home and on the move.
- Access to games - once available on the server end - takes a matter of seconds. There is no need to download the game to the end-user device. It is a better user experience in this respect.

4.3 Cloud AR/VR

Cloud AR/VR will enable immersive computing technologies to flourish by reducing the cost of ownership for hardware. 5G will make mobile-first immersive computing applications more accessible, usable, intelligent and start to deliver greater user experience.

Figure 4 shows the service architecture of Cloud VR games, which is constructed on both the central and edge clouds. Some of the functions of the rendering and game engines are deployed on the edge cloud, implementing user-side gaming logic computing and image rendering. The edge cloud is closer to users, meaning lower latency and a more satisfactory real-time interaction experience. Game servers, however, are deployed on the central cloud, implementing other functions of the game engine and user status synchronization.

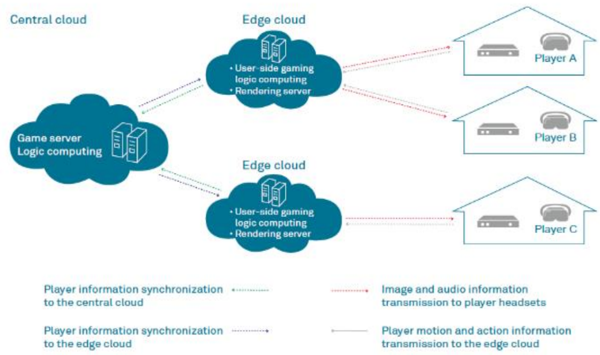

Fig. 4 – Service architecture diagram of Cloud VR games

5. CONCLUSION

5G networks require continuous innovation through cloud adoption to customize network functions and enable on-demand network definition and implementation and automatic O&M. Physical networks are constructed based on DCs to pool hardware resources including part of RAN and core network devices, which maximizes resource utilization. In addition, E2E network slicing provides logically separated virtualized network slices for diversified services, which significantly simplifies network construction for dedicated services.

CloudRAN is built based on MCE. Multi-connectivity helps aggregate access capabilities of multiple RATs, frequency bands, and site types to maximize network efficiency. Based on the control and user plane separation, 5G core networks using component-based control planes, programmable user planes, and unified database will simplify signaling interaction and allow for the deployment of distributed gateways.

Last but not least, a new trend Cloud X comes with 5G technology will deliver improved network latency which further enhances the end user experience.

Paper No. 8

DYNAMIC OPTIMISATION OF PEAK DEMAND CHARGE USING MACHINE LEARNING ALGORITHMS

Authors/Speakers: Ir Dave C.H. Chan, Director
Mr Kenneth K.Y. Lee, Technical Manager
Dr Pan P. Lee, Senior R&D Engineer
Information, Communications and Building Technologies
ATAL Building Services Engineering Ltd

DYNAMIC OPTIMISATION OF PEAK DEMAND CHARGE USING MACHINE LEARNING ALGORITHMS

Ir Dave C.H. Chan, Director
Mr Kenneth K.Y. Lee, Technical Manager
Dr Pan P. Lee, Senior R&D Engineer
Information, Communications and Building Technologies
ATAL Building Services Engineering Ltd.

ABSTRACT

Apart from enhancing building energy efficiency, peak demand management is also an important topic in building industry. In a typical office building, the occurrence of monthly peak demand varies from season to season. Depending on the actual chiller plant configuration and load variation, peak demand in summer often occurs during the morning start-up or noon period. In practice, however, the impact of different equipment operations on peak demand is not fully taken into account in the central air-conditioning control. Therefore, this provides opportunities to minimise peak demand by using advanced building load control and chiller start-up sequencing strategies.

This paper presents a new approach to optimise peak demand charges using machine learning (ML) algorithms. This approach comprises three major components, namely peak demand monitoring and analysis, cooling load prediction, as well as optimisation of equipment sequencing.

First, an advanced data acquisition method is used to obtain the high frequency data of all central air-conditioning equipment (both water and air-side systems). With the high resolution data, the occurrence and causes of peak demand in buildings can be fully analysed using big data analytics. Second, based on the historical load data and weather conditions, the ML-based cooling load model is developed to predict the required cooling load. This helps to effectively formulate chiller and air handling unit (AHU) start-up sequencing strategies under various load conditions. Third, by adjusting the equipment start-up sequencing, the peak demand charge can be fully optimised under various load conditions. A case study will be used to illustrate the proposed approach.

1. INTRODUCTION

Peak demand management is particularly important to electricity companies as it not only helps to minimise electricity generation capacity, reduce the cost of electricity supply, but also enhance the operation reliability of electricity transmission facilities. In order to reduce peak demand, electricity companies formulate the tariff structure in a way where on top of electricity consumption charge, the demand charge is charged for the customers with high electricity demand. The amount of the demand charge is calculated based on the maximum demand (in kVA) over a month. The higher the demand, the higher the demand charge would be. Recent research indicated that although peak demand in commercial buildings occurs for a period of time, it still contributes to the cost up to 50% of the total electricity bill [1].

A number of demand management methods have been advocated in different countries (e.g. demand shedding, demand shifting and on-site generation) [2]. However, there is still a limited study focusing on the occurrence and causes of peak demand in buildings, as well as how machine learning can be used to minimise peak demand.

Thanks to the advances in technology, a huge amount of high frequency data can be obtained effectively through Building Management System (BMS) [3]. Using big data analytics, the conditions where the peak demand occurs can be examined in details. Once the causes of peak demand are fully analysed, the corresponding measures to minimise the peak demand can be formulated and implemented in the actual building. In this paper, a case study is used to illustrate the approach to detect peak demand, investigate its causes, as well as how ML-based cooling load prediction can be used to reduce the unnecessary peak demand. The amount of savings in terms of peak demand and energy use are also discussed.

2. PEAK DEMAND MONITORING AND ANALYSIS

2.1 Importance of High Frequency Data

In order to analyse the occurrence and causes of peak demand, it is important to obtain the high frequency data of key electrical equipment in buildings. The definition of high frequency data varies from different fields. For the building industry, the time interval with less than 1 minute is considered as high frequency data. Without the high frequency data, it is difficult to identify the occurrence and causes of peak demand. As the proportional–integral–derivative (PID) control is commonly adopted in the building system control, the response of AC equipment due to changes in target value is often less than 1 minute.

Figure 1 shows the difference between the high frequency (15s) and typical data (10min) on chiller power. For the peak demand analysis, non-high frequency data (e.g. 10min) is unable to preserve the characteristics of demand profile (as indicated in yellow region of Figure 1). With the high frequency data, the trend of chiller power, especially for the sudden change, can be clearly observed.

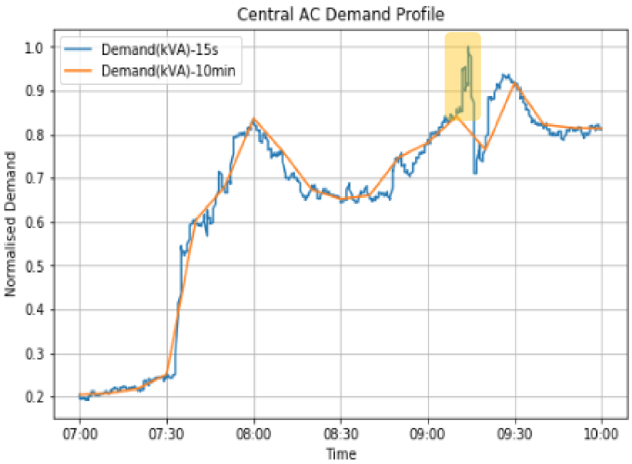

Fig. 1 - Comparison of demand between the 15s and 10min data

2.2 Demand Data Aggregation

The total electricity demand in buildings comprises various systems, including central AC systems, lighting systems, lifts and escalators, plumbing systems, etc. Due to the cost consideration, it is common that electrical equipment with large power consumption and variable loads (e.g. chillers, VSD pumps) is installed with the individual power meter.

In this study, only the demand of the central AC system is considered as (1) the central AC system accounts for more than 50% of the total energy consumption, and the profile of the total building demand can be largely explained by the AC system [4]. (2) As other systems, such as lighting systems, are typically regarded as the constant load (which the demand of the loads keeps constant when these kinds of equipment are switched on). Unlike the variable AC load system, there is a limited opportunity to optimise the electricity demand from the constant load.

A Grade-A office building is used to illustrate the peak demand optimisation approach. With the advanced data acquisition method, 15s interval of data log for the whole AC systems (including both water- and air-side systems) can be achieved. The equipment to construct the demand profile including:

- Chillers
- Chilled water pumps
- Condenser water pumps
- Cooling towers
- AHUs
- Pre-treated air units (PAUs)

2.3 Automatic Detection of Peak Demand

Based on the raw data, the high resolution demand profile was developed. Figure 2 illustrates the monthly demand profile of the central AC system in the case study building. The average demand over a period of 30 minutes was first calculated. According to the Hong Kong Electric (HKE), the peak demand is defined as the largest averaged demand value occurs in a month.

It is found that the peak demand occurred on 24 June 2019. The peak demand calculated by the detection program was validated with electricity bill. Although some electrical demand such as lighting systems are not included in the calculation, the calculated and actual demand are still in the same order of magnitude.

2.4 Causes of Peak Demand

With the domain knowledge, the influential factors contributing to the peak demand in the AC system are summarised as follows:

- Chiller plant start time and its control settings
- Chiller switching method
- Individual AHU start time schedule and its control settings
- Individual PAU start time schedule and its control settings
- Individual mean floor temperature and its set point

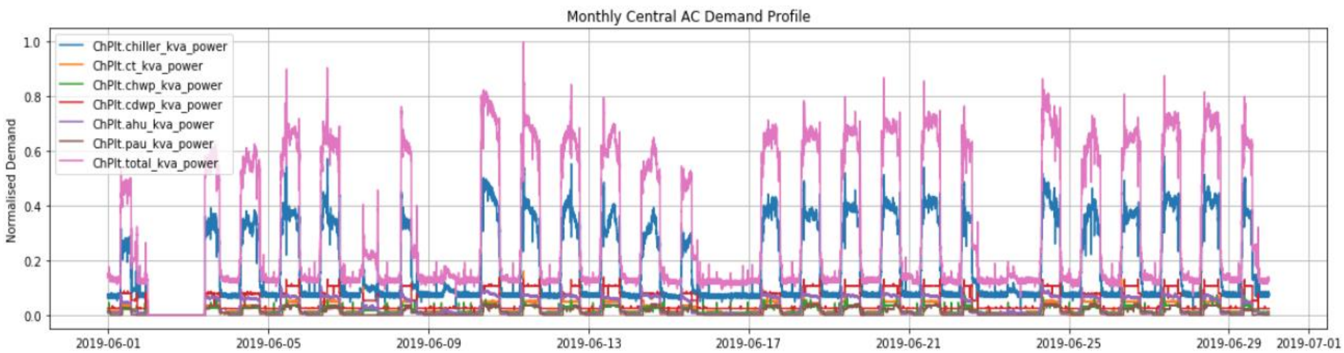

Fig. 2 - Monthly demand profile of central AC system

How these influential factors affect the peak demand in June 2019 is discussed. Figure 3 shows the details of occurrence of peak demand and related influential factors in June 2019.

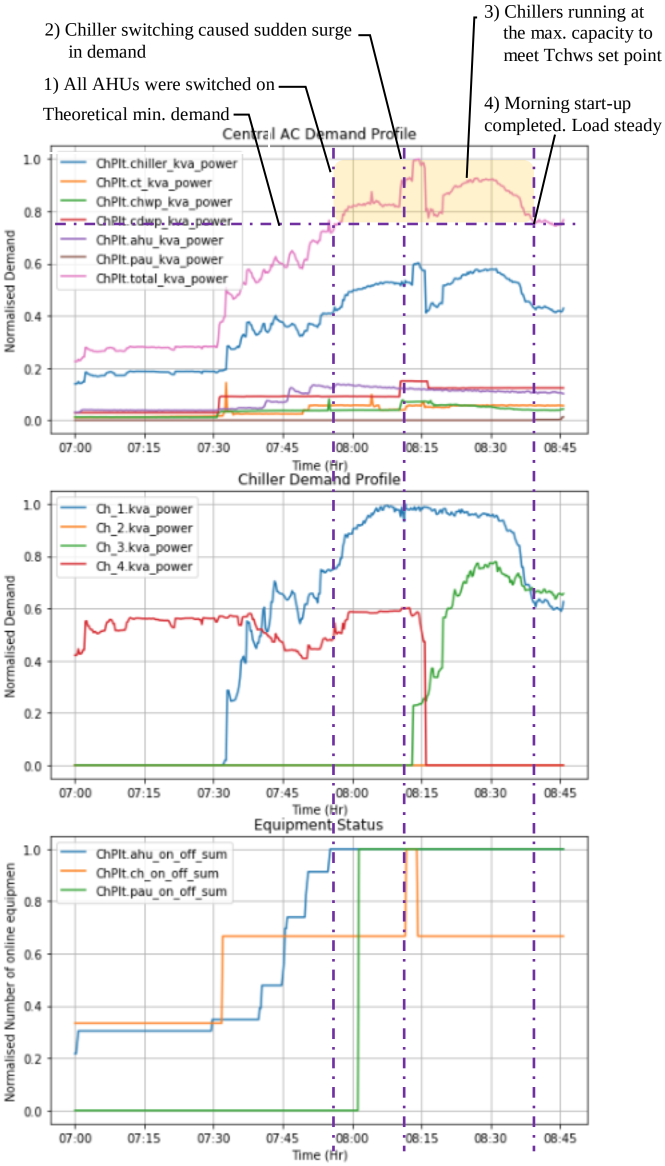

Fig. 3 - Profiles of central AC, individual chiller demand and equipment status during the morning start-up period

From 7:30am to 7:55am, the remaining 70% of AHUs started to operate. The chiller plant was operating at almost full load to handle all start-up (or pull-down) load, leading to the increase in demand (kVA). Around 8am, both chillers (1 large + 1 small) were operating at the full load, providing an indication for additional cooling capacity to meet the required cooling load.

From 8:11am to 8:14am, the switching of chiller plant operation was carried out. Table 1 shows that the chiller plant was switched from Chiller 1 & 4, to Chiller 1, 3 & 4, to Chiller 1 & 3 (from 1 large + 1 small chiller to 2 large chillers).

During the chiller switching, the AHU start-up load was not yet fully handled. The chiller switching from Chillers 1 & 4 to Chillers 1 & 3 caused the new operating chiller running at the full load conditions to meet the required chilled water temperature (Tchws) set point. As a result, the disturbance from chiller switching during the morning start-up period led to the occurrence of unnecessary peak demand (as indicated in yellow region of Figure 3).

Time	Ch 1	Ch 2	Ch 3	Ch 4*
24/6/2019 7:32	On	Off	Off	On
24/6/2019 8:11	On	Off	On	On
24/6/2019 8:14	On	Off	On	Off

** Ch 4 denotes small chiller*

Table 1 - The operation pattern of each chiller during the morning start-up period

Around 8:40am, all start-up loads from AHUs were fully handled. The total demand decreased to the minimum level, and the chiller plant was running at the steady condition.

In short, the occurrence of peak demand in the case study building is attributed to the two main reasons:

- First, a large number of AHUs were switched on within a short period of time, leading to the large start-up load being handled by chillers.
- Second, chiller switching occurred during the morning start-up period, and this additional cooling capacity provided by chillers causes the new operating chillers running at the full load, resulting in the further surge in demand.

In fact, the occurrence of peak demand due to the above causes can be minimised and even avoidable by optimising the AHU start time schedule and predictive optimal chiller plant control during the morning start-up period.

2.5 Relationships between Energy Use and Demand during the Morning Start-up Period

It is worth noting that the peak demand can be simply minimised if each AHU starts one by one with an early start time. For example, currently 70% of AHU starts from 7:30am to 7:55am in the case study building. If the start time of first AHU is rescheduled from 7:30am to 6:00am, and each AHU is switched on after 5 minutes of the previous started AHU. It is expected that the yellow region, shown in Figure 3, will be largely decreased.

However, this will increase the energy use as the central AC system starts much earlier than the required period of AC provision (e.g. AC is provided starting from 6:00am). This results in the unnecessary energy use.

In addition, if the cooling capacity provided by chillers are less than the required capacity (for example, only one chiller is switched on during the morning start-up period), then it will take much longer time to cool down the room temperature to the required set point. This may result in the situation where the required room temperature set points in each floor have not yet been fulfilled after the start of office hour (e.g. 9:00am).

Therefore, the balance between energy use and demand during the morning start-up period is very important, and the AC system operation shall be managed and controlled using advanced techniques such as machine learning.

3. MACHINE LEARNING-BASED COOLING PREDICTION

Short-term cooling load prediction is crucial to the optimisation of central AC system operation, especially for the morning start-up period. As discussed in Section 2.4, when the cooling capacity is overly provided by chillers during the start-up period, the operating chillers will be running at the maximum capacity to meet the chilled water temperature set point for a period of time, resulting in the occurrence of unnecessary peak demand.

With the cooling load prediction, it enables the central AC system to operate with the optimal cooling capacity of chillers during the morning start-up period. Therefore, the level of peak demand can be well managed.

In order to predict cooling load accurately, machine learning is used in this study. Machine learning (ML) allows systems to automatically learn and improve from data without being explicitly programmed. The performance of machine learning is particularly good at revealing nonlinear and complex patterns in big data. To develop such a ML-based model, it is important to identify the critical features relating to cooling load for machines to learn.

3.1 Feature Extraction

The main purpose of feature extraction is to obtain representative information from data for the model input. In this study, both engineering and statistical features are extracted to develop the cooling load prediction model.

Engineering features mean that the features are extracted using engineering knowledge, theories and laws in physics, while statistical features are constructed based on the key summary statistics, such as minimum, maximum, percentiles and mean values of the measurements.

From the engineering perspective, weather conditions and building occupancy are the critical factors affecting cooling load. In general, the outdoor dry-bulb temperature, relative humidity and ultraviolet (UV) radiation can well describe weather conditions. Since building occupancy is highly correlated with work schedule in office buildings, hours of day, days of week and holiday are the important features for cooling load prediction. It is worth noting that the key summary statistics on the above factors are also constructed as the related statistical features.

In this case study, the following features are extracted, and the year of 2018 data are used as the raw dataset.

- Outdoor dry-bulb temperature
- Outdoor relative humidity
- Ultraviolet (UV) radiation
- Hours of day
- Days of week
- Holiday
- Cooling load

3.2 Model Development

In this study, random forest (RF) is selected as the machine learning prediction technique [5]. Random forest has been successfully used for building energy predictions in previous studies [6]. In random forest, the predictor comprises a collection of randomised base regression trees by bootstrap aggregating or bagging. Random forest works by averaging multiple deep decision trees, and the model is trained on various parts of the same training set with the goal of reducing the variance.

3.3 ML-based Prediction Results

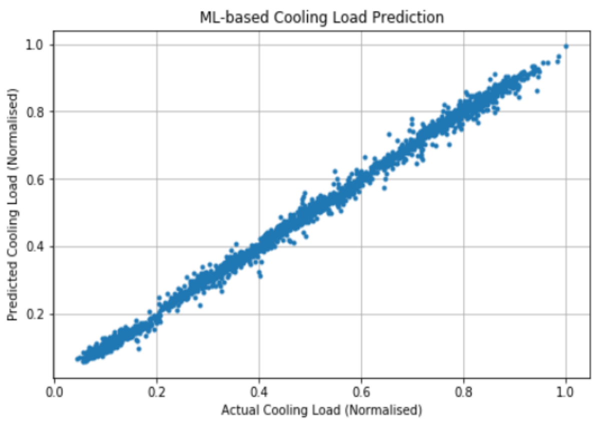

Fig. 4 - Comparison between the predicted and actual cooling load

Figure 4 shows the comparison result between the predicted and actual cooling load. It is demonstrated that random forest provides the accurate prediction and leads to R^2 scores of 95.6% for hour-ahead predictions.

In addition, the result of hour-ahead prediction is used to formulate the optimal chiller start-up operation. Table 2 illustrates the result using the ML-based cooling load prediction for the chiller morning start-up. It is found that 96.1% of accuracy can be achieved to predict the optimal cooling capacity of chillers in operation to deal with the start-up load in year of 2018.

		Predicted Chiller Start-up pattern			
		0L1S	1L0S	1L1S	2L0S
Optimal Chiller Start-up pattern	0L1S	20.8%	0.4%	-	-
	1L0S	0.4%	45.3%	-	-
	1L1S	-	0.8%	14.0%	0.4%
	2L0S	-	-	1.9%	16.2%

Table 2 - Result comparison between the predicted and optimal chiller operation pattern for the morning start-up

4. OPTIMIMAL AHU START TIME SCHEDULE

Apart from the accurate prediction of cooling load for the morning start-up, it is also essential to formulate the optimal AHU start time schedule to prevent chillers from running at the full capacity during the start-up period. Once the chillers are running at the full capacity for a period, it is most likely that the peak demand will occur. As discussed in Section 2.5, the optimal AHU start time schedule means the balance between demand and energy use during the morning start-up period.

This section attempts to systemically formulate the optimal AHU start time schedule using big data analytics. In the case study building, several engineering and statistical features were extracted to formulate the optimal AHU start time schedule.

The key features extracted in the case study building are shown as follows:

- AHU start time
- AHU supply air temperature set point
- AHU start-up (pull-down) duration
- VAV box room temperature before the start up
- VAV box room temperature set point
- VAV box start-up (pull-down) duration
- AHU energy use (kW)
- AHU demand (kVA)
- Chiller demand (kVA)
- Outdoor air temperature

4.1 Evaluation of Key Features for Each AHU

To extract and evaluate these features, it involves all AHUs and floors in the case study building. The algorithm is developed to determine the value of the above key features for each AHU automatically. It is worth noting that some of the features need to be calculated specifically, for example, AHU and VAV box start-up durations, as well as the impact on chiller demand (e.g. change in demand after AHU starts). As the start-up load varies from floor to floor, some floors require longer duration to cool down to the required set-point. One floor (8/F) is used as an example to illustrate the approach.

As shown in Figure 5, the AHU at the eighth floor (8/F) started at 7:40am and required approximate 13 minutes for the start-up process. The supply air temperature was set at 17°C. It took around 35 minutes to cool down the open-plan floor to the pre-defined set point. It is noted that the AHU and thermal performance on the above features in each floor may behave differently even in the same building. It is vital to calculate these features automatically and provide the summary statistics to identify the longest and shortest time required for the morning start-up.

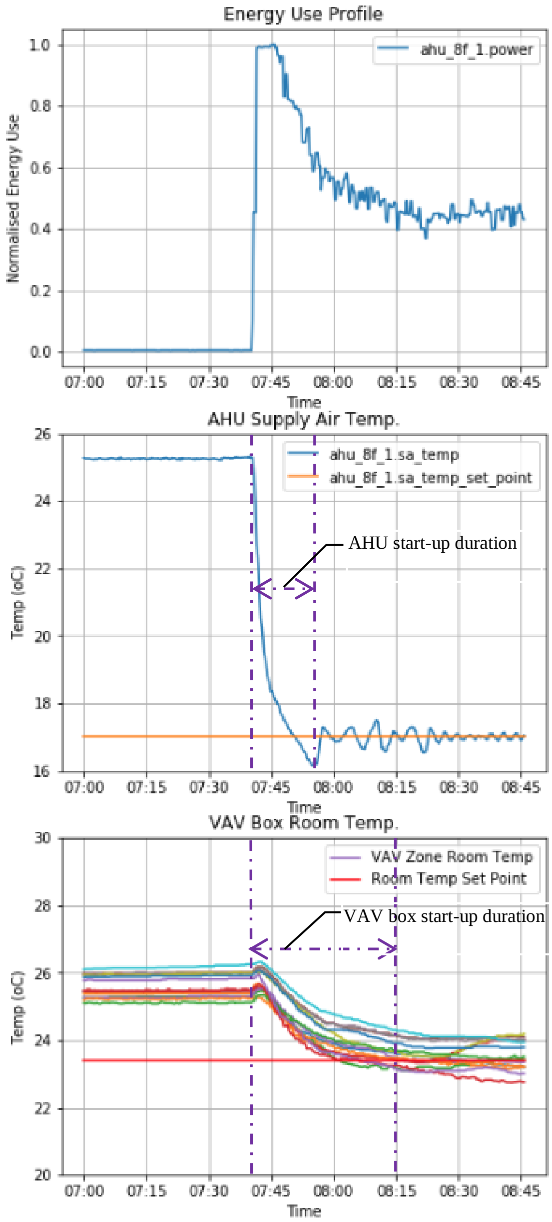

Fig. 5 – Example of AHU key performance and VAV box time-series chart with high resolution data

These statistics help formulate the optimal AHU start time schedule and systemically review the performance after the rescheduling of AHU operation.

4.2 Optimisation of Equipment Scheduling

In this study, optimisation algorithm is developed to automatically formulate the schedule of the AHU start time for each AHU. The ultimate goal of the algorithm is to strike a balance between energy use and demand during the morning start-up period. Therefore, the optimisation algorithm comprises two components. The first component is to forecast the maximum required peak demand, while the second component is to determine AHU start time schedule without exceeding the maximum required demand.

For the first component, the cooling load prediction model can be used to forecast the maximum required demand after the morning start-up period (e.g. 9:00am). The predicted demand will be the upper ceiling of the demand. If the demand is higher than the upper ceiling, the unnecessary demand occurs. Therefore, that upper ceiling can be associated with the maximum number of AHU being started without exceeding the maximum required demand.

For the second component, since the historical data record the required AHU and VAV system start-up duration, as well as the impact on the overall demand by each AHU start-up under the various outdoor weather conditions. Based on the historical data and latest weather conditions, the number and start time of individual AHU can be determined to ensure that the demand will not exceed the maximum required level.

As the optimisation algorithm can evaluate the start-up performance each day, the latest performance statistics can be analysed and improve the optimisation algorithm. This can ensure that the calculated optimal AHU schedule provides the sufficient time for chillers to cool down the start-up load with the controllable surge in demand. As such, the balance between energy use and demand can be achieved during the morning start-up period.

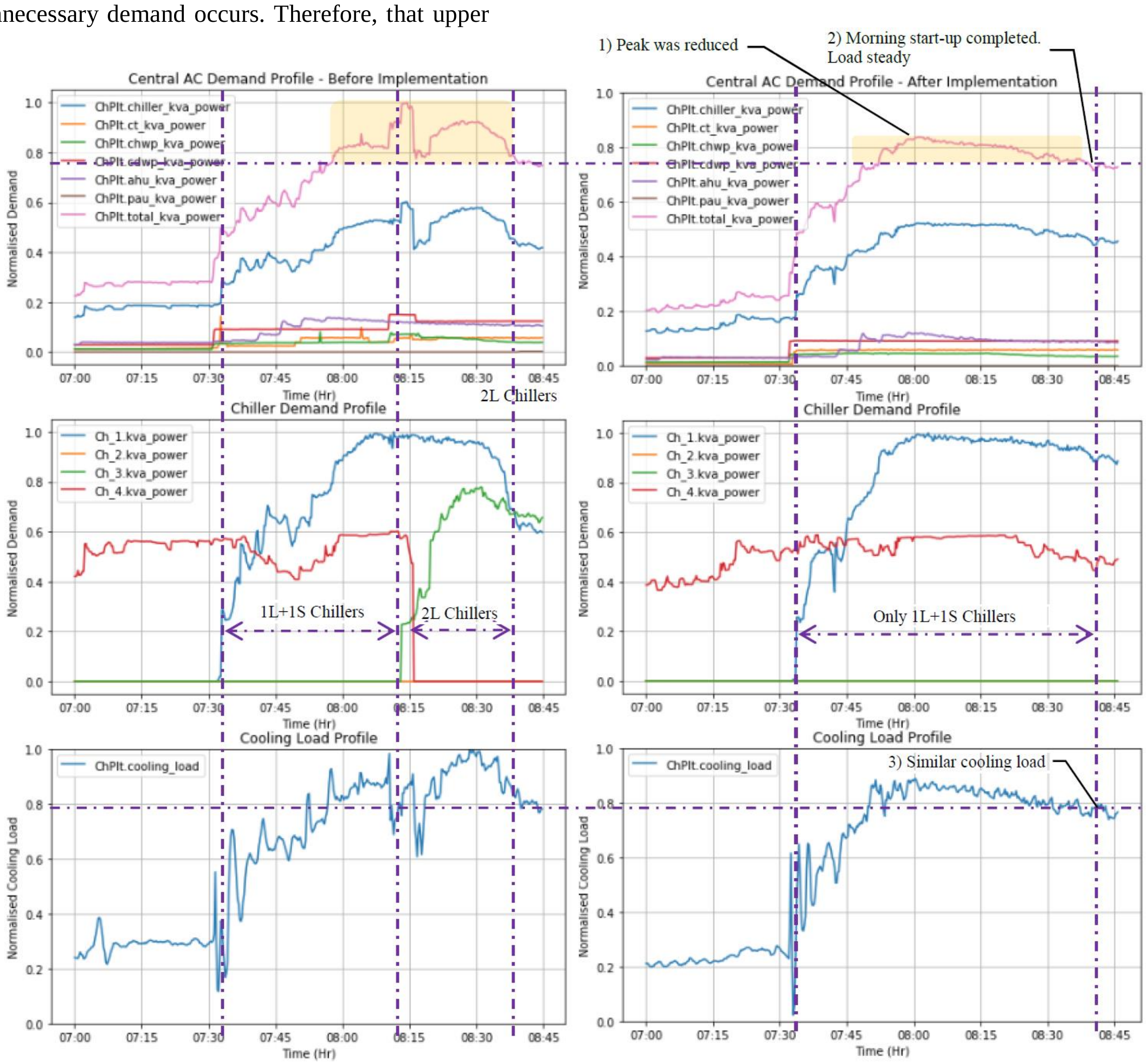

Fig. 6 - Comparison between before and after implementation of peak demand optimisation

5. IMPLEMENTATION RESULTS

Combined with the optimal AHU start time schedule and ML-based cooling load prediction, the peak demand can be well managed and reduced. The proposed approach to optimise peak demand charges was implemented in the case study building, and how the proposed approach can reduce the peak demand will be discussed with an example of the similar cooling load condition (around 0.8 of the normalised cooling load) for comparison. Figure 6 shows the impact on the demand profile before and after the implementation of peak demand optimisation.

Prior to the transition from the night mode to morning mode in the chiller plant operation, the ML-based cooling load prediction model first automatically requests for the necessary input data, including the weather forecast result by Hong Kong Observatory, days of the week, special day (e.g. holiday), the summary statistics of pervious 7-day cooling load, etc. Based on these input data, the model predicts the two hour-ahead cooling load, which is the completion time for the whole morning start-up process.

In the example (Figure 6), based on the cooling load prediction result, it is advised that 1 large + 1 small chillers should be operated to provide optimal cooling capacity to cope with the start-up load. It is clearly observed that by using the peak demand optimisation there is no sudden surge in demand (Figure 6, right chart).

More importantly, less cooling capacity provided by chillers does not affect the thermal comfort in the indoor environment. Although both chillers (1L+1S) were running at the full capacity for a longer period, it is still able to complete the whole start-up process before 9:00 am.

The peak demand was decreased by 8% when the peak demand optimisation was implemented. Although the energy saving is not the main target in the morning start-up process, 5.8% of energy savings were achieved as compared with the conditions where no optimisation of peak demand was carried out.

6. CONCLUSION

The proposed approach for peak demand optimisation comprises three major components (1) peak demand monitoring and analysis; (2) ML-based cooling load prediction; and (3) optimisation of equipment sequencing.

The above approach was implemented in the Grade-A office building. Using the big data analytics, the occurrence and causes of peak demand were investigated in details. It was found that the peak demand occurred during the morning start-up period in summer, and it was mainly attributed to the over-provision of chiller cooling capacity and the similar start time for most AHUs during the start-up period. Given in the case study, when the above two conditions (excessive cooling capacity and sudden release of the start-up load) happen at the same time, the unnecessary peak demand occurs.

To provide the optimal cooling capacity of chillers to deal with the start-up load before the office hour, machine learning technique is proposed to adopt for cooling load prediction. Based on the historical data such as weather conditions, days of the week, special day and the summary statistics of pervious 7-day cooling load, the ML-based cooling load prediction model can achieve 96.1% of accuracy to predict the optimal cooling capacity of chillers. Besides, by analysing the required duration for each AHU and VAV system to meet the required set point, the optimal AHU start time schedule could be formulated to make a balance between energy use and demand.

By using the proposed peak demand optimisation, the peak demand and energy use were decreased by 8% and 5% respectively. It is worth noting that the occurrence of monthly peak demand varies from season to season. In winter, the peak demand may not happen during the morning start-up period. Therefore, the continuous use of big data analytics to detect peak demand, identify its causes and provide actionable measures to minimise peak demand is critical to the overall energy and demand management.

REFERENCES

1. Shan, K., Wang, S., & Tang, R. (2018). Direct chiller power limiting for peak demand limiting control in buildings—Methodology and on-site validation. Automation in Construction, 85, 333-343.

2. Motegi, N. (2007). Introduction to Commercial Building Control Strategies and Techniques for Demand Response--Appendices.

3. ITB, 2018, Hong Kong Smart City Blueprint, Innovation and Technology Bureau, Hong Kong Special Administrative Region of the People's Republic of China (HKSAR).

4. EB (2018). Hong Kong's Climate Action Plan 2030+, Environment Bureau, Hong Kong Special Administrative Region of the People's Republic of China (HKSAR).

5. Liaw, A., & Wiener, M. (2002). Classification and regression by random forest. *R news*, *2*(3), 18-22.

6. Fan, C., Xiao, F., & Zhao, Y. (2017). A short-term building cooling load prediction method using deep learning algorithms. *Applied energy*, *195*, 222-233.