THE HONG KONG
INSTITUTION OF ENGINEERS
ELECTRICAL DIVISION

The 42nd Annual Symposium
Thursday
24 October 2024

ELECTRICAL ENGINEERING TOWARDS THE ERA OF INDUSTRY 5.0

Ballroom
Sheraton Hotel
Nathan Road
Kowloon
Hong Kong

SYMPOSIUM PROGRAMME

08.30 Registration and Coffee

09.00 Welcome Address
- Ir Banson KC Lam
  Chairman, Electrical Division, The HKIE

09.05 Opening Address
- Ir Eric SC Ma, JP
  President
  The Hong Kong Institution of Engineers

09.20 Keynote Speech
- Dr.- Ing. Benny Drescher
  Chief Technical Officer
  Hong Kong Industrial Artificial Intelligence & Robotics Centre
  Hong Kong Productivity Council

1. New Initiatives in Power Systems

09.50 Enhancing Grid Resilience with Grid-Visualization
- Mr. Mike KW Ng, Principal Manager - Smartgrid Technology and Innovation
- Mr. Alvin CK Lit, Principal Manager - Smartgrid Development
- Ir Jason SC Au, Lead Engineer - Smartgrid Development
- Dr. Jiaxin Wen, Engineer - Smartgrid Strategy
  The Department of Smartgrid and Innovation, Power Systems
- Mr. Jeff KW Sun, Manager - Technical Services
  The Department of Technical Services, Power Systems
  CLP Power Hong Kong Limited

10.10 Enhancing Reliability of Electricity Supply with Innovations
- Mr. Ryan S Chan, Chief Construction & Maintenance Engineer (Central)
- Mr. YP Pau, Construction & Maintenance Engineer I
- Mr. Kevin NH Leung, Support Engineer II
- Mr. Benny WL Cheung, Engineer I
  The Hongkong Electric Co. Limited

10.30 A New Way towards Clean, Renewable and Efficient Electric Power Supply System
- Mr. Dick CY Lee, General Manager
  The Jardine Engineering Corporation Limited
- Mr. Govi Ramasamy, Chief Commercial Officer
  Hyliion Holdings Corporation, USA

10.50 Discussion

11.05 Coffee Break

2. ***EV Charging and Battery Technology***

11.35 PFAS-Free Technology - Solution for Sustainable Battery Systems
- Dr. Priscilla SW Huen, R&D Technical Manager
- Dr. Bill KP Ho, Chief Technology Officer
  GRST Holdings Limited, Hong Kong

11.55 The Specific and More Onerous Requirements for Low-voltage Assemblies in Electric Vehicle Charging Applications
- Mr. Tom W Mennell, Technical Standards Manager
  Schneider Electric Ltd. UK

12.15 Discussion

12.30 Lunch

3. Decarbonization

14.00 Building Integrated Photovoltaics Application to Decarbonize Hong Kong
- Ir Felix HH Chan, Associate
- Ms. KM Miu, Engineer
- Ms. Y Yin, Assistant Engineer
  Climate and Sustainability Group
  Ove Arup & Partners Hong Kong Ltd.

14.20 The Carbon Footprint Ecological Portfolios to Accelerate Decarbonization in Mainland China

- Dr. Y Tao, Head
  SiTANJI China Business & Ecological Development
  Siemens Limited China

14.40 From Massive Electrification to Decarbonization - Harnessing Power Electronics for a Greener Planet

- Ir Dr. HL Yiu, Fellow Member
  The Hong Kong Institution of Engineers

15.00 Discussion

15.20 Coffee Break

4. AI Applications

15.50 Maximizing Value in Engineering with GenAI Powered Digital Twin

- Ir Terence LL Lui, Chief Executive Officer
- Ir Luiz WH Lui, Product Manager
  Varadise Limited, Hong Kong

16.10 Integrated Centralized Platform - The Smart Railway Station Commander

- Ir HW Chan, Deputy General Manager - Operations Innovation Hub
- Ms. Summer HY Ng, Data Analyst
  MTR Corporation Limited

16.30 Discussion

16.45 Summing Up

- Ir Andrew KW Yan
  Symposium Chairman
  Electrical Division, The HKIE

Closing Address

- Ir Prof. Sir J Lu
  Dean, College of Engineering
  City University of Hong Kong

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

Dr. - Ing. Benny Drescher
Ir Professor Sir J Lu
Mr. Mike KW Ng
Mr. Alvin CK Lit
Ir Jason SC Au
Dr. Jiaxin Wen
Mr. Jeff KW Sun
Mr. Ryan S Chan
Mr. YP Pau
Mr. Kevin NH Leung
Mr. Benny WL Cheung
Mr. Dick CY Lee
Mr. Govi Ramasamy
Dr. Priscilla SW Huen
Dr. Bill KP Ho
Mr. Tom W Mennell
Ir Felix HH Chan
Ms. KM Miu
Ms. Y Yin
Dr. Y Tao
Ir Dr. HL Yiu
Ir Terence LL Lui
Ir Luiz WH Lui
Ir HW Chan
Ms. Summer HY Ng

Sponsors

Siemens Limited
CLP Power Hong Kong Limited
The Hongkong Electric Co. Limited
ESYLUX Asia Limited
The Jardine Engineering Corporation Limited
Keystone Electric Wire & Cable Co. Limited
Kum Shing Group
C&K Instrument (HK) Limited
Chat Horn Engineering Limited
Fed-Supremetech Limited
FSE Engineering Group Limited
Gammon E&M Limited
Greenland Engineering Co. Limited
Mitsubishi Electric (Hong Kong) Limited
MTR Corporation Limited
Schneider Electric (Hong Kong) Limited
S.G.H. Electric Wire & Cable Co. Limited
SPL Lighting (Hong Kong) Co. Limited
TE Connectivity Hong Kong Limited
Hong Kong Electrical Contractors' Association Limited

42nd ANNUAL SYMPOSIUM ORGANIZING COMMITTEE

Symposium Chairman:	**Ir Andrew KW Yan**
Members:	**Ir Banson KC Lam**
	Ir Tim CT Leung
	Ir Ben CK Lam
	Ir Dr. FC Chan
	Ir WS Tam
	Ir Hugo CY Chan
	Ir Ian YL Lee
	Ir Stanley KW Leung
	Ms. TT Suen
	Ir Alex TH Fu
	Ir Vincent CT Leung
	Ir Henry TL Chan
	Ir Raymond KM Sze
	Mr. Indi WF Wong
	Mr. Stan WK Mou
Hon. Secretary and Treasurer:	**Ir YK Chu**

Paper No. 1

ENHANCING GRID RESILIENCE WITH GRID-VISUALIZATION

Authors/Speakers:

Mr. Mike KW Ng, Principal Manager - Smartgrid Technology and Innovation
Mr. Alvin CK Lit, Principal Manager - Smartgrid Development
Mr. Jason SC Au, Lead Engineer - Smartgrid Development
Dr. Jiaxin Wen, Engineer - Smartgrid Strategy
The Department of Smartgrid and Innovation, Power Systems
Mr. Jeff KW Sun, Manager - Technical Services
The Department of Technical Services, Power Systems
CLP Power Hong Kong Limited

ENHANCING GRID RESILIENCE WITH GRID-VISUALIZATION

Mr. Mike KW Ng, Principal Manager - Smartgrid Technology and Innovation
Mr. Alvin CK Lit, Principal Manager - Smartgrid Development
Mr. Jason SC Au, Lead Engineer - Smartgrid Development
Dr. Jiaxin Wen, Engineer - Smartgrid Strategy
The Department of Smartgrid and Innovation, Power Systems
Mr. Jeff KW Sun, Manager - Technical Services
The Department of Technical Services, Power Systems
CLP Power Hong Kong Limited

ABSTRACT

The increasing frequency of extreme weather events in recent years, poses significant challenges to power grid operation by causing physical interference and potential damage to infrastructure which may cause power supply interruptions. To address this emergent challenge and secure the safe operation of the grid, CLP Power Hong Kong Limited (CLP Power) has developed an advanced centralized asset and worksite activity management system known as Grid-Visualization (Grid-V). Grid-V integrates various monitoring and management systems and leverages artificial intelligent (AI) technology. It provides real-time monitoring of the condition of critical assets, such as transmission overhead line circuits, power substations, and worksite activities. The AI component of Grid-V can detect disturbances, such as hill fires, smoke, or flying objects, to those critical assets, and alert operation staff to take prompt actions. The AI feature also enables detection of physical security intrusions, enhancing the physical security protection of power substations. The deployment of Grid-V has significantly enhanced grid resilience by proactively identifying and mitigating risks, supported by continuous monitoring from multiple sources and AI-assisted analytic functions.

1. INTRODUCTION

In recent years, the frequency and severity of extreme weather events worldwide have significantly increased, that drive the raising concerns of the public. These events, such as hurricanes and storms, pose significant challenges to power grid operations for many power utilities worldwide [1]. Severe storms with strong winds can lead to a potential risk of transmission tower collapse, causing widespread power outages [2]. Heavy rainfall and flooding can submerge critical components like electrical substations, resulting in prolonged service disruptions [3]. Therefore, it is necessary to enhance the network reliability and resilience.

Remote monitoring critical assets and their surrounding environment is considered an effective support to enhance network reliability and resilience [4]. However, the network contains large volumes of the assets, such as substations, transmission lines and switchgears. It is impractical to assign the operational staff to continuously monitor the assets concerned. AI can simultaneously process vast amounts of data [5] and thus is introduced into the monitoring system to achieve cost-effective and efficient data analysis on the monitored data, to facilitate the operational management on the network [6].

For example, in the case of inspecting transmission overhead lines, traditional inspections would require inspectors to spend several days on routine patrols. While with the assistance of AI-assisted fixed monitoring system, operators can view not only the real-time situation remotely but also receive the warning signal timely. Operators can take relevant actions based on the analysis to secure the network, such as scheduling the ad-hoc maintenance tasks or assigning the repair team to attend the concerned location more effectively.

Taking this a step further, CLP Power integrates all remote monitoring systems into one single platform called Grid-Visualisation (Grid-V). With AI-supported smart analysis, this platform allows operators to have a comprehensive view of the entire power grid. It provides easy access to live video feeds and delivers smart analysed results from all integrated systems. This integration enhances operators' ability to monitor and make informed decisions about the power grid, thereby further bolstering network reliability and resilience.

2. TECHNIQUE FOR AI IN GRID-V

AI technology is employed for processing the data to achieve a rapid and effective assessment on monitored assets. In exploration of AI applications for enhanced supervision, Grid-V integrates two primary processing architectures: edge and centralised processing.

2.1 Edge Processing

Edge processing involves the installation of the AI module within the monitoring system, enabling real-time analysis of data at the edge of the network. Upon receiving monitored data from surveillance cameras or drones, the monitoring system can directly assess the integrity and status of the monitored assets. This localised processing significantly enhances the system's responsiveness and efficiency in detecting and responding to potential threats.

The edge processing architecture is shown in Figure 1, where the monitored data is processed by using Video Analytics (VA) box, and the results, such as warning signals, or reports are transmitted to the cloud, which facilitates operators' swift and informed decision-making.

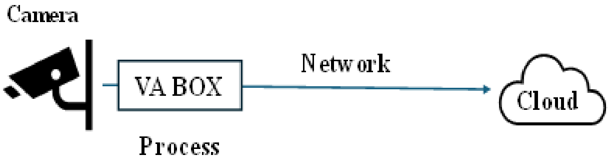


Fig. 1 - The Edge-Processing Architecture

This architectural framework offers three main benefits:

a) Reduced Latency: By processing data locally at the edge, the system can provide immediate alerts and responses, crucial for time-sensitive incidents. This minimisation of processing time enhances the system's ability to timely identify and mitigate potential risks.

b) Bandwidth Efficiency: Edge processing ensures that only relevant and pre-processed data is transmitted to central servers. This selective data transmission optimises bandwidth usage, reducing network congestion and operational costs associated with excessive data transfer.

c) Enhanced Privacy and Security: The ability to process sensitive data locally at the edge minimises the exposure of critical information during transmission. This approach strengthens data privacy measures and reduces vulnerabilities to potential cyber threats, safeguarding the integrity of the monitored assets.

By leveraging edge processing within the monitoring system, organisations can effectively enhance their asset management, respond promptly to emerging threats, and optimise operational efficiency through streamlined data processing and analysis.

2.2 Centralised Processing

The centralised processing systems consolidate data from diverse sources into a central server for comprehensive analysis, as depicted in Figure 2.

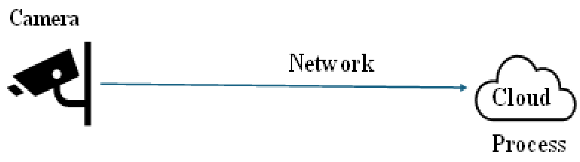


Fig. 2 - The Centralized Processing Architecture

This conventional approach offers 4 notable advantages:

a) Comprehensive Analysis: Centralised systems leverage substantial computational resources, facilitating intricate data analysis across vast datasets. The centralised nature of data aggregation enables in-depth examination and correlation of information from various sources, enhancing the system's analytical capabilities.

b) Scalability: Centralised systems exhibit scalability by accommodating an expanding array of devices and data sources. This flexibility allows for the seamless integration of new data streams and devices into the existing infrastructure without necessitating extensive modifications, thereby supporting the system's growth and adaptability over time.

c) Resource Optimisation: Centralised processing systems can optimise resource allocation by pooling computational power and storage capacities within a centralised server environment. This centralised resource management enhances efficiency and streamlines data processing tasks, contributing to improved system performance and operational effectiveness.

d) Consolidated Management: Centralised systems offer centralised data management and control, simplifying the monitoring and maintenance of the overall system. This centralisation oversights facilitate uniformity in data handling and system operations, promoting cohesive management practices and ensuring consistency in data analysis procedures.

By utilising centralised processing systems, organisations can harness the benefits of robust computational capabilities, scalability, resource optimisation, and consolidated management, thereby enhancing their analytical proficiency and operational efficiency in handling diverse and voluminous datasets.

3. APPLICATION OF AI IN GRID-V

There are three main applications of AI in Grid-V to enhance grid resilience. Firstly, the AI technology is employed for detecting environment disturbance to critical asset in the transmission network, including the transmission overhead lines and towers. Besides this application, Grid-V can also detect the intrusion of substations and achieve worksite activity monitoring. These three applications are introduced in the following three subsections respectively.

3.1 Anomaly Detection of Transmission Network

The utilisation of AI-powered video analytics can play a vital role in monitoring the assets in the transmission network, providing an enhanced level of surveillance and threat detection. The system can be programmed to identify and respond to a variety of potential risks, including hill fires, instance of third-party interference and the overhead line components.

a) Fire Detection. In the case of hill fires, the AI-powered video analytics can quickly detect the emergency of smoke, flames, and the progression of the blaze, triggering immediate alerts to grid operators on where a hill fire is detected, see Figure 3. This real-time information enables a swift and coordinated response, facilitating the rapid deployment of resources and the implementation of targeted mitigation strategies to protect the integrity of the transmission infrastructure.

Fig. 3 - The Detection of Hill Fires

b) Detection of Third-party Interference Around the Transmission Overhead Lines. The AI-powered VA can also be trained to identify and respond to instances of third-party interference, such as crane approaching to the transmission overhead line circuits. By analysing the video feed for suspicious behaviour patterns, the system triggers alerts and enables the timely intervention of emergency response teams to protect the critical infrastructure.

c) Overhead Line Component Detection. The drones equipped with a camera is employed to achieve autonomously navigate along predetermined routes and capture images at fixed locations, as shown in Figure 4.

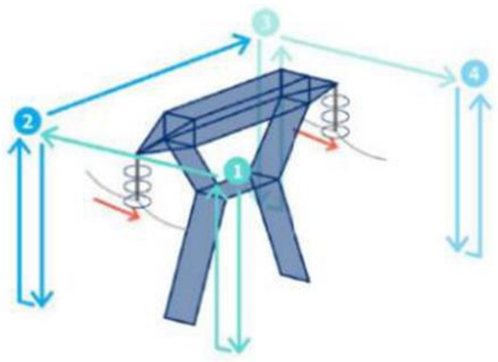


Fig. 4 - The Predetermined Routes of Drones for Detection of Overhead Line Component

Subsequently, the system utilises AI algorithms to perform rapid evaluations of the structural integrity of transmission towers and the other components based on the acquired images. As shown in Figure 5, a damaged insulator on the tower has been detected using the AI technology [7]. This innovative methodology presents substantial efficiencies in terms of labour resources.

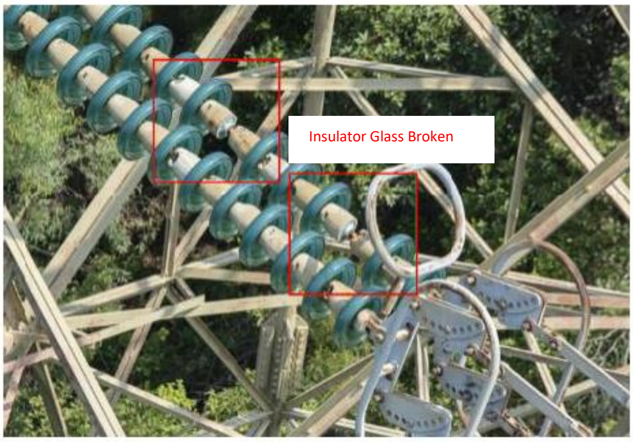


Fig. 5 - A Damaged Insulator is Detected by using AI Technology

3.2 Intrusion Detection of Substations

One of the key applications of AI and VA in Grid-V is the implementation of security's motion guard and fence guard alarm detection functions of the CCTV surveillance system for the power substations. These intelligent VA algorithms can continuously monitor the designated areas, detecting any unauthorised movement or intrusions as shown in Figure 6.

Fig. 6 - Security's Fence Guard Intrusion Alarm for Power Substation

By leveraging deep learning models, the system can accurately distinguish between authorised personnel, wildlife, and potential threats, promptly triggering alerts and enabling immediate response for the grid operator.

3.3 Worksite Activity Monitoring

AI technology in Grid-V is also employed to monitor unsafe behaviour in worksites in real-time, ensuring strict compliance of safety processes and requirements.

In the event of unsafe behaviour or non-compliance acts, relevant project-in-charge personnel are promptly notified to response the workforce safety alert, aiming to enhance work safety. Two tests in the worksite have been conducted.

Firstly, site test was conducted to detect personal protective equipment (PPE) at a construction site. The trial concluded that the advanced AI technology can conduct comprehensive and accurate detection of PPE on the person. Site supervisor can timely remind the worker to ensure a safe working environment.

Besides, site test was conducted to detect fire. The test results shown in Figure 7 proved that the employed AI technology can effectively detect the fire in the worksite.

Fig. 7 - Successful Detection of Fire at Worksite During the Trial

4. CONCLUSTION & WAYFORWARD

The deployment of Grid-V makes full use of the advanced AI technology to enhance supervision of assets and workforce safety, which largely increases the working efficiency. Grid-V has substantially elevated the resilience and operational efficiency of power grid. Through its sophisticated real-time monitoring and AI capabilities, Grid-V has shown capability in reducing downtime, optimising resource allocation, and enhancing the safety of worksite activities. CLP Power is committed to operational excellence and application of innovative technologies which enable a more agile and responsive power network, ensuring reliable power service delivery. In the future, AI capability of Grid-V would be further enhanced so as to bolster grid resilience and reliability, particularly against adverse weather.

ACKNOWLEDGEMENT

The authors acknowledge the support of this Grid-V project from the management of CLP Power Hong Kong Limited. In addition, colleagues from other departments of the company deserve special thanks for their support on this project.

REFERENCES

1. Y. Lv et al., "Review on Modeling of Impact of Extreme Weather on Source-Grid-Load-Storage," 2023 IEEE 7th Conference on Energy Internet and Energy System Integration (EI2), Hangzhou, China, 2023, pp. 1840-1845, doi: 10.1109/EI259745.2023.10512945.

2. A. Poudyal, C. Wertz, A. M. Nguyen, S. U. Mahmud, A. Dubey and V. Gunturi, "Spatiotemporal Impact Assessment of Hurricanes and Storm Surges on Electric Power Systems," 2023 IEEE Power & Energy Society General Meeting (PESGM), Orlando, FL, USA, 2023, pp. 1-5, doi: 10.1109/PESGM52003.2023.10252559.

3. M. Bahrami, M. Vakilian, H. Farzin and M. Lehtonen, "Pre-Flooding Island Formation in Distribution Systems Resolving Local Critical Infrastructures Interdependency," 2021 25th Electrical Power Distribution Conference (EPDC), karaj, Iran, Islamic Republic of, 2021, pp. 5-10, doi: 10.1109/EPDC53015.2021.9610817.

4. Y. Yang, "Research on Intelligent Monitoring and Fault Warning of Power Systems Based on Smart Systems and Computer Vision," 2023 5th International Conference on Artificial Intelligence and Computer Applications (ICAICA), Dalian, China, 2023, pp. 505-509, doi: 10.1109/ICAICA58456.2023.10405523.

5. Y. A. Regev, H. Vassdal, U. Halden, F. O. Catak and U. Cali, "Hybrid AI-based Anomaly Detection Model using Phasor Measurement Unit Data," 2022 IEEE 1st Global Emerging Technology Blockchain Forum: Blockchain & Beyond (iGETblockchain), Irvine, CA, USA, 2022, pp. 1-6, doi: 10.1109/iGETblockchain56591.2022.10087111.

6. M. Alqudah and Z. Obradovic, "Enhancing Weather-Related Outage Prediction and Precursor Discovery Through Attention-Based Multi-Level Modeling," in IEEE Access, vol. 11, pp. 94840-94851, 2023, doi: 10.1109/ACCESS.2023.3303110.

7. J. Li, J. Sun, J. Chan, "Video Analytics Applications in Power Utility Business," for ICEE Conference 2023 – "Frontiers in Carbon Neutrality Power and Energy".

Paper No. 2

ENHANCING RELIABILITY OF ELECTRICITY SUPPLY WITH INNOVATIONS

Authors/Speakers: Mr. Ryan S Chan, Chief Construction & Maintenance Engineer (Central)
Mr. YP Pau, Construction & Maintenance Engineer I
Mr. Kevin NG Leung, Support Engineer II
Mr. Benny WL Cheung, Engineer I
The Hongkong Electric Co. Limited

ENHANCING THE RELIABILITY OF ELECTRICITY SUPPLY WITH INNOVATION

Mr. Ryan S Chan, Chief Construction & Maintenance Engineer (Central)
Mr. YP Pau, Construction & Maintenance Engineer I
Mr. Kevin NH Leung, Support Engineer II
Mr. Benny WL Cheung, Computer Hardware Engineer II
The Hongkong Electric Co. Limited

ABSTRACT

The Hongkong Electric Company, Ltd. (HK Electric) is one of the two power companies in Hong Kong and has been supplying electricity to Hong Kong Island and Lamma Island for over 130 years, with supply reliability better than 99.999% since 1997.

With the pursuit of excellence as one of our core values, we strive to continue improving various aspects of our business operations, not only improving the operational efficiency but also meeting the even higher expectations of high supply reliability, power quality, and occupational safety through a number of innovation projects which include Smart Circuit Breaker Monitoring and Analytic System, AI Cable Condition Diagnosis, Smart Monitoring System for LV cable network and cable tunnel, Uninterrupted LV backfeed with Mobile Battery Energy Storage System and etc.

A strong and robust innovation culture has been nurtured within the Company and numerous innovation projects have come to a success throughout the years. This paper presents some highlighted innovation projects that have been successfully implemented in HK Electric's Transmission and Distribution network and have realized significant benefits for the Company's operations.

1. INTRODUCTION

Committed to the pursuit of excellence, HK Electric continuously strives to enhance its operational efficiency, supply reliability, power quality, and occupational safety. In addition to the conventional operation and maintenance regimes adopted, a number of innovative projects were kicked-off in the past few years, and the outcomes of these projects had been realized as useful tools and enhancing the reliability of the transmission and distribution network [1][2].

2. SMART SWITCHGEAR MONITORING AND ANALYTIC SYSTEM

Switchgear is one of the most important part of the power grid, and the integrity of the switchgear is essential to the supply reliability. Any operational failure of the switchgear, especially for those high voltage switchgears in the primary substation, under cable fault conditions will result in massive supply interruptions for the customers. To prevent this, a tailored solution for monitoring the health of circuit breaker mechanism was successfully developed by our electrical engineers.

Measuring the current profile of the operation coils of a circuit breaker is a proven technique to analyse the condition of the mechanism of the switchgear. However, off-the-shelf products in the market normally require outage of the circuit breaker to carry out measurements and have no networking function. Also, the cost of the coil profile measuring equipment is relatively high compared to the cost of the switchgear and it may not be justifiable to retrofit the equipment at each panel.

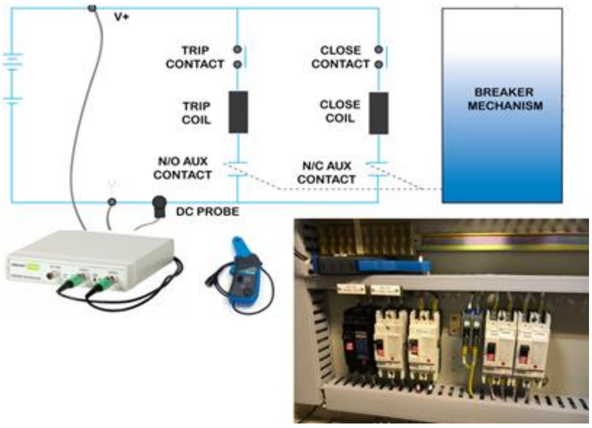


Fig. 1 - The Arrangement of CMBS

The patented Circuit Breaker Monitoring System (CBMS) [Patent No. HK30064886] introduced here is composed of a centralised high-speed digital scope, DC current probes and a single board computer. The system captures the current waveform of all circuit breakers during their operation and digitises the waveform signal collected for analysis. The collected data will then be sent back to the central data server through the network for further evaluation.

A customised statistical model based on the data of the Company's circuit breakers was developed to identify the abnormalities of the trip coil current profile by comparing the data with the past records of the same circuit breaker and the mean values of the peers. The duration, magnitude, peak and the shape of the captured current profile will also be analysed. Based on the analysis results, the health condition of the circuit breaker can be classified and maintenance schedule can be prioritised. For those outliners identified with high risk, immediate follow-up action will be taken to prevent the circuit breaker from jeopardizing the system reliability.

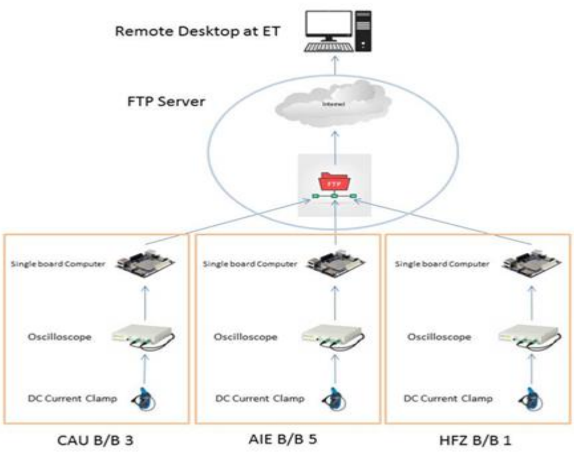


Fig. 2 - The Overall System Set-up for the Centralized CMBS

For the switchgears at distribution substations, a similar online condition monitoring solution was also devised. To cater for the huge number of switchgears in the distribution network, instead of retrofitting the CBMS at each distribution substation to capture the whole current waveform, a smart tool using similar philosophy was developed by our engineers to facilitate the site staff in measuring the control current duration of the switchgear during the routine switchgear operation test as the current duration directly correlates to the performance of the operating mechanism of the switchgear. The design of this measurement device is simple and innovative, providing a go/no-go indication for engineers to assess the condition of switchgears.

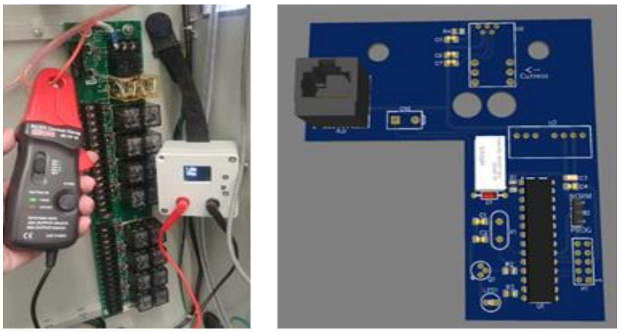


Fig. 3 - Switchgear Operation Time Sensor for Distribution Switchgear

In 2023, there were 85 switchgears with potential mechanism defects were identified with the aid of this smart tool, and the defects were subsequently rectified. If these defects could not be cleared timely, it would seriously affect the supply reliability to our customers and resulted in prolonged electricity interruptions to large number of customers in case of cable fault incident.

This innovative project demonstrated ‘small change leading big gain’, with the simple tool customized to meet operational needs and this patented smart device also received the bronze award for the Innovation Award at the HKIE MIS Industry Award 2023. [Patent No. HK30106651]

To further automate the measuring process, the feasibility of integrating this control current duration measurement function into our in-house developed Distribution Management System (DMS) RTU was explored. This health check function will become the standard feature of our DMS RTU and an alarm will be triggered to alert System Control engineer if the current duration has exceeded the threshold. This automated health check process not only increases the frequency of checking but also enhances the operational efficiency.

3. CABLE INCIPIENT FAULT DETECTION AND ALERT SYSTEM

Besides the smart monitoring system and tools developed for monitoring the healthiness of circuit breakers and switchgears, another tailored cable incipient fault detection and alert system was also developed by our engineers.

Before the defect of a cable circuit develops into a fault, some transient earth fault current due to discharge may occur. However, as the duration and magnitude of this transient earth fault current are relatively short or small, the conventional mechanical IDMT protection relay or old liquid type fault indicator may not be able to capture the fault current and alert system operator to take proper action. Although replacing these old type mechanical IDMT protection relays or fault indicators with the fast-acting ones can resolve this issue, it will take a long time to complete, as such replacement will involve massive modification, wiring work, and circuit outage.

To address this pain point, a quick-win solution using the earth fault current transformer (CT) of the existing liquid-type fault indicator as an input source was devised. By using the fast-response numerical relays with multiple inputs, outputs, and alarm level settings, a high-speed earth fault detection system was designed and retrofitted to all primary stations with old mechanical relays within 10 months to detect incipient fault and improve system reliability.

Fig. 4 - Cable Incipient Fault Detection System

To eliminate the need of dispatching an engineer to site to identify the circuit suffering from incipient fault and hence improving the response time of duty engineer, a tailor-made SMS alert system was built so that duty engineer can receive the SMS alerts about the information of feeder with incipient fault. Based on the SMS and cable information, system operator can formulate a contingency plan and take immediate action before the incipient fault develops into a fault and cause supply interruptions to the customers.

Fig. 5 - Sample SMS Notification Message

4. APPLICATION OF PERFLUOROCARBON TRACER (PFT) FOR LEAK LOCATION ON TRANMISSION FLUID-FILLED CABLES

The transmission network of HK Electric is mainly composed of underground self-contained fluid-filled (SCFF) cables and cross-linked polyethylene (XLPE) cables. The SCFF cables use pressurised cable fluid as insulation media and their performance is very reliable. When the SCFF cable is put into service, the cable fluid is heated by load current, and the pressure inside cable builds up, resulting in expansion of the cable fluid, which will be pushed back to the underground tanks for temporary storage. When the cable temperature decreases due to load decrease, the cable fluid contracts, and the cable fluid temporarily stored in the cable fluid tanks is then pushed back to the cable body by the pressure of the cable fluid tanks to maintain the cable fluid inside the cable body. To ensure the normal operation of the SCFF cable, the cable fluid pressure is monitored. However, the metal sheath of the SCFF cable may crack due to thermal expansion during the load cycle or be damaged due to corrosion or other factors. As a result, the cable fluid leakage will occur.

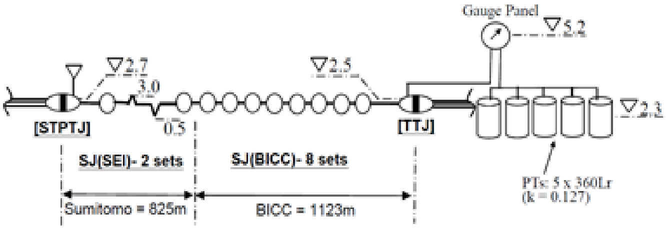


Fig. 6 - Typical Cable Fluid Arrangement of SCFF Cable

Locating the cable fluid leak is a very difficult process, as the cable is buried underground. Historically, the predominant technique adopted to locate cable fluid leaks involved "cable freezing" with liquid nitrogen. This method typically requires multiple freezing operations and road excavations to pinpoint the leak point before the leak repair work can be carried out. Apart from the inconvenience causes to the general public and high repair costs due to multiple road excavations, this leak location method will lead to prolonged circuit outages. Also, repeated cable freezing may also weaken the mechanical strength of the metal sheath of the SCFF cable and lead to another fluid leak in the future.

To shorten the leak location process, a Perfluorocarbon Tracer (PFT) leak location system for locating leaks on SCFF cables was introduced in 2015. By tagging the cable with fluid leak using PFT, the leak point can be located above the road surface, as the PFT in the cable fluid leaks from the cable will evaporate to the road surface, and the leak point can then be pinpointed by a field instrument installed in the test van.

Fig. 7 - PFT Leak Location System

Since the commissioning of our first PFT leak location system at the end of 2015, over 30 cable fluid leaks have been pinpointed successfully by this system, and the accuracy of the system is, on average, within two metres. However, the accuracy may be affected by the leak rate, cable burial depth, presence of underground pipe ducts, and the road pavement material.

Fig. 8 - PFT Leak Location Test Van

A significant drop in the annual cable fluid consumption for topping up leaky cables was recorded after introducing this cutting-edge technology. In addition, the number of road excavations and the total circuit outage days were also reduced after introducing the PFT leak location system. To avoid interference from the residual PFT at the site and hence affecting the accuracy of pinpointing, a new system with different PFT signature is being acquired so that the leaks from different hydraulic sections along the same cable route can be differentiated.

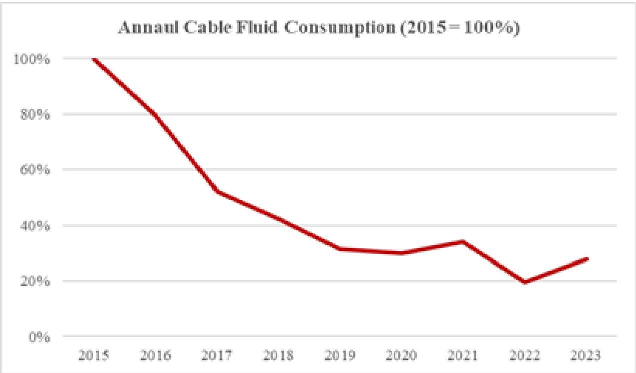


Fig. 9 - Annual Cable Fluid Consumption for Topping up Leaky SCFF Cable

5. CABLE DIAGNOSIS WITH HEALTH INDEX

The health of medium voltage cable is of utmost importance for reliable power distribution, and a number of cable health classification tools and algorithms have been devised to facilitate our engineers in formulating action plans and prioritising the replacement work [3], [4].

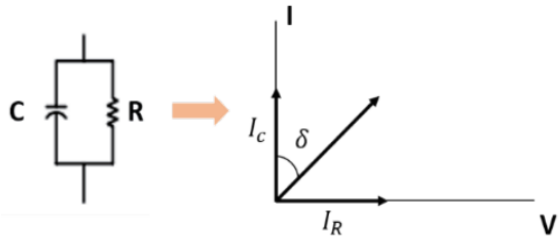
Locating the PD source using online and offline PD diagnosing methods has been adopted by the Company. This method first uses online PD diagnosing tools to conduct an initial screening for a number of power cables, then deploys offline PD mapping tools to countercheck and locate the suspected defective cable components. The effectiveness of this screening method has been validated and confirmed.

Furthermore, to apply the new metrics to the cable network, a review over 3,000 sets of Tan Delta (TD) measurement results from the past 10 years was conducted, and based on the study results, specific evaluation criteria of Tan Delta results were established.

a) Tan Delta Test

The Very Low Frequency (VLF) Tan Delta test has been used to determine the overall insulation condition of underground power cables since 2010. When a power distribution cable is in a good condition, it more or less acts like a perfect capacitor. The voltage and current are phase-shifted by 90 degrees, and the current through the insulation is capacitive. However, if there are impurities in the insulation, e.g., moisture, air pockets, and water trees etc., the resistance of the insulation decreases. The current and voltage will no longer be shifted by 90 degrees, and the extent can indicate the contamination level of the insulation. The extent of contamination is evaluated by using Tan Delta (tan δ) as:

$$\tan\delta = \frac{true\ power}{reactive\ power} = \frac{U^2/R}{U^2\omega C} = \frac{1}{\omega CR}$$



To determine the maintenance priority, a five-level Health Index based on the Tan Delta results is used.

Tan Delta is an indication of the overall insulation condition of the power distribution cable. However, the cause, such as aging effects, impurities, water trees and etc., for non-ideal insulation measurement results can vary. As such, it is necessary to study and propose new evaluation metrics to single out the deteriorations related to water trees and formulate the mid- and long-term cable replacement plan.

b) Tan Delta Stability

This parameter refers to the time dependence of TD. Eight sets of TD values are measured, and the standard deviation (STD) is calculated. Generally, the measured TD should remain stable for a healthy cable unless there is a vibration of water molecules, which can alter the conduction properties of the insulation layer over time.

c) Difference of Tan Delta (DTD)

This parameter represents the difference between the mean TD values measured at different test voltage. Similarly, a cable is deemed weak if the DTD is large, which indicates that the insulation losses increase more dramatically as the test voltage goes up.

d) R Value

This parameter is calculated as a ratio of the highest mean TD of one phase to the lowest mean TD of another one among three phases. This ratio denotes the insulation discrepancy among the three phases. Generally, the mean TD of the three phases should be roughly similar when tested for a healthy cable.

With the help of these decision-making tools, some incipient faults are identified and rectified before they developed into faults, and a decreasing trend of HV cable faults resulting in tripping in last ten years was recorded.

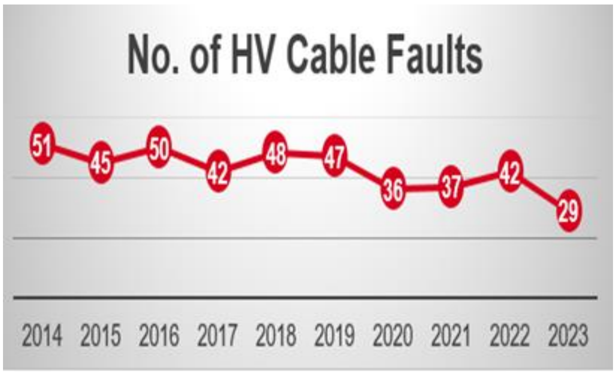


Fig. 10 - Number of HV Cable Fault

Moreover, the collaboration with the Centre for Advances in Reliability and Safety Ltd. (CAiRS), an InnoHK research centre affiliated with the Hong Kong Polytechnic University, to explore the feasibility of diagnosing power cables using Artificial Intelligence (AI) methods was kicked off in 2022, and the AI model for diagnosing the health of power cable was established. The model can perform the first screening automatically and identify the high-risk cables for further analysis.

6. LV SMART SENSOR

Currently, HK Electric's distribution network houses over 10,000 LV cutouts, and there are no remote monitoring devices for these service cutouts. This absence of monitoring means that engineers face significant time delays in locating and isolating faulty parts when a cable fault arises. Historical data reveals that over 60% of Customer Minutes Loss (CML) in HK Electric's power network results from incidents related to LV cables or apparatus.

To improve the visibility of the LV network, it is necessary to retrofit the remote monitoring device to LV service cutouts to monitor the condition of LV cables/cutots. Besides performing those basic functions, like measuring the voltage and current of the cutouts, as other off-the-shelf product do, this smart LV sensor will trigger an alarm when zero voltage, over-current, or overheating is detected.

To suit the customised needs, a modern Internet of Thing (IoT) device with above features was developed solely by our engineers. This self-powered LV Smart sensor uses the company-own LoRaWAN platform and employs small Rogowski coils, instead of the conventional current transformers, to resolve the space limitation issue of the cable chamber of LV service cutout for detecting the earth fault current. By adapting the non-contact voltage detection method, there is no supply interruption to the customer during the retrofitting of this IoT sensor. With this smart IoT device, the faulty cable section can be identified and isolated rapidly. Hence, the electricity supply to the customers can be promptly restored. Additionally, with this smart sensor, the real-time status of the LV cutouts and the associated service cable can be monitored.

Fig. 11 - Inhouse Developed LV Fault Indicator and the Wiring Connection

The implementation of smart sensors will substantially enhance the visibility of the LV network and facilitate the fault restoration and fault analysis. Moreover, the data acquired by the LV smart sensor also serves as the foundation of data analysis, optimizing LV asset utilization, operation, and maintenance.

7. MOBILE BATTERY ENERGY STORAGE SYSTEM AND POWER CHANGE-OVER SYSTEM (MBESS)

There are over 1 million components in the power system and supply interruption cannot be completely avoided due to unforeseeable equipment failure. Speedy restoration of supply to customers under equipment failure conditions is also a critical link of a reliable network. Using mobile generator with quick connectors for supply restoration is one of the quick and effective means. However, due to site constraints, such as noise and emission concerns, the use of mobile generator as supply source may not be feasible for some sites.

To overcome these hurdles, using Mobile Battery Energy Storage System (MBESS) to replace the mobile generator was formulated to act as a mobile generator.

The MBESS features a lithium iron phosphate (LFP) battery, selected for its superior thermal stability and charging efficiency compared to traditional ternary lithium-ion batteries. This LFP battery can be rapidly recharged within 2 hours, and its 380 V, 3-phase, 50 Hz output enables automatic synchronization with the grid for co-generation purposes. An onboard fire suppression system using Novec 1230 further enhances safety.

The design of the MBESS is optimized for quick, safe, and accurate connection without specialized tools. Its modular, detachable container design allows access to many locations, with the flexibility to eliminate the need for a dedicated driver if necessary. A bi-directional 250 kW Power Conversion System integrates the power inverter and battery charger into a single unit, simplifying installation and operation.

Fig. 12 - Energy Storage Truck (EST)

However, the weakness of the MBESS is the supply duration as the supply duration is tied up with the battery capacity of the Energy Storage Truck (EST) and swapping of the EST during the prolonged operation of the MBESS cannot be avoided. To maintain continuous supply to customers and enable seamless swapping of the EST, an innovative solution using a Power Changeover Truck (PCT) to achieve uninterrupted cutover was formulated.

The PCT, featuring an extremely fast 630 A static transfer switch with a transfer time of less than 5 milliseconds, is the key to achieving uninterrupted power transfer. When the first EST reaches the end of its discharge cycle, the PCT can seamlessly switch the AC loads to the second EST, allowing the first EST to be disconnected for recharging without any interruption to the customer's supply.

Besides using the MBESS and PCT for supply restoration under the equipment failure situations, the uninterrupted changeover capability can also be used as standby supply source for critical events that requires extraordinarily high reliability of power supply.

Fig. 13 - Use of EST and PCT to Maintain Supply Security of Important Event

8. CABLE TUNNEL INSPECTIONS WITH SMART ROBOTIC INSPECTOR

Cable tunnels are critically important to the power transmission and distribution network as they can prevent the power system from interference by the weather and other external influences, hence improving the supply reliability of the power system. The maintenance team needs to enter the cable tunnel to conduct the routine inspections every 6 months. In some occasions, such as after the black rainstorm and typhoon, additional inspections have to be arranged to ensure the apparatus installed inside the cable tunnel is in good condition. However, as the cable tunnel is classified as a confined space and a series of pre-work risk assessments and risk mitigation measures have to be carried out before the site staff can enter the tunnel for inspection. Despite this, the risks associated with work inside the confined space cannot be eliminated completely. Hence, with the objective of improve operational efficiency and ensure safety in confined spaces, feasibility of using robots to conduct the routine inspections was conducted and a number of solutions were evaluated. The use of conventional fixed installations and track-type mobile monitoring devices is not preferred in view of the high installation and maintenance costs and limited coverage. Also, they are susceptible to being damaged by the hot and humid environment condition inside the cable tunnel.

Due to the environmental complexity in the tunnel, robots are considered a better choice to serve multiple missions such as the inspection, incident alerting and automating the process of data collection and recording. Finally, a smart inspection solution with robots for the cable tunnel was deployed in early 2024.

The robotic inspector is equipped with built-in high definition and infrared cameras and several environment sensors to detect gas content, humidity and temperature inside the cable tunnel so that the inspector can detect the environment and inspect cable conditions inside the tunnel while collecting various data.

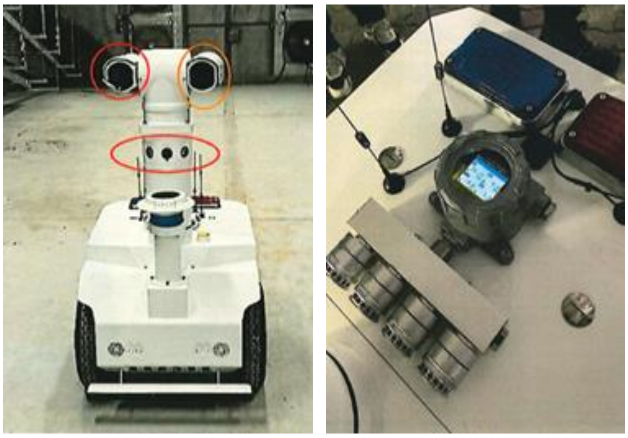


Fig. 14 - Robotic Inspector for Cable Tunnel Inspection

Utilising the high-speed and low-latency advantage of 5G technology, the robotic inspector can transmit real-time images and condition data of the tunnel to a web-platform so that engineers can review the camera footage and the tunnel condition in the office. Real-time alerts will also be triggered to the tunnel management console for any abnormal situations.

Moreover, in case of emergency, the robotic inspector will serve as the pilot and provide the real-time information to facilitate the engineers in assessing the site condition and arranging necessary measures to minimise the potential risk before accessing the cable tunnel.

With the help of the robot, the inspection frequency increases from half-yearly to daily to ensure the apparatus inside the cable tunnel is in good condition, in a cost-effective and safety manner. Also, the data collection will contribute to big data analytics to formulate the preventive maintenance programme.

9. CONCLUSION

HK Electric's commitment to innovation and excellence has not only sustained its high supply reliability but also enhanced its operational efficiency and safety standards. The successful implementation of various innovative projects discussed above underscores the Company's proactive approach to embracing new technologies. These innovation projects provided significant benefits to the daily operation of the transmission and distribution network. Moving forward, the Company remains dedicated to fostering a culture of innovation to meet future challenges and uphold its legacy of reliability and excellence in the power industry.

ACKNOWLEDGEMENT

The authors are grateful to the senior management of The Hongkong Electric Co., Ltd. for permission to publish this paper.

REFERENCES

1. HK Electric Sustainability Report 2023 [https://www.hkelectric.com/documents/en/InvestorRelations/InvestorRelations_GLNCS/Documents/2024/ESR2023%20full%20version.pdf]

2. HK Electric Innovation Report 2023 [https://www.hkelectric.com/documents/en/Sustainability/Running%20a%20Sustainability%20Business/Innovation/InnovationReport_eng.pdf]

3. Dr. Ke ZHU, Dr Genghong LU, Mr. HO Nam Yim, Mr. Chao LEI, Mr. WONG Ming Kwong, Mr. IP Chi Lam, Mr. PUI Yu Lin, and Dr. Siqi BU "Breakthrough for power distribution cable diagnosis using Artificial Intelligence" Hong Kong Engineer Vol 52, April 2024. [https://www.hkengineer.org.hk/issue/vol52-apr24/cover_story/]

4. Dr. Ke ZHU, "Use of insulation resistance imbalance degree for the condition assessment of power distribution cables" HKIE Tractions Vol 30 Issue 4, December 2023. [https://www.hkengineer.org.hk/issue/vol52-apr24/cover_story/]

Paper No. 3

A NEW WAY TOWARDS CLEAN, RENEWABLE AND EFFICIENT ELECTRIC POWER SUPPLY SYSTEM

Authors/Speakers: Mr. Dick CY Lee, General Manager
The Jardine Engineering Corporation Limited
Mr. Govi Ramasamy, Chief Commercial Officer
Hyliion Holdings Corporation, USA

A NEW WAY TOWARDS CLEAN, RENEWABLE AND EFFICIENT ELECTRIC POWER SUPPLY SYSTEM

Mr. Dick CY Lee, General Manager
The Jardine Engineering Corporation Limited
Mr. Govi Ramasamy, Chief Commercial Officer
Hyliion Holdings Corporation, USA

ABSTRACT

Renewable fuels are gaining increased attention due to their ability to reduce air pollution and greenhouse gas emissions in comparison to traditional fossil fuels. The heat linear generator represents a novel energy conversion method characterized by its compact structure, potential for multifuel combustion, and reduced friction loss, making it adaptable to various renewable fuel sources.

We present a contemporary approach to modernizing the 19th century-era Stirling engine. Recognized for remarkable efficiency, Stirling engine adoption had been hindered by the classical system architecture and practical manufacturing challenges such as design complexity, heat exchanger efficiency, and low power density. A reimagination of the system architecture and modern additive manufacturing technology has advanced to a stage where components can now be efficiently produced that feature the intricate geometries and precise details necessary for crafting efficient, power-dense generators.

Proposed heat linear generator is expected to deliver not just incremental enhancements, but step-change improvements in operating capabilities when compared to conventional generator systems, expanding the potential for their application in distributed power systems in sectors where environmental sustainability, fuel flexibility and efficiency are paramount.

1. INTRODUCTION

Internal combustion engines find extensive use in automobiles, trains, and power facilities. Historically, fossil fuels have been the primary energy source for traditional internal combustion engines.

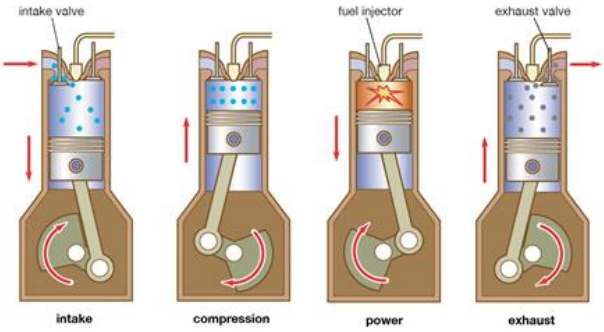


Fig. 1 - Internal Combustion

However, the byproducts of fossil fuel combustion, such as CO, CO2, NOx, and others, contribute to environmental issues like the greenhouse effect and global warming. The extraction and consumption of fossil fuels strain natural resources, resulting in environmental harm like water resource depletion and land disruption. Consequently, researchers are actively exploring renewable fuel alternatives, such as hydrogen and ammonia, to supplant fossil fuels.

A heat linear generator emerges as a promising power generation system due to its compact design, ability to utilize multiple fuels, high power density, and reduced friction losses. Its adaptability to various fuels enables the swift integration of renewable sources for electricity production. Implementing heat linear generators with renewable fuels offers significant potential across diverse sectors, including hybrid vehicles, combined heat and power setups, and power plants. This integration stands to curb carbon emissions linked with fossil fuel extraction and usage while decreasing reliance on traditional power origins.

In contrast to standard internal combustion engines employing a crank-link mechanism, the distinguishing characteristic of a heat linear generator lies in its linear reciprocating motion. Key components encompass the combustion cylinder with free-piston engine and the linear generator, the latter driven by gas pressure produced through cylinder combustion to generate electricity by altering magnetic field lines.

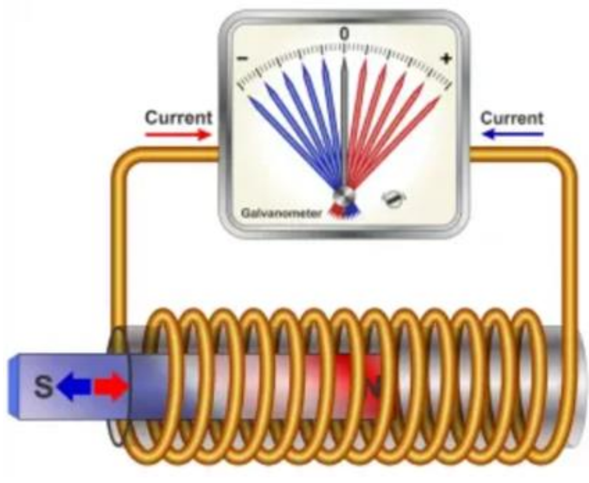


Fig. 2 - Generate Electricity by Altering Magnetic Field Lines

2. HEAT LINEAR GENERATOR

Unlike conventional internal combustion engines (ICE), the Heat Linear Generator, shown in Figure 3, consists of an innovative closed-cycle heat engine that uses external continuous flameless oxidation to produce electricity using double-sided linear mechanics, which allows for a very power-dense solution. Heat linear generator is a highly efficient generator that produces power with near-zero criteria pollutant emission and, when fueled with hydrogen, virtually zero greenhouse gas (GHG) emissions all without the need for any aftertreatment systems.

Three key technologies enabled by additive manufacturing drive the Heat Linear Generator's advantages: 1) an external flameless oxidation system producing extremely low emissions, 2) a highly efficient linear heat engine, and 3) simplicity of design, with a single moving part per shaft.

Fig. 3 - 200kW Heat Linear Generator

The Heat linear generator harnesses the power of a heat engine to propel a linear generating system, deriving its linear motion from temperature differences inside the engine. The generation of heat within the system occurs through an external flameless oxidation of fuels, like natural gas, hydrogen, or propane which minimizes the generation of harmful emissions. This thermal energy causes helium gas enclosed within a sealed cylinder to expand, thereby propelling linear motion in a connected piston-shaft system, which includes a sequence of permanent magnets situated on the shaft passing through electrical coils to produce electricity.

Subsequently, the counter-motion generated by a piston at the opposite end of the shaft flows the helium gas to the cold side of a piston where excess heat is efficiently dissipated. This cyclical process continues, resulting in a continuous source of electrical power for so long as heat is supplied to the generator.

2.1 Permanent Magnet Tubular linear Generator

In the Heat linear generator setup displayed in Figure 4, a permanent magnet tubular linear generator is utilized. This generator consists of a mover with magnets and high magnetic permeability silicon steel sheets, along with a stator featuring three-phase windings. The magnets on the mover are magnetized transversely, with adjacent magnets having similar poles facing each other and silicon steel sheets aiding in magnetic conduction between them. The stator is predominantly crafted from multiple strands of copper wire wound into three phases, where phases A and C are wound in one direction while phase B is wound in the opposite direction. The magnetic circuit is depicted in Figure 5.

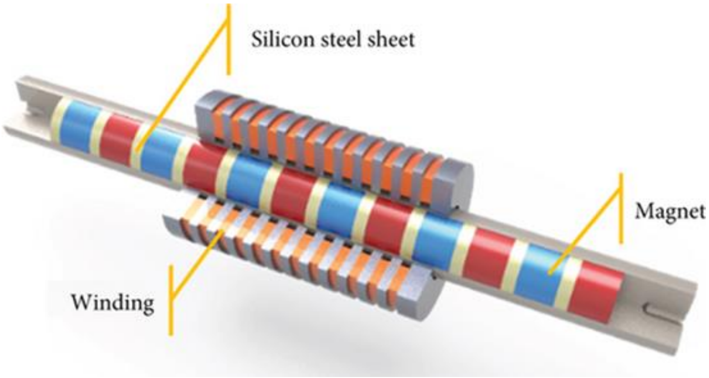


Fig. 4 - Structure of Linear Generator Configuration

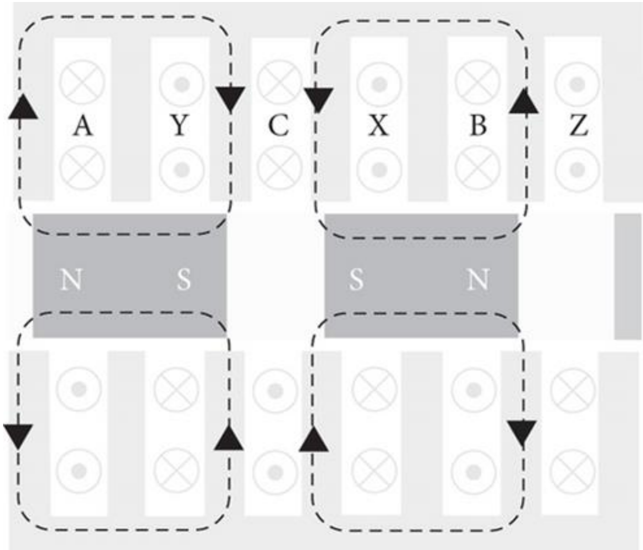


Fig. 5 - Magnetic Circuit for Linear Generator Configuration

3. STRUCTURE OF HEAT LINEAR GENERATOR

As shown in Figures 6 and 7, the Heat linear generator consists of four key elements, including a central linear electric motor/generator bookended by twin sets of reactors, heaters, and chillers.

These latter three components are produced through additive printing technology while other components are conventionally manufactured. The linear generator consists of copper coils surrounding a magnet array mounted on a shaft that runs through the generator's center. Pressure is created by heat transfer from the reactor into a sealed volume of helium gas within the heater, which expands as it heats up and applies force to pistons in opposing actions, causing the system to oscillate back and forth.

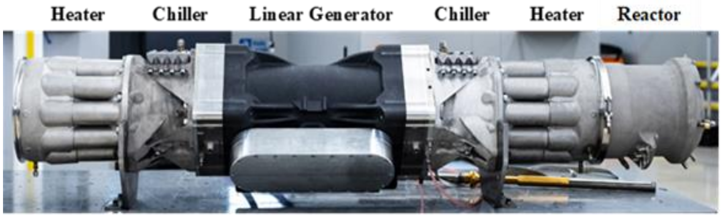


Fig. 6 - Single Shaft of the Heat Linear Generator

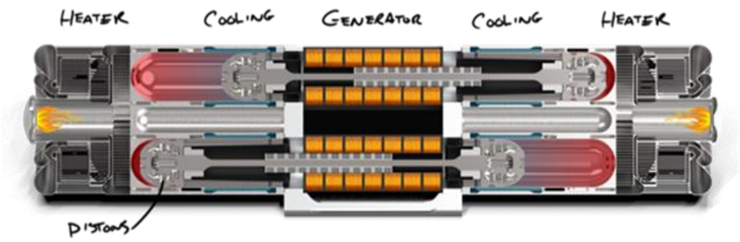


Fig. 7 - Key Elements of the Heat Linear Generator

The standalone generator set, or genset system, includes the Heat linear generator along with an enclosure that houses key balance-of-plant elements such as the cooling system, generator controls, a battery system, and high voltage electrical components. See Figure 8.

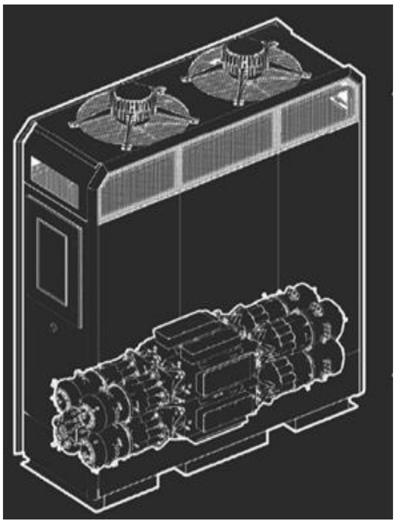


Fig. 8 - A 200 kW Generator System

Heat linear generators present several advantages over conventional generators, with key benefits including reduced maintenance, attributable to their simplified design with few moving parts. Additionally, they can exhibit higher efficiency by circumventing the mechanical losses linked to rotating components such as bearings and gears while producing less noise and vibration. In this case, each generator relies on a single moving part: a translating shaft riding on pressurized helium bearings instead of oil-based lubricants.

While heat engines have long been recognized for their high levels of efficiency and simplicity of operation, practical limitations such as heat exchanger performance, friction, and dead volume can significantly reduce their overall efficiency.

4. FEATURE OF HEAT LINEAR GENERATOR

Additive manufacturing has advanced to a stage where efficient systems like the Heat linear generator can be built without the limitations of conventional subtractive manufacturing. As shown below in Figure 9a & 9b, enabled by advances in additive manufacturing systems, parts are designed with a large number of intricate flow channels for the movement of heat, cooling water, helium and exhaust gases such that contact surface areas for heat transfer are maximized.

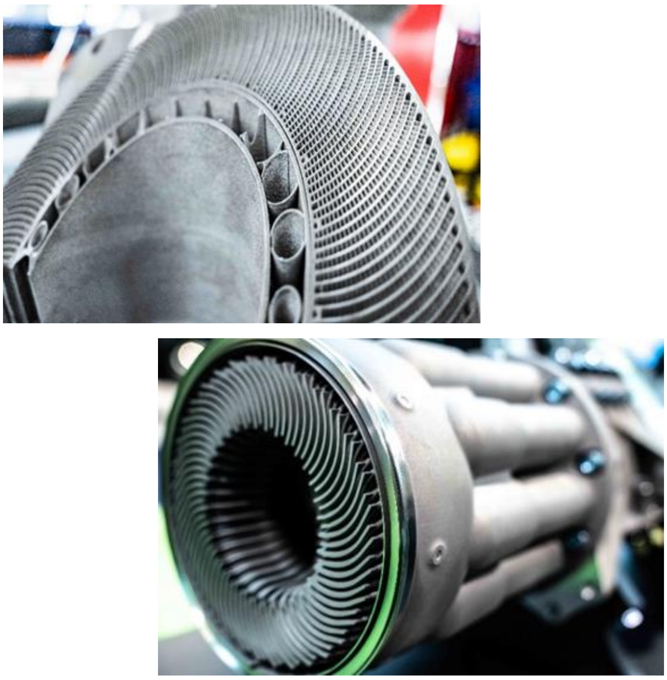


Fig. 9a & 9b - Intricate Nature of Additive Manufacturing Components

The Heat linear generator is expected to surpass the efficiency of conventional reciprocating generating systems of a similar size when employing various fuel sources. See Figure 10.

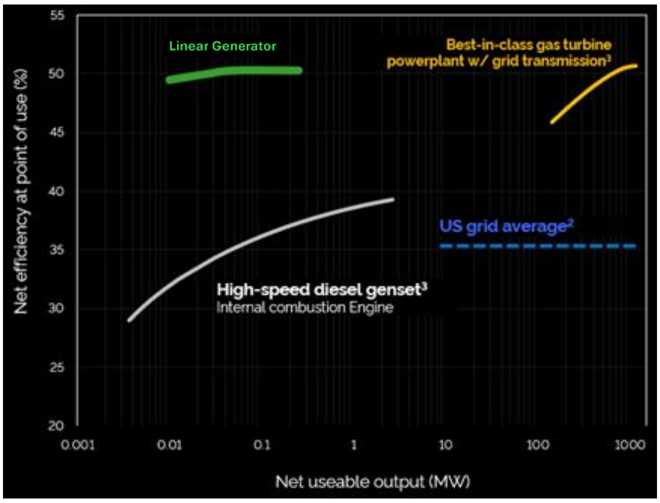


Fig. 10 - Efficiency vs. Competitive Set

Notably, its high efficiency remains consistent across a broad range of output power levels. In contrast, technologies such as fuel cells reach peak efficiency at low power levels but experience diminishing efficiency as output increases towards full power. The design of the Heat linear generator offers a distinct advantage in power adjustment by modulating operating parameters and the rate of heat introduction, enabling seamless power adjustments without compromising the efficiency of the generator.

It is anticipated that the Heat linear generator will achieve an electrical generating efficiency of nearly 50%, calculated by considering the usable output power in relation to the energy from the fuel source.

High efficiency is expected to remain consistent across a wide range of output power levels, spanning from tens of kilowatts to multiple megawatts. In contrast, internal combustion diesel generators typically operate within an efficiency range of 25% to 40% over a similar power spectrum, while the electrical power grid in developed economies is estimated to operate at an efficiency between 33% and 40%. Notably, best-in-class grid-level gas turbine powerplants can obtain efficiencies ranging between 45% to 55%.

However, these powerplants have a much larger minimum power level (typically 10+ MW) and incur transmission and distribution losses between 5% and 10%, which can be circumvented by locating generation near the point of consumption.

Conventional generators emit pollutants as a result of incomplete combustion of fuel-air mixtures, with the formation of NOx compounds being particularly prominent. Unlike conventional generators, which often employ internal combustion engines operating at high temperatures with rapid and incomplete fuel combustion, design of the Heat linear generator allows for continuous fuel oxidation at low pressure, lower temperatures and at extended reaction times. This is achieved partly through the recirculation of exhaust gases, which serves to prolong combustion duration and pre-heat incoming air, which increases system efficiency.

As a result, the Heat linear generator is anticipated to achieve remarkably low levels of emissions, with CO2 and NOx emissions expected to be reduced by over 95% compared to best-in-class diesel engines without the use of aftertreatment systems. See Figure 11.

One of the notable advantages of the Heat linear generator is an expected reduction in maintenance requirements and cost. Conventional generators incur high usage-based maintenance expenses, typically ranging between 5% and 20% of total operating cost.

With one moving shaft, the design of the Heat linear generator significantly mitigates efficiency losses attributed to friction, enhances the system's operational longevity, and eliminates the need for oil-based lubricants commonly found in conventional generators. Consequently, the heat linear generator is expected to operate much longer than a conventional generator before requiring periodic maintenance or an overhaul.
The Heat linear generator is also expected to operate across a diverse spectrum of approximately 20 available fuel sources and fuel mixtures, including natural gas, propane, gasoline, jet fuel, and alternative fuels like bio-diesel, hydrogen and ammonia.

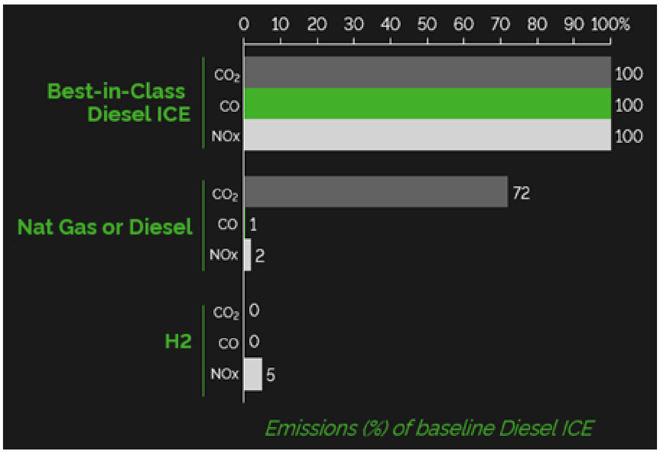


Fig. 11 - E Untreated Emissions vs. Diesel ICE

Moreover, the generator will be able to transition between these fuels or fuel blends, requiring no physical modifications to its external flameless oxidation system. As the energy landscape evolves, the Linear Generator's fuel-agnostic nature positions it as a future-proof solution to a range of electricity generation needs.

Finally, because of the technology execution of the Linear Generator, waste heat generated from traditional manufacturing processes such as steel production can be used directly to produce electricity – in essence producing electricity without any fuels.

5. COMPARISON TO INCUMBENT TECHNOLOGIES

Key attributes of the Heat linear generator that sets it apart from conventional generation technologies, include:

a) Generator Efficiency: Higher efficiency than conventional internal combustion engines across a broad range of load factors.

b) Low Maintenance: With only a single moving part per shaft, the Heat linear generator is expected to reduce both periodic maintenance expenses and expected overhaul costs.

c) Fuel Agnostic: While many traditional generators operate on a single fuel source or require system modification to achieve fuel flexibility, the Heat linear generator is truly fuel-agnostic, and can switch between fuel choices during operation.

d) Higher Power Density: The unique architecture and features of the generator enable it to achieve a high level of power density.

e) Modularity: The power output of the Heat linear generator can be modulated by changing the level of heat applied to the system. For larger power applications above 200 kW, multiple Linear Generators can be assembled to operate as a single unit.

6. CONCLUSIONS

The Heat linear generator architecture and functioning explained in this technical brief represent a significant breakthrough in distributed power generation. It's fuel agnostic nature, high efficiency, ultra-low emissions, and low maintenance has the potential to address the energy problems faced by multiple sectors and industry across the world in a cost-effective manner.

Overall, the ongoing research and development in the field of heat linear generators and their integration with renewable fuels signify a significant step towards a more sustainable energy future, offering a pathway to reduce carbon emissions, enhance energy efficiency, and promote the adoption of cleaner power generation technologies.

REFERENCES

1. Yidi Wei, Zhengxing Zuo, Boru Jia, Zhiyuan Zhang, Huihua Feng, Kun Liang "Performance Characteristic of Permanent Magnet linear generator for Energy Conversion with Renewable Fuels on Free piston engines"

Paper No. 4

PFAS-FREE TECHNOLOGY -
SOLUTION FOR SUSTAINABLE BATTERY SYSTEMS

Authors/Speakers: Dr. Priscilla SW Huen, R&D Technical Manager
Dr. Bill KP Ho, Chief Technology Officer
GRST Holdings Limited, Hong Kong

PFAS-FREE TECHNOLOGY - SOLUTION FOR SUSTAINABLE BATTERY SYSTEMS

Dr. Priscilla SW Huen, R&D Technical Manager
Dr. Bill KP Ho, Chief Technology Officer
GRST Holdings Limited, Hong Kong

ABSTRACT
Growing demand of batteries raises the concern of dealing waste batteries. Some batteries contain per- and polyfluoroalkyl substances (PFAS) which are "forever chemicals" that can hardly be degraded naturally. To tackle this issue, a PFAS-free technology which is compatible to different kinds of battery chemistry is developed. Comparison between PFAS-containing and PFAS-free technologies are discussed in terms of manufacturing and recycling in this paper.

1. INTRODUCTION

Due to the development of electromobility and renewable energy systems, the demand of batteries is increasing significantly. Among different types, lithium-ion battery is the dominant class being used and over 2000 GWh of Li-ion batteries were added to the market globally in the past five years [1]. Without proper recycling strategies, kilotons of end-of-life (EOL) batteries would be discarded in the next decades (see Figure 1) and accumulate in landfill, becoming another source of e-wastes.

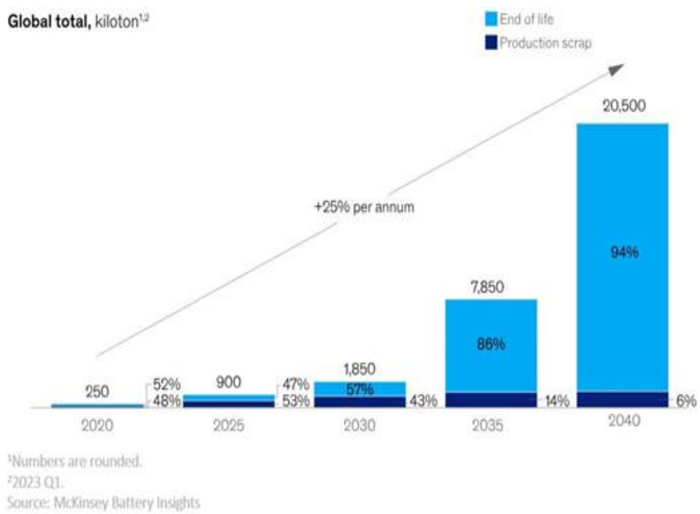


Fig. 1 - Amount of Production Scrap and End-of-Life Batteries Available for Recycling Predicted by McKinsey Battery Insights [2]

Apart from making a positive impact to the environment, recycling of batteries also brings economic benefits to the industry. For the production of Li-ion batteries, cathode has the highest contribution to battery cost. In some scenarios, recovery and reuse of valuable materials from waste batteries can reduce the cost by 44% [3].

However, current battery recycling strategies are energy-consuming and complex due to the presence of PFAS in Li-ion batteries. Polyvinylidene fluoride (PVdF), a member of PFAS, is a binding material commonly used in Li-ion batteries. There are two main functions of binding material: one is stabilization of electrode slurry and another is binding active material and conducting material to the current collector (see Figure 2). In order to separate the cathode layer from the current collector, the electrodes are usually heated to a high temperature at which PVdF will decompose, or immersed in organic solvents to dissolve PVdF [4]. The former method emits huge amount of carbon dioxide, while the latter method involves the usage of large quantity of N-methyl-2-pyrrolidone (NMP) that is considered a carcinogenic solvent. For the purpose of reducing carbon footprint of whole battery lifespan, development of green and non-fluorinated binding material becomes inevitable.

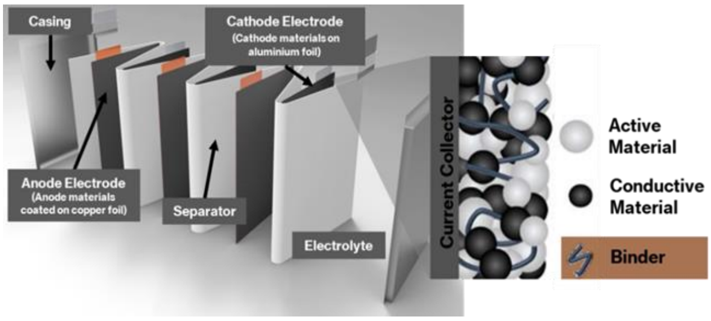


Fig. 2 - Structure of a Pouch Cell Type Li-ion Batter

2. PFAS-FREE TECHNOLOGY

As a green alternative to PVdF, a series of PFAS-free binders are developed by GRST to meet the requirements of different battery chemistries (e.g. LFP, NMC, LCO and LMO) and applications (e.g. consumer electronics, electromobility and energy storage). The PFAS-free binders possess wide electrochemically stable window and can be dissolved in both water and organic solvents. Compared to PVdF, the PFAS-free binders are more stable in alkaline medium. Advantages of replacing PVdF with the PFAS-free binders in electrode manufacturing and battery recycling are further elaborated in the following sections.

2.1 Electrode Manufacturing

Preparation of electrodes using PVdF and the PFAS-free binders are basically the same. Firstly, cathode material, binding material and conductive materials are thoroughly mixed in solvent to prepare a slurry. Subsequently, a layer of slurry is coated on top of current collector and dried. The dried electrode is then cut into specific size and shape for battery assembly.

A well dispersed and stable slurry is always the foundation of producing batteries of good quality. Slurries should possess good flowability at a specific range of viscosity in order to produce smooth electrode coatings. However, for cathode active materials especially high-nickel content cathodes, there are always alkaline residues e.g. lithium hydroxide coming from the synthesis process. Alkaline residues would attack PVdF causing dehydrofluorination and cross-linking of the binding material, and gradually result in gelation of slurry. Moisture in air would also accelerate gelation of slurry and therefore there is always a strict humidity control for PVdF-based manufacturing process. Since the PFAS-free binders are more tolerant to alkaline and moisture, slurries made with the PFAS-free binders have better storage stability. Energy consumed to control humidity level in the electrode manufacturing area can also be lowered.

Typically, NMP is the solvent for PVdF-based slurry. For the PFAS-free slurries, water can be the solvent in some cases. Since water has lower boiling point than NMP, the drying temperature of the PFAS-free electrode is 40-60 °C lower. In addition, water vapour can be discharged to atmosphere and solvent recovery system is no longer necessary. As a result, energy consumption and carbon footprint of the electrode manufacturing process can be greatly reduced.

2.2 Battery Recycling

Cathode active materials that contain lithium and transition metals have the highest value of recycling. There are two sources of recycling active materials: scrapes collected from the production line after cutting of electrodes and electrode materials obtained from waste batteries which are also called “black mass”.

Collected black mass are usually dissolved in acid to obtain metal salts for regeneration of cathode active material. For the PFAS-free electrodes/batteries, taking the advantage of solubility of the PFAS-free binders in water, black mass can simply be separated from the current collector via washing in aqueous solvent (see Figure 3).

Before regeneration of cathode active material, binder should be removed to increase the purity of materials. The PFAS-free binders are pH controllable and can precipitate at a given pH solution. When black mass undergoes the leaching process, the PFAS-free binders will precipitate in solid form and it can be easily removed by simple filtration. Compared to the current recycling technologies, GRST recycling technology based on the PFAS-free system is more cost-effective and environmentally friendly (see Figure 4).

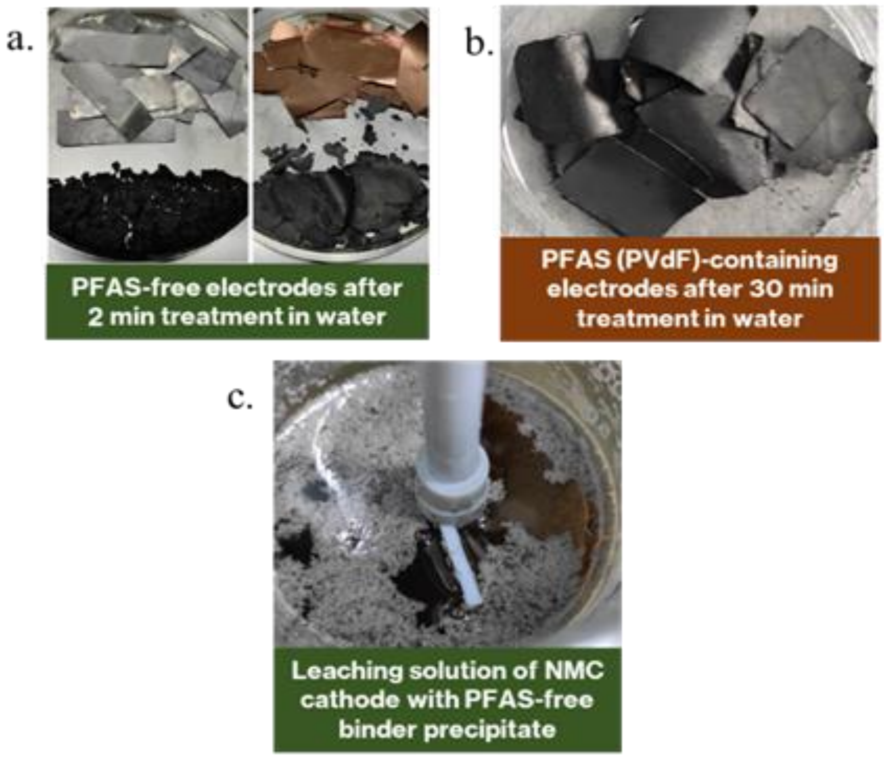
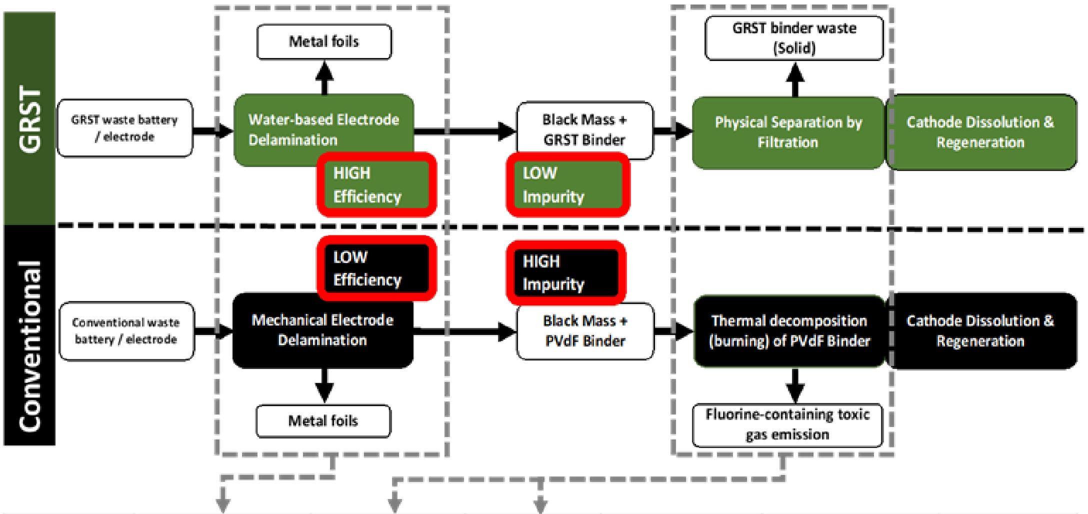


Fig. 3 - a) Successful Separation of Black Mass and Metal Foil in Water of PFAS-Free Electrode. b) Unsuccessful Separation of Black Mass and Metal Foil in Water of PVdF electrode. c) Leaching Solution of NMC Cathode with PFAS-Free Binder Precipate



	Material Separation Efficiency (Metal Foils and Black Mass)	Methods to Separate Binders from Black Mass	Processing Conditions (Temperature)	Waste Handling Costs and CAPEX	Overall Recycling Costs (CAPEX and OPEX)	Overall Energy Consumption and Carbon Footprint
GRST PFAS-free Recycling	High	Physical Separation in Water	Low (Room temperature)	Low (Water-waste treatment only)	Low	Low
Conventional Mechanical + Thermal Recycling	Low	Thermal decomposition / Burning	High (400-600°C)	High (High temperature furnace and toxic gas collection & treatment)	High	High

Fig. 4 - Comparison between GRST and Conventional Recycling Technologies

3. IMPACT OF PFAS-FREE TECHNOLOGY

Cost and carbon footprint of batteries vary with the cathode chemistry. For example, NMC811 battery pack has higher carbon footprint than LFP battery pack due to raw material extraction activities. General manufacturing process of GRST battery products (Figure 5) are taken as examples to investigate the impact of adopting PFAS-free technology. When PVdF/NMP system is replaced by PFAS-free binder/water system, CO_2 emission of the cell manufacturing can be decreased by 45% and at the same time saving 3% on the cell price.

Total saving in CO_2 emission will be higher when the battery cells/packs are recycled. Around 55% of NMC811 and 35% of LFP lifetime carbon emission are caused by mining and mineral processing [1]. Substitution of mined pristine materials by recycled materials can efficiently reduce carbon emission coming from the extraction of cathode materials. A statistic conducted by McKinsey & Company mentioned a reduction of carbon emission from 74 to 53 kgCO_2eq/kWh when NMC cathode is produced from recycled materials [2]. Since recycling technology based on PFAS-free system is basically a physical separation of materials in aqueous solvents and does not involve any thermal decomposition at elevated temperature, carbon footprint correlating to material extraction processing is expected to decrease further.

4. CONCLUSION

PFAS-free technology is proven an environmentally friendly and economical approach for the production and recycling of Li-ion batteries. This technology is not only limited to Li-ion batteries, but can also be adopted for other rechargeable batteries such as sodium ion batteries

GRST PFAS-free pouch cell	
Battery Type	NMC
Nominal Capacity (Ah)	4.5
Nominal Voltage (V)	3.7
Application	Electronics, small appliances

GRST PFAS-free prismatic cell	
Battery Type	LFP
Nominal Capacity (Ah)	280
Nominal Voltage (V)	3.2
Application	Energy storage system

GRST PFAS-free battery pack for energy storage system	
Product model	PAFP-288A90
Cell Type	LFP
Nominal Capacity (Ah)	90
Nominal Energy (kWh)	2.6
Rated Voltage (V)	28.8
Weight (Kg)	19.5±1
Dimensions (mm)	L344 x W152 x H237

Fig. 5 - Different Types of Cell/Battery Pack Products using the PFAS-Free Binders

and solid-state batteries. For the development of more sustainable battery system, PFAS-free technology is believed to be the trend of future generation of batteries.

REFERENCES

1. International Energy Agency, Batteries and Secure Energy Transitions- World Energy Outlook Special Report, 2024, https://iea.blob.core.windows.net/assets/cb39c1bf-d2b3-446d-8c35-aae6b1f3a4a0/BatteriesandSecureEnergyTransitions.pdf

2. McKinsey & Company, 2023, https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/battery-recycling-takes-the-drivers-seat

3. Gutsch, M. and Leker, J., "Costs, carbon footprint, and environmental impacts of lithium-ion batteries- From cathode active material synthesis to cell manufacturing and recycling", Applied Energy, Volume 353, Part B, 2024, 122132.

4. Rensmo, A. et al., "Lithium-ion battery recycling: a source of per- and polyfluoroalkyl substances (PFAS) to the environment?", Environ. Sci.: Processes Impacts, Volume 25, 2023, 1015.

Paper No. 5

THE SPECIFIC AND MORE ONEROUS REQUIREMENTS FOR LOW-VOLTAGE ASSEMBLIES IN ELECTRIC VEHICLE CHARGING APPLICATIONS

Author/Speaker: Mr. Tom W Mennell
Technical Standards Manager
Schneider Electric Ltd. UK

THE SPECIFIC AND MORE ONEROUS REQUIREMENTS FOR LOW-VOLTAGE ASSEMBLIES IN ELECTRIC VEHICLE CHARGING APPLICATIONS

Mr. Tom W Mennell
Technical Standards Manager
Schneider Electric Ltd. UK

ABSTRACT

Currently, electric vehicle is an important part of the world-wide drive for sustainability and being carbon neutral. Low-voltage assemblies controlling and protecting supplies to electric vehicle charging hubs are therefore a vital part of such installations.

Low-voltage assemblies installed in car charging hubs have specific and more onerous requirements than those for typical applications. In some respects, these are not adequately covered by current IEC assembly standards. Current loading is very high, continuous and may be managed to full load for long period of time. Earthing and earth leakage may present challenges to ensure safety of the user. Space for installation may be restricted and accessible to the public with the associated considerations for public safety. Harmonics generated by chargers require attention. Outdoor assemblies often offer benefit with the need to consider the impact of solar irradiance. Remote monitoring and control can be beneficial if charger availability is essential.

This paper will identify the additional requirements for low-voltage assemblies to be installed in electric vehicle charging hubs. It also provides guidance to specifiers seeking to provide a reliable and safe supply for electric vehicle users.

1. INTRODUCTION

With the move towards a carbon neutral society in the relatively near future, there is considerable pressure to migrate transport away from fossil fuel to greener sources of energy. Most expect that in the immediate future electric vehicles will play a significant role in this transition.

Where parking space permits, many vehicles will ordinarily be charged at home from the domestic electricity supply, and whilst this will produce its own set of issues, these are not the subject to this paper. Other vehicles will be charged in hubs, where charging can take place over several hours, or in-service stations and similar where a high-power fast charging is essential if electric vehicles are to win the confidence of drivers and replace fossil fuelled vehicles.

The characteristics of car chargers and the electric vehicle charging application impose more onerous demands on the electrical installation, and specifically, any low-voltage assemblies used in the installation, compared to the typical application. In the case of the low-voltage assembly, the following must be considered if issues are to be avoided:

a) All circuits are likely to operate at full load current continuously and simultaneously, and in many instances, be managed to the full load capacity of the supply.

b) In some applications, especially service stations, the heaviest load will coincide with peak temperature and solar effects. A factor that needs careful consideration with outdoor assemblies and indoor assemblies when they are housed in relatively small fibreglass enclosures or similar.

c) Earthing systems and earth leakage protection requires particular attention if safety obligations are to be fulfilled.

d) Many assemblies for electric vehicle charging applications are located in areas accessible to the general public, necessitating addition safety considerations, particularly when fast chargers and the associated heavy current are involved.

e) At present virtually all electric vehicle chargers rectify an AC supply to provide DC for charging. Inevitably this leads to harmonics in the AC supply which can aggregate to more than permitted by the public electricity utility.

f) When indoor assemblies, e.g., panel boards, are housed in minimal size enclosures, the housing, and the switchgear it contains should be regarded as an outdoor assembly and verified to the appropriate standards.

The purpose of this paper is to identify how issues associated with low-voltage assemblies, and in particular those to be installed outdoors, for electric vehicle charging applications, can be avoided.

2. STANDARDS

Low-voltage installations for electric vehicle charging applications in Hong Kong must conform to the Code of Practice for the Electricity (Wiring) Regulations [1] including Clause 26S, Charging Facilities for Electric

Vehicles. All equipment including low-voltage assemblies erected in an installation must conform to the relevant product standard (IEC).

As outdoor low-voltage assemblies for electric vehicle charging supplies are often located in areas that are accessible to the public, additional safety features are necessary, compared with other applications, where access can be more restricted. This is recognised in the IEC 61439 series [2]: outdoor assemblies for electric vehicle charging applications must conform to IEC 61439-7 [3]. Compared with a typical low-voltage assembly for an industrial application, this includes a number of mechanical tests to ensure that people who, misguidedly, climb on the assembly, run into it, attempt to pierce it with a sharp object, etc. will not have any adverse effect on its normal operation and will, so far as is reasonably practical, protect the public from harm.

3. NETWORK TOPOGRAPHY

As with most low-voltage applications there is no single standard way of deriving and tariff metering the supply to electric vehicle charging hubs. This is in part due to load typically varying from 32A single phase for low power chargers to over 600A, three phase, for superfast chargers.

Where a small number of low-power chargers are to be installed in an existing network, most probably the supply will be taken from the existing network. In new installations, or where high power is necessary, it is likely a new supply will be required from the electricity utility.

When a new supply is taken from the Electricity Utility, it can, depending on local practices and the capacity of the supply, be metered on the high voltage side of transformer, or metered on the low-voltage side. If the metering is on the low-voltage side, it can be in distribution substation, in a separate metering pillar or integrated into the low-voltage distribution pillar managing the supplies to the electric vehicle chargers. Figures 1 and 2 show a typical arrangement of a distribution pillar incorporating tariff metering and a supply utility cutout providing overload and short circuit protection, and a point of isolation.

4. LOW-VOLTAGE ASSEMBLY RATED CURRENTS

In the most recent editions of the IEC 61439 series, the rated current associated with assemblies have been redefined. They are now defined in IEC 61439-1 [4] as follows:

4.1 Rated Current of an Assembly (*I*nA)

It is the *rated current which can be distributed by an assembly without the temperature-rise of any of the parts exceeding specified limits.*

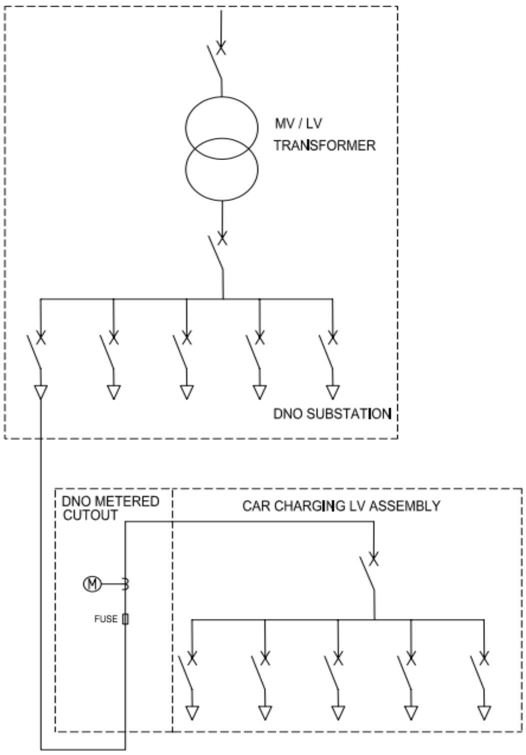


Fig. 1 - Typical DNO Supply Arrangement to an Electric Vehicle Distribution Assembly

Fig. 2 - Typical Low-Voltage Assembly with Integral Tariff Metering Facility

This is further amplified as:

The rated current of an assembly is the lowest value of the total group rated current *I*ng of the incoming circuit(s), which is either the group rated current of the single incoming circuit, or the sum of the group rated currents of the incoming circuits operated in parallel and simultaneously within the assembly, or, the total current that the main busbar can distribute in the particular assembly arrangement.

4.2 Rated Current of a Device (In)

In BS EN 61439-1, this is assumed to be the free air rating of the device under defined conditions in accordance the devices product standard, e.g., IEC 60947-2 [5] in the case of a circuit breaker.

4.3 Group Rated Current of a Main Circuit (*I*ng)

It is the *rated current which a main circuit can carry considering the mutual thermal influences of the other circuits that are simultaneously loaded in the same section of the assembly.*

Again, this is further amplified in IEC 61439-1 as follows:

The group rated current of a main circuit is the current that can be carried by this circuit when it is loaded continuously and simultaneously together with at least one other circuit in the same assembly or section of the assembly, in a specific arrangement as defined by the original manufacturer.

When *I*ng is declared, the original manufacturer must state the specific arrangements which are covered by the group rated current in terms of type(s), ratings and maximum number of circuits/functional units allowed to be installed in the same assembly or section, and the arrangement(s) of functional units within the sections and/or assemblies.

IEC 61439 permits the manufacturer to declare any arrangements of group rated currents for their assembly, including very low group rated currents for circuits relative to the device rating. Alternatively, they can use the guidance provide in the standards and as given in Table 1.

Type of Load	Assumed Loading Factor
Distribution – 2 and 3 circuits	0.9
Distribution – 4 and 5 circuits	0.8
Distribution – 6 to 9 circuits	0.7
Distribution – 10 or more circuits	0.6
Electric actuator	0.2
Motors ≤ 100 kW	0.8
Motors > 100 kW	1.0

Table 1 - Values of Assumed Loading

Further, in accordance the standard, if the user specification simply lists ratings for circuits, the assembly manufacturer can, and likely will, assume the ratings specified are the rated currents of the devices, I_n. This takes no account of any derating necessary for enclosing the device, or the effects of grouping a number of loaded devices in an assembly.

In view of the relatively imprecise method of defining the rating of circuits within assemblies to IEC 61439, it is imperative when considering the electric vehicle application, that the specifier details the design current of each circuit, including the incoming circuit, to be connected to the assembly. As generally, there is no diversity allowed for the electric vehicle applications, (see Clause 722.311 of IEC 60364-7-722 [6]), it is then the assembly manufacturer's responsibility to verify that the assembly provided is capable of operating with all circuit loaded, continuously and simultaneously, to the design current of the network in which the assembly is to be installed.

Whilst initially, as the number of electric vehicles is relatively low, a typical assembly with an assumed loading factor of 0.6 may appear adequate and not have any issue. However, as the number of electric vehicles increases, so will the load on the assembly, and overheating will occur. It is essential that any low voltage assembly installed in an electric vehicle application is capable of delivering the anticipated loads when the installation is fully utilised.

5. PROTECTION COORDINATION

Rapid, ultra-rapid and truck chargers are becoming more common. These can require high current supplies with the associated transformers rated up to 3.0MVA, and the associated low-voltage assemblies rated at 5,000A. Inevitably this increases the prospective short circuit current to 70kA or more. It is therefore essential to ensure adequate breaking capacity is provided at all points in the network, including within the low-voltage assembly. Where practical, full selectivity should be provided to ensure minimum disturbance to supplies in the event of a fault. If this cannot reasonably be achieved, cascade protection, using a suitable combination of circuit breakers, may be appropriate.

Fig. 3 - Typical Low-Voltage Assembly with Cascade Protection for Low Power Chargers Protected by MCBs

6. EARTH LEAKAGE PROECTION

The requirements for earth leakage protection are complex. Except where protected by electrical separation, Clause 26S of the Hong Kong Code of Practice for the Electricity (Wiring) Regulations requires each charging point for an electric vehicle is to be protected by an RCD of at least Type A. IEC 60364-7-722 has the same requirement, noting that systems with DC transfer to the vehicle are excluded. IEC 61851-1 [7] has the same requirements as IEC 60364-7-722 plus a supplementary note in Clause 8.5 indicating that the earth leakage requirements only apply to AC transfer to the vehicle. BS 7671 [8] has a note in Regulation 722.531.3.101 which states; 'Requirements of the selection and erection of RCDs in the case of supplies using DC vehicle connectors according to BS EN 62196 series are under consideration'.

To determine the earth leakage protection required in the low-voltage assembly managing the electricity supplies to electric vehicle chargers, it is essential to know what facilities are included in the charging equipment. If AC transfer of power to the electric vehicle is provided and there is no earth leakage protection in the charging equipment, as tends to be the case with lower power chargers, Type B RCD or equal with an operating current not exceeding 30mA must be provided for protection against electric shock. Higher power charging equipment often includes protection against electric shock either by means of electrical separation or integral earth leakage protection. If this is the case and the supply network includes a protective circuit of sufficiently low earth loop impedance, no further protection in the low-voltage assembly is required.

When the electricity utility does not provide a protective earth (TT supply), the situation is further complicated. As there is no assured low impedance earth back to the supply, earth leakage protection must be provided at the point where the consumer connects to the electricity utility supply, usually in the case of electric vehicle charging, the low-voltage assembly.

In order to minimise interruptions in supply in the event of an earth leakage, it is the good practice to provide selectivity between the earth leakage protection at the incoming supply point and any incorporated in the electric vehicle charging equipment by providing within the low-voltage assembly, earth leakage protection on the feeder to each charging unit.

To add yet a further complication, some designs of electric vehicle charging equipment rely on a functional earth current for correct operation. When this is the case, any earth leakage equipment upstream of the charging equipment must not operate due to the functional earth current. This will require an earth leakage setting above 30mA for any RCD in the low-voltage assembly. It may also be sufficient to provide Type A earth leakage protection in the low-voltage assembly that is not blinded by a DC current.

Unfortunately, when the transfer from the electric vehicle charging equipment to the vehicle is via DC, the standards are less well developed. The very dated IEC 61851-23 [9] may provide some assistance but ultimately, it is the responsibility of manufacturer's, installers and users to ensure adequate protection against electric shock.

7. OPEN CIRCUIT NEUTRALS

In installations where the electricity supply utility provides a combined neutral and earth (PEN) conductor, open PEN protection should be provided. This isolates the installation when the PEN conductor is broken as there is no reliable safety earth connection back to the supply.

8. CLIMATIC PRECAUTIONS

With all low-voltage switchgear, indoor and outdoor types, condensation can be an issue if there are periods of negligible loading, as is typical in electric vehicle charging applications.

Insulation can absorb moisture reducing its dielectric properties to an unacceptable value. Condensation on insulation can lead to tracking and flashover.

Concerns over condensation often prompts the specification of highly sealed enclosures. For example, IP65 in accordance with IEC 60529 [10]. This is counterproductive. Whilst not preventing condensation within the assembly, the high IP effectively stops any natural ventilation, pushing designers to consider forced cooling for higher current ratings with all the attendant concerns regarding maintenance of the cooling system.

Other methods of managing condensation are much more effective. An enclosure with passive filters over ventilation apertures to provide protection in accordance with IP54 of IEC 60529 allows natural convection and cooling with the air flow mitigating the effects of condensation. When there is insufficient difference in temperature between the air temperature inside the enclosure and that outside the assembly to generate air flow it needs to be stimulated by an anti-condensation heater. Condensation does not occur at a particular temperature. Ideally, to prevent condensation, the air temperature within the enclosure should be at least 5ºC above the outside temperature. Alternatively, the anti-condensation heaters can be controlled by a humidistat detecting the humidity within the assembly.

In addition, some components, particularly those electronics are sensitive to low temperatures. When this is the case, supplementary heating should be provided to raise the temperature within the assembly to the minimum required for the sensitive devices. Considering the minimum temperature and anti-condensation requirement it is desirable that the heater is controlled by a combined thermostat and humidistat.

Whilst there is no doubt that the minimum temperature within the assembly, and the condensation, need to be managed in outdoor assemblies, it is of equal concern with indoor assemblies, particularly if they are housed in small fibre glass enclosures, or similar, without supplementary heating and anticondensation measures.

9. SOLAR EFFECTS

Solar effects are not considered in IEC 61439-7, but Clause 15B of Hong Kong Code of Practice for the Electricity (Wiring) Regulations, quite rightly deems they are considered. For electric vehicle charging application, the maximum load is likely to coincide with peak ambient temperature and maximum solar effects. If the assembly cannot be installed in a totally shaded area, the solar effects must be considered.

An arbitrary derating of the assembly and the load current carrying components may not be adequate, it does not ensure an optimised assembly arrangement. IEEE C37.24 [11] is a little more discerning, but again it does not cover all aspects. Not only must the load current carrying capability of the assembly and the main components be considered, but also the thermal capabilities of the auxiliary components. In particular, electronic components often have a relatively low maximum operating temperature.

Fig. 4 - Outdoor Assembly Undergoing Temperature Rise Tests with Simulated Solar Effects

The effects of solar irradiance on the performance of an assembly are extremely complex. They are affected by the shape (length, height, and width) of the assembly, reflective nature of the outer surface of the assembly, ventilation within the assembly, position of components within the assembly, etc.

CIBSE [12] are one suitable reference for the level of irradiance to be considered. Both beam and diffuse solar irradiance on the top and all four sides of the enclosure must be considered. Only tests with simulated solar effects can optimise and validate the performance of an assembly.

10. CORROSION PROTECTION

Whilst electric vehicle charger technology is moving quickly, resulting in the possibility that vehicle chargers may be replaced in a relatively short period of time, it is unlikely the infrastructure that provides the electricity supplies to them will need to be replaced. An anticipated life of 25 years or longer, possibly with upgrades, should be expected. Accordingly, any low-voltage assembly should be provided with commensurate corrosion protection.

The minimum corrosion performance requirements given in IEC 61439-7 only provide very modest protection, particularly when the equipment is installed in coastal regions. Any concerns can be overcome by using stainless steel enclosures, but these are costly.

A more economic, yet durable solution, is to use enclosures fabricated from pre-galvanised mild steel suitably painted and verified as having a defined performance.

For most applications an adequate performance is provided if the paint system is verified as conforming to corrosive category C5, durability range high, as defined in ISO 12944-6 [13]. Subject to the installation location it will provide a time to first maintenance of 25 years.

11. HARMONICS

Operation of an electric vehicle charger will generate harmonics in the electricity supply, with the actual level of harmonics imposed upon the supply being a function of the design of the individual charger and the characteristics of the supply. Clause 4D 15B of Hong Kong Code of Practice for the Electricity (Wiring) Regulations requires an assessment to be made on any harmonic current to ensure they have no harmful effect on other electrical equipment, services or the electricity supply.

If it is determined that the maximum harmonic content is exceeded, this can be simply resolved by connecting an active harmonic filter. This injects an opposite polarity harmonic and effectively cancels the harmonic generated by the electric vehicle chargers.

12. INCORPORATION OF ELECTRONICS

The air temperature within a low-voltage assembly can be very high, 80°C or more is not uncommon, particularly in high current rating assemblies. These temperatures are outside the capability of most electronic devices, which are often limited to around 60°C.

As these limitations are often overlooked, the IEC is producing a document, (IEC TS 63290, at final vote stage), recommending good practice when incorporating electronic equipment in low-voltage assemblies. Of necessity this requires any devices within an assembly is placed in an area where temperature are within its normal operating range and that preferably, electronic components are in a separate compartment.

13. INTERNAL ARCING FAULTS

Whilst internal arcing faults within low-voltage assemblies are very rare occurrences, protection of the public against it is paramount. On the very rare occasions that internal arcing faults do occur in properly designed and verified low-voltage assemblies, the results can be catastrophic. As prospective fault currents increase, so are the consequences. Where assemblies are located in areas accessible to the public, the risks need to be considered.

There are different methods of mitigating the effects of arcing faults including arc quenching, partially containing the arc, and exhausting it to a safe area, remote operation, operatives using PPE, etc. For the safety of the public, partially containing the arc and exhausting it to a safe area is the minimum. Test in accordance with IEC/TR 61641 [14] are necessary to make sure anyone adjacent to the assembly, if an arcing fault occurs, are not likely be seriously harmed.

Fig. 5 - Assembly Enclosed in Cotton Indicators and Prepared for Internal Arc Fault Test

14. REMOTE MONITORING & OPERATION

Some low-voltage assemblies providing supplies for electric vehicle charging applications only provide basic protection for each circuit. Other means are relied upon to report issues on the charging facilities. For example, a customer may use their telephone to report when they are not able to charge their car. However, more direct and timely means of reporting outages and restoring supplies by means of remote monitoring and control are increasingly attractive. Such measures include:

a) Enhance reliability and availability of charging facilities as often demanded. For example, 99% up time is now required by Regulation in the UK.

b) Enable providers of electric vehicle charging facilities who operate over a large number of sites to determine the reason for the loss of supply remotely, and when it is safe to do so, restore supplies remotely.

c) Reduce the cost of down time by eliminating the need for engineers to visit the site of the chargers.

d) Improve customer service and public image.

15. FURTHER CONSIDERATIONS

The IEC 61439 series of standards are fundamentally safety standards. It is therefore essential that any low-voltage assembly, and particularly those installed in areas accessible to the public, conform to, and are fully verified as conforming to, applicable part of the series.

IEC 61439-7 is the applicable part of the IEC 61439 series for low-voltage assemblies installed in electric vehicle charging hubs. It includes mechanical requirements commensurate with the application.

When an indoor panel board or distribution board with or without other devices is housed in a close-fitting outer enclosure, the outer enclosure is part of the assembly and should be included in the design verification of the complete assembly.

A complete factory tested low-voltage assembly saves time on site and can provide more assurance in respect of design, quality and conformance to standards.

Where space is a constraint, outdoor assemblies offer significant benefit.

16. FUTURE PROOFING

The anticipated life of an electrical installation and that of an electric vehicle charger is very different, making it vital that any low-voltage assemblies forming part of the installation are of a very flexible, changeable, and upgradeable design in order that they are readily adapted to match the needs of new chargers and/or the number of chargers, as and when they may be installed. Adaptations should be quick and easy, not require structural changes to the assembly or the busbar system and be consistent with the requirements of the circular economy.

17. CONCLUSION

Low-voltage assemblies managing supplies to electric vehicle charging hubs require specific features to ensure they provide all the personnel and equipment safety necessary for the application. Outdoor low-voltage assemblies offer significant benefits. Of course, their design, as with that of the indoor equivalent, must take fully into account the specific needs of the application if issues in service are to be avoided. Correctly designed and fully verified in accordance with BS EN IEC 61439-7, outdoor assemblies should (i) not need any form of building to protect them, (ii) require less space for their installation, (iii) require less time to install, and (iv) are more cost effective initially and as the requirements of the installation evolve.

Fig. 6 - 5000A Outdoor Low-Voltage Assembly, Prior to Despatch from Factory, Main Door Open and Complete Solar Shielding

REFERENCES

1. Code of Practice for the Electricity (Wiring) Regulations.

2. IEC 61439 Series: Low-voltage switchgear and controlgear assemblies.

3. IEC 61439-7 Low-voltage switchgear and controlgear assemblies - Part 7: Assemblies for specific applications such as marinas, camping sites, market squares, electric vehicle charging stations.

4. IEC 61439-7 Low-voltage switchgear and controlgear assemblies Part 1: General rules.

5. IEC 60947-2 Low-voltage switchgear and controlgear - Part 2: Circuit-breakers.

6. IEC 60364-7-722 Low-voltage electrical installation - Part 7-722: Requirements for special locations – Supplies for electric vehicles.

7. IEC 61851-1 Electric vehicle conductive charging system - Part 1: General requirements.

8. BS 7671:2018 Amendment 2: 2022 Requirements for Electrical Installation, IET Wiring Regulations Eighteenth Edition.

9. IEC 61851-23 Electric vehicle conductive charging system - Part 23: DC electric vehicle charging station.

10. IEC 60529:1992, Amendment 2 2013 Degrees of protection provided by enclosures (IP Code).

11. IEEE Std C37.24-2017 Guide for Evaluating the Effect of Solar Radiation on Outdoor Metal Enclosed Switchgear.

12. CIBSE, The Chartered Institution of Building Services Engineers.

13. ISO 12944-6:2018 Paints and varnishes – Corrosion protection of steel structures by protective paint systems Part 6: Laboratory performance test methods (ISO 12944-6:2018).

14. IEC/TR 61641:2014 Enclosed low-voltage switchgear and controlgear assemblies — Guide for testing under conditions of arcing due to internal fault.

Paper No. 6

BUILDING INTEGRATED PHOTOVOLTAICS APPLICATION TO DECARBONIZE HONG KONG

Authors/Speakers: Ir Felix HH Chan, Associate
Ms. KM Miu, Engineer
Ms. Y Yin, Assistant Engineer
Climate and Sustainability Group
Ove Arup & Partners Hong Kong Ltd.

BUILDING INTEGRATED PHOTOVOLTAICS APPLICATION TO DECARBONIZE HONG KONG

Ir Felix HH Chan, Associate
Ms. KM Miu, Engineer
Ms. Y Yin, Assistant Engineer
Climate and Sustainability Group
Ove Arup & Partners Hong Kong Ltd.

ABSTRACT

Hong Kong's 2050 decarbonization targets necessitate embracing sustainable energy technologies, with Building Integrated Photovoltaics (BIPV) emerging as a key player. BIPV systems, which incorporate photovoltaic materials into building structures and façade system, offer a dual benefit of energy production and architectural enhancement. Despite initial challenges in cost and integration, BIPV's potential to meet a significant portion of Hong Kong's energy demand through clean sources is increasingly recognized.

The city's dense urban fabric presents unique opportunities for BIPV to contribute to a greener skyline. Collaborations among the government, industry, and academia are pivotal in promoting BIPV's adoption, evidenced by successful implementations in various building types. These projects showcase BIPV's versatility and its contribution to Hong Kong's sustainability objectives.

This paper will delve into the current state of BIPV technology, its market position, and types, as well as the challenges and opportunities it presents for Hong Kong's decarbonization goals. It will also discuss the implications of BIPV adoption for the city's architectural landscape and energy policies, ultimately presenting a case for BIPV as a key component in the transition towards a greener Hong Kong.

1. INTRODUCTION

Over the past centuries, Hong Kong has warmed up in accordance with the worldwide trend. According to the record from Hong Kong Observatory, the average temperature in Hong Kong has risen by 0.12°C per decade since 1885, and the number of very hot days (with temperatures exceeding 33°C) has increased from an average of 11 days per year in the 1980s to 17 days per year in the 2010s. In addition to temperatures rising, record-breaking high temperatures have been recorded more frequently than they used to. These climate changes become the most challenging issue of our time and each one of us are involved. Human activity is the primary way that raises the concentration of greenhouse gasses in the atmosphere, which further leads to climate change. As a compact high-density city, most everyday activities carried out by Hong Kong residents take place in skyscrapers. It is commonly known that buildings in Hong Kong contribute to over 90% of electricity usage and approximately 60% of the city's greenhouse gas emissions [1]. In comparison to the global average, this number is comparatively high.

Therefore, the Hong Kong Special Administrative Region (HKSAR) launched the Climate Action Plan 2050 to commit in achieving carbon neutrality before 2050 and half of that by 2035. Specifically in energy saving and green buildings sector, Climate Action Plan 2050 set clear goal that the electricity consumption of commercial buildings shall reduce by 30% to 40% and that of residential buildings by 20% to 30% compared with 2015 level by 2050, and to achieve half of the above targets by 2035 [2].

One widely used method to achieve carbon neutrality target is by increasing the proportion of electricity generated by renewable energy, such as solar, etc. Climate Action Plan 2050 also set out the renewable energy potential in increasing the share of renewable energy in the fuel mix for electricity generation to 7.5% to 10% by 2035 and 15% by 2050 [2].

Given Hong Kong's unique hilly landscape and high land prices, it is impractical to apply photovoltaic solar panels on the ground level as in mainland China and other countries. Alternatively, the widespread presence of skyscrapers gives an opportunity to implement building integrated photovoltaic (BIPV) technology as an effective strategy for reducing carbon emissions.

2. LATEST BIPV TECHNOLOGY

Referenced by IEA-PVPS, A BIPV module is a construction product combined with a PV module that is intended to be a part of the building envelope, and a BIPV system is a photovoltaic system which contains both the mechanical mounting mechanisms and electrical components required which connected the PV modules to external AC or DC circuits [3]. A typical photovoltaic module comprises a series of inter-connected solar cells, which are encapsulated in a polymer material and are protected at the front by a protective layer and at the rear by a cover layer. The electric current generated in the photovoltaic active layer is transmitted through metallic wires or ribbons connected to a junction box located outside the module.

According to the categorization of BIPV by IEA-PVPS, the types of solar cells can be categorized into two main groups, crystalline silicon as the traditional one and thin-film cells as the well-developed one [4].

In terms of crystalline silicon solar cell, the most commonly used solar active materials are mono-crystalline silicon and poly-crystalline silicon. As for thin-film solar cells, the available technologies are known as Cadmium Telluride (CdTe), Copper Indium Gallium Selenide (CIGS) and amorphous silicon (a-SI).

Sourced from NREL Best Research - Cell Efficiency Chart, the current highest recorded efficiency of diverse kinds of solar PV cells are compared, including the first-generation cell known as crystalline silicon, second-generation thin-film and other third generation cells including multijunction cells, single-junction gallium arsenide cells and emerging photovoltaics, as shown in Figure 1 [5]. The chart shows the development of the highest recorded cell efficiency of varied materials over the past decades.

Crystalline silicon cell is generally considered as the most conventional PV cell which is made from solid crystalline silicon wafers, either mono-crystalline or poly-crystalline. Crystalline silicon cell is the most popular PV panel material nowadays with over 95% market share, and 90% of that is mono-crystalline silicon [6]. The reason shall be the conversion efficiency of mono-crystalline silicon is higher than poly-crystalline for same time life duration and degradation rate.

Thin film technology is wildly acknowledged as the second-generation of solar PV cell. There are generally three main types of thin film including amorphous silicon (A-Si), Cadmium Telluride (CdTe) and Copper Indium Gallium Selenide (CIGS). A-Si used to dominate the market as it requires a low processing temperature and enables a massively scalable output on a flexible and low-cost substrate with just a little silicon material required. However, relatively lower efficiency and shorter life span compared to other thin film technology leads to its fading out. CdTe currently

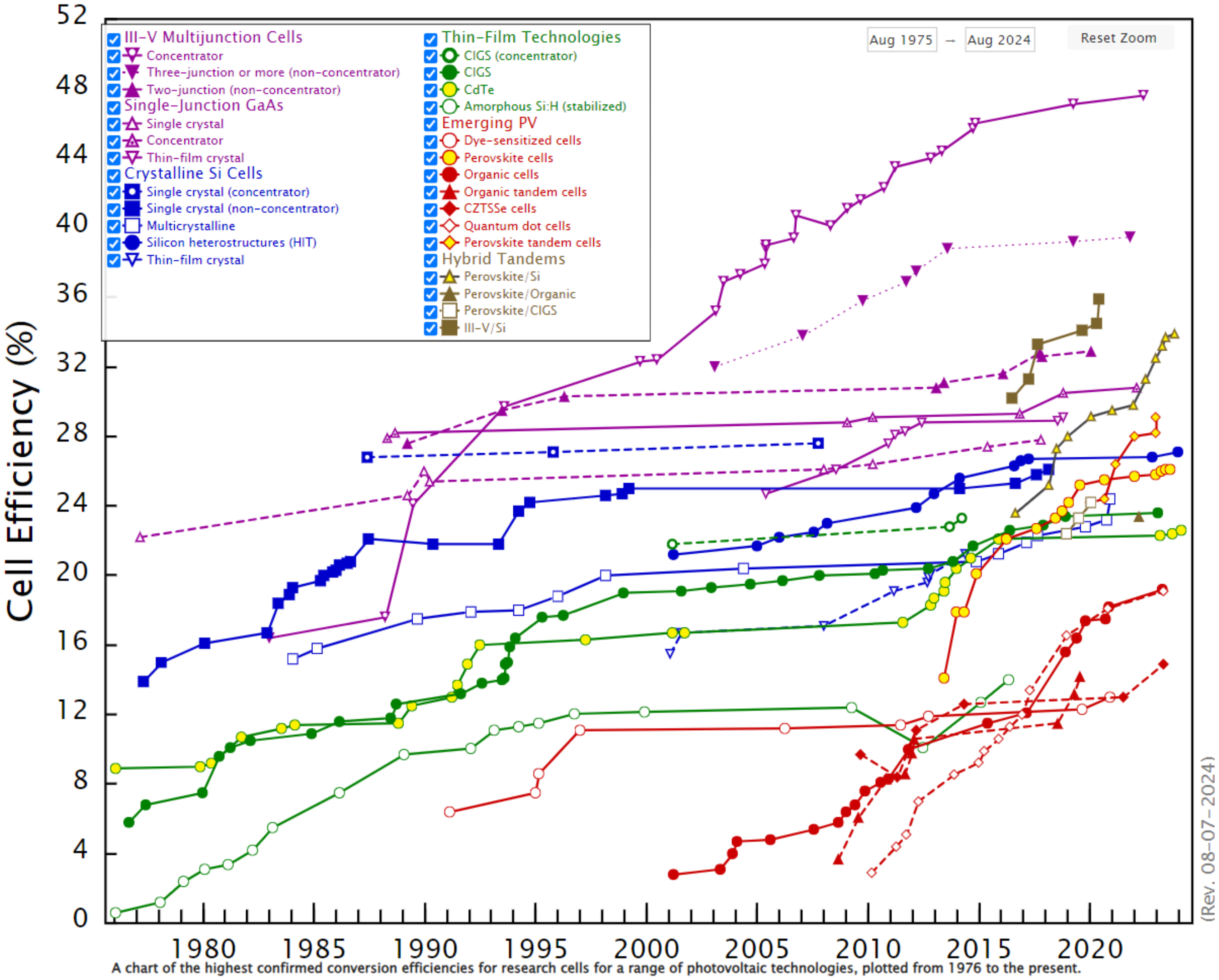


Fig. 1 - Best Research - Cell Efficiency Chart [5]

dominated the thin-film market with more than 90% share [6]. With similar conversion efficiency as CdTe, manufacturing CIGS cells can be more complex due to the rarity of indium, as well as the complex stoichiometry and multiple production phases, which restricting large-scale production and lead to its limited market share currently [7].

The detailed characteristics of each type of PV cells are summarized in Table 1 below.

Typical Product					
PV Cell Technology	Mono-Crystalline	Poly-Crystalline	A-Si	CIGS	CdTe
Family	Crystalline Silicon		Thin Film		
General Installation Method	Mount with supporting frame on building surface, OR Install as laminated glass in BIPV		Direct attach on any building surface	Direct gluing on any building surface	Mount with supporting frame on building surface
Flexibility	Stiff	Stiff	Flexible	Flexible	Stiff
Transparency	Opaque	Opaque	Opaque	Opaque	Opaque/Transparant
Common Efficiency in The Market	17%-24%	13%-18%	~10%	10%-19%	10%-18.6%
Common Supplier Warranty	20 years	20 years	2-5 years	5 years	10 years
Technical Maturity	Mature	Mature	Mature	Developing	Developing
Market Share Globally	96%	<1%	<1%	<1%	2%
Model Price	$$-$$$	$$	$$-$$$	$$$$	$$$

Table 1 - Comparison of Common Solar PV Modules in the Market

2.1 BIPV Applications

Based on the study from Fraunhofer ISE in 2024, the trend of technological advancement and commercial use of several types of photovoltaic technologies in the past four decades are shown in Figure 2 [6].

It illustrated that the wafer-based crystalline silicon ("c-Si"), including monocrystalline silicon ("mono-Si") and multi-crystalline silicon ("multi-Si") or, in another name, polycrystalline silicon ("poly-Si") dominant in the PV cell market in 2023 with about 97.5% of the share while the thin film cells only occupied 2.5% of the market share.

Apart from the traditional wafer-based crystalline silicon and well-developed thin film PV cell, there are some innovative PV cell technologies at research and development stage, with attractive conversion efficiency more than 30% [5].

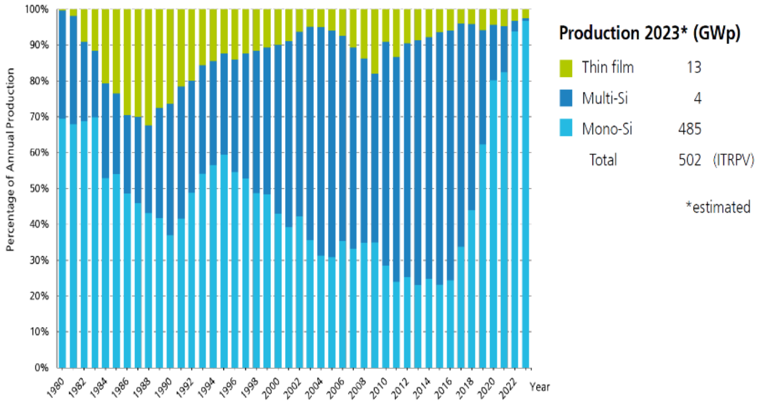
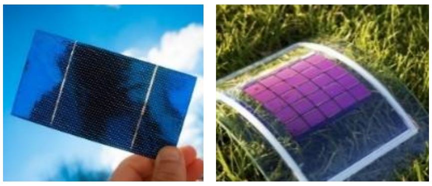


Fig. 2 - Percentage of Global Annual Production in PV Production by Technology [6]

The most common third-generation cell technologies are summarized in Table 2.

Most Common Third-Generation Cell Technologies



	Perovskites	Organic PV Cells
Highest Efficiency in the Lab	23.7%	18.2%
Possible Application	BIPV/BAPV Spray-on PV	BIPV/BAPV
Market Status	R&D	BIPV/BAPV Market entry
Advantages	➢ Low production cost ➢ Comparable efficiency ➢ Flexible and printable	➢ Low carbon footprint in the manufacturing stage ➢ Lightweight, flexible, transparent, and printable
Limitation	Low durability	Low efficiency Low durability
2020 U.S. Benchmark Cost [8]	USD0.38/W	-

Table 2 - Comparison of Innovative Solar PV Modules in the Research and Development Stage

Perovskite solar cell is a type of thin-film cell named after their characteristic crystal structure. It is generally easy to assemble and can achieve efficiencies comparable to crystalline silicon. However, due to the susceptibility of the crystals to dissolution, this material struggles to withstand humid conditions. Consequently, researchers are focused on enhancing their durability and developing large-scale, and cost-effective manufacturing processes [9].

Organic PV cells emerged as a breakthrough technology in photovoltaic industry. It is environmentally friendly with low-carbon impact as it requires little energy during manufacturing. The appearance of the organic PV cells can be customized by its transparency and colour. However, this kind of PV cell currently achieves only about 50% of the efficiency of market-leading crystalline silicon cells and tend to have shorter lifespans. Current research and development efforts are focusing on enhancing its efficiency to broaden its practical applications [10].

Suggested by the IEA-PVPS, there are 12 main types of BIPV systems for application, which are grouped into three families: roof, façade and external integrated devices as shown in Figure 3 [4].

BIPV system can be installed in both new buildings and retrofit projects. Any external building surface may serve as a potential site for a BIPV installation. Based on the urban planning and architectural characteristics of Hong Kong, the most common building elements being integrated are considered as canopy, solar shading, roofing, skylight, curtain wall, double skin façade, window and masonry wall.

Given the requirement of architectural appearance and functional consideration, the most suitable type of BIPV can be chosen from above to employ across all external building surfaces, while harmonizing with its aesthetic and functional design.

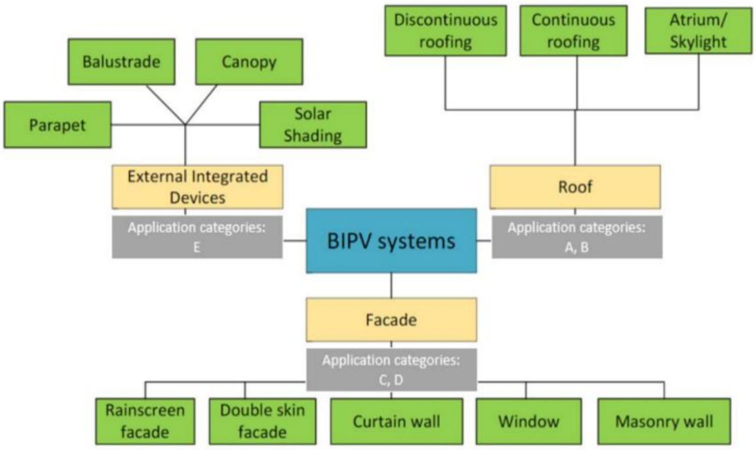


Fig. 3 - BIPV System Classification [4]

3. CURRENT STATE OF BIPV IN HONG KONG

3.1 Market Analysis

3.1.1 BIPV suppliers in Hong Kong/Global

The local suppliers in Hong Kong are limited and Hong Kong market is more receptive to custom-made BIPV products than standardised ones. However, there are various suppliers with a big share in the global BIPV industry located in East Asia and Mainland China.

3.1.2 Existing BIPV projects in Hong Kong

Over the past few years, there are numbers of medium and large scale BIPV projects completed in Hong Kong. These BIPV projects included government buildings, commercial buildings, schools, etc. The majority of these systems are designed to connect directly to the grid to avoid battery storage. Certain projects involve the retrofitting of BIPV systems onto established structures, whereas others incorporate BIPV as an integral component of new construction. Some pilot projects are outlined in the following sections.

The BIPV System Pilot Project by the HKSAR Government was the first technical trial of BIPV system in Hong Kong. There are three different installation locations of BIPV including roof, sun shading and skylight, as shown in Figure 4. An integrated monitoring system was installed to record and supervise the daily operation of the system.

(a) Retrofit government project: Wan Chai Tower

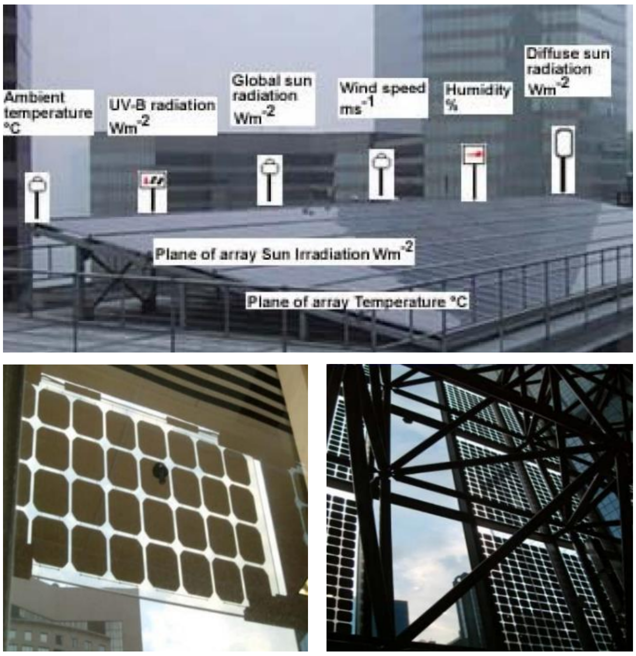


Figure 4 - BIPV Application at Wan Chai Tower, Hong Kong (top: BIPV on roof; bottom left: sun shading & bottom right: skylight)

The factsheet in Table 3 summarised the information of this case [11].

Project	Wanchai Tower		
Installation Position	Roof	Sun shading	Skylight
Location	Roof	Middle section of the building	Ground floor lobby
Orientation	10 degree to horizontal, facing south	Vertically facing south	Vertically facing south
PV Modules	Polycrystalline	Monocrystalline	Monocrystalline
No. of panels per string	18	21	5
No. of strings	7 string per group, 2 groups	8 string per group, 2 groups	7 strings
Total no. of panels	252	336	35
Total PV panel area	165 m^2	232 m^2	96 m^2
System rated power	20 kW	20 kW	10 kW

Table 3 - Fact Sheet- BIPV at Wanchai Tower

(b) New commercial project: K11 Victoria Dockside

The BIPV project shown in Figure 5 is located at Tsim Sha Tsui, Hong Kong. In 2019, the new-built development, K11 Atelier en Victoria Dockside, adopted 96 pieces of rooftop-mounted conventional PV panels and 310 pieces of semi-transparent BIPV panel at the high-level of the building, contributing a total system capacity of 115kW. Arup was the consultant on the feasibility study, glare study, system design, tender procurement, and construction supervision of this project. Table 4 summarised the information of this case.

Fig. 5 - BIPV Application at K11 Victoria Dockside, Hong Kong

Project	K11 Victoria Dockside
Location	Tsim Sha Tsui, Hong Kong
Project Description	Applying BIPV in a new-built development
Client	New World Development
Status	Completed
Completion Year	2019
Type of System	PV & BIPV Laminated Glass
Suppliers of the Modules	BenQ (PV) & CSG holding (BIPV)
No. of PVT panels	PV: 96 / BIPV: 310
System rated power	115kW

Table 4 - Factsheet – K11 Victoria Dockside, Hong Kong

(c) Findings and challenges

The BIPV projects in Hong Kong are relatively small to medium scale and are conducted mainly by the government and big real estate developers. Besides, there are only a few companies in Hong Kong who supply and sub-contract for BIPV. However, we believe with the fast-growing technology in BIPV, there will be more mature and advanced products and suppliers play in the market. Integrating BIPV system into green features of a building will be a progressive step for Hong Kong in solar energy applications.

4. HONG KONG STATUTORY REQUIREMENT OF BIPV IMPLEMENTATION

4.1 Safety Requirement in Fire and Electricity

In Hong Kong, the majority of customers prefer rooftop solar applications due to the lack of consolidated fire requirements for BIPV materials. As BIPV panels are considered part of a building's structure, their fire properties should refer to the "Fire Safety in Building 2011" (June 2023 Edition). However, the non-combustibility requirements stated in this code are intended for building materials only and the applicability of components of BIPV, e.g. junction box, and wiring etc. are not clearly defined yet.

Currently, three international standards apply to the fire safety requirements of BIPV systems: IEC 61730, UL 1703 (recognized by NFPA), and EN 13501 (applicable in Europe). Given the absence of a consolidated standard in Hong Kong, it is advisable to consult the local authorities, industry experts and suppliers to ensure safe BIPV integration.

4.2 Structural Design Requirement

As BIPV can integrated into window, curtain wall, shading and skylight, etc. which is part of building structural element that shall comply with essential structural design requirements. As per "Code of Practice on Wind Effects in Hong Kong" (2019 Edition) by Building Department, there is no specific requirement for BIPV used as part of the building element. Based on the "General Specification for Building Services Installation in Government Buildings of the HKSAR" (2022 Edition) published by Architectural Services Department, the PV and/or BIPV module on mounting to the building element or structure with design to be carried out by a registered structural engineer with due consideration of wind load, safety, and proper access for maintenance. However, no detailed guideline or requirement is published to define the testing method and threshold of design.

At international level and regional level, the standardized design and requirement of BIPV is relatively slow in progress over past years. However, there are some regional standards which have been issued out for public reference, for example "EN 50583: Photovoltaics in building" and "IEC PT 63092: Photovoltaics in buildings", which specify the physical, electrical, structural and other functional and safety requirement [12]. Therefore, international standards may be used to substitute the absence of BIPV requirement in Hong Kong.

4.3 Mechanical and Optical Requirement

There are other performance requirements of BIPV, mainly in mechanical and optical aspects, some key indicators can be deformation under load, resistance to thermal stress and vibrations, thermal transmission value, solar heat gain coefficient, transmittance and reflectance, etc. Currently, there is no local standard of BIPV in Hong Kong. However, to determine the thermal transmittance, known as U value of a BIPV product or system, the calculation method referring from ISO 10292, the guarded hot plate method referring from ISO 10291, or the heat flow meter method referring from ISO 10293 can be applied. As for optical characterization of BIPV modules, it may refer to the international standard ISO 9050, which is equivalent but not identical to the EN 410 standard that is referenced in EN 50583 [13]. These standards specify the methodology for determining the luminous and solar characteristics of glazing in buildings.

4.4 Findings and Challenges

Knowing that BIPV module serves more than a building envelop, it has the function of generating electricity and as a building component. Therefore, BIPV module as a multifunctional element shall comply with specific safety, functional and other regulation requirements based on its type and installation location. Given the complexity of BIPV in materials and applications, it is difficult to standardize the BIPV manufacturing, installation and performance requirements. There are some ISO and regional standards which apply to BIPV. However, the set of standards for BIPV modules and system to characterize and evaluate their performance are still in slow progress in Hong Kong. Currently, there is no localized guideline and standard for BIPV in Hong Kong.

5. CHALLENGES & RECOMMENDATIONS

5.1 Technical Challenges

Over the past several decades, the industry of BIPV is developing in a fast trend with diverse types of products. However, the technical challenges resulting from the use of BIPV in buildings have not yet been overcome. There are some major barriers identified and summarized below.

Firstly, the high upfront costs and long payback period as primary barriers: Majority of BIPV product in Hong Kong is tailored or customized product due to building aesthetic consideration. Besides, there are limited local BIPV suppliers and contractors. The production and installation process of BIPV is highly relied on imports. Thus, the initial cost of the BIPV product and system are relatively higher than conventional building materials.

Secondly, the uncertainty of energy-related behaviour of BIPV modules in the market [14]: The main performance indicators related with energy include thermal, solar, optical and electrical aspects. The field data on BIPV product energy performances and degradation rate are still in progress and require bigger database. Meanwhile, due to BIPV behaves different from building elements, it is difficult to evaluate its functional performance. Currently, there is no public guideline or standard in Hong Kong to specify the design and performance of a BIPV product and system.

Thirdly, the good balance between architectural aesthetic and BIPV performance: The optical properties of BIPV product including visible light transmittance, reflectiveness and colour rendering, will closely affect ambient visual comfort and on-site electricity generation. Architecturally adapted BIPV design can impact its electricity output, which further lower the conversion efficiency of the whole BIPV system compared with conventional PV system.

Moreover, the connection of a BIPV system to the grid is a very common practice in some overseas countries [15]. However, the grid connection terms and conditions are assessed by third parties, for example CLP and HK Electric [15]. Alternatively, off-grid connection requires the installation of large battery system. The initial cost of the bulky battery and its ongoing maintenance fee can be a great hurdle for the owner, combined with safety issue.

These technical barriers may have an effect on business models as they directly impact the design, production, transportation, installation and maintenance process of a BIPV system, and affect the cost-effectiveness in long run.

5.2 Policy Recommendations

The primary obstacles to implement BIPV systems include the complexity of feed-in tariffs setup, public awareness and acceptance, governmental financial assistance through subsidies, guidance and standard from the technical department.

Based on the survey, potential PV adopters had different policy preferences. Residential participants exhibited a strong inclination towards subsidies, whereas institutional respondents mostly favoured regulatory interventions and commercial stakeholders showed a preference for feed-in tariff schemes [16].

In general, it is highly recommended that Hong Kong government starts to take lead on adopting the enabling framework to guide, nurture and regulate BIPV development effectively. In the meantime, scholars and experts should try as much as possible to consult the setup of technical guideline and standard for BIPV in its whole life circle. Stakeholders from the public and private sectors shall take active actions on pilot projects and repeatable practices on BIPV application to show their leadership in advanced technology and carbon neutrality.

5.3 Market Potential

Looking back the development path of BIPV industry, it is believed that new solutions will be proposed in various aspects regarding design, configuration, production, positioning, monitoring and performance.

Under the initiative of carbon neutrality in Hong Kong, the benefits of BIPV extend beyond its economic gains from electricity generation, it plays a significant role in increasing on-site power generation and facilitating the local transition of energy usage. Furthermore, as a building element, BIPV can offer comparable or superior functionalities to conventional building materials while is helping in compliance with legal energy performance standards for buildings. The potential of BIPV solutions to enhance real estate value is also highlighted, thereby increasing the appeal of these investments, assuming that the stakeholders involved can effectively capitalize on this value [17].

To increase the growth in BIPV market, it is essential for the private sector, combined with government to enhance the utilization of renewable energy products. Considering the prevalence of high-rise buildings in Hong Kong, the primary opportunity for BIPV implementation shall be integrated into the design of buildings, public facilities and urban infrastructure, both new and retrofit project.

6. CONCLUSION

6.1 Summary of Findings

Following the initiative by Climate Action Plan 2050 which commits in achieving carbon neutrality before 2050 and half of that by 2035, solar energy capture becomes a vital solution to increase the share of renewable energy in the fuel mix usage and achieve energy transition ultimately.

There are various BIPV products in the market from the first generation knowing as crystalline silicon and then came the second generation as acknowledged as thin-film type, and the most advanced technology such as organic PV cell is in research and development stage. Based on the study, crystalline silicon dominates the market with 97.5% share and the rest of that is thin-film type. BIPV system can be installed in both new buildings and retrofit projects. Any external building surface may serve as a potential site for BIPV installation. The BIPV projects in Hong Kong are relatively small to medium scale and are conducted mainly by the government and big real estate developers. Besides, there are only a few companies in Hong Kong who supply and sub-contract for BIPV. However, with the fast-growing technology in BIPV, there will be more mature and advanced products and suppliers play in the market.

As BIPV module has the function of generating electricity and as a building component, therefore, it is a multifunctional element that shall comply with specific safety, functional and other regulation requirements based on its type and installation location. Given the complexity of BIPV in materials and applications, it is difficult to standardize the BIPV manufacturing, installation and performance requirements. There are some ISO and regional standards applies to BIPV. However, the set of standards for BIPV modules and system to characterize and evaluate their performance are still in slow progress in Hong Kong.

There are some major technical barriers for easier and wider market introduction of BIPV. The high capital cost and long payback period are the primary barriers, in addition to the uncertainty of actual performance of BIPV modules in the market. Moreover, the good balance between architectural aesthetic and electricity conversion is a big challenge. These technical barriers may have an effect on business models as they directly impact the design, production, transportation, installation and maintenance process of a BIPV system.

6.2 Closing

The challenges associated with wide and fast implementation of BIPV have not been overcame. The most urgent issue is to simplify and standardize the tests and requirements of BIPV products and systems for easier marketing promotion.

In general, it is highly recommended that the Hong Kong government start to take lead on adopting the enabling framework to guide, nurture and regulate BIPV development effectively. Meantime, scholars and experts should try as much as possible to consult the setup of technical guidelines and standards for BIPV in its whole life circle. Stakeholders from the public and private sectors shall take active actions on pilot projects and repeatable practices on BIPV application to show their leadership in advanced technology and carbon neutrality.

To increase the growth in BIPV market, it is essential for the private sector, combined with the government to enhance the utilization of renewable energy products. Considering the prevalence of high-rise buildings in Hong Kong, the primary opportunity for BIPV implementation shall be integrated into the design of buildings, public facilities and urban infrastructure, both new and retrofit projects.

REFERENCES

1. Hanmin Dong, L. Z. (2023). Transition towards carbon neutrality: Forecasting Hong Kong's buildings carbon footprint by 2050 using a machine learning approach. Sustainable Production and Consumption, 633-642.

2. Hong Kong’s Climate Action Plan 2050. (2021). Retrieved from Hong Kong's Climate Action Plan 2050: https://www.eeb.gov.hk/sites/default/files/pdf/cap_2050_en.pdf

3. Karl Berger et al. (2018). International definitions of “BIPV”. IEA PVPS Task 15.

4. Pierluigi Bonomo et al. (2021). Categorization of BIPV Applications. IEA-PVPS.

5. NREL. (2024). Best Research-Cell Efficiency Chart. Retrieved from NREL: https://www.nrel.gov/pv/cell-efficiency.html

6. Fraunhofer. (2024). Photovoltaics Report. Freiburg: Fraunhofer ISE.

7. IRENA. (2019). Future of Solar Photovoltaic: Deployment, investment, technology, grid integration and socio-economic. Abu Dhabi: IRENA.

8. National Renewable Energy Laboratory (NREL), Independent Contractor. (2021, November). Photovoltaic (PV) Module Technologies: 2020 Benchmark Costs and Technology Evolution Framework Results.

9. Neeraj Kant, Pushpendra Singh. (2021). Review of next generation photovoltaic solar cell technology and comparative materialistic development. Materials Today: Proceedings.

10. ASCA. (2024). ASCA® Technolog. Retrieved from ASCA® Technolog: https://www.asca.com/asca-technology/

11. Edward W. C. LO. (2005). Overview of building integrated photovoltaic (BIPV) systems in Hong Kong. Department of Electrical Engineering and Power Electronics Research Centre, The Hong Kong Polytechnic University.

12. Karl Berger et al. (2019). Analysis of requirements, specifications and regulation of BIPV. IEA.

13. Karl A. Berger et al. (2020). Multifunctional Characterisation of BIPV. IEA.

14. Nuria Martín-Chivelet, K. K. (2022). Building-Integrated Photovoltaic (BIPV) products and systems: A review of energy-related behavior. Energy and Buildings.

15. EMSD. (2007). Technical guideline on grid connection of renewable energy power systems. EMSD.

16. Daphne Ngar-Yin Mah et al. (2017). Barriers and policy enablers for solar PV in cities: Perspectives of potential adopters in Hong Kong. Asian Energy Studies Centre.

17. Philippe Macé et al. (2020). Development of BIPV Business Cases. IEA.

Paper No. 7

THE CARBON FOOTPRINT ECOLOGICAL PORTFOLIOS TO ACCELERATE DECARBONIZATION IN MAINLAND CHINA

Author/Speaker: Dr. Y Tao
Head
SiTANJI China Business & Ecological Development
Siemens Limited China

THE CARBON FOOTPRINT ECOLOGICAL PORTFOLIOS TO ACCELERATE DECARBONIZATION IN MAINLAND CHINA

Dr. Y Tao
Head
SiTANJI China Business & Ecological Development
Siemens Limited China

ABSTRACT

Rely on green technology innovation, like blockchain, industrial edge computing, carbon twin, there are carbon footprint ecological (ECO) applications and solutions for different groups and scenarios built, helping going-global companies interact with data from their upstream and downstream and third-party verifiers, effectively improve the authenticity, accuracy and comprehensive recognition of carbon emission-related data of going-global companies, help achieving full-chain carbon footprint transparency and efficient collaboration across value chain, enhancing green competitive advantages.

Go beyond static reporting of CO2 emissions and start managing product decarbonization with the help of dynamic product carbon footprint (PCF). Based on CO2 values measured where the emissions occur and aggregated along the value chain, dynamic PCF quantifies the results of improvement measures and turns emission data into a management tool for efficient product decarbonization at scale.

In this paper, we will discuss the challenges and solutions for our Carbon Footprint ECO Portfolios, and also examine real-world PCF projects implementation in various countries to showcase the effectiveness of PCF implementation in achieving carbon neutrality and ensuring reliability of green supply chain.

1. INTRODUCTION

Responding to climate change giving new missions to green and low-carbon development of global industries and bringing new challenges, green has become a bright background for high-quality development of the overseas economy.

China's "1+N" policy framework promotes low-carbon transformation throughout lifecycle:

a) Upgrade industrial structure, promote low-carbonization of the whole product lifecycle.

b) Energy low-carbon transformation, innovation and improvement, renewable energy development.

EU restricts market access and sets green trade barriers for importing:

a) Carbon border adjustment mechanism (CBAM) and Carbon border tax on imported products.

b) Market entry barriers and product carbon footprint declarations.

Companies continuously promote green products, factories, industrial parks and supply chains. Green elements have become one of the core competitiveness of enterprises.

Through digital solutions, we will establish a complete carbon management system as performance measurement indicators, and as a collaboration system to promote the coordinated development of stakeholders and achieve low-carbon transformation and green overseas expansion with low cost and high efficiency.

2. KEY DRIVERS

China has unveiled the implementation of Carbon Footprint Management, madding efforts for high-quality development and achieving the "dual carbon" goals.

China's Ministry of Ecology and Environment, along with 14 other departments, jointly issued the "Implementation Plan for Establishing a Carbon Footprint Management System".

Fig. 1 - China has Unveiled the Implementation of Carbon Footprint Management, Madding Efforts for High-quality Development and Achieving the "Dual Carbon" Goals

a) Shanghai - Action plan to accelerate the establishment of a PCF management system and create a green and low-carbon supply chain.

b) Zhejiang - Action plan to establish the PCF management system.

c) Shandong - Notice on issuing the Shandong Product Carbon Footprint Assessment Work Plan (2023 - 2025).

3. ACCELERATES THE JOURNEY OF DECARBONIZATION

Let us have a closer look at the role of supply chain in the decarbonization efforts. Depending on own position in the value chain, up to 90% of products' PCF originate in the supply chain. In consequence, driving improvements in the supply chain is a key lever. However, decarbonizing the supply chain is challenging:

a) It is dealing with a diverse group of partners, in size, industry focus and also maturity with regard to sustainability in general and PCF in specific.

b) Information, if any, is received in various, often unstructured, formats (e.g. excel attachments to emails), so the data from different suppliers is not comparable.

c) The need for granularity on product level requires data specific to suppliers and their products and data with a decent level of trustworthiness.

Our invention / innovation / practice enables companies to collect and manage exactly that.

The Carbon Footprint ECO Portfolio introduced here drives a paradigm shift in the approach to Product Carbon Footprints:

a) Based on industry average carbon values, PCFs are estimated.

b) While this is in order for a first assessment or an identification of carbon hotspots, this is not sufficient to drive decarbonization going forward. It is because the secondary data-based PCFs reflect the carbon footprint of a somewhat similar average product, not the PCF.

c) The results do not reflect improvements happening in the supply chain.

In order to get control of the PCF, drive and quantify the decarbonization of the products, it takes what we call "Dynamic PCF".

a) PCF values that are aggregated along the supply chain.

b) Gathering PCF data where emissions occur, making the data flow along the supply chain.

c) Such a data flow enables frequent, even pro-active updates of PCF data: From your suppliers' suppliers all the way to you and your customers.

d) Turning PCFs into dynamically updated product attributes that quantify the success of reductions measures in the supply chain.

e) Allows setting specific targets per material and supplier.

f) Enables proving and improving products carbon footprints

In order to cater for an increasing number of requests for Product Carbon Footprints, the efficiency in collecting, processing and distributing the related information needs to be increased - both internally and externally.

Externally:

a) Carbon Footprint ECO Portfolio's multi-standard compatibility makes it easy to exchange structured information with partners up and down the value chain.

b) Provided web-based as Software as a Service, Carbon Footprint ECO Portfolio enables onboard new suppliers with just a few clicks.

Internally:

a) Defined roles in Carbon Footprint ECO Portfolio streamline internal collaboration.

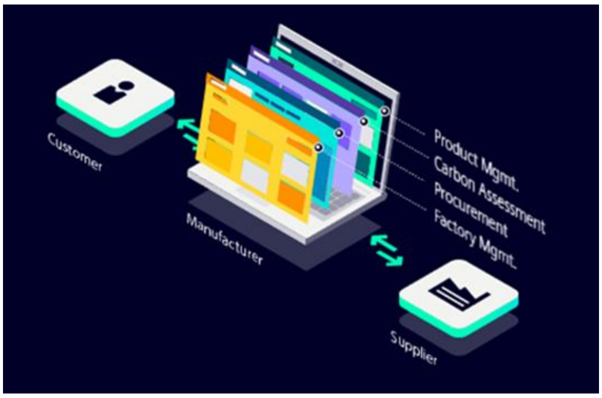


Fig. 2 - Carbon Footprint ECO Portfolio Enables PCF Management in Cross-Functional Collaboration

b) Product managers handle customer requests for PCF.

c) Carbon Assessment experts provide the PCF information required based on information from the shop floor as well as the supply chain.

d) Procurement requests PCFs from suppliers, being that "one face to supplier" procurement can leverage PCF information also for supplier selection and development.

e) Companies can assign roles flexibly, product and procurement categories as well as business reflect the organizational structure of a company and assign clear roles and responsibilities as well as access rights.

3.1 How to Build the Trusted Network to Link Exchange and Verify Carbon Footprint Information based on Blockchain Technology

The Carbon Footprint Eco Portfolios enable trusted cross-company exchange of emissions data along supply chain while preserving the data sovereignty of stakeholders:

a) Peer-to-peer communication, no central data base.

b) Each company retains control over its emission data and decides when and with which business partners the information is shared.

c) Carbon footprint data can be verified by accredited verifiers.

d) Verifiable credentials for data trustworthiness and comparability.

e) Ensure accuracy, trustworthiness, data sovereignty compatibility and efficient management of carbon footprints.

3.2 Xitanji Joint Solution of Innovative International Carbon Footprint Online Verification

Joining hands with partner TÜV SÜD, Xitanji Joint Solution of Innovative International Carbon Footprint Online Verification based on AI-based carbon factor is launched, matching for customers:

a) Significantly improve the efficiency of carbon footprint verification.

b) Empower supply chain carbon data exchange and supply chain management and other multi-scenario needs.

c) Help meet the needs of international carbon footprint verification needs and achieve green going global.

3.3 Green and Low-carbon Services for Enterprises Going Global

Together with partner TÜV SÜD, the Green and Low-carbon Services for Enterprises going global, with the following features:

a) Rely on technological innovation to promote enterprise transformation and upgrading, build green and low carbon competitiveness.

b) Comply with the ISO14067 and international standards, and efficiently meet global carbon footprint disclosure requirements.

c) Meet the market and customer's needs of carbon inventory and carbon verification, efficiently and seamlessly meet the carbon disclosure requirements of CBAM.

d) Cover the requirements categories of CBAM in different situations, and support data analysis and integration on demand.

4. REAL WORLD PCF PROJECTS

The Carbon Footprint Eco Portfolios joins hands with industry and partners to create a win-win green and low-carbon ecology. SiGREEN is a comprehensive product carbon footprint solution for managing and reporting supply chain and production emissions in real life examples.

4.1 SiGREEN together with Global Chemical Companies Enable PCF Data Exchange Across an Entire Industry and Decarbonize the Sector

SiGREEN contributes to the entire chemical sector to make it more sustainable. It deploys across the 51 TfS (Together for Sustainability) members. See Figure 3 below.

Fig. 3 - Together for Sustainability – A Global Initiative of 51 Chemical Companies aim to Promote Sustainability in the Chemical Industry's Supply Chain

a) Relying on SiGREEN to create a standardized product carbon footprint data interaction solution.

b) Establishing a climate-neutral value chain based on interactive data and its own carbon emissions.

c) Integrating carbon emissions across the entire value chain.

d) Promoting and accelerating the low-carbon transformation of the entire chemical industry.

e) Supporting partners safely share their PCF data powered by the 'Together for Sustainabiligy' PCF Guideline.

f) Tackling the chemical industry's scope 3 challenge.

g) Allowing companies exchange emissions data from their supply chain securely and confidently.

4.2 Covestro Engineering Plastics Seamless PCF Data-Exchange Across Industries

Highlights:

Cross-industry data exchange from Together for Sustainability to Catena-X Automotive Data Space.

Initial situation:

a) As part of various value chains, Covestro needs to report PCF values to customers, often in different standard formats and on multiple platforms. The approach chosen by BMW as a pioneer in the Automotive value chain, was to follow the Catena-X standard and to rely on the Catena-X data ecosystem.

b) To track and reduce scope 3.1 upstream emissions, a major contributor to Covestro's products PCF, data is exchanged amongst suppliers via the Together for Sustainability standardized format.

c) Therefore, a solution to enable sharing of data along the supply chain in a customized way is needed.

Solution:

a) Requesting supply chain data and sharing PCFs with customers via SiGREEN. The solution enables secure and standardized data exchange, securing the data sovereignty of the data provider.

b) As a certified Catena-X solution, SiGREEN facilitated the data exchange between the automotive and the chemical industry.

Benefits:

a) Providing insights into supply chain emissions, allowing for better and data-based decisions towards measures to reduce greenhouse gas emissions.

b) Being able to share a once-created PCF with customers from different industries without further effort.

c) Streamlining the process of sharing and verifying data saves time and effort.

4.3 Carbon Footprint Eco Portfolios Pilot in Digital Factory SEWC

Another Carbon Footprint Eco Portfolios pilots in digital factory - Siemens Electronics Works Chengdu, China (SEWC), realizing transparency and verification of the carbon footprint of two PLC products:

a) Own emission quantified precisely and efficiently: With SiGREEN Connect EWC, relying on edge computing technology, the product-related carbon emission data is automatically collected and accurately decomposed from Energy Manger Pro and Manufacturing Execution System (MES).

b) Enabling efficient exchange of product related emissions along supply chains: With SiGREEN Web, three suppliers of SEWC shared the carbon emissions of the raw materials.

c) 1500C PCF Journey Visualization: From the cradle to the gate, a clear demonstration of the carbon footprint of the product at every step.

4.4 Customer Case in Low-Carbon Green Recycling of Industrial Waste - Trusted Actual PCF for Recycling of Retired Batteries

It helps customers to face requirements of the EU's new battery bill for carbon footprint disclosure, scientific calculation methods of carbon emission data in the entire process of decommissioned battery raw materials and recycling, trusted actuarial and traceability, etc.

a) Accurately and efficiently quantify carbon emissions in production and manufacturing processes：Rely on edge computing technology to realize system docking, automatically collect and accurately decompose carbon emission data related to products from the manufacturing system and energy management system.

b) Enable safe and trusted exchange of product-related emissions in the supply chain, through the calculation model of battery product production and retired battery waste recycling, using blockchain technology, the product-related carbon emission in supply chain is calculated and managed.

c) Transparent carbon footprint of retired battery recycling products: From cradle to gate, establish a carbon emission digital twin cockpit to clearly and transparently display the carbon footprint of each step of the product to meet the carbon footprint disclosure requirements of the new battery law.

4.5 Join Hands with Suppliers and Partners, Cabron Footprint Eco Portfolios Helps Realize the PCF of Servo Motor Products and its Materials

In the digital factory, Siemens' Numerical Control Ltd.

(SNC), we pilot the transparent PCF of 4 MLFB (Maschinen Lesbare Fabrikate Bezeichnung in German, or Machine-readable Product Designation) Servo Motors in K2/K7 production line:

a) Automatic data collection of energy related data and manufacturing data from energy management system and production line via SiGREEN Connect.

b) Reliable calculation of factory-related product carbon emission (Scope 1 & 2).

c) Two suppliers share their material PCF with SNC via SiGREEN Web; other materials are scientifically estimated through Product Liftcycle Management tools, like Teamcenter Product Cost Management (TCPCM) / GaBi LCA (Life Cycle Assessment) and other methods (Scope 3).

d) Select specific products to pass TÜV certification.

e) Supports suppliers to realize the automatic calculation of their products' PCF, by network environment construction, electricity meter deployment, and MES data collection, etc.

f) The carbon emission of bill of materials (BOM) of silicon steel sheets and shafts produced by suppliers is estimated by Lifecycle Assessment (LCA); the PCF value of silicon steel sheets/rotary shafts is shared with SNC through SiGREEN Web.

g) Each company chooses at least one material to pass TÜV certification.

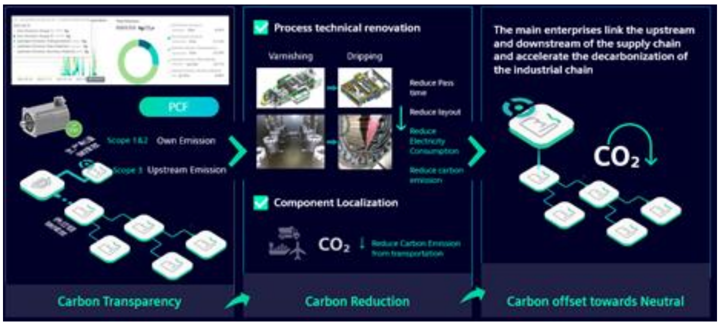


Fig. 4 - Servo Motor Carbon Reduction Path - Transparent PCF, Identify Hotspots, Design and Implement Carbon Emission Reduction Roadmaps, Accelerate Decarbonization

As part of various value chains, SNC needs to achieve carbon twinning and automated data collection through XiTANJI, combined with the platform's factor library capability, and through XiTANJI to achieve supply chain-side carbon footprint calculation and standardized format data exchange and sharing

After realizing the transparency of carbon footprint, we found out the links that can reduce carbon, and together with the process engineers, we realized the process optimization to meet the product quality requirements, from the Varnishing paint process to the dripping paint process, to significantly reduce the electricity consumption of carbon emission.

At the same time, we optimize the carbon emissions from suppliers' transportation and logistics, and select suppliers with lower carbon emissions from green transportation or distribution. Reduce carbon emission from transportation.

Finally, the carbon neutralization of SNC's motors was achieved by relying on the carbon reduction measures that have been implemented so far, combined with the purchased carbon sinks.

With the support of suppliers, the Carbon Footprint Eco Portfolios accelerates the decarbonization with SNC & suppliers and got the Zero-carbon product certificate.

Fig. 5 - Transparent PCF of 4 MLFB Servo Motors in K2/K7 Production Line, Zero-Carbon Product Certificate

5. CONCLUSION

In conclusion, as a software-as-a-service solution, Carbon Footprint ECO Portfolio provides you with the flexibility to enhance your PCF management with increasing customer demand. In its basic version, Carbon Footprint ECO Portfolio works stand-alone, without any need for technical installation or integration. That makes it easy to start with, for you as well as your supply chain partners. As you scale your PCF management, Carbon Footprint ECO Portfolio provides numerous options to make PCF management an integral part of your process and system landscape. As part of Industrial Operations X on Siemens Xcelerator, the open digital business platform, Carbon Footprint ECO Portfolio offers interfaces to compatible solutions and services, from Siemens and selected partners. Customers, for example, use the Simatic Energy Manager Pro to capture energy consumption in their own facilities. Not only to manage energy better but also to transfer metered consumption of e.g. electricity, gas and heat to Carbon Footprint ECO Portfolio as the basis for accurate own emission calculation.

Paper No. 8

FROM MASSIVE ELECTRIFICATION TO DECARBONIZATION - HARNESSING POWER ELECTRONICS FOR A GREENER PLANET

Author/Speaker: Ir Dr. HL Yiu
Fellow Member
The Hong Kong Institution of Engineers

FROM MASSIVE ELECTRIFICATION TO DECARBONIZATION - HARNESSING POWER ELECTRONICS FOR A GREENER PLANET

Ir Dr. HL Yiu
Fellow Member
The Hong Kong Institution of Engineers

ABSTRACT

Climate change is one of the most pressing challenges of our time. It is calling for an urgency in driving global efforts towards reducing greenhouse gas emissions. In response, a massive electrification moves, coupled with advancements in power electronics, presents a viable pathway to help achieving decarbonization significantly. This paper delves into how electrification in a massive way helps decarbonization and the pivotal role of power electronics in enabling efficient electrification across various sectors, outlining key opportunities and discussing the challenges that need to be addressed especially the device technology needed to realize a greener planet.

Massive electrification entails the widespread adoption of electric technologies in end-use sectors such as transportation, industry, and residential areas. This shift is essential for reducing reliance on fossil fuels and directly lowering emissions. Furthermore, the decarbonization of electricity generation through increased use of renewable energy sources, such as solar and wind, is critical. Efficiency improvements in energy use and management further enhance the benefits of electrification.

Power electronics are instrumental in this transition. They enable the efficient conversion and control of electrical energy, facilitating the integration of renewable energy sources into the grid, the development of electric vehicle (EV) infrastructure, and the enhancement of smart grid functionalities as well as energy storages. This paper highlights advancements in power electronics, the use of wide bandgap semiconductors or known as the third-generation semiconductor technology like Silicon Carbide (SiC) and Gallium Nitride (GaN) for the development of advanced converters and inverters. The paper updates the recent development of the third-generation semiconductor infrastructure in Hong Kong. These include the development of the Microelectronics Centre and the Microelectronics Research and Development Institution.

In conclusion, the paper emphasizes that while significant challenges remain, the integration of advanced power electronics with massive electrification efforts offers a pathway to a greener planet. Continued innovation, investment, and supportive policies are essential to overcoming these challenges and realizing the full potential of this transformative approach to combating climate change.

1. INTRODUCTION

Climate change is one of the most pressing challenges of our time. The urgent need for climate action is underscored by the scientific consensus that human activities, particularly the burning of fossil fuels, are driving climate change. The Intergovernmental Panel on Climate Change (IPCC) emphasizes the necessity for rapid and extensive transitions in energy, land, urban, and industrial systems to limit global warming to 1.5°C above pre-industrial levels [1]. Achieving these targets requires significant reductions in greenhouse gas emissions, primarily through transitioning to cleaner energy sources.

The Paris Agreement and the 21st Conference of the Parties (COP21) in 2015 set out electrification as a keyway to decarbonization. This leads to the subsequent adoption of massive electrification, which is involving the widespread adoption of electric technologies across various sectors, is critical for decarbonization. This includes electrifying transportation, industrial processes, and residential heating and cooling systems, alongside decarbonizing electricity generation and improving energy efficiency.

Power electronics play a crucial role in this transition by enabling the efficient conversion and control of electrical energy, integrating renewable energy sources, and supporting electric vehicle (EV) infrastructure. Hong Kong is playing a role in the development the third-generation semiconductor infrastructure in Hong Kong. These include the development of the Microelectronics Centre and the Microelectronics Research and Development Institution.

The conclusion highlights that despite significant challenges, integrating advanced power electronics with massive electrification efforts presents a promising route to a greener planet. To overcome these challenges and fully realize the potential of this transformative approach to combating climate change, continued innovation, investment and supportive policies are crucial.

2. The URGENT NEED FOR CLIMATE ACTION

The scientific consensus is clear: human activities, particularly the burning of fossil fuels, are driving climate change which is one of the most pressing challenges of our time. IPCC has highlighted the need for rapid and far-reaching transitions in energy, land, urban, and industrial systems to limit global warming to 1.5°C above pre-industrial levels [1]. Achieving this requires significant reductions in greenhouse gas emissions, primarily by transitioning away from fossil fuels to cleaner energy sources.

Conference of the Parties (COP) under the United Nation Framework Convention on Climate Change (UNFCCC) is a forum for all the concerned parties to gather together to discuss, share, and decide on conventions on climate change [2]. At its 21st COP (COP21) held in Paris 2015, the parties adopted the so called "Paris Agreement", aims to limit global warming to well below 2°C and pursue efforts to limit it to 1.5°C. Achieving these targets necessitates substantial reductions in carbon dioxide and other greenhouse gas emissions. Compared to the Kyoto Protocol (COP3) which set mandatory emissions reduction targets for industrialized countries and incorporated a market-based approach, the Paris Agreement allows countries to set their own targets and emphasizes global cooperation to achieve its objectives. Transport emission accounts for approximately a quarter of global energy-related greenhouse gas emissions, and reducing it is crucial for climate goals. The parties made declaration which aims to increase electro-mobility to support a less-than 2-degree Celsius global temperature rise and target electric powered vehicles adoption to at least 20% of all road vehicles by 2030 [3].

3. MASSIVE ELECTRIFICATION: A PATHWAY TO DECARBONIZATION

Massive electrification refers to the widespread adoption of electric technologies across various sectors, including transportation, industry, and residential areas. This transition is critical for achieving climate goals and reducing greenhouse gas emissions. Figure 1 illustrates a comparison of emission management of traditional combustion vehicle against electric vehicle.

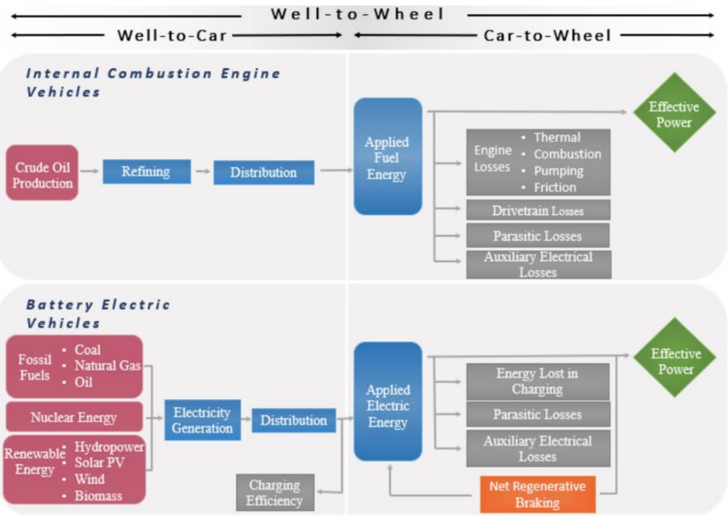


Fig. 1 - Downstream Tail Emission and Upstream Emission Reduction (Adoption from Athanasopoulou et al. (2018) [5]

By consolidating the source of energy to the generation and electrifying the downstream utilization, the control of emission can be more effective when more renewable energy or low carbon footprint energy is made available to the source. Carbon capturing management can be more effective at the generating source than at the tail [4].

In a case study in Canada, electrification involves (a) electrification of end-use sectors including transportation, industrial and residential, (b) de-carbonization of electricity generating supply, and (c) efficiency improvements [6].

As the transportation sector is a major source of greenhouse gas emissions, transportation electrification through the adoption of electric vehicles (EVs) can significantly reduce emissions. According to the International Energy Agency (IEA), global EV sales must reach 43 million per year by 2030 to stay on track with climate goals [7]. Industrial processes are energy-intensive and often rely on fossil fuels. Electrification of industrial processes, such as using electric arc furnaces for steel production and electric heating for various applications, can reduce emissions and improve efficiency. In the residential sector, electrifying heating and cooling systems can reduce reliance on natural gas and oil. Heat pumps, for example, are an efficient alternative to traditional heating systems and can be powered by renewable electricity. To support downstream decarbonization, the electricity supply itself must be decarbonized. This involves increasing the share of renewable energy sources such as wind, solar, and hydropower in the energy mix. Advances in power electronics are critical for integrating these variable renewable energy sources into the grid. Efficiency improvements in energy use in all of the above and implementation of power management further enhance the benefits of electrification. Power electronics especially smart power management control systems enable precise control over energy conversion and distribution, reducing losses and improving overall system efficiency.

4. THE ROLE OF MODERN SMART POWER ELECTRONICS

Modern Smart Power electronics are crucial for facilitating the transition to a decarbonized energy system. These technologies enable the efficient conversion and control of electrical energy, making it possible to (a) integrate renewable energy sources, (b) develop EV infrastructure, and (c) enhance smart grid functionalities.

Power conversion and storage of the variable output of renewable energy sources to provide stable and usable electricity. Advanced converters and inverters are essential for integrating solar and wind power into the grid, ensuring a reliable and balanced energy supply. High power motor drivers and chargers are essential for the operation and charging of EVs. These technologies manage the flow of electricity between the battery and the motor, ensuring efficient energy use. Additionally, advanced power electronics are core to the development of fast-charging infrastructure, which is necessary for the widespread adoption of EVs. Due to the dynamics in load demand at different locations and time, the electricity distribution through the smart grid enhances the management and distribution of electricity. They enable real-time monitoring and control of the grid system, facilitating the integration of renewable energy sources and the balance of supply and demand. Smart grids also support the deployment of decentralized energy systems, such as microgrids. Figure 2 illustrates the various components in a modern smart grid system deploying modern smart power electronics [8].

5. OPPORTUNITIES & CHALLENGES

While massive electrification and advancements in power electronics offer numerous benefits, several challenges in technology, economic, and regulatory areas are needed to be addressed. Advanced power electronics devices for improving efficiency and reliability require new materials to deliver the performance. Wide bandgap semiconductors, such as Silicon Carbide (SiC) and Gallium Nitride (GaN), offer significant advantages over traditional silicon-based devices, including higher efficiency, faster switching speeds, and greater thermal stability [9]. The installing new technology takes time and intensive capital investments in infrastructure. The cost of such new infrastructure can be a barrier to widespread adoption. Significant investment in research, development, and massive deployment is necessary to drive down costs and scale up the use of modern smart power electronics and electrification technologies. In any case, as the electricity infrastructure is a highly regulated industry with a lot of legacy system installed, supportive policies and regulations are critical for promoting electrification and ensuring a smooth transition. This includes incentives for renewable energy, EVs, and energy efficiency improvements. Governments and regulatory bodies must work together to create an enabling environment for these technologies.

Several case studies illustrate the practical applications and benefits of power electronics in various sectors: (a) Renewable Energy Integration: Projects like the Hornsdale Power Reserve in South Australia demonstrate how advanced power electronics can enable the integration of large-scale battery storage with renewable energy sources, providing grid stability and reliability [10]. (b) Electric Vehicle Infrastructure: The expansion of EV charging networks, such as Tesla's Supercharger network, showcases how power electronics facilitate fast and efficient charging, supporting the adoption of EVs [11]. Smart Grid Development: Initiatives like the Smart Grid Demonstration Programme in the United States highlight the role of power electronics in modernizing the grid and improving energy management [12] [13].

6. ADVANCEMENTS IN POWER ELECTRONICS: SiC & GaN TECHNOLOGIES

The development of wide bandgap semiconductors (also known as the 3rd generation or 3rd type semiconductors), particularly Silicon Carbide (SiC) and Gallium Nitride

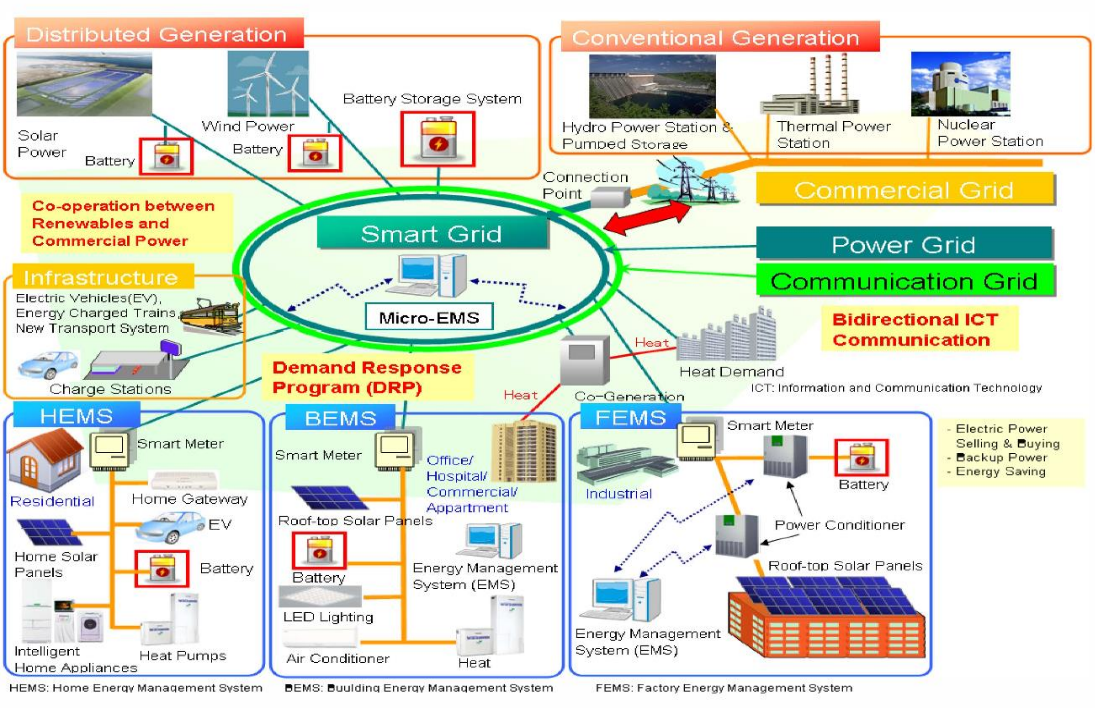


Fig. 2 - Concept of Smart Grid (Adopted from Kobayashi (2014) [8]

(GaN), represent a significant advancement in power electronics over the traditional Silicon (Si) based devices. These materials offer superior performance compared to traditional silicon-based devices due to its high electron mobility behaviour and low on-resistance when the device is turned on, making them ideal for high-efficiency and high-power applications [9].

SiC has several advantages over traditional silicon, including a higher breakdown electric field, higher thermal conductivity, and lower switching losses. These properties enable SiC devices to operate at higher voltages, temperatures, and frequencies, resulting in improved efficiency and reduced cooling requirements. The SiC power transistor component market could reach to over US$13B with compound average growth rate (CAGR) to be about 30% pa [14]. SiC is particularly suitable for applications that require high efficiency and high-power density, such as inverters for renewable energy systems, EV powertrains, and industrial motor drives. The use of SiC in these applications can lead to significant energy savings and reduced system costs. Major suppliers are STMicroelectronics, WOLFSPEED, Semiconductor Components Industries, Littelfuse, Infineon, Diodes, Microchip, ROHM, Toshiba, SemiQ, Sansha Electric, etc.[14].

GaN offers even higher electron mobility than SiC, allowing for faster switching speeds and higher efficiency. GaN devices can operate at higher frequencies, which reduces the size and weight of passive components, such as inductors and capacitors, in power electronic systems [9]. The GaN power transistor market could reach to over US$2.5B with compound average growth rate (CAGR) to be over 40% pa. GaN device is well-suited for low to medium power applications, such as power supplies for consumer electronics, data centers, and telecom equipment. The high efficiency and compactness of GaN devices make them ideal for applications where space and energy efficiency are critical. Major suppliers are Efficient, Fujitsu, GaN Power, GaN Systems, Infineon, Navitas, NexGen Power, On Semiconductors, Panasonic, Power Integrations, ROHM, SOITEC, Texas Instruments, Transphorm, and VisIC [15].

The key material performance parameters of SiC, GaN and traditional Si used in power devices are summarized in Figure 3 [16], [17], [18], [19].

While Si-based power devices are well-established and cost-effective, SiC and GaN technologies offer superior performance in terms of efficiency, thermal management, and high-frequency operation. These advantages make SiC and GaN crucial for applications requiring high power density and efficiency, playing a vital role in decarbonization efforts and the transition to renewable energy sources. The technology is controlled by major players in the market currently and the fabrication technology and equipment are relatively simple compared with deep sub-micron digital CMOS process, this represents a high market potential and research opportunities for Hong Kong academia and technology companies.

Attribute	Silicon (Si)	Silicon Carbide (SiC)	Gallium Nitride (GaN)
Bandgap Energy	1.1 eV	3.26 eV	3.4 eV
Breakdown Voltage	Moderate	High	High
Thermal Conductivity	150 W/mK	490 W/mK	130 W/mK
Switching Speed	Moderate	Fast	Very Fast
On-Resistance	Higher	Lower	Lowest
Operating Temperature	Up to 150ºC	Up to 650ºC	Up to 400ºC
Efficiency	Moderate	High	Very High
Size and Weight	Larger and Heavier	Smaller and Lighter	Smallest and Lightest
Manufacturing Complexity	Established, less complex	More complex	Most complex
Cost	Lower	Higher	Highest
Application Examples	General power electronics	High-power applications (EVs, solar inverters)	RF amplifiers, fast chargers, high-frequency power converters

Fig. 3 - Summary of Material Performance and Costs of Si, SiC, and GaN

7. MICROELECTRONICS DEVELOPMENT IN HONG KONG

The Hong Kong Microelectronic Center (MEC) and the upcoming Hong Kong Microelectronics Research and Development Institute (MRDI) are pivotal in advancing the region's microelectronics industry. Located in Yuen Long InnoPark, MEC leverages Hong Kong's strong research capabilities in third-generation semiconductor materials to support industry development and pilot production of cutting-edge technologies. It fosters a robust microelectronics ecosystem through collaboration with leading universities and research institutes globally [20]. Meanwhile, the MRDI, set to be established in 2024, will spearhead research collaboration on third-generation semiconductors among universities, R&D centers, and the industry. By utilizing the comprehensive manufacturing industry chain in the Greater Bay Area and the mainland, MRDI aims to transform R&D outcomes into economic benefits, further solidifying Hong Kong's position as an international innovation and technology hub [21] [22].

8. CONCLUSION

In conclusion, addressing climate change requires urgent and comprehensive action, particularly through the adoption of massive electrification and advanced modern smart power electronics. The integration of these technologies is essential for reducing greenhouse gas emissions and transitioning to decarbonization future and a greener planet. Despite the significant challenges, the potential benefits of this transformative approach are immense. Continued innovation, investment, and supportive policies are crucial to overcoming these challenges and achieving global climate goals.

Additionally, the development of wide-bandgap semiconductors such as silicon carbide (SiC) and gallium nitride (GaN) is vital. These materials offer superior efficiency and performance in high-power and high-frequency applications, making them key components in the next generation of power devices. Hong Kong's initiatives in developing third-generation semiconductor infrastructure, such as the MEC and the MRDI, exemplify the proactive steps needed to foster a sustainable and resilient future.

REFERENCES

1. "Global Warming of 1.5 ºC -." Accessed: Aug. 06, 2024. [Online]. Available: https://www.ipcc.ch/sr15/

2. U. N. Environment, "UNEP at the climate COP | UNEP - UN Environment Programme." Accessed: Aug. 05, 2024. [Online]. Available: https://www.unep.org/explore-topics/climate-action/what-we-do/unep-climate-cop

3. "The Paris Declaration on Electro-Mobility and Climate Change and Call to Action | UNFCCC." Accessed: Aug. 06, 2024. [Online]. Available: https://unfccc.int/news/the-paris-declaration-on-electro-mobility-and-climate-change-and-call-to-action

4. M. Idris and R. H. Koestoer, "Environmental life cycle assessment of conventional and electric vehicles: lessons learned from selected countries," J. Innov. Mater. Energy Sustain. Eng., vol. 1, pp. 1–19, Aug. 2023, doi: 10.61511/jimese.v1i1.2023.27.

5. L. Athanasopoulou, H. Bikas, and P. Stavropoulos, "Comparative Well-to-Wheel Emissions Assessment of Internal Combustion Engine and Battery Electric Vehicles," Procedia CIRP, vol. 78, pp. 25–30, 2018, doi: 10.1016/j.procir.2018.08.169.

6. K. Vaillancourt, O. Bahn, E. Frenette, and O. Sigvaldason, "Exploring deep decarbonization pathways to 2050 for Canada using an optimization energy model framework," Appl. Energy, vol. 195, pp. 774–785, Jun. 2017, doi: 10.1016/j.apenergy.2017.03.104.

7. "Outlook for electric mobility – Global EV Outlook 2024 – Analysis," IEA. Accessed: Aug. 06, 2024. [Online]. Available: https://www.iea.org/reports/global-ev-outlook-2024/outlook-for-electric-mobility

8. T. Kobayashi, "Power electronics technology in smart grid projects -Applications and experiences-," 2014 Int. Power Electron. Conf. IPEC-Hiroshima 2014 - ECCE ASIA, pp. 1868–1873, May 2014, doi: 10.1109/IPEC.2014.6869839.

9. None, "Wide Bandgap Semiconductors: Pursuing the Promise," 1218257, Apr. 2013. Accessed: Aug. 06, 2024. [Online]. Available: https://www.energy.gov/eere/amo/articles/wide-bandgap-semiconductors-pursuing-promise

10. "Hornsdale Power Reserve - South Australia's Big Battery." Accessed: Aug. 06, 2024. [Online]. Available: https://hornsdalepowerreserve.com.au/

11. Arpit Darbari, "Innovation in electric vehicle charging: A case study of tesla's supercharging network," World J. Adv. Eng. Technol. Sci., vol. 12, no. 2, pp. 270–278, Jul. 2024, doi: 10.30574/wjaets.2024.12.2.0295.

12. "Smart Grid Demonstration Programme: Overview: Recovery Act: Archive | SmartGrid.gov." Accessed: Aug. 06, 2024. [Online]. Available: https://www.smartgrid.gov/archive/recovery_act/overview/smart_grid_demonstration_program.html

13. "Transmission Innovation Symposium April 2021 Modernizing the U.S. Electrical Grid," Apr. 2021. Accessed: Aug. 06, 2024. [Online]. Available: https://www.energy.gov/sites/default/files/2021-05/Hardware%20OReilley%20King.pdf

14. "Silicon Carbide MOSFETs Market." Accessed: Aug. 06, 2024. [Online]. Available: https://www.transparencymarketresearch.com/silicon-carbide-mosfets-market.html

15. "Power GaN Devices Market." Accessed: Aug. 06, 2024. [Online]. Available: https://www.transparencymarketresearch.com/gan-power-devices-market.html

16. B. J. Baliga, Wide Bandgap Semiconductor Power Devices: Materials, Physics, Design, and Applications. Woodhead Publishing, 2018.

17. S. K. Pullabhatla, P. B. Bobba, and S. Yadlapalli, "Comparison of GAN, SIC, SI Technology for High Frequency and High Efficiency Inverters," E3S Web Conf., vol. 184, p. 01012, 2020, doi: 10.1051/e3sconf/202018401012.

18. S. Musumeci and V. Barba, "Gallium Nitride Power Devices in Power Electronics Applications: State of Art and Perspectives," Energies, vol. 16, no. 9, Art. no. 9, Jan. 2023, doi: 10.3390/en16093894.

19. K. Shenai, R. S. Scott, and B. J. Baliga, "Optimum semiconductors for high-power electronics," IEEE

Trans. Electron Devices, vol. 36, no. 9, pp. 1811–1823, Sep. 1989, doi: 10.1109/16.34247.

20. "MEC." Accessed: Aug. 06, 2024. [Online]. Available: https://www.hkstp.org/en/rental/space/advanced-manufacturing/mec

21. "$10b to promote new industrialisation," Hong Kong's Information Services Department. Accessed: Aug. 06, 2024. [Online]. Available: http://www.news.gov.hk/eng/2023/10/20231025/20231025_085513_793.html

22. "Budget Speech by the Financial Secretary (5)." Accessed: Aug. 06, 2024. [Online]. Available: https://www.info.gov.hk/gia/general/202402/28/P2024022800146.htm

Paper No. 9

MAXIMIZING VALUE IN ENGINEERING WITH GENAI POWERED DIGITAL TWIN

Authors/Speakers: Ir Terence LL Lui, Chief Executive Officer
Ir Luiz WH Lui, Product Manager
Varadise Limited, Hong Kong

MAXIMIZING VALUE IN ENGINEERING WITH GENAI POWERED DIGITAL TWIN

Ir Terence LL Lui, Chief Executive Officer
Ir Luiz WH Lui, Product Manager
Varadise Limited, Hong Kong

ABSTRACT

The convergence of digital twin technology and Generative AI (GenAI) represents a groundbreaking shift in engineering and construction management.

This paper explores the potential of these technologies in the construction industry to streamline data management, enhance decision-making, and retain knowledge in a systemized way. We present real-world case studies that highlight innovative applications of digital twins and GenAI, delivering tangible value through better incident management, progress tracking, and compliance, bringing us one step closer to Construction 2.0.

1. INTRODUCTION

The rise of digital twin technology has significantly changed how engineering projects are managed. Digital twins provide a virtual representation of physical assets, processes, or systems, enabling real-time monitoring and control. By integrating data from systems such as Building Information Modeling (BIM), Internet of Things (IoT) sensors, and Building Management Systems (BMS), digital twins offer a holistic view of construction projects.

Fig. 1 - Integration of BIM, GIS, IoT and Other System Data in Digital Twin

Generative AI (GenAI), in contrast, analyzes large volumes of structured and unstructured data. In construction, GenAI enhances decision-making and facilitates knowledge transfer. Together, digital twins and GenAI promise solutions to key challenges in construction management, leading to greater efficiency and improved outcomes.

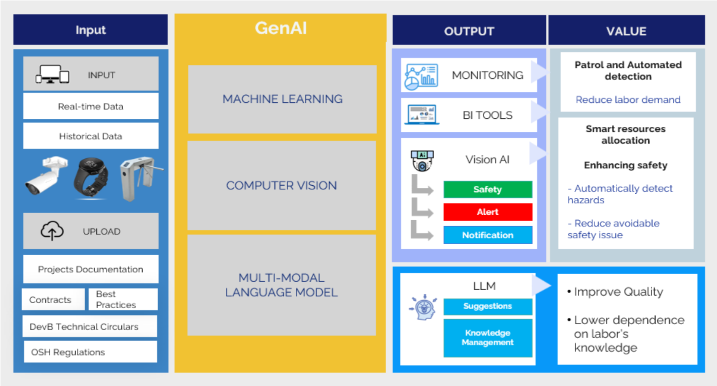


Fig. 2 - GenAI can Process Data Collected from Different Sources and Provide a Comprehensive Analysis of Complicated Construction Projects in a Holistic Manner

2. DATA MANAGEMENT CHALLEGNES IN CONSTRUCTION PROJECTS

2.1 Fragmented & Decentralized Data

Construction projects generate data across numerous platforms and systems, including IoT sensors, BIM models, BMS, work orders, and service requests. Additionally, operational data such as meeting notes, task management systems, camera footage, weather information, and GIS data from around the world are crucial for decision-making. Information is often incomplete or outdated, leading to time-consuming reporting processes. This slows down progress monitoring and introduces inefficiencies.

Digital twins provide a universal approach to centralize and integrate all these data sources, offering an all-round view of project activities, making it easier to track progress, assess risks, and make decisions.

Fig. 3 - Digital Centralizing Fragmented Project Data

2.2 Data Visualization Without Insight

Current data visualization tools present data but often fail to provide actionable insights. While reports and charts can show issues like project delays, they do not indicate underlying causes or provide recommendations. GenAI overcomes this limitation by analyzing historical and real-time data holistically across multiple data sources. It processes unstructured data and identifies patterns in safety violations, inefficiencies, and more, offering actionable insights to project managers and stakeholders.

2.3 Retaining Experience and Knowledge

In many cases, critical knowledge and expertise are retained by individuals rather than systems. When personnel leave or transition out of a project, this expertise is often lost, causing inefficiencies and knowledge gaps.

Digital twins, in conjunction with GenAI, capture decision-making processes, creating a systemized knowledge base. This ensures that expertise is retained within the system, making seamless knowledge transfer.

3. EMERGING TECHNOLOGIES FOR CONSTRUCTION

3.1 Digital Twin Technology as Common Data Environment (CDE)

Digital twin technology is becoming the standard for creating a Common Data Environment (CDE) in construction. CDEs act as a central repository where project data, documents, and BIM are stored, accessible by all stakeholders. This improves communication, collaboration, and project management efficiency.

Furthermore, the integration of digital twins supports end-to-end operations, from collecting and visualizing data to decision-making, implementation, and ongoing review. These systems also enable automation and enhanced data analysis, ensuring the full operational cycle is streamlined and optimized for future performance.

3.2 Analyzing Unstructured Data with GenAI

A major breakthrough in the use of GenAI in construction is its ability to analyze unstructured data, such as emails, documents, images, and even meeting notes or camera footage from construction sites. Traditionally, construction projects struggle to make use of unstructured data, but when combining digital twin with a central pool of data with GenAI capability, it extracts valuable insights from these sources. This capability allows for a comprehensive understanding of project performance, leading to more accurate forecasts and improved decision-making.

Fig. 4 - GenAI can Directly Extract Information from 3D Spatial Data

4. CASE STUDIES OF DIGITAL TWIN & GENAI

4.1 Incident Management & Recommendations

In one case study, a digital twin system was used to monitor workers performing tasks at height. When AI CCTV detects a safety violation incident, digital twin will not only send alert signals to responsible personnel, but also additional information and recommendations to the project-in-charge (PIC).

Fig. 5 - CCTV AI System Combined with other Management System

The PIC can quickly check the historical trends of this risk and performance of the contractor with help from GenAI, and decide if this is a one-off incident or a systematic flaw in safety management system.

Furthermore, based on the situation, GenAI can gather information from regulations, codes of practice and project method statements to recommendations tailor made for such incidents, empowering inexperienced frontline staff to perform the right decision.

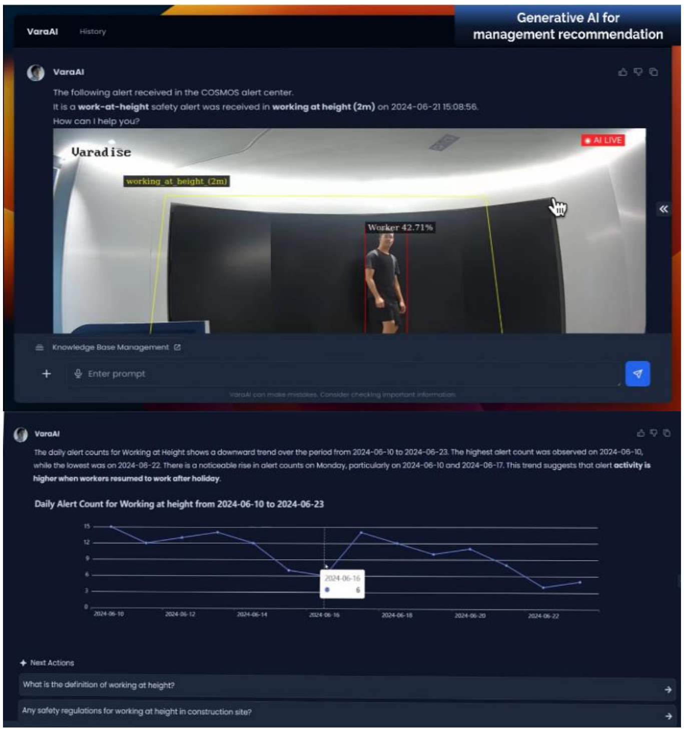


Fig. 6 - GenAI helps Identify Patterns in Safety Violations, and Offers Actionable Insights to the Stakeholders

4.2 Progress Management & Summary

In another example, a project smart site management platform (SSMP) powered by digital twin technology is integrated with Digital Works Supervision System (DWSS), connected to Integrated Capital Works Platform (iCWP).

The SSMP equipped with GenAI capability interprets DWSS data standard published by Development Bureau, and provide reports and analytic on demand. GenAI can answer details about a specific case, a type of works or an overall view of performance, and provide recommendations to improve performance.

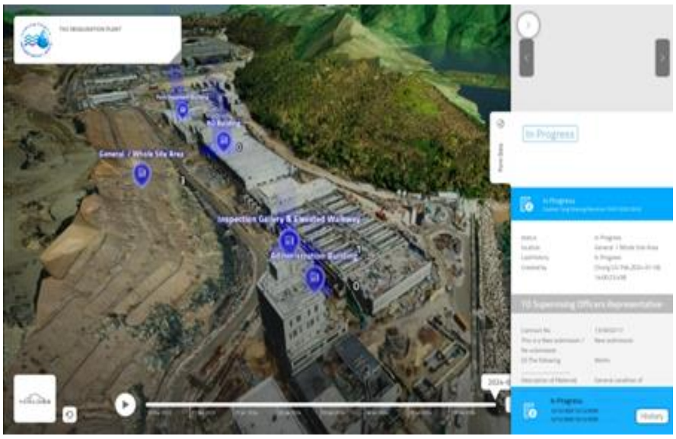


Fig. 7 - Work Done Record Integrated with BIM & iCWP

Furthermore, by asking GenAI for further information, it can retrieve images and videos at that particular time and location to provide visual evidence.

The GenAI powered digital twin consolidated data from various sources to create real-time progress reports. It added value by providing insights into potential delays and recommending resource optimization strategies, allowing managers to make proactive decisions.

Fig. 8 - With the assist of Multi-modal Language Model, GenAI helps to Generate Insights, Reporting and Advices for Different Levels of Construction Personnel with Variant Needs

4.3 ESSW Compliance with Smart Devices

In a third case, GenAI powered digital twin technology enabled real time compliance with the Electrical Safety Systems of Works (ESSW) regulations.

Multiple digital solutions are adopted in this project, including smart lock system and permit to work system, and connected to a centralized management platform (CMP). The whole ESSW process is digitalized and monitored by GenAI technology in real time.

Fig. 9 - Smart Lock System for Electric Box Management

In case of violation, an alert will be sent to Authorized Person (AP), Certified Person (CP) & Responsible Person (RP) for immediate action.

It will also generate reports for ESSW to review system performance, and provide recommendation based on Code of Practice.

GenAI provided a more real time monitoring on overall ESSW management performance in a more holistic and human like capability compare with traditional rule based alert approach. More use cases and capability of GenAI technology is still undergoing different trials in this project.

5. CONCLUSION

The integration of digital twin technology and GenAI holds immense potential for transforming the construction industry. These technologies tackle major challenges in data management, decision-making, and knowledge retention, helping to improve project outcomes, safety, and sustainability. As we move towards Construction 2.0, the role of digital twins and GenAI in engineering will only grow.

There are numerous opportunities for future collaboration and innovation in this space. By working together, industry players, researchers, and technology providers can unlock the full potential of these technologies. All stakeholders are invited to engage in discussions and projects to push the boundaries of what is possible in engineering and construction.

Paper No. 10

INTEGRATED CENTRALIZED PLATFORM - THE SMART RAILWAY STATION COMMANDER

Authors/Speakers: Ir HW Chan, Deputy General Manager - Operations Innovation Hub
Ms. Summer HY Ng, Data Analyst
MTR Corporation Limited

INTEGRATED CENTRALIZED PLATFORM - THE SMART RAILWAY STATION COMMANDER

Ir HW Chan, Deputy General Manager -
Operations Innovation Hub
Ms. Summer HY Ng, Data Analyst
MTR Corporation Limited

ABSTRACT

MTR keeps cities moving by providing caring, innovative, and sustainable services that are accessible to everyone. A resilient railway operation, equipped with strategies to effectively cope with the dynamic operational situations and potential risks, is crucial. To create a resilient railway system, MTR has developed an Integrated Centralized Platform (iCP), the Smart Railway Station Commander.

The "i-Centralized Platform (iCP)" is a Cloud-based Application Platform empowered by the technologies of AI and Big Data Analytic. The iCP helps integrate data from a wide variety of sources from Station Facilities plants via an extensive long range wide area network (LoRaWAN) data Infrastructure. This platform enables data-driven decision-making and optimization of railway operations and maintenance.

The AI and analytics capabilities of the iCP platform empower MTR to move beyond reactive, manual management of the railway system. It provides the real-time visibility, predictive intelligence, and data-driven decision support needed to continuously optimize performance and enhance the resilience of this critical transportation infrastructure.

The iCP platform is also a key to driving productivity gains across MTR's operations. It provides maintainers with real-time diagnostics, while enabling control center staff to optimize resource allocation based on unified data. Serving as a centralized hub for cross-functional data sharing and analysis, the platform empowers stakeholders to collectively review performance, identify issues, and develop solutions to facilitate seamless coordination, and enable a more proactive response to challenges.

Sensors and the Internet of Things (IoT) provide valuable real-time data for monitoring and decision-making, in particular for Electrical & Mechanical facilities, combined with a robust data infrastructure for linking sensors and running intelligent railway applications.

These technologies give us unique ways of connecting people to things and things to things, strengthening our ability to gather vast amount of data, and enabling us to have greater insights than ever before. This data intelligence framework serves as a model for enhancing the resilience and efficiency of railway systems.

1. INTRODUCTION

Integrated Centralized Platform (iCP) is a visualization platform with centralized station facilities' monitoring system and real time threshold alarm, empowered by the technologies of Artificial Intelligence (AI) and Big Data Analytic, and the LoRaWAN Internet of Things (IoT) Infrastructure, to provide predictive maintenance solution of MTR station assets. Interactive dashboards of different systems are centralized and will be updated timely to the operators and the Facility Management Engineering Control Center for equipment health monitoring.

This paper consists of four sections to demonstrate how MTR connects things to people. Firstly, the design of the LoRaWAN Infrastructure in the MTR underground railway system will be illustrated for Connecting Things to Things. After that, the system architecture of Integrated Centralized Platform overview will be introduced, along with data flow architecture for Connecting Things to People. More than that, the system design of alert delivery and acknowledgement will be introduced for Connecting People to People. Moreover, the design and real-life use cases of the Big Data Analytic Platform will be discussed. Lastly, a summary will be provided.

2. DESIGN OF LoRaWAN INFRASTRUCTURE

2.1 LoRaWAN Infrastructure for Underground Railway Systems

MTR has deployed over 4000 LoRa sensors across various facilities to gather data for condition monitoring. Ensuring signal penetration is crucial to achieve comprehensive coverage at MTR stations and throughout the extensive tunnels for seamless data transmission to the data warehouse, enabling real-time condition monitoring, data visualization, and alerts.

An issue must be addressed that the environment of MTR is difficult to set up IoT-based wireless sensor network via the transmission of radio frequency (RF) signal due to the relatively narrow nature of underground structures in stations and tunnels that enlarge the reflections of RF signal. It is also not feasible to presume the RF signal of sensors to penetrate through the thick walls and metallic doors of the underground station structure. To ensure the coverage of RF signal for the transmission of sensor data, a system is introduced to establish the LoRaWAN network via the leaky feeder cables.

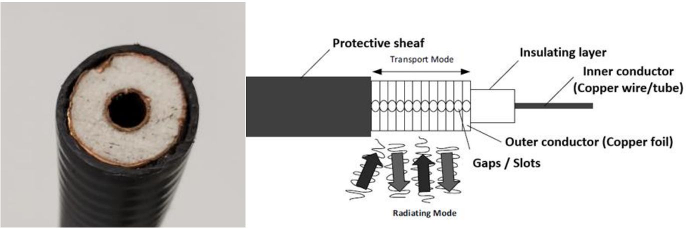


Fig. 1 - A Leaky Cable (Left: Cross Section; Right: Cable Structure)

The system extends the IoT gateway coverage with the shared use of leaky feeder cables of the radio system. To ensure a successful deployment, there are three prerequisite requirements. First, signal interoperability of the IoT and radio systems is achieved without interference. Whereas the RF signals of MTR's trunked transmission radio system occupies the frequency bands from 400 to 430 MHz and from 800 to 830 MHz, the RF signals of the LoRaWAN IoT System occupy a different frequency band, e.g., from 920 to 925 MHz to ensure the combination of the RF signals can be carried out effectively.

Secondly, the essential radio network is compatible with the frequency band of IoT System. A Point of Interface (POI) is connected at the upper end of the leaky cables as a physical interface between the new IoT gateway and the existing radio system. The POI integrates and transmits the downlink RF signals to the leaky cables and divides the uplink RF signals from the leaky cables to different systems according to their operating frequencies.

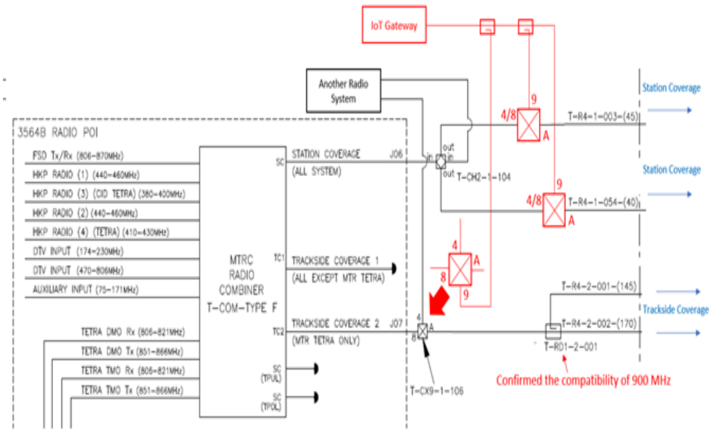


Fig. 2 - Radio Schematic Diagram of POI Integration for 900 MHz RF Signal Transmission

The new IoT gateway links up the LoRaWAN with the Cooperation Data Network (CDN) for reaching the remote network and application servers. With the LoRaWAN coverage extended by leaky feeder cables, only one IoT gateway is required in each station. In this application, the IoT gateway is solely installed next to the existing radio systems commonly in the telecom equipment room (TER) to ease the implementation. LoRa Network Server connects wireless IoT technology over long distances, linking sensors to a centralized operating system. On site apparatuses that consist of IoT Gateway must be installed, to enable LoRaWAN communication for data transmission from onsite IoT sensors to remote Application Servers. This setup enables seamless connectivity between various devices, bridging the gap from facilities to IoT sensors and from sensors to the monitoring system iCP.

Fig. 3 - Setup of LoRaWAN Infrastructure (Left is IoT Gateway, Right is Point of Interface)

2.2 LoRa is the Selected Protocol for the Integrated Centralized Platform

LoRaWAN is selected as the low power wide area network (LPWAN) protocol of the IoT system in MTR Railway Network. It performs better than other traditional IoT technologies like NB-IoT, Sigfox in terms of coverage, power consumption and operation cost, especially in the underground environment.

First, LoRa provides a long communication distance which is sufficient to cover the whole station back-of-house area via the leaky cable network. This can reduce the demand of sensor-to-network connection along the extensive railway network and hence minimize the quantity of IoT gateway required. Secondly, LoRa operates on a separate network and does not rely on any external Mobile Network Operator (MNO). Only negligible license fee is required for maintaining LoRaWAN networks in the entire MTR Railway Network. Also, a comparatively low preventative maintenance cost can be reserved for battery replacement due to the extremely low power consumption of LoRa sensor.

These advantages offer more cost-effectiveness and flexibility for the long-term IoT deployment in MTR railway system. Therefore, LoRaWAN operating in frequency brand from 920 to 925 MHz is selected for this application.

To ensure the LoRaWAN reliability, performance assessments are conducted to check the LoRaWAN coverage throughout the station including all platforms and equipment rooms. The received signal strength indicator (RSSI) values at different locations with line of sight (LOS) communication with the leakage cable is confirmed above the sensitivity level of the SF 7, which is -123 dBm. When one of the closest station gateways is malfunctioning, another station gateways can communicate with the sensors in adjacent stations via the leaky feeder cables linked up in the railway tunnels. This connection of multiple gateways provides a degree of redundancy.

2.3 Application of LoRa IoT Sensors Example Usecases

2.3.1 Hall sensors and LoRa ADC sampling sensors for platform screen door fault detection

Platform Screen Doors (PSDs) and Automatic Platform Gates (APGs) are installed in most MTR platforms enhancing passenger safety and improving operational efficiency. However, their integration introduces complex challenges related to electrical safety, particularly concerning stray current protection. As passengers interact with PSDs while boarding, disembarking, and waiting for trains, it becomes imperative to implement robust safety measures to mitigate potential electrical hazards.

The use of a Leakage Current Monitor (LCM), equipped with Hall effect sensors and LoRa ADC sampling sensors have been installed and specifically designed to monitor leakage currents associated with PSDs. This sensor is strategically installed on track bonding conductors and plays a vital role in detecting insulation degradation and stray current leakage. It is configured to issue alarms when leakage currents exceed predefined thresholds. Such measures help minimize stray current leakage and touch voltage exposure, thereby safeguarding passengers and ensuring the reliability of the system.

In addition to the LCM, the APG Motor Current Sensor represents another significant advancement in the monitoring of APGs. This sensor is designed to detect the electrical current associated with the opening and closing operations of the APG motors. By analyzing this electrical current, the sensor can identify anomalies that may indicate underlying mechanical issues, such as bearing wear or other faults.

The non-intrusive nature of the APG Motor Current Sensor allows for continuous monitoring without disrupting normal operations. This capability is crucial for preventing unexpected downtime and costly repairs. Early detection of potential issues enables maintenance teams to intervene promptly, thereby mitigating the risk of system failures and enhancing the reliability of transit operations. Increased currents during door operations may signal poor performance conditions, and timely analysis allows for proactive maintenance interventions.

Fig. 4 - Hall Sensors

Fig. 5 - LoRa Leakage Current Sensor

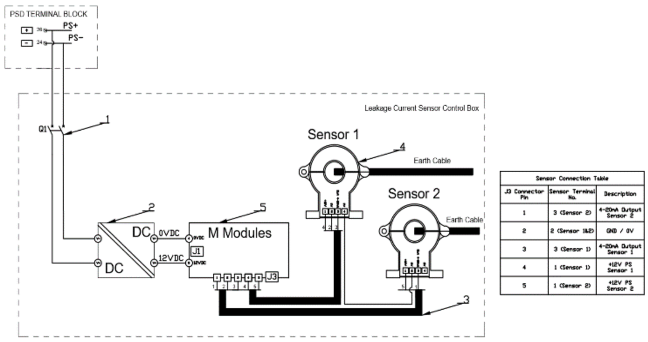


Fig. 6 - Leakage Current Sensor Schematic Diagram

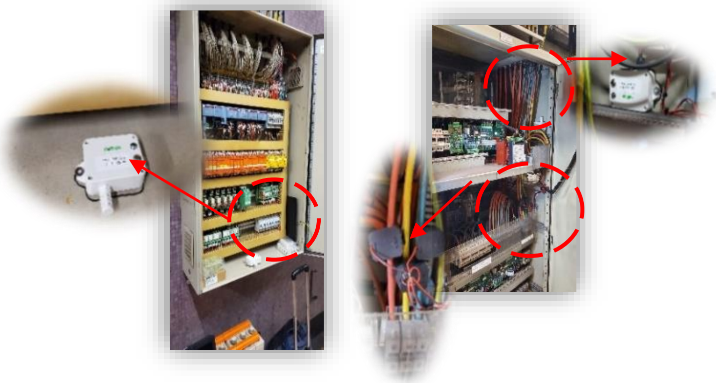


Fig. 7 - Hall Sensor at PSD and APG Power Distribution Panel

2.3.2 Magnet sensors for trackside access door detection system

A trackside access door detection system is being implemented to the whole MTR networks for

Fig. 8 - Trackside Access Door Sensor

monitoring all the access gates into tunnels. Dual Magnet sensors are installed on these gates for detecting the door open/close status. If any unauthorized track access is detected and confirmed, alarms will be raised to the control centre immediately for safety reason.

2.3.3 Current monitoring of fire service pump

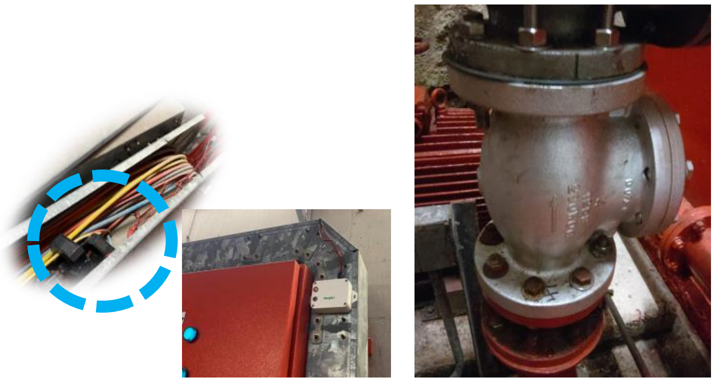


Fig. 9 - Monitoring Operation Current of Fire Service Pump

An use case for condition monitoring of the fire service jockey pump utilizing the LoRa current sensor is presented here. Over a span of seven days, the maintenance team observed an abnormal change in operational frequency. This prompted an investigation that revealed a malfunctioning non-return check valve, which was found to be sticky, leading to an improper return of pressure to the fire service tank and causing unnecessary cycling of the jockey pump. In response, the maintenance team promptly executed a rectification by cleaning and lubricating the check valve, restoring its normal functionality. Following these corrective actions, continuous monitoring with the LoRa sensor indicated a significant reduction in the jockey pump's operating frequency, reflecting improved efficiency and reduced wear on the system.

2.3.4 Lift intelligent monitoring system

The Lift Intelligent Monitoring System (LIMS) is a cutting-edge solution designed to optimize the safety, efficiency, and performance of modern elevator systems. By employing a comprehensive array of monitoring technologies, LIMS provides real-time insights into various critical components of the lift, facilitating proactive maintenance and enhancing overall operational reliability.

One of the core features of LIMS is Driving Current Monitoring, which continuously tracks the electrical current drawn by the lift motor. By analyzing changes in current, the system can quickly identify potential mechanical issues or inefficiencies, enabling maintenance teams to address problems before they lead to significant failures. In addition, Suspension Ropes Monitoring is vital for ensuring the structural integrity of the lift. Sensors measure the tension and wear on suspension ropes, providing real-time data that helps prevent catastrophic failures and ensures compliance with safety standards.

To further enhance safety, LIMS incorporates Brake Monitoring and Solenoid Temperature Monitoring. The braking system is crucial for passenger safety, and monitoring its performance ensures that the brakes function correctly and respond promptly in emergencies. Meanwhile, tracking the temperature of the solenoid - which controls the lift doors - helps prevent overheating and potential malfunctions. Additionally, Motor Vibration Monitoring and Motor Temperature Monitoring are essential for detecting issues such as misalignment or overheating, allowing for timely interventions that can prevent more serious problems.

Fig. 10 - Lift Intelligent Monitoring System

Passenger comfort is also a priority within the LIMS framework. The system includes features like Lift Car Ride Comfort Monitoring, which assesses ride quality by analyzing acceleration and jerk during travel. This ensures a smooth experience for passengers.

Furthermore, Floor Levelling Monitoring guarantees that the lift car aligns accurately with each floor, reducing the risk of accidents during entry and exit. Finally, Door Gap Monitoring ensures that the gap between the lift doors remains within safe limits, addressing potential safety risks associated with entrapment.

By integrating these advanced monitoring technologies, the Lift Intelligent Monitoring System significantly enhances the safety and reliability of elevator operations, besides reducing maintenance costs and downtime.

3. OVERVIEW OF SYSTEM ARCHITECTURE AND DATA FLOW

3.1 Timely Data Transmission

Figure 11 illustrates the overall system architecture of the Integrated Centralized Platform solution.

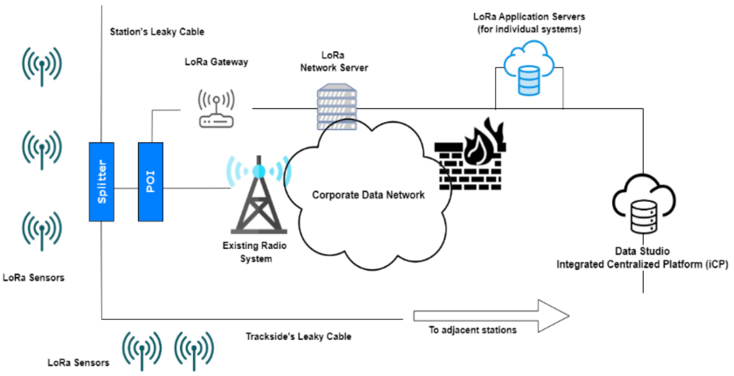


Fig. 11 - System Architecture of Integrated Centralized Platform (iCP)

Integrated Centralized Platform (iCP) composed of two sub-systems, namely LoRaWAN Infrastructure and Cloud Backend.

The Cloud Backend refers to the Cloud-Based Application Platform empowered by the technologies of AI and Big Data Analytic that collect the sensor payload and provide centralized monitoring and management of those critical systems in stations.

In order to ensure compatibility with future development and foster collaboration among our Control Centre, front-line Operation and Maintenance staff, and Data Centre to enhance data-driven decision-making, iCP is structured on a cloud-based architecture, enabling us to develop and deploy applications using a fully managed end-to-end serverless platform.

3.2 Cloud-based One-stop Analytic & Real-time Monitoring Platform

The Integrated Centralized Platform (iCP) is a cloud-based one-stop analytic and real-time monitoring platform designed to facilitate asset monitoring, asset management, and data analytics for railway station equipment. Its advanced features enable engineers, Facility Management Engineering Center, and senior management to effectively utilize innovative technologies for the betterment of cities.

Integrated Centralized Platform incorporates LoRa sensor data collection, gathering information from over 4,000 sensors. These sensors cover a wide range of equipment, including Supply Air Compressors, Escalators, Platform Screen Door/Automatic Platform

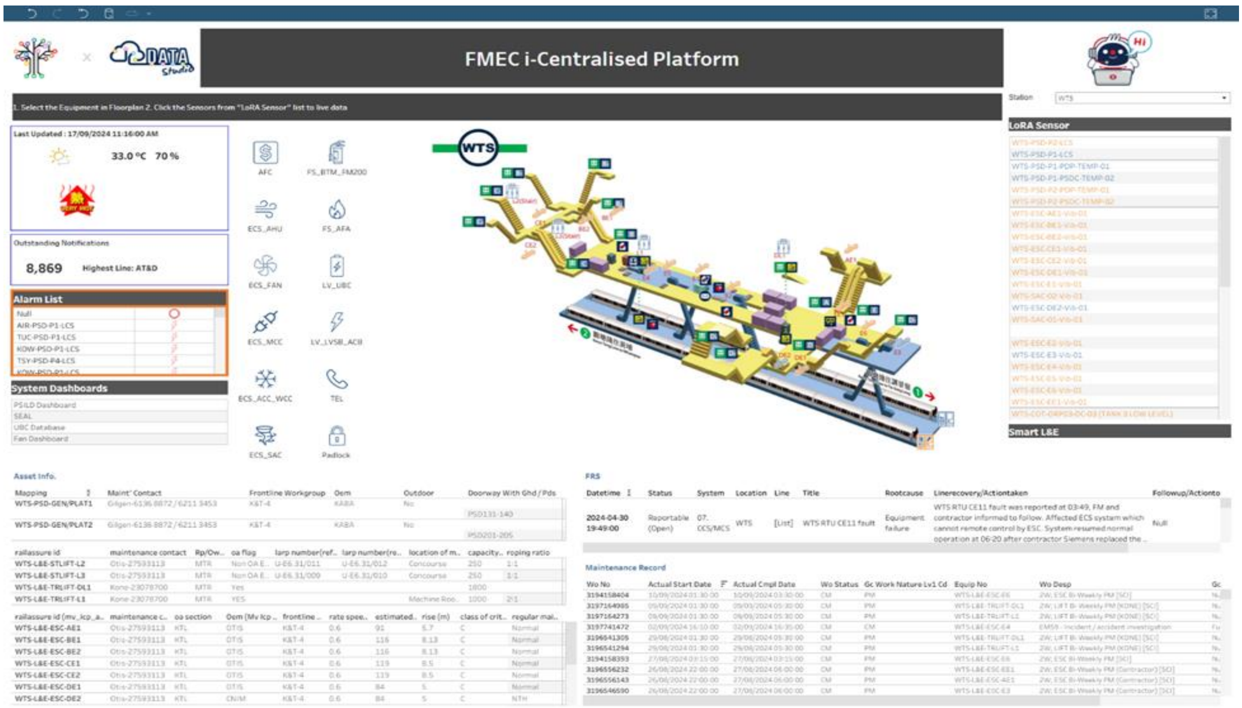


Fig. 12 - Integrated Centralized Platform with Equipment Details & Real-time Alarm

Gate, leakage current detection, cooling towers, and more. By collecting data from these sensors, it provides valuable insights into the performance and condition of various equipment types with analytic dashboards and automatic alarms.

Integrated Centralized Platform integrates over 24 operation and equipment dashboards including but not limited to escalators, platform screen door monitoring dashboard, providing a comprehensive analysis of station facilities. Integrated Centralized Platform can be used to identify maintenance needs, detect potential equipment failures or performance degradation before they occur. This feature is essential for ensuring smooth operation and reliability of critical systems within the railway stations.

3.3 Development of Interactive Dashboards and Alarms for Critical Systems

To visualize real-time alert details, Integrated Centralized Platform utilizes Grafana as a platform for alarm configuration. Over 90 alarm thresholds are created by more than 15 types of equipment. This allows engineers to set up customized alarm thresholds and parameters based on historical data, equipment specifications, and maintenance best practices. By analyzing real-time sensor data and comparing it to established patterns and thresholds, the platform can identify early warning signs of potential equipment failures or deviations from optimal performance for engineers to take proactive measures to address the identified issues before they escalate into major disruptions or failures. The integration of predictive maintenance within the alarm system not only helps in preventing disruptions but also ensures operational efficiency from timely maintenance interventions, such as scheduling preventive repairs or replacements, optimizing maintenance schedules, and reducing unplanned downtime.

iCP includes an all-rounded alarm system that provides comprehensive notification and visibility of alarms. The alarm notifications are displayed in multiple locations, including the main page and station map. The station map features a sensor list for each equipment, using color codes to identify alerts, making it easier for engineers to locate and address issues promptly. Additionally, key stakeholders receive email notifications, ensuring that the relevant parties are informed about critical alarms in a timely manner, facilitating the seamless connection between Things and People.

4. ENHANCING CONNECTIVITY: LEVERAGING ICP TO STREAMLINE PEOPLE-TO-PEOPLE CONNECTIONS

4.1 After the Implementation of iCP: Empowering Seamless Collaboration

In the realm of operational efficiency and effective communication, the integration of iCP presents a transformative solution to connect individuals seamlessly.

Centralized Information Hub: iCP consolidates data from over 24 systems to eliminate data silos, offering a one-stop repository for swift access to crucial asset details. This integration streamlines the response

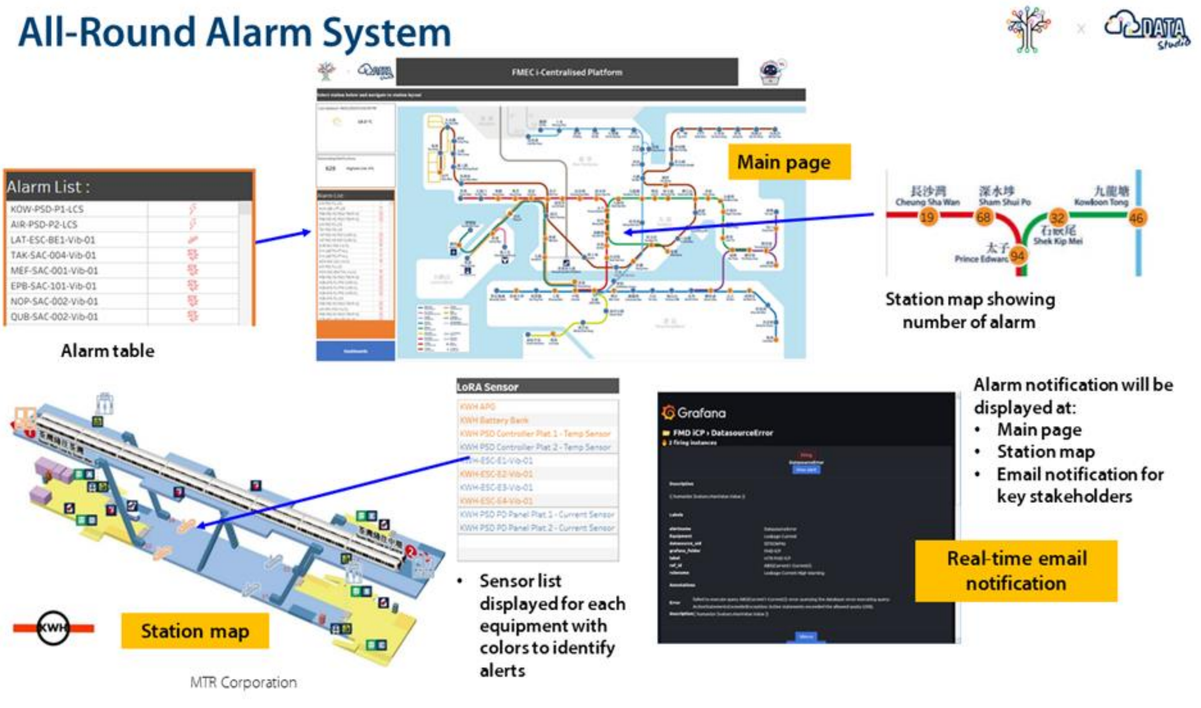


Fig. 13 - Statistical Technique with Time Series Analysis for Predictive Maintenance

process, enabling staff to extract relevant information within minutes, enhancing operational agility significantly.

Real-Time Updates: The centralized hub in iCP ensures that all stakeholders have access to up-to-date information, enabling swift responses to alerts and incidents. Real-time data synchronization across systems ensures that decision-makers are working with the most current information available.

Acknowledgement Feature: Introducing such a feature within iCP alerts revolutionizes communication dynamics. This feature ensures the efficient transmission of alerts and directives across all stakeholders, fostering accountability and task completion. It establishes a structured mechanism for monitoring follow-up actions, driving continuous operational enhancement and optimization.

5. CONCLUSION

In conclusion, MTR strives to create the betterment of society and bring together commuters, families, tourists and professionals by providing a safe and service critical environment.

Throughout the paper, the design of the LoRaWAN Infrastructure has been illustrated with applications of IOT sensors including Hall sensors & LoRa ADC sampling sensors, LoRaWAN dry contact sensors and magnet sensors in the first section.

After that, system architecture of Integrated Centralized Platform (iCP) overview has been introduced with data flow architecture. Moreover, the design of Big Data Analytic Platform has been described, with Cloud-based One-stop Analytic & Real-time Monitoring Platform and the development of Interactive Dashboards and Alarms for Critical Systems

Other than that, the All-In-One & acknowledgement features of Integrated Centralized Platform (iCP) has been introduced for the enhanced connectivity.

The centralized system monitoring and alarm-triggering platform, coupled with real-time IoT sensors, are anticipated to play a crucial role in monitoring station systems and assets. This integrated solution aims to provide valuable insights and decision support by identifying potential risks promptly, enabling timely mitigation measures. Ultimately, this system aims to establish a safe and service-critical environment within MTR, facilitating seamless connectivity between devices and individuals.