THE HONG KONG
INSTITUTION OF ENGINEERS
ELECTRICAL DIVISION

The 40th Annual Symposium
Thursday
20 October 2022

CO-INNOVATION 4O

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

SYMPOSIUM PROGRAMME

08.30 Registration

09.00 Welcome Address
- Ir Mandy M.Y. Leung
  Chairman, Electrical Division, The HKIE

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

09.20 Keynote Speech
- Ir Professor Christopher Y.H. Chao
  Vice President (Research and Innovation)
  The Hong Kong Polytechnic University

1. Sustainability & Switchgear

09.50 Bridging the Engineering & Corporate Sustainability Gap
- Ms Giuliana Auinger, Partner & Vice President, Sustainability Business, Schneider Electric Asia Pacific Ltd.
- Ir Ian Y.L. Lee, Solution Director, Schneider Electric Hong Kong Ltd
- Ms Viki W.T. Tong, Senior Sustainability Consultant, Schneider Electric Asia Pacific
- Ms Kathryn K.H. Chow, Project Engineer, Veolia Environmental Services Hong Kong Ltd.

10.10 F-Gas Free Switchgear - A Real Alternative to SF6 Gas Insulated Switchgear
- Dr - Ing. Karthik Reddy Venna, Product Life Cycle Manager
- Mr Andreas König, Product Life Cycle Manager
- Mr Florian Wolfrum, Product Life Cycle Manager
  Siemens AG, Smart Infrastructure, Germany

10.30 Discussion

10.45 Break

2. Building & Construction

11.15 Innovative Way to Achieve ZERO Harm in Construction Site
- Ir Victor W.F. Tse, Construction Manager
- Ir C.H. Wong, Project Manager
- Ir Harriet Y.H. Chan, Deputy Project M&E Manager
- Mr Herrick H.Y. Chu, Project Mechanical Engineer
- Mr Hans C.H. Cheung, Assistant Mechanical Engineer
  Gammon E&M Limited

11.35 An Effective Approach for Decarbonising Building - Zero Carbon, Digital and ESG
- Dr Tony N.T. Lam, Director
- Mr Felix H.H. Chan, Senior Engineer
- Ms Jill C.Y. Leung, Engineer
- Mr Guo-Jun Li, Engineer

  Arup Climate & Sustainability Group

11.55 Transformation into a Sustainable Wastewater Treatment Works: Yuen Long Effluent Polishing Plant
- Ir Sam C.L. Lui

  Senior Electrical and Mechanical Engineer
  Drainage Services Department
  The Government of the HKSAR

12.15 Discussion

12.30 Break

3. Mass Transit & Electric Vehicles

14.00 Application of Visualized Overhead Line Remote Earthing System in MTR
- Ir William K. F. Lee, Chief Engineering Manager - Services (Capital Works)
- Mr Ken T. K. Yiu, Senior Engineer - Overhead Line (Capital Works)
- Mr David C. W. Lo, Engineer - Overhead Line (Capital Works)

  E&M Engineering Department
  Capital Works Business Unit
  MTR Corporation Limited

14.20 Ammonia Fuel Cells & Its Applications to Electric Vehicles
- Ir Professor Eric K.W. Cheng

  Director
  Power Electronics Research Centre
  Department of Electrical Engineering
  The Hong Kong Polytechnic University

14.40 Design of An Innovative In-wheel Motor for Electric Drive Axle of a 12-Meter Commercial Bus
- Dr Li Chen, Technical Director
- Dr C.P. Lo, Managing Director
- Mr Kenny K.M. Leung, Engineer
- Mr Can C.K. Choi, Engineer

  Green Mobility Innovations Ltd.

15.00 Discussion

15.20 Break

4. Power Systems

15.50 Smart Meter Data-Driven Incipient Fault Detection
- Ir Howard H.C. Wan, Principal Manager - Special Projects
- Ir Eric F.W. Tong, Engineer
  Asset Management Department
- Ir Terry K.P. Fung, Manager - Project Controls & Resources Planning
  SmartGrid & Innovation Department
  CLP Power Hong Kong Limited

16.10 Commissioning of the First F-Class Combined Cycle Gas Turbine (CCGT) Unit Equipped with Selective Catalytic Reduction (SCR) System in Hong Kong
- Mr K.K. Wu, Project Engineer, Mechanical Department, Projects Division
- Mr T.K. Ku, Engineer, Sustainability Department, Corporate Development Division
  The Hongkong Electric Co. Ltd.

16.30 Discussion

16.45 Summing Up
- Ir Y.H. Leung
  Symposium Chairman
  Electrical Division, The HKIE

Closing Address
- Ir Aaron K.M. Bok
  The President, The HKIE

Acknowledgement

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Authors/Speakers

Ir Eric Y.H. Pang, JP
Ir Professor Christopher Y.H. Chao
Ms Giuliana Auinger
Ir Ian Y.L. Lee
Ms Viki W.T. Tong
Ms Kathryn K.H. Chow
Dr-Ing. Karthik Reddy Venna
Mr Andreas König
Mr Florian Wolfrum
Ir Victor W.F. Tse
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Ir Professor Eric K.W. Cheng
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Mr Kenny K.M. Leung
Mr Can C.K. Choi
Ir Howard H.C. Wan
Ir Eric F.W. Tong
Ir Terry K.P. Fung
Mr K.K. Wu
Mr T.K. Ku

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Paper No. 1

BRIDGING THE ENGINEERING & CORPORATE SUSTAINABILITY GAP

Authors/Speakers: Ms Giuliana Auinger, Partner & Vice President,
Sustainability Business, Schneider Electric Asia Pacific Ltd.
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ABSTRACT

Due to the mounting concern of Environmental, Social, and Governance (ESG) criteria, sustainability tops the list of items in most companies' agenda. This is evidenced by the recent soaring trend of sustainable bond issuance in Hong Kong, one of the leading international financial centres. This paper will explain how companies from different fields drive the sustainability development in Hong Kong with a three-level hierarchy model. Clients, including monetary institutes, banks, developers, etc., finance green projects or raise capital via Green Loans, Sustainability Linked Loan (SLLs), and Green Bonds. Consultants, at the same time, are responsible for adopting green and innovative technologies on engineering designs as well as assessing sustainability performance of projects based on BEAM Plus, LEED, and GRESB. Contractors and suppliers such as Schneider Electric Hong Kong (SEHK), play a key role in both provision and configuration of green and innovative technologies, including IoT, BIM, Digital Twin, Machine Learning, AI, etc. The collaboration of these three parties drives the whole sustainability journey in Hong Kong where room for development is still noticeable. Therefore, in this paper, we aim to discuss how these three parties can bridge the engineering and corporate sustainability gap.

1. INTRODUCTION

1.1 Environmental, Social, and Governance (ESG)

Environmental, Social, and Governance, or in short, ESG, are areas to benchmark a company's sustainability performance. Other than the concerns of climate change, the reason why ESG has caught people's eye is mainly a positive link between ESG performance and financial performance or value creation.

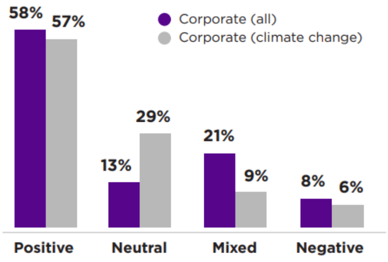

Fig. 1 - Correlation between ESG and Financial Performance (Based on 245 Studies between 2016 and 2020) (Whelan et al., 2021)

Companies managing their ESG risks are likely to stand out among those who do not. According to a study conducted by NYU Stern School of Business, a positive relationship between ESG and financial performance was found in Figure 1 [1] for 58% of the "corporate" studies based on operational metrics such as ROE and ROA. Moreover, the integration of ESG analysis with the evaluation of investment opportunities by Bank of Singapore corroborated the value of ESG metrics in today's financial assessment of a company. By reporting a company's ESG performance based on different frameworks, the reported key performance indicators (KPIs) can impact a company's financial performance and ratings. For example, Hang Seng corporate sustainability index is one of the local indicators that can influence financial corporate's decisions.

With the increasing awareness of ESG from both the public and corporates, sustainability is no longer a slogan, but something to act on.

2. HOW TO ACHIEVE SUSTAINABILITY

This section will detail the structure of the three-level hierarchy model which illustrates the corresponding roles played by different stakeholders in achieving sustainable development.

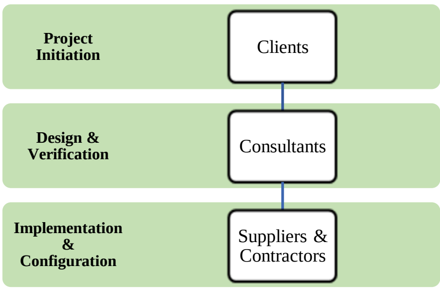

Fig. 2 - Three-layer Hierarchy

2.1 Clients

The first level, clients, including governments, banks, developers, etc., are the main drivers of Hong Kong's sustainability journey considering from financial and governance perspectives. Not only do they help creating environmental value, such a practice can also benefit themselves in terms of finance, compliance, and corporate image.

2.1.1 Finance

Through green financing, clients can issue green loans and SLLs to subsidize eligible green projects based on the following indicative categories:

1. Renewable Energy
2. Energy Efficiency and Conservation
3. Pollution Prevention and Control
4. Waste Management and Resource Recovery
5. Water and Wastewater Management
6. Nature Conservation/Biodiversity
7. Clean Transport
8. Green Buildings
9. Climate Change Adaptation

Green Loans are generally taken out from the government or large corporates to finance green projects that aim to improve the environment and to facilitate the transition to a low carbon economy. Due to its relatively low interest rate, the use of loan is stipulated and continuous report on the project is required. For example, the interest rate at PBoC is around 1.75% for 60% of the green loan, which is similar to the Loan Prime Rate.

Unlike Green Loans, SLLs are any forms of loan instruments which do not need to be allocated exclusively to green project, in other words, no restriction on the use of proceed, with a lower interest rate. SLLs however require borrowers to achieve a certain sustainability performance in light of their predetermined sustainability performance targets as well as predefined KPIs.

Green Bonds are the bonds with a relatively high interest rate issued by the government or large corporate to fund their green projects [2]. Basically, Green Bonds raise fund from the government, large corporates, and public individuals while Green Loans or SLLs raise fund from the first two stakeholders only.

By utilizing the above financial subsidies, clients have an alternative source to provide more financial initiatives for qualified green projects in order to maintain business sustainability.

2.1.2 ESG corporate compliance

Statutory requirements concerning sustainable development, energy usage and saving, and greening become stricter which drive companies to comply with. Taking Building Energy Code of Practice (BEC) as an example, the minimum coefficient of performance (COP) requirement for several categories, such as Unitary Air-conditioner, variable refrigerant flow (VRF) System, and Chiller, has been raised from a lower value stated in the 2018 version to a higher value stated in the 2021 version, which implies a pursuance of energy-efficient equipment from the local government.

Air-cooled VRF Minimum COP at cooling mode (Modular unit of top-discharge fan (s))		
	2018	2021
Capacity ≤20 kW	3.6	3.9
20kW < Capacity ≤ 40kW	3.6	3.9
40kW < Capacity ≤ 80kW	3.45	3.7
80kW < Capacity ≤ 200kW	3.45	3.5
200kW < Capacity	3.3	3.4

Table 1 - Difference in Minimum COP Requirement Difference between BEC 2018 and BEC 2021 [3]

2.1.3 Corporate image

Apart from the above mentioned, issuance of green bonds and loans can improve corporate brand value by attracting investors who value sustainability. With reference to the research issued by HKU Business School, stock prices soar at the same time when green bonds are issued. This phenomenon could be seen from a hike in stock price of one of the sustainability pioneers in Hong Kong, Swire Properties Limited, back in January 2018 after its first 10-year green bond issuance.

Fig. 3 - Stock Price Trend of Swire Properties Limited in January 2018 [4]

Based on the green project updates stated in the 2020 green finance report by Swire Properties [5], apart from fulfilling local and international green building certification requirements, adoption of chiller optimization control systems, PV panel installations, biodiesel tri-generation system are additional engineering design elements that require the technical expertise from consultants and suppliers to be implemented, which will be covered in the following sections. One of the green projects launched by Swire Properties, One Taikoo Place, benefited from HK$3,403 million green bond. With adoption of above green elements, it earned a success in energy saving by more than 33% per annum. This project is also certified with Final Platinum for BEAM Plus, LEED and WELL respectively.

2.2 Consultants

After clients have initiated a green project, consultants in the 2nd level of the hierarchy model, play a role in applying sustainability designs for construction or configuration and evaluating sustainability design in both new and existing buildings. Usually, consultants utilize the following standards to conduct sustainability assessment:

1. BEAM Plus
2. LEED
3. WELL
4. ISO50001
5. GRESB

2.2.1 BEAM Plus

BEAM Plus is Hong Kong's leading initiative to independently assess the sustainability design of a development, with an aim of making buildings more efficient and emitting less carbon [6]. The assessment starts from master planning, building design to construction, and finally fitting-out work. After that, a certification with one of the four grading scales, Platinum, Gold, Silver, and Bronze, will be awarded to projects based on the credit scores in the following 10 aspects:

BEAM plus assessing aspects	
1.	Integrated Design and Construction Management (IDCM)
2.	Community Aspects (CA)
3.	Sustainable Site, Site Aspects (SS, SA)
4.	Green Building Attributes
5.	Management
6.	Materials and Waste Aspects
7.	Energy Use
8.	Water Use
9.	Health and Wellbeing, Indoor/ Outdoor Environmental Quality (HWB, IEQ, OEQ)
10.	Innovations and Additions

Table 2 - BEAM plus Assessing Aspects [7]

2.2.2 LEED

As one of the most widely used green building rating systems in the world, LEED is applicable for virtually all building types, such as new and existing construction, interior fitting-out work, operation and maintenance, and core and shell [8]. Similar to BEAM Plus, it also has four grading scales, Platinum for 80 points or above, Gold for 79 to 60 points, Silver for 59 to 50 points, and certified for 49 to 40 points based on the 7 aspects as listed in Table 3 with respective weightings.

LEED Assessing Aspects		Weightings
1.	Climate Change	35%
2.	Direct Human Health Impact	20%
3.	Water resources impact	15%
4.	Biodiversity Impact	10%
5.	Green Economy	10%
6.	Community Impact	5%
7.	Natural resources Impact	5%

Table 3 - LEED Assessing Aspects (U.S. Green Building Council, 2022)

2.2.3 WELL

The WELL Building Standard™ version 2 (WELL v2™) is a vehicle for buildings and organizations to deliver more thoughtful and intentional spaces that enhance not just sustainability performance, but also human health and well-being supported by the latest scientific research [9]. Platinum, Gold, Silver, Bronze grades will be given to projects that can achieve 80, 60, 50, 40 points respectively. There are 10 areas to consider in the whole assessment process:

WELL Assessing Aspects	
1.	Air
2.	Water
3.	Nourishment
4.	Light
5.	Movement
6.	Thermal comfort
7.	Sound
8.	Materials
9.	Mind
10.	Community

Table 4 - WELL Assessing Aspects [9]

2.2.4 ISO50001

Apart from the standards that focus on assessing the sustainability related aspects in building design and construction phases, ISO50001 sets as a framework to assess the effectiveness of in-house energy management. An effective energy management system helps organizations efficiently manage their energy use, thereby improvement in productivity. It also involves energy policy development and implementation, goal setting for energy use establishment, action plans design for reaching them and measuring progress, new energy-efficient technologies implementation, energy waste reduction, and current processes improvement for cutting energy costs. The whole audit process is listed in Table 5.

ISO50001 Certification Process	
1.	Initial visit
2.	Agreement/contract between CB and the organization seeking ISO5001 Certification
3.	Document review
4.	First stage assessment
5.	Certification audit
6.	Follow-up visit
7.	Surveillance visit
8.	Renewal audit

Table 5 - ISO50001 Certification Process

2.2.5 GRESB

Fig. 4 - GRESB Rating Score (Union Investment, n.d.)

Established in 2009, GRESB is a validated ESG standard for investment of infrastructure and real estate globally, aiming to benchmark the performance of real estate companies in terms of management, performance and development components [10]. Not only does GRESB enhance transparency in ESG reporting, it has recently expanded the scope by mapping to specific features in green building rating systems, such as WELL to report ESG performance in a cross-disciplinary approach.

2.2.6 Popularity of different standards in Hong Kong

Among the five standards mentioned above, GRESB is less popular. For the remaining four, the popularity of them in Hong Kong differs according to the number of registered projects stated on their official websites.

Number of Registered Projects in HK	
BEAM Plus	2026
LEED	342
WELL	193
ISO50001	10

Table 6 - Number of Registered Projects of BEAM Plus, LEED, WELL, and ISO50001 in Hong Kong

As shown in Table 6, BEAM Plus has the largest number of registered projects in Hong Kong while LEED and WELL take the second and third places with a number of 342 and 193 respectively. It is noteworthy that K11 Atelier King's Road developed by New World Development Company Limited (Figure 5) has been awarded WELL Platinum, BEAM Plus Platinum, and LEED Platinum, which is the first building received these three certificates with the highest rating at the same time. This newly built office tower marked a major milestone on the prevalence of these standards. Table 7 gives a summary of common sustainability assessments in Hong Kong.

Fig. 5 – Picture of K11 Atelier King's Road (from New World Development Company Limited. Copyright 2022 by New World Development Company Limited.)

LEED	BEAM plus	WELL	ISO50001	GRESB
1. Climate Change	1. Integrated Design and Construction Management (IDCM)	1. Air	1. Initial visit	1. Stakeholder engagement
2. Direct Human Health Impact	2. Community Aspects (CA)	2. Water	2. Agreement/contract between CB and the organization seeking ISO5001 Certification	2. Performance indicators
3. Water Resources Impact	3. Sustainable Site, Site Aspects (SS,SA)	3. Nourishment	3. Document review	3. Building certification
4. Biodiversity Impact	4. Green Building Attributes	4. Light	4. First stage assessment	4. Monitoring &EMS
5. Green Economy	5. Management	5. Movement	5. Certification audit	5. Risks and Opportunities
6. Community Impact	6. Materials and Waste Aspects	6. Thermal comfort	6. Follow-up visit	6. Policy and Disclosure
7. Natural Resources Impact	7. Energy Use	7. Sound	7. Surveillance visit	
		8. Materials	8. Renewal audit	
		9. Mind		
		10. Community		

Table 7 - Summary of Common Sustainability Assessments in Hong Kong

2.3 Suppliers and Contractors

The last level of the three-layer hierarchy is Suppliers and Contractors who play critical roles in the whole sustainability journey in 2 ways:

1) Provide technologies and products that can support the implementation of sustainability measures with reference to green building design specifications from an engineering perspective.
2) Monitor and visualize the effectiveness of sustainability measures being adopted by data collection.

In this section, several state-of-the-art methodologies of collecting and manipulating data, including Ecostruxure, Digital Twin, and Machine Learning, would be covered.

2.3.1 EcoStruxure

An intelligent platform of 3 layers with working principle of "eco-system", which provides data management securely and efficiently. To make this interoperable, a three-layer system is required to play the role as the foundational technology backbone.

First layer (Connected Products)

Including all physical and digital components adopted and connected for data logging and power products, for instance, sensors, smart meters and even light bulbs. In practical cases, sensors and smart meters would collect information as building data from indoor, depending on the needs of proprietors and tenants. Apart from indoor, outdoor related data like wind velocity, relative humidity and solar radiation could also be found for further processing via various devices and systems.

Second layer (Edge Control)

Edge control is the actual control made locally, which is assisted by the algorithm installed in the edge controllers. The real-time building parameters could be monitored by the Facility Managers and settings may be varied via the edge control system with respect to the actual condition. In reality, IoT could be utilized with

Fig. 6 - Three-layer Architecture of IoT Platform

building management, from measuring parameters like ambient temperature, levels of air pollutants and lighting density.

All of which will improve users' comfort by BMS control such as via HVAC automation.

Third layer (Apps, Analytics & Services)

With the building parameters collected, analysis could provide insights into the current state of the building, to prioritise maintenance and give setting suggestions.

For instance, estimation of assets' failure could be done by the Facility Manager with the assistance of Advisors for monitoring and controlling the assets, such as MCCBs. The time of interruption of devices would be eliminated and unnecessary waste of human power could be avoided, in order to improve the sustainability of power and energy.

It is beneficial to the consultants in designing the buildings, as data collected would be analyzed and verified.

3. DISCUSSION

Due to the COVID-19, demand of digital technology has been escalating recently, consultants and contractors are expected to innovate new engineering design and products to further interlink sustainability with engineering development, and bridge the engineering and corporate sustainability gap in the early stage of a project, while contractor and supplier would take over the role in operation and maintenance stage.

Listed below are the possible solutions regarding linkage of sustainability and engineering.

As the maturity of the IoT technology has improved, different Business Process Management strategies could be carried out, like Examples 1 and 2 below:

Example 1:

CCTV is installed in a lecture hall. In the past, we only record the video image. In fact, using Video Analytics, we could count the number of people in the lecture hall, put the result in level 3 of the IoT Platform for record. Then the HVAC control system could pick this "number of people" figure and use it to regulate the fresh air supply.

Example 2:

A CCTV camera was installed in an atrium viewing the openings of 10 shops. Using Video Analytics, the number of heads coming out from and going in to each of the shops (by counting heads with faces, and heads without faces…) could be counted. This could further be developed into the people flow report against different period of the day and different time of the years to count the people flow. The marketing and leasing department could then use the result to decide the rental rate of the shops based on the people flow analysis.

3.1 BIM for lifecycle solutions

The advancement in BIM has facilitated clients, consultants and contractors in achieving a sustainable building lifecycle. In this section, we will discuss what is BIM and how it can be a digital solution to bridging the sustainability gap.

3.1.1 Building Information Modelling (BIM)

In terms of 7 recognized dimensions, BIM acts as "process of designing and operating a building", which offers advantages in the project lifecycle of design and build, such as providing construction with less wasteful and safer environment [11]. By utilizing threedimensional building modelling software, cross-disciplinary collaboration is achieved.

Dimension		Details
3D	Geometry	Providing 3-dimensional structure geographically
4D	Time	Relating to duration and timeline
5D	Cost	Estimating and analyzing budget
6D	Sustainability	Studying impacts to environmental, economic, and social sustainability
7D	Facility Management	Assisting the maintenance management with respect to buildings' lifecycle

Table 8 - Dimensions of BIM

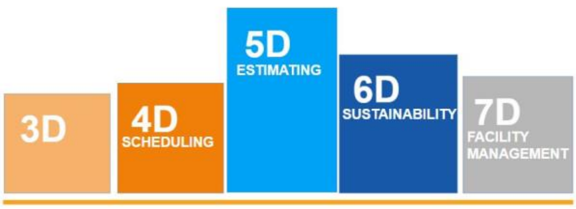

Fig. 7 - 7 Dimensions of BIM Execution Plan (Autodesk, n.d.)

3.1.2 The role of consultants and BIM

When consultants are designing a building, instead of drawing the layout plan, we could use BIM to simplify the process. Features, such as windows and staircases, can be dragged and dropped into the design frame. Coupled with the operating parameters, the software can automatically generate the 3D image and model of the building. With additional E&M components, the changes in parameters can be calculated accurately, with reference to the existing project data base. Altogether the software can learn from the previous projects, and construct a better model with improved performance in various aspects. For example, the software can suggest the ideal window size, by estimating the OTTV based on previous data.

However, simplifying the design process alone, cannot achieve sustainability. A sustainable and resilient building must have excellent energy performance, which can be accounted for, by BIM. The foundation of a smart energy management is to estimate the electrical load. In BIM, one can easily allocate electrical devices into rooms. Combined with parameters such as rating and sizing, electrical routing can be automatically generated. This could also be done, using tools such as ETAP (electrical transient analyzer programme) and Hevacomp, which synchronise the schematic diagram with the layout drawings.

ETAP enables simulation, efficient design, monitoring, control, operator training, optimizing, and automating power systems, an integration for electrical digital twin platform and delivers the intelligent solution for enterprise. It could provide collaboration with Revit in transferring electrical data and connecting them, such as validate BIM design with ETAP and reduce cost.

By automating the above process and storing data in cloud, stakeholders can immediately visualize building performance. Visualizing data such as energy performance, operating and maintenance cost not only help with assessing the winner of the bid but also allow designer to improve the sustainability of a building.

3.1.3 Technological advance in BIM for contractor and clients

With the designing phase completed, consultants must collaborate with contractors on the construction phase. The traditional way of communication by printout documents has led to detrimental mistakes and misunderstanding such as losing copies. BIM tackle this problem by allowing collaboration of different parties on the same design. By looking at the same model, contractors can select the most sustainable and efficient equipment. For example, utilizing weather data to define the specification. From that, they could select the best combination of products that reduce HVAC energy consumption.

Recently, many contractors are discovering the advantages of 6D BIM, known for its sustainability potential, it generates the simulation with numerous combinations for the building being designed, such as the materials used, users could select different materials with respect to the outdoor environment [12]. Since different materials contribute to carbon footprint emission correspondingly, it could easily generate the estimated building embodied carbon of related selection, and we could decide the most appropriate materials after considering the factors. For example, options are provided for selecting window glass from China or France separately with identical quality. For a proposed building in Hong Kong, the system would show the carbon emission of whole building with all associated material. It could easily observe that the carbon emission of French glass is much larger due to transportation. This helps to deliver a green building solution in a comparatively more eco-friendly and safer way by carbon auditing scope 3.

The same software could be handed over to the clients and facility manager (FM) once the construction is completed. In this operation and maintenance stage, real data are captured to update the assumed parameters in the design phase. This provides real-time building performance that stem from historical data. From the performance, the model can perform sustainable RCx (Retro-commissioning) automatically, to optimize each equipment such as chiller, pump and AHU, etc. All of which greatly save the energy cost.

To take one step further, we could integrate AI and Machine Learning into existing system [13]. For example, certificates of sustainability or green building assessments could be generated to designers automatically, like BEAM plus and LEED. Since the system has been input the certifying information, the assessment is performed by examining if the building meet the standard or not.

The designers could select the target rating specified by the clients, then the related requirement would be shown as a table in the system. Moreover, the intelligent system would also suggest the alternative design of the building if it does not meet the related requirement. The building could become more sustainable by referencing to the previous projects and achieve the desired green building certification.

3.2 Digital Twin

A BIM model can be enhanced with a digital twin, a virtual replica of both living and non-living physical assets and systems. This offers the facility manager (FM) to visualize the dynamic environment in real-time while enabling more efficient allocation of resources.

An escalating trend in adopting digital twin could be found in both public and private sectors in Hong Kong, with two examples shown below:

> *Example 3:*
>
> *Gammon Construction, a leading contractor in Hong Kong, adopted concrete "digital twin" integrating sensors in detecting the curing rate with BIM [14]. This allowed a digital twin of on-site concreting and also real-time data like pours visibility and rate of curing. It is beneficial to various stakeholders, in terms of clients, consultants and contractors, which allows considerable manpower-saving and avoidance of potential human error. Moreover, this innovative project also brought benefits in carbon reduction, in saving over 110 tons of concrete waste.*

> *Example 4:*
>
> *One of the local examples is the Hong Kong University of Science and Technology (HKUST), digital twin is connected to BMS, enabling numerous of extra supports, which give the monitoring of real-time condition, simulations for a more environmental -friendly campus, and increasing efficiency of serval building services systems [15]. The digital twin could also act as the reference for indicating current room availability to users, by showing floor plans with different colors.*

3.3 IoT for Carbon Auditing (Scope 1, 2, 3)

The mounting pressure on consultants, contractors and clients to reduce their carbon footprint has brought great concern on carbon reporting. Carbon auditing is an increasingly popular method for transparency in emission data. It is a method to measure the emission of greenhouse gas of an organization and building within a defined system boundary, which follows the three scopes shown below.

Scope 1 refers to the greenhouse gas emissions from organizations **directly**, such as the pollutants come from the vehicles and equipment owned by them.

Scope 2 is the **indirect emissions** from the generation of electricity and energy they purchase, or any usage of energy consumed by the reporting organization.

Scope 3 covers all other indirect emissions **associated with the company's value chain**, for example from the company's products while customers are using them.

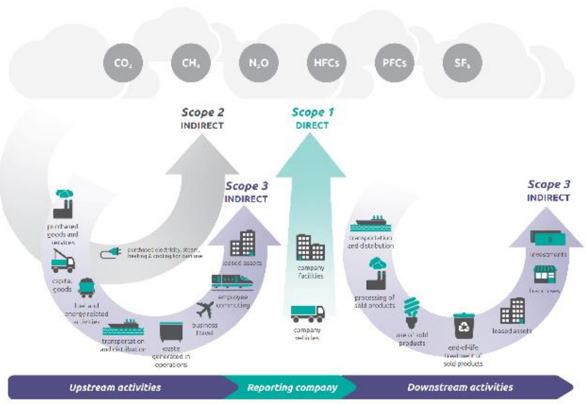

Fig. 8 - Scopes of Carbon Auditing (Compare Your Footprint, 2018)

Digital solutions such as the EcoStruxure Building and Resource Advisor, aim to simplify the process of carbon reporting, using IoT and artificial intelligence. Connected products such as sensors could be installed across clients' infrastructure. These communicate with edge control solutions, which monitor and visualize the trends in carbon and energy data. Ultimately, the top analytic level uses these data to provide smart insights, onto how users can improve their sustainability performance.

By utilizing the three-level structure, IoT solutions can generate reports for carbon auditing, provide suggestions on energy performance, and most importantly, lead us towards a sustainable and resilient urban future.

From the above discussion, it is clear that digital technology is the key towards bridging the engineering and corporate sustainability gap. Solutions such as BIM and digital twin should be utilized by clients, consultants and contractors to make the most out of their energy and resources. Together with IoT and artificial intelligence, sustainable lifecycle solutions are clearly attainable.

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Paper No. 2

F-GAS FREE SWITCHGEAR – A REAL ALTERNATIVE TO SF6 GAS INSULATED SWITCHGEAR

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ABSTRACT

Sulfur hexafluoride (SF6) is widely used in electrical switchgear equipment at both medium and high voltage, due to its excellent insulation and arc quenching properties and thus ensures a safe and reliable power distribution in the networks. In medium voltage gas-insulated switchgears (GIS), SF6 gas is predominantly used as an insulating medium as well as interrupting medium for load-break switching applications. However, SF6 has a Global Warming Potential (GWP) of 25200 times higher than CO2, it is thus considered as one of the strongest greenhouse gases. When emitted into the atmosphere, often during decommissioning of the switchgear, SF6 gas stays in atmosphere for up to 3200 years and contributes to Global Warming.

Various fluorinated gas (F-Gas) regulatory bodies like European Commission, or California Air Resources Board (CARB) call for alternatives to SF6 gas for both insulation and switching behavior of the switchgear. This led to various alternatives currently available in the market from different manufacturers. Each of them has different characteristics and handling needs when compared with today's SF6.

1. Clean Air/Dry air/Synthetic air – Mixture of N_2, O_2, CO_2
2. C5-FK (Fluoroketone $C_5F_{10}O$) mixed with N_2, O_2, CO_2
3. C4-FN (Fluoronitrile C_4F_7N) mixed with N_2, O_2, CO_2

Many third-party institutions have done their individual analysis of these alternatives and published their technical brochures. In this paper, a summary of these analyses is presented with additional experiences from F-gas-free solution from Siemens AG where "Clean Air" alternative is used. It covers different aspects like environmental, health and safety, gas stability and gas handling which are important for evaluation of switchgear solutions over the entire lifecycle. It is also discussed how the proven vacuum technology is used along with "Clean Air" in order to replace SF6 as an interrupting medium in load break switch applications instead of using other F-Gas alternatives.

1. INTRODUCTION

Gas insulating switchgear (GIS) is one of the key component in the medium voltage network for reliable supply of power from source to load. These switchgear have been using SF6 gas as insulating medium and for current interruption because of its excellent properties for these tasks for more than 40 years. SF6 is a reliable gas and is neither toxic nor flammable and does not have any carcinogenic, mutagenic or repro toxic (CMR) characteristics. However, it shows a high global warming potential (GWP) of 25200 according to European F-Gas regulation [1]. For this reason, several countries are planning to ban SF6 usage in switchgear and deadlines have been set for certain ratings already in some of these countries. In the medium voltage distribution sector, SF6 free switchgear like Air Insulated Switchgear (AIS) and Solid Insulation Switchgear (SIS) are available and have their niche customers. However, to replace SF6 GIS with these alternatives is not preferred due to limitations such as size, risk of fire and lower flexibility and customization.

Fig. 1 - 36kV Indoor MV Switchgear Comparison (AIS on left, SF6 GIS on right). [2]

Thus, for the past several years the focus has been turned towards the development of SF6-free alternatives for the GIS while keeping its key features of compact size, flexibility, and reliable operation. Today, there are three key alternatives existing in the market from various GIS manufacturers.

1. Clean Air/Dry air/Synthetic air – Mixtures of N_2, O_2, CO_2
2. C5-FK (Fluoroketone $C_5F_{10}O$) mixed with N_2, O_2, CO_2
3. C4-FB (Fluoronitrile C_4F_7N) mixed with N_2, O_2, CO_2

These three alternatives can be further categorized under two types:

1. F-Gas free alternatives: Mixtures of natural origin gases such as N_2, O_2 & CO_2 at their respective proportions are being used. These gas mixtures do not contain any artificial chemicals and fluorinated components.

2. F-Gas alternatives: Two types of F-Gas alternatives are currently available in the market where a fluorinated compound called fluoroketone (C5-FK) mixed with N_2, O_2, & CO_2, and fluorinated compound called fluoronitrile (C4-FN) also mixed with N_2, O_2, & CO_2 combinations.

In this paper, the status of various regulatory frameworks in limiting SF6 gas usage and a simplified comparison between the above-mentioned alternatives together with SF6 gas is discussed. Furthermore, a short introduction is given to Siemens F-gas free switchgears that are currently available.

2. F-GAS REGULATIONS AROUND THE WORLD

The Kyoto Protocol (1997) aimed to reduce the emission of gases that contribute to global warming. SF6 was listed and its potential impact on environment when released into the atmosphere has become the subject of regulatory policies internationally [19], as summarized below.

In 2009, the U.S. Environmental Protection Agency (EPA) published a regulation for the mandatory reporting of greenhouse gases (including SF6) from large emissions. This was quickly followed by California Air Resources Board (CARB) and Massachusetts Department of Environmental Protection (MDEP) with their own SF6 emissions reporting regulations. In 2020 CARB even proposed phase out dates for SF6 usage for different rating levels.

In 2014 the European Commission passed the Regulation No 517/2014, commonly known as the “2014 F-gas Regulation.” This Regulation strengthened the previous measures and introduced far-reaching changes by: (1) Limiting the total amount of the most important F-gases (HFCs) that can be sold in the EU. (2) Banning the use of F-gases in many new types of equipment where less harmful alternatives are widely available, and (3) Preventing emissions of F-gases from existing equipment by requiring checks, proper servicing, and recovery of the gases at the end of the equipment's life and a certification of personal managing such gases.

Currently a new proposal for the review of the EU F-gas regulation [1] is drafted, which also include dates of prohibition of usage of SF6 with GWP 25200 in electrical switchgear for different voltage levels.

In Asia, there are currently no separate SF6 regulations in place focusing the T&D operators. However, countries like Japan, South Korea, and China have introduced their own restrictions on SF6 usage. In Japan the switchgear manufacturers and utilities have created their voluntary action plan in late 1990’s to reduce SF6 emissions, improve SF6 inventory tracking and also developing alternative solutions.

China is now considering new regulations or standards to further reduce SF6 usage and emissions. This led to a dedicated working group with switchgear OEMs, utilities, O&G companies to investigate the use of SF6 in power industry and potential measures to reduce its usage and also find alternatives to SF6.

3. WHY F-GAS FREE ALTERNATIVES FOR SF6

Finding an alternative to SF6 that can exactly match its properties is not possible as a single gas compound. The focus of recent research activities on SF6 alternatives is either on only natural origin gases or fluorinated gas compounds with natural origin gases as carrier gases.

Any potential alternative must have a low GWP and be compliant with the strict criteria that current switchgear must meet [2] [3]. These specifications include:

1. Sufficient dielectric strength even at low operating temperatures.

2. Good arc quenching and current interruption capability especially for load current switching capability for MV load switches.

3. Minimal environmental impact i.e. having low GWP and showing no ozone depletion potential (ODP), no water pollution potential, etc.

4. Stable behavior over lifetime, even under electrical stress and compatibility with switchgear materials.

5. Sufficient heat dissipation and heat capacity for current carrying purposes.

6. Applicable for indoor and outdoor switchgear down to ambient temperatures of at least -30ºC.

7. Health & safety aspects i.e, non-toxic or have a low acute toxicity, be non-carcinogenic, nor mutagenic, nor repro-toxic, generate no toxic metabolites.

8. Reasonable in availability of the gas by multi-sourcing on the market and at affordable costs.

9. End of life gas handling.

In 2017, there was a comparison made on SF6 alternatives based on the knowledge standpoint at that time. It was summarized in Figures 2.

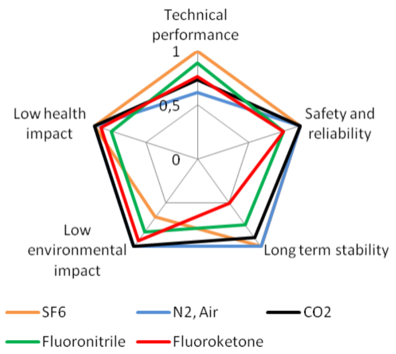

Fig. 2 - Comparison of SF6 Alternatives based on Different Criteria [4]

Considering low environmental and health impact as well as safety and reliability during operation and handling of the equipment, the natural origin gases have promising properties.

In the current paper, an updated evaluation of these alternatives with current state of the knowledge is made for each key specification listed here.

3.1 Dielectric Strength

This is one of the important features of the switchgear that ensures reliable operation of the equipment throughout its lifetime and at all possible temperatures. SF6 gas has excellent dielectric properties which applies for temperatures ranging from -40°C to 55°C. On the other hand, none of the alternatives can match with excellent SF6 properties at a given pressure except GWP.

A series of tests on various simplified arrangements and a variety of gas mixtures at different pressure levels had been done [5]. One of such arrangements and the respective results are shown in Figure 3. It is evident that C4-FN showed similar results as SF6 and both C5-FK and natural origin gases are lagging at the chosen pressure levels.

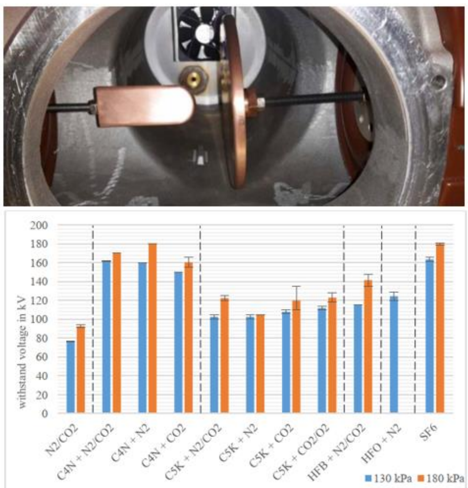

Fig. 3 - Average Withstand Voltages for the Given Arrangement with 130 kPa and 180 kPa, only Critical Polarities

The natural origin gases showed improved withstand voltages up to 43% when the pressure rises from 130 kPa to 180 kPa absolute and offered further potential at higher pressures to fulfil the insulation level for rated voltages up to 40.5 kV. The filling pressures of existing SF6 switchgear is in the range of 50 kPa (rel.) up to 120 kPa (rel.). For natural origin gases higher filling pressure within the hermetically sealed vessels are required. For welded stainless-steel vessels, the target is filling pressures up to 100 kPa (rel.). For aluminum alloy casted vessels, the filling pressure is targeted to be up to 250 kPa (rel.) [6]. This proved that with an optimized switchgear design with e-field uniformity measures and right selection of pressure, the medium voltage switchgear will achieve the same technical ratings of a SF6 switchgear by keeping the same dimensions and footprint as SF6.

The F-gas alternative mixtures performed better at dielectrics but unfortunately restricted by their high boiling points to a limited partial pressure that cannot be increased as shown in Figure 4. It is a challenging task for F-gas alternatives to work in lower temperatures thus limiting their applications in cold countries.

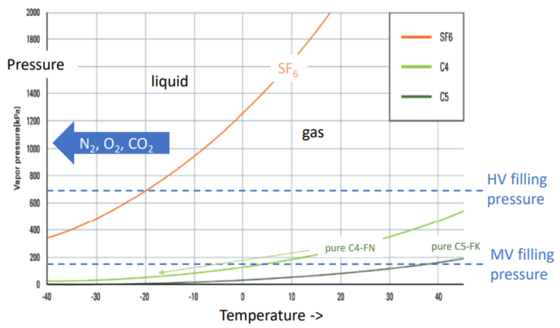

Fig. 4 - Temperature vs Pressure Dependence of C5-FK & C4-FN Gases

3.2 Arc Quenching and Current Interruption Capability

For the arc quenching and current interruption capability in the medium voltage switchgears, vacuum circuit breakers (VCB) are being used for decades proving their reliability in SF6 gas insulated switchgears. Thus, for primary distribution switchgear, alternative gases are used only as insulating medium, keeping VCBs further for current interruption.

For secondary distribution switchgear, load current interruption is done in SF6 gas. For SF6 free switchgears, this calls for two options. Either use the same alternative gas for load current interruption or implementing a vacuum interrupter for load break switching applications [7].

As switching in C5-FK or C4-FN could lead to gas decomposition with toxic byproducts which in an unexpected event can even be released into atmosphere [8][9], designing an innovative switch with vacuum interrupter in auxiliary path has been considered as a reliable and effective solution.

More detailed information about this innovative solution is described in Section 4.

3.3 Environmental Impact

The sole reason for searching alternatives for SF6 gas is because of its detrimental effects on climate change due to its high GWP of 25,200. This means the alternatives shall not be in any case create another detrimental effect on environment.

Natural origin gases like example N_2, O_2 & CO_2 – have no Ozone Depletion Potential (ODP = 0) and a very low Global Warming Potential (GWP $\leq$ 1). Furthermore, they are extremely stable, non-toxic, non-flammable and suitable for all operating temperatures. Their climate impact is also very low, presenting no risks when released into the atmosphere, during operations or at the end of its lifespan.

The F-gas alternatives on other hand like C4-FN have a GWP of ~ 2750 [1] and when used in mixture with dry air, its GWP ~ 700, calculated based on formula in EU F-Gas regulation. The C5-FK has a GWP < 1.

The new draft proposal of EU F-gas regulation shows the way for natural origin gases with some exceptions allowed for GWP > 10. However, it is foreseeable that this value could be further reduced in the next step. This would put the usage of C4-FN under risk in EU region.

With respect to C5-FK, when escaped or leaked into the air, it is demonstrated that under the light energy it can be decomposed in air as illustrated in Figure 5 [10]. The main element of its degradation is trifluoroacetic acid (TFA) and perfluorocarboxylic acid (i-PFBA). The TFA in particular is rapidly separated into water droplets and reach the land and oceans via rain, snow and fog. TFA is classified as “Harmful to aquatic life with long lasting effects” in its material safety datasheet. In addition, as TFA is a strong acid, it readily forms trifluoroacetate salts with minerals in soils and surface water.

Both gases are belonging to PFAS (Per- and polyfluoroalkyl substances) category. They are considered as Forever Chemicals. These gases are currently subject to a restriction proposal made by 4 EU Member States (Germany, Netherlands, Sweden, Denmark) and Norway, under the REACH Annex XV Restriction Dossier [11].

3.4 Gas Stability

The lifetime of the gas mixtures must be aligned with the expected lifetime of the switching equipment. Various ongoing installation must give additional information on the stability of the mixtures and the long-term behavior of the alternative gases for the two key properties - insulation and arc quenching when applicable.

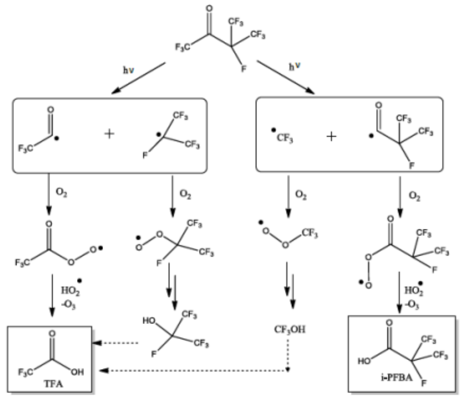

Fig. 5 - Atmospheric Decomposition Path of C5FK after Photolysis

One important factor to consider while evaluating the stability of the gas during lifetime is their leakage rates. The state-of-the-art leakage rates as per the standard IEC62271-1 is 0.1%/yr. This is currently guaranteed by switchgear manufacturers based on the intensive tests.

The “permeation” issue for all alternatives which are using natural gases as main gas or carrier gas is not an issue with the availability of various sealing materials with very low permeation coefficient [12]. With right sealing material and right switchgear design, it is proved that leakage, due to permeation, can be drastically reduced thus ensuring the gas stability during the lifetime and fulfill the requirement of sealed for life.

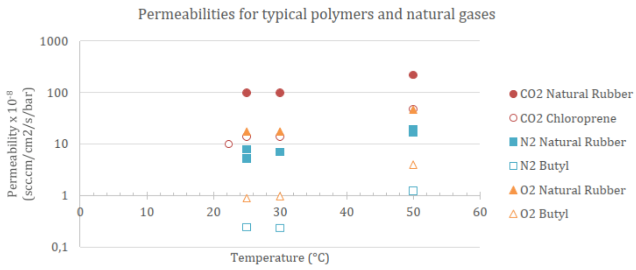

Fig. 6 - Permeability Coefficients for Different Possible Rubbers used for Sealing and Gases [12]

3.5 Health & Safety

Health and safety aspects are one of the most critical factors while selecting the alternative gases for SF6. A detailed analysis has been done by authors in [13] and the summary is shown in Figure.7. Various scenarios of gas decompositions are evaluated like decomposition under partial discharges, under arced conditions. In principle, the PPE used for arced SF6 (see Annex B in IEC 62271-4 [14]) is adoptable to arced non-SF6 gases and gas mixtures. For natural origin gases like Synthetic air, less personal protective equipment is needed compared to SF6 [15]. However, in case of F-gas alternatives where Perfluoroisobutene (PFIB) is expected to occur as byproduct, a self-contained breathing apparatus is strongly recommended since conventional gas filter masks may not be effective against PFIB.

3.6 Heat Dissipation

Heat dissipation of all the studied alternatives is reported to be lower than SF6. Thus, design changes are necessary to reach same values as of SF6 [12].

Gas	Sulfur hexafluoride	Synthetic Air	Carbon dioxide	Fluoronitrile (C4N)	Fluoroketone (C5K)
Chemical Formular	SF_6	N_2 (80% ± 1%) + O_2 (20% ± 1%)	CO_2	$(CF_3)_2CFCN$	$(CF_3)_2CFC(O)CF_3$
CAS No.	2551-62-4	7727-37-9 (N_2) 7782-44-7 (O_2)	124-38-9	42532-60-5	756-12-7
Molar mass	146,1 g/mol	28,8 g/mol	44,0 g/mol	195,0 g/mol	266,0 g/mol
$GWP^1{}_{100}$	22.800	0	1	2.100	<1
ODP[2]	0	0	0	0	0
Boiling point at 101 kPa	-64°C	< -183°C	-79°C (sublimation)	-4,7°C	26,9°C
OEL[3] (ppm_v)	1.000	-	5.000	65	225
LC50[4] 4h rat (ppm_v)	>>10.000[5]	-	>>10.000[5]	>10.000 <15.000	>10.000 < 20.000***
Decomposition temperature[6]	500°C	~7.000°C (N_2) ~4.000°C (O_2)	> 2.000°C	> 700°C	~727°C
Water solubility	31 mg/L	20 mg/L (N_2) 39 mg/L (O_2)	1700 mg/L	0,272 mg/L	<0,001 %wt
CMR[7] effects****	none	none	none	Not mutagenic[8] CR: Not classified	Not mutagenic[8] CR: Not classified
Additional gases used for gas mixtures	N_2 or CF_4	-	O_2 N_2	CO_2 / $CO_2 + O_2$	$CO_2 + O_2$ synthetic air
Main decomposition products of gas mixtures**	Sulfur compounds, HF, metal fluorides	NO_2, NO metal oxides	CO carbon soot	organofluorine compounds and powder, CO, HF	organofluorine compounds and powder, CO, HF

* note that values given in table 1 can differ between different countries and change with newer versions of safety data sheets
** decomposition products may occur in low concentrations e.g. due to electric arcing, material incompatibility or hydrolysis
*** C5K itself is actually a liquid. As a consequence, the inhalation toxicity assessment is made as a vapour
**** it is important to note that stricter OEL values apply, if non-SF_6 gases with CMR effects are used

Fig. 7 - Overview of Gas Specific Properties when Assessing EHS Aspects [13]

3.7 Reasonable Availability of the Gas

This is an important criteria for the users in terms of gas handling and re-filling process. At the moment the F-Gas alternatives C5-FK & C4-FN are considered as a single source alternative manufactured by chemical company 3M. Since they are artificial chemical gases with a relatively complex structure, it could be difficult to have more companies that can manufacture these gases. They are currently only available under the brand name Novec™ 5110 & Novem™ 4710 respectively by 3M. Due to this reason, with less production sites, the cost of transportation of medium can be expensive and shall be considered by customers.

The natural origin gases on the other hand are the mixture of atmospheric gases and can be manufactured easily. There are many companies that are currently offering these mixtures like Linde, Air Liquide etc.

3.8 Gas Handling & End-of-life Procedures

The gas handling and End-of-life (EoL) treatment is important factor for the MV switchgear. Especially in case of repairs inside gas tank at site, C5-FK & C4-FN/air mixtures must be handled with a specific gas handling equipment. Also, the gas handling equipment will be complex and only a certified training personal should do the task.

Equipment with natural origin gases will be easier to handle and reduce the service efforts at site. When it comes to EoL treatment, the natural origin gases can be released into the atmosphere.

For both C5-FK & C4-FN for ecological and economic reasons they should be handled using closed-loop practices in order to reclaim the used material. As used gases for the alternative gas mixture can contain more hazardous decomposition products, end of life procedures have to be developed. Also reusing C4-FN or C5-FK by adding fresh gas to the production process, as commonly employed for SF6, is technologically not feasible. A detailed procedure of EoL treatment of these two F-gas alternatives are given in [16].

Based on the above parameters, it is clear that F-gas free alternatives like natural origin gases are the reliable and ecologically best alternatives for SF6 instead of F-gas alternatives that are currently available in the market.

Siemens has developed environmentally, and climate-friendly gas insulated switchgear (GIS), called blue GIS [17]. Based on natural-origin components of the ambient air, our **"Clean Air"** solution is not only SF6-free but also F-gas free, being extremely stable, non-toxic, non-flammable and suitable for all operating temperatures. All of these with the switchgear having the same footprint at today's SF6 solutions. More information about Siemens F-Gas free switchgear is given in the following section.

4. SIEMENS F-GAS FREE SWITCHGEARS

Siemens has been working on fluorine-gas-free switchgear for several years under blue GIS portfolio. The basis of the blue GIS is using Clean Air as an insulation medium, and vacuum interrupter for current interruption and arc quenching by keeping the well-known advantages of gas-insulated switchgear as shown below. The Siemens "blue portfolio" already includes F-gas-free solutions for the 12 kV and 24 kV voltage levels. Siemens has solutions in service for both primary and secondary 12 kV gas-insulated systems, while the first 24 kV solutions are already deployed, and 40.5 kV versions are going to be introduced accordingly. In total, several thousand solutions are installed in the field.

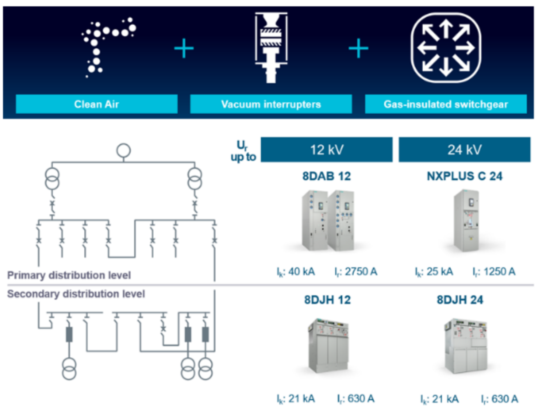

Fig. 8 - Siemens Blue GIS Advantages and Portfolio

In the primary distribution level, the following switchgear are available as blue GIS.

8DAB 12: It is a sealed for life, single phase encapsulated single busbar (SBB) & double busbar (DBB) switchgear with busbar compartments filled with Clean Air. With its design, phase-to-phase faults are completely eliminated which increases the safety and reliability of the switchgear. Also due to its modular concept, it allows good flexibility in design optimization based on the individual project requirements keeping the same footprint as todays SF6 design.

Fig. 9 - 8DAB12 Switchgear SBB & DBB up to 12kV, 40kA & 2750A

NXPLUS C 24: The hermetically sealed NXPLUS C 24 is environmentally independent, and its compact dimensions allow efficient use of space for the 24kV Level. Furthermore, it can be easily combined with the existing SF6 switchgear installation, which make it attractive for substation extension or mixed line-ups where F-gas-free solutions are not yet available.

Fig. 10 - NXPLUS C 24 Switchgear SBB up to 24kV, 25kA & 1250A

8DJH: For secondary distribution, the products 8DJH 12 and 8DJH 24 having high modularity allows an efficient use for all kind of configurations up to 12 kV and 24 kV voltage level with same compactness as of today. Especially where space is limited for ring-main-units, it is essential to have the same footprint and features like environmental independency or operating temperatures. Both switchgears are available in different single-feeder or block versions. Typical types are ring-main feeders with load-break function, transformer feeders with switch-fuse combination and circuit breaker feeders.

Fig. 11 - 8DJH 12 RRL (left) Switchgear up to 12kV, 21kA & 630A, 8DJH 24 RRT (right) switchgear up to 24kV, 21kA & 630A

The heart of the new ring-main-unit switchgear is the innovative load-break switch with vacuum interrupter in the auxiliary path. The Siemens blue switch uses a specially designed vacuum interrupter which is used to quench the switching arc of load breaking current. Functions like switching ON, main current flow, short-circuit making capability are implemented, and meeting the isolating distance requirements in a F-gas free Clean Air gas. The compact dimension of the blue Switch enables compact switchgear design by using the same operating principal as that of SF6 switchgear [18].

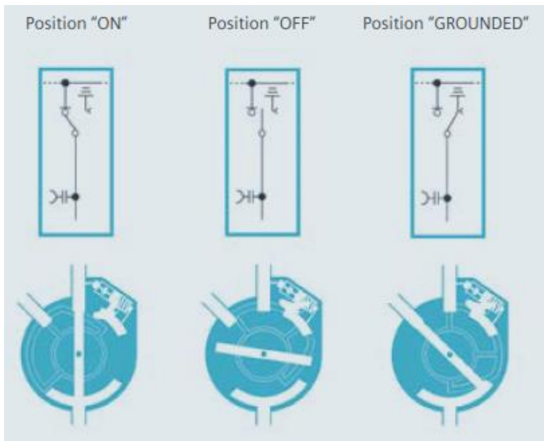

Fig. 12 - Blue Switch with Positions (diagram) of the Switch Disconnector with Vacuum Interrupter

5. CONCLUSION

In this paper various topics regarding SF6 alternatives are discussed in detail, with a key focus on three different alternatives that are currently available in the market. A comparison of these alternatives has been done based on the crucial features that are expected for an SF6 alternative switchgear. In table 1 below, the summary of the comparison is given.

It is evident that F-Gas free alternatives are the only alternative for SF6 that fulfill all the key features required and, in some cases, even better than the SF6 like Environmental, Health and Safety aspects.

Key criteria for SF_6-free alternatives	SF_6	F-gas free alternatives	F-Gas alternatives
Dielectric strength	★★★	★★ ★★★ At higher pressure	★★★
Arc quenching and current interruption	★★★ (in VCB) ★★★ Load break in SF_6	★★★ (in VCB) ★★★ Load break in Vacuum	★★★ (in VCB) ★★ Load break in alternative gas
Impact on environment	★	★★★	★★
Health and safety	★★	★★★	★★
Operating temperatures	★★★	★★★	★★
Availability of the gas	★★★	★★★	★
Gas handling & End-of-life	★★	★★★	★
Regulations & Restrictions	★	★★★	★

Table 1 - Comparison of F-gas Free Alternatives and F-gas Alternatives in terms of Key Features for SF6-free Switchgears

In addition to the above comparison, an update on F-gas regulations around the world has also been summarized. Furthermore, a simplified overview of Siemens blue GIS portfolio is shown where an F-gas free insulating medium called Clean Air is used which the combination of natural origin gases like N2, CO2 & O2. This gas has showed a potential that the blue GIS will also be available up to 40.5 kV in the coming future.

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Paper No. 3

INNOVATIVE WAY TO ACHIEVE ZERO HARM IN CONSTRUCTION SITE

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ABSTRACT
ZERO Harm is always the first priority and core value in the construction industry. The world is facing a new industrial revolution marked by the rise of digital technology. In construction site, several innovative ways such as 5G smart infrastructure, Common Data Environment (CDE) and Digital Work Supervision System (DWSS) have already been incorporated with the traditional site safety management to ensure a smooth and safe construction process. 5G mobile network links everyone and everything together to accelerate the process of digital transformation in construction site; CDE is a digital information platform that centralizes project data storage and access; and DWSS digitizes all the inspection processes and helps to communicate and address safety related issues in real-time to enforce standards across the projects. With the help of digital technology, it is for sure that the site safety risk can be minimized, and Digitalization can transform site safety management to a more effective manner.

1. INTRODUCTION

1.1 Digitalization at Construction Industry

The world is facing a new industrial safety revolution marked by the rise of digital technology. Although there has been progress towards digitization, the construction industry still trails behind compared to other industries like retail and manufacturing. There is always a continuing challenge when it comes to fixing the basics. Project planning, for example, remains uncoordinated between the office and the site and is often done on paper, performance management is inadequate, and supply-chain practices are still unsophisticated. The digitization of an industry is not only about changing the way of working, shifting from tradition to new, but it is about changing the culture of the industry.

Figure 1 shows the digitalization index among different industry, the construction industry is among the least digitized, which may be the main reason of project delay and over budget, as the construction labour productivity has not kept pace with the overall economic productivity. To cope with this situation, construction industry should embrace new digital technologies, implement innovative measures, introducing new safety and communication technologies in construction site to improve operations. See Figure 2.

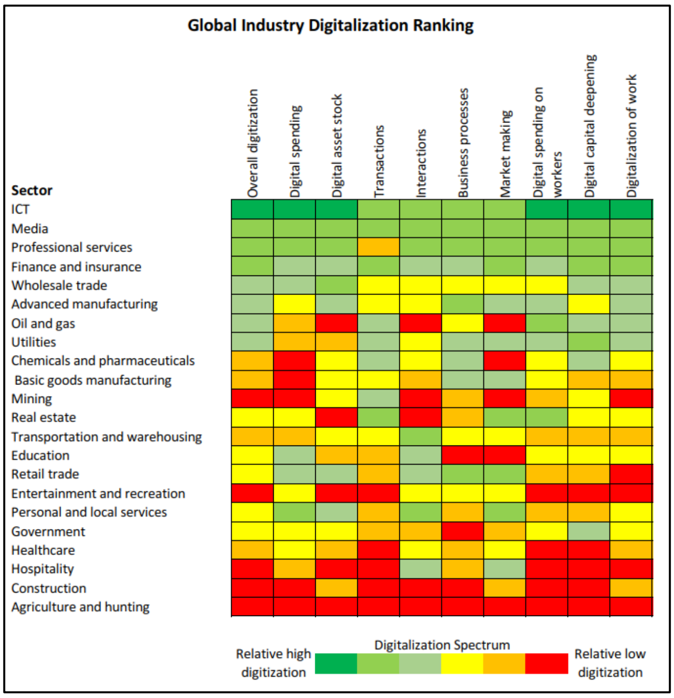


Fig. 1 - Global Digitalization Ranking among different industry (Reference to McKinsey Global Institute Industry Digitization Index, 2017)

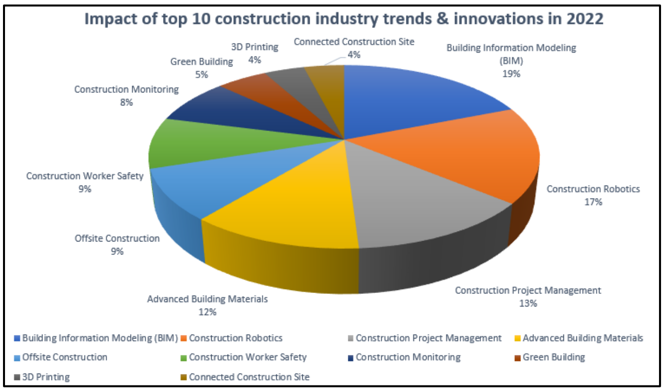


Fig. 2 - Top 10 Construction Industry Trends & Innovation in 2022 (Reference to StartUs Insights' tree map, 2022)

Companies prefer a more collaborative approach and make the overall construction lifecycle much more transparent. Solutions to this end include advanced BIM software and cloud-based management tools.

Moreover, the application of the Internet of Things (IoT) and reality technologies, such as AI CCTV to ensure worker safety and connect job sites. Advanced building materials have enhanced properties and fit modern construction methods like modular and sustainable construction. Additionally, technology such as Digital Work Supervision Systems (DWSS) digitalizes construction monitoring and inspection, making it easier for construction planners and site supervisors.

The future of construction sites will be more content driven, report with details and embedded with different means of technology to facilitate data analysis. This paper aims to explore and define the concept of digital transformation in construction industry in recent Hong Kong construction projects and examine how the application of smart construction site can minimize site safety risks though data analysis.

1.2 Smart Construction Site

Smart construction site is a construction site which integrates artificial intelligence, sensor technology, virtual reality and other high-tech technologies into buildings, machinery, personnel wearing facilities and other objects in the construction. Smart Construction Site has changed the traditional management method of construction projects. It can make the process smarter, simpler and save a lot of manpower and material resources and at the same time ensuring good quality and safe construction site.

In China, smart construction site has already been implemented for years. Most of the application has installed with AI CCTV to provide real-time visual management of the construction site and link so that the construction site perception is more thorough with comprehensive network interconnected within the site.

Fig. 3 - Smart Construction Site Setup Example in China

Smart construction sites are the first step towards a smart city. Building and construction normally account for 20% of energy use and 30% of which is wasted according to the research of MIT, 2013. Smart solutions can transform them into energy-efficient and sustainable buildings to reduce carbon emission.

Integrated with traditional Building Management System (BMS), integrated Building Management System (iBMS) is a computer-based automated system installed in construction sites, it allows communication with connected objects, as well as traditional automation and condition monitoring system, centralize different systems in the construction sites and bring unique benefits to facilities operators.

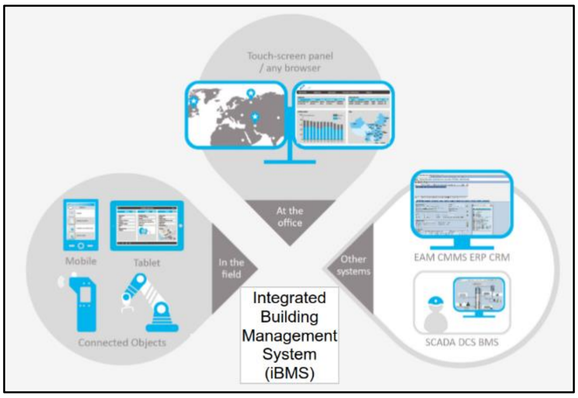


Fig. 4 - Integrated Building Management System at Construction Industry

With all of these digital data in placed, the concept of Digital twins were then also introduced. Digital twins allow building to develop in a sustainable manner at the planning stage, providing insights in real time and allowing organizations to maximize efficiencies and reduce cost, the life cycle of construction with digital method can be shortened compare to the traditional method. One of the example of using laser scanning data to streamline digital ordering recently in Hong Kong could highly increase the lead time 50% in ductwork system with a typical building configuration.

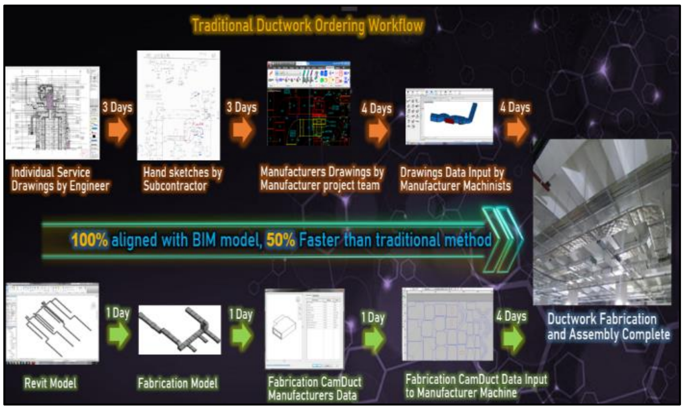


Fig. 5 - An Example of Construction Life Cycle of Tradition Method vs Digital Method

From digital twins, more forward looking brings along with Smart Cities concept. Smart Cities are a growing trend around the world. The smart city concept, though, is about more than just creating a connected and efficient urban environment. It is also about providing ready access to the services that people need, while, at the same time, minimizing the impact on the environment. All of the above build a corner stone for safety implementation to construction site with better monitoring system.

2. METHODOLOGY

2.1 Digital Work Supervision System (DWSS)

The Digital Works Supervision System (DWSS) is recently a hot topic also in the construction industry as a management system to enhance the standard and the efficiency of work supervision as well as the quality and safety of work. From the recent Technical Circular (Works) No. 3/2020 from the Development Bureau, it is also noted that the government is trying to lead the construction industry by implementing "Construction 2.0" where DWSS is to be adopted as a web-based centralized platform for collection of construction works information and managing workflow at different stages of the construction project. Focusing on safety aspect, the use of DWSS at Construction Stage have some impact on how safety is being managed during the construction cycle.

DWSS helps to digitize inspection processes including Request for Inspection / Survey (RISC) form management, Site Diaries, Site Safety Records, Site Cleansing and Labour Return Records.

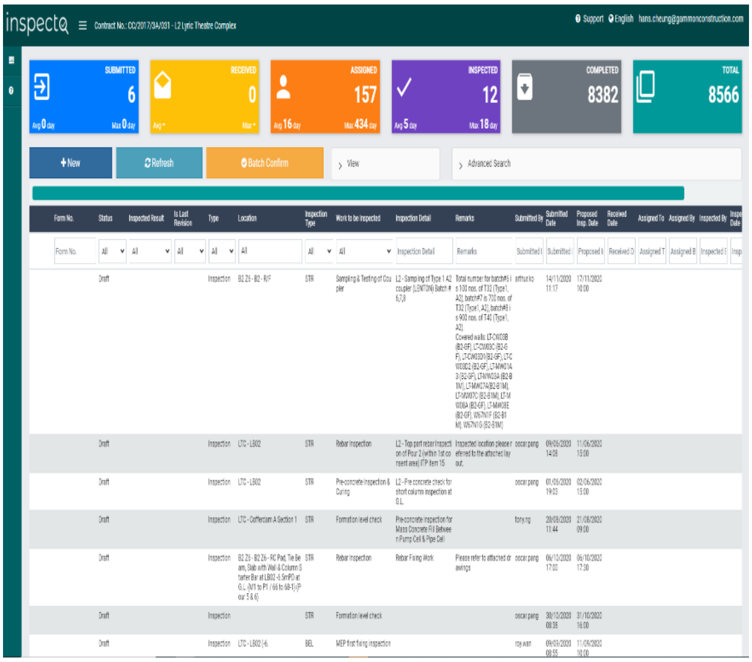


Fig. 6 - An example of DWSS System Managing Construction Data

Different type of DWSS platform or software may have different man-machine interface (MMI). However, the ultimate goal is to create a paperless environment where also this construction information can become part of the data base for future retrieval as well as data analysis. We can see therefore the needs and capability of this kind of DWSS on how they can table up the data for decision maker seeing the big picture on a construction site become crucial.

For example, a site diary with trade labour profile, their in / out record or the types of workers in a construction site can bring insights on what kind of risk activities may be the highlight under different time interval of a construction project. The other example would be an overview of RISC form management would be able to help the team to identify when and what to inspect at difficult areas (eg. High Level access / area with ceiling closed out) to ensure works are completed without defect in order to minimize the frequencies of further high-level visit of front line workers.

More than that, a good DWSS platform can facilitate sharing and works being distributed to correct stake holders in a mega scale project where works normally are demarcated in a fragmented manner. Bridging this kind of communication gap ensures normally a smooth transition between design information, method statements can be shared, and distributed to site team to maintain a safe system of works.

In a general term, a good DWSS could also facilitate the development of a good Construction Design Management (CDM) environment to the team as correct information are being shared across and improve project safety team culture.

2.2 5G Smart Control Centre

5G Smart Control Centre administers a camera-based digitally enabled construction site for improved monitoring of Safety, Productivity and Quality. Real-time data is fed into the Centre from digital platforms, providing a centralised pool of intelligence which is then presented in an easy-to-read format for the benefit of the team, especially frontline workers, and project stakeholders.

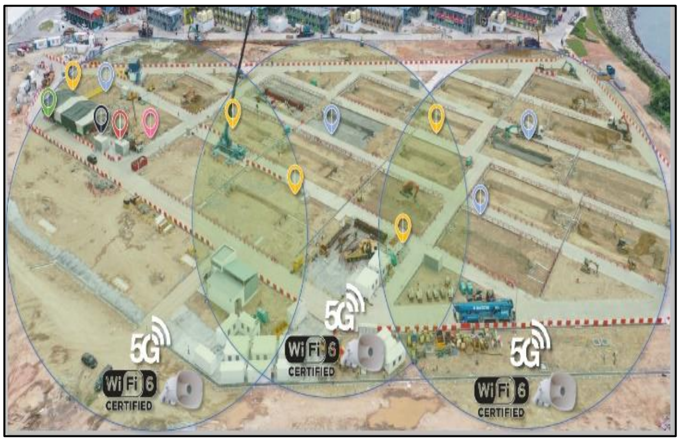


Fig. 7 - 5G AI Cameras at Penny's Bay

In June 2020, one of the major Main Contractor in Hong Kong when facing a tight programme challenge introduced the concept of a centralized hub for site monitoring. While 700 nos. high-quality requirements habitable quarantine units were urgently needed to complete in the tight 3-month time frame for stopping the spread of COVID-19 in Hong Kong. It was therefore crucial to execute the project with meticulous control, not allowing any hiccups in progress or safety that might distract the contractor from achieving the programme.

5G Smart Control Centre with various Digital Platforms were established that on and off-site activities can be real-time monitored by stakeholders of the project. With the wireless 5G network, complicated infrastructure and cabling is no longer necessary so that it is easy and flexible to implement in fast-track construction site.

AI cameras with 5G technology providing digital, active safety measure on site. It includes, Mask and Helmet Detection, Fatal Zone Detection and Smoking / Fire Detection. Camera captured the unsafe act and transfer to data to the PA system through low latency 5G network so that "Instant" alert can be provided to the workers.

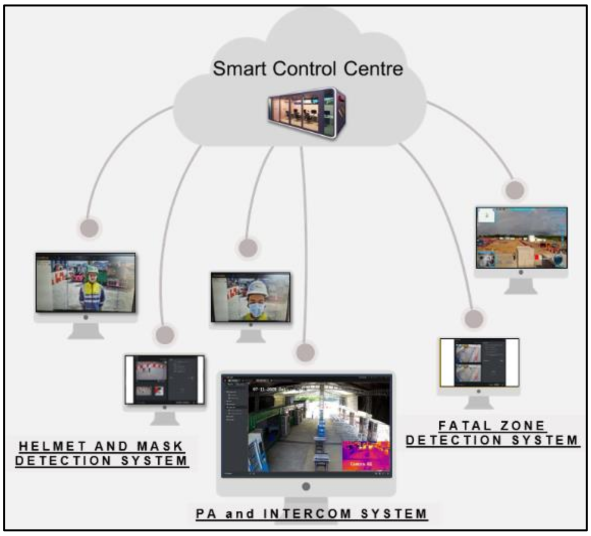


Fig. 8 - Functions of AI Cameras at Construction Site

Further centralized digital system linking with progress monitoring and inspection record, real time tracking data including Factory Production, Logistics and Site Installation status are presented in an easy-to-digest format and showing in the Centre. This allows project team, particularly frontline staff with no prior digital or data expertise, to understand, analyse and use the information to improve decision making and planning.

Fig. 9 - Digital System to Monitor Site Progress

Smart Control Centre driven both tangible and non-tangible value in construction project:

- 80% defects eliminated during MIC Manufacturing. Most of the defects were verified in SCC and rectified in Factory.
- 33% safety supervisors cost reduced
- 25% labour cost reduced due to precise allocation of labour force against real time monitoring of delivery of MIC
- Effective Progress Report
- Completed the project in 87 Days, 3 days ahead the programme
- Successfully granted the Subsidy Scheme for Encouraging Early Deployment of 5G, with $500,000 Funding from OFCA

The 5G Smart Control Centre connects people and bridges the gap between people and technology. Digital data improve the work productivity, quality, safety and profit. With robotics, IoT, AI and 5G adoption increasing, more and more data will be collected and processed.

Fig. 10 - 5G Smart Control Centre at Penny Bay Showing Real Time Management

The 5G Smart Control Centre will become more comprehensive and may extend to small control stations around the construction site to connect more and more stakeholders. The example quoted demonstrated how to link up between DSSW / CCTV / 5G / Digital use in real site situation.

2.2.1 A.I. software chatbot and integrated project management

A.I. software chatbot were first developed to automate repetitive workflows. By tailor making questions and answers in an interactive platform, routine procedures or checklist can be automated for engineers / supervisors easier to input. The application of this was first applied to site focusing progress reporting and checking. One of the very good examples would be site plant machine and scaffold checking records, which traditionally relied on human checking on statutory record sticking to an adverse site condition environment, now can be done through photo records with A.I. software chatbot, where prompting the users inputting correct photos and required answers on checking items.

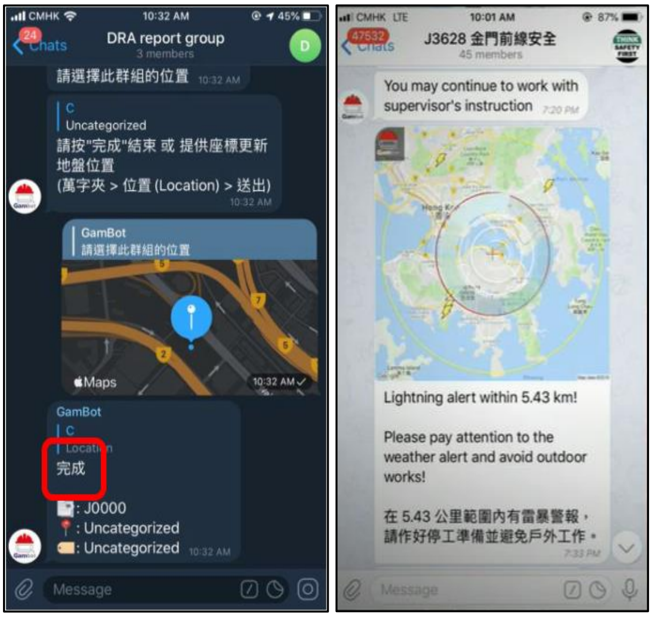


Fig. 11 - A.I. Software Chatbot Facilitating Site Safety Management

The overall data can also be monitored at a centralized project management dashboard, indicating what are the top items in concern. One of the most important things of such is that with digitalization then the quality and quantity of individuals carrying out inspection or checking can then be measured. Measurable data then become Key Performance Indicators (KPI), and further strengthen site safety management by setting objecting and goal on achieving the required safety performance for individual project team members. The system can then also be evolved into other safety site management tools which is elaborated in the next section.

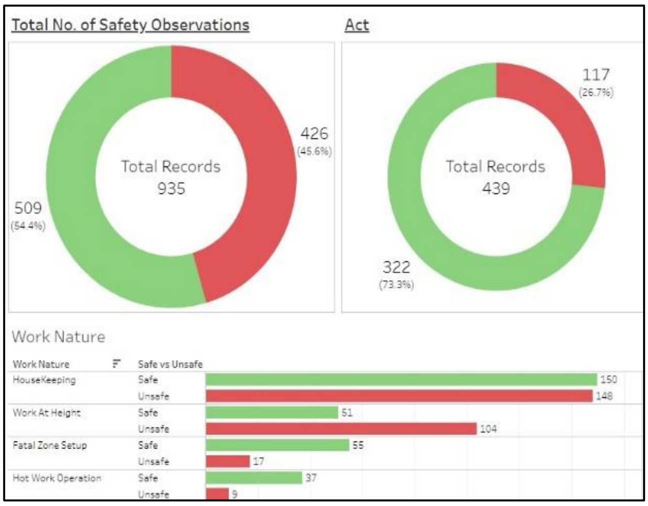


Fig. 12a - Centralized Digital Platform Harvesting Digital Data Facilitating Site Safety Management Action

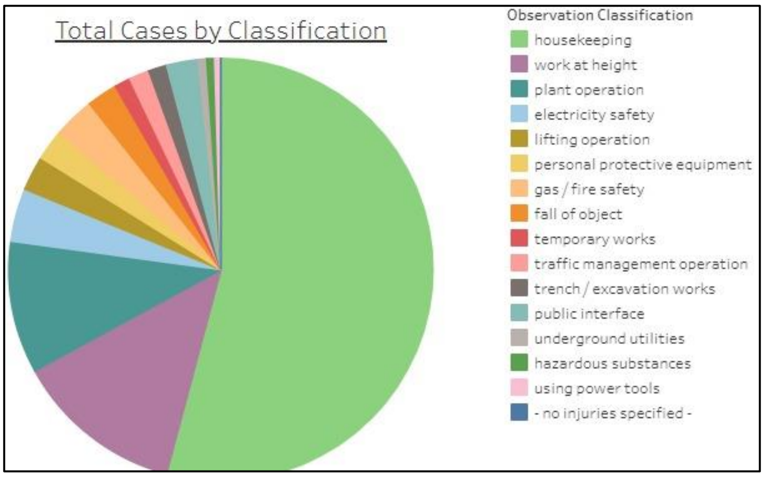


Fig. 12b - Centralized Digital Platform Harvesting Digital Data Facilitating Site Safety Management Action

2.2.2 Digitalizing dynamic risk assessment

In site safety management point of view, dynamic risk assessment (DRA) and field control briefing have always been one of the useful tools in ensuring front line supervisors and engineers communicate thoroughly with the workers. A dynamic risk assessment is a process of continuous monitoring with risks analysis.

Therefore, under dynamic and changing site condition, hazards or high-risk activities were being reviewed and identified in order to remove them from site.

The traditional method on documenting this kind of risk assessment relies only on paper, where a lot of such information was not being able to carry forward to management level to reveal the site situation to proactively resolve site risks.

In view of digitalizing construction data, one of the contractors in Hong Kong introduced iDRA, as shown in Figure 13, having all the DRA data captured digitally, and present in a dashboard format. With such, the risk on site can be easily reviewed in a centralized platform and further analysed.

To further promote environmentally friendly site situation, the input of these data can all be done now through a mobile phone, making the front-line workers easier to generate required information as well compatible with photo records.

Under this integrated project management system, the number of workforces can also be closely monitored on site.

The safety culture also changes from a traditional passive reporting to a much more proactive approach in reporting site observations as well as near miss through digitalization.

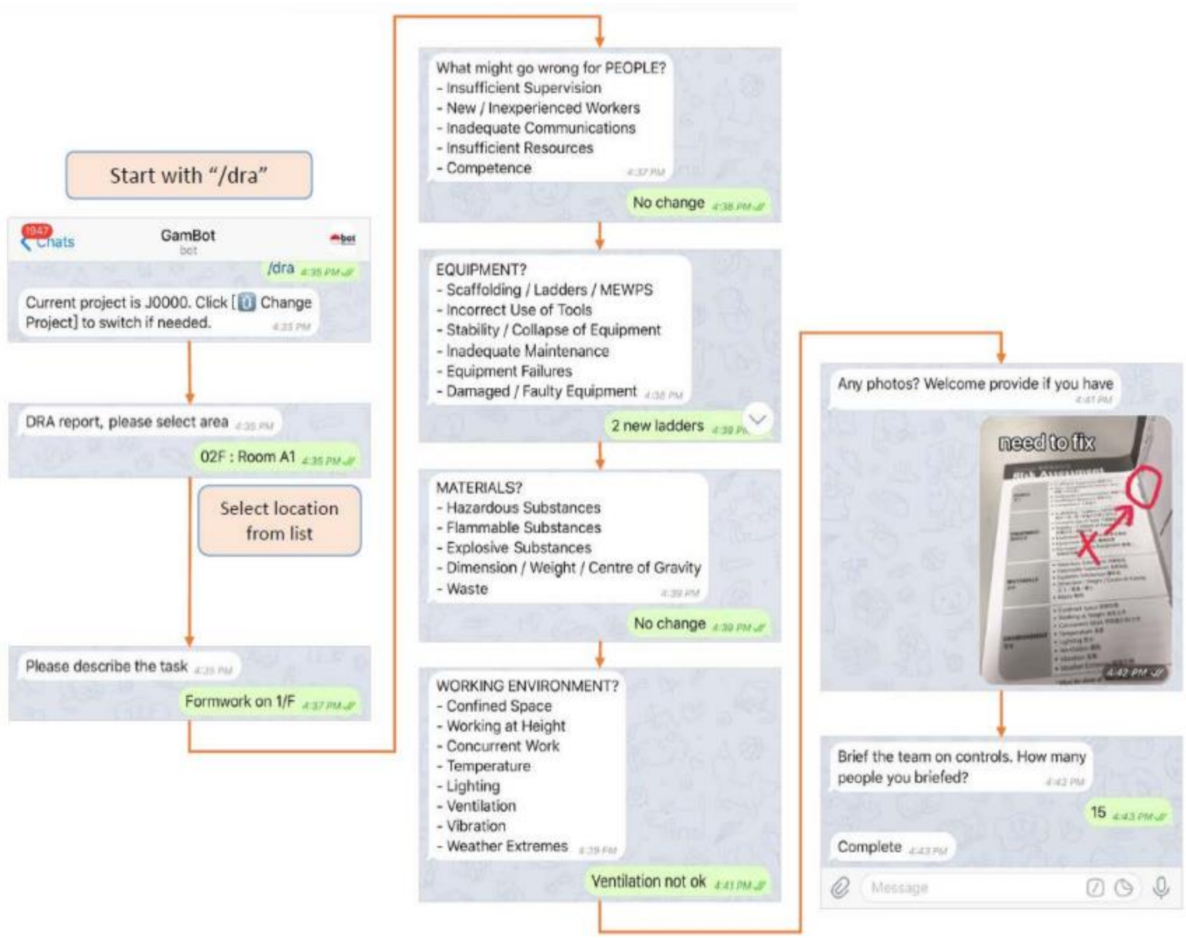


Fig. 13 - Digitalizing Dynamic Risk Assessment (iDRA)

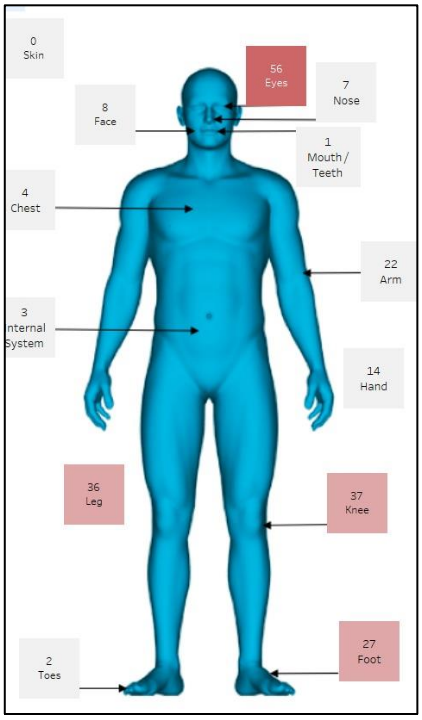


Fig. 14 - Automatic Categorization for Incident / Accident Man for Project Management with A.I. Data Analysis

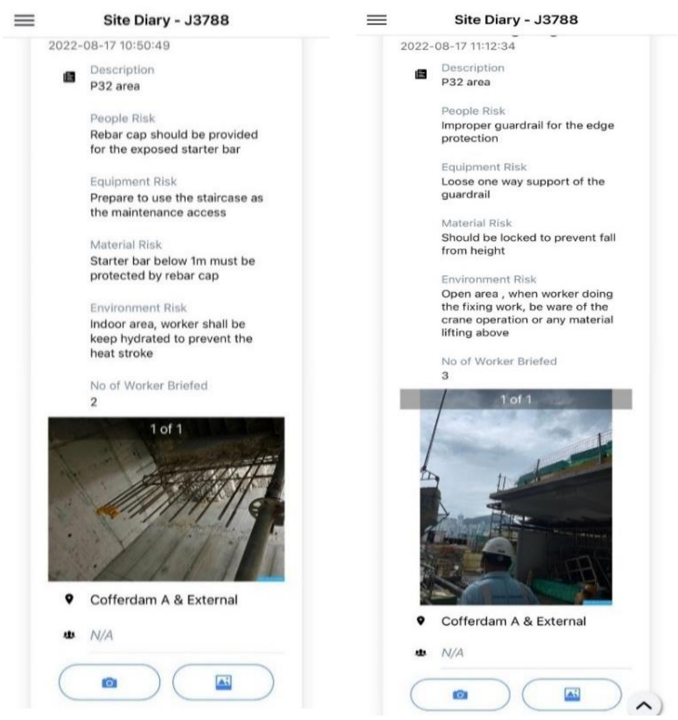


Fig. 15 - Digital Means for Reporting Site Diary / Near miss / DRA

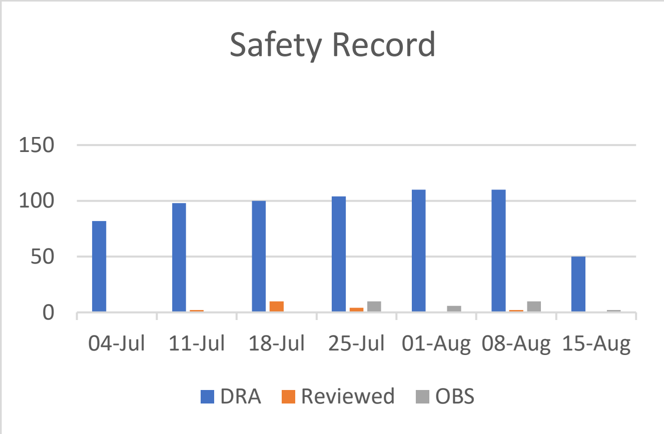


Fig. 16 - Extract from Centralized Digital Platform DRA Weekly Safety Record as KPI for Individuals

2.2.3 Digital supply chain monitoring platform

Apart from the above digital measurements, information flowing into the 5G Smart Control Centre also included Digital Supply Chain Monitoring Platform, which allows teams to remotely oversee all aspects of Modular Integrated Construction (MiC) unit production at the factory. It contains the following modules for managing off-site fabrication:

Production and Installation Progress

- With scannable QR tags, front line staff at both factory and on site are able to read and update status

Resource Management

- The resource level provided at the fabrication yard is collected in the system that ensures the rate of production is maintained.

Quality Assurance

- Quality inspection records are maintained in the system such that issues can be tracked over time.

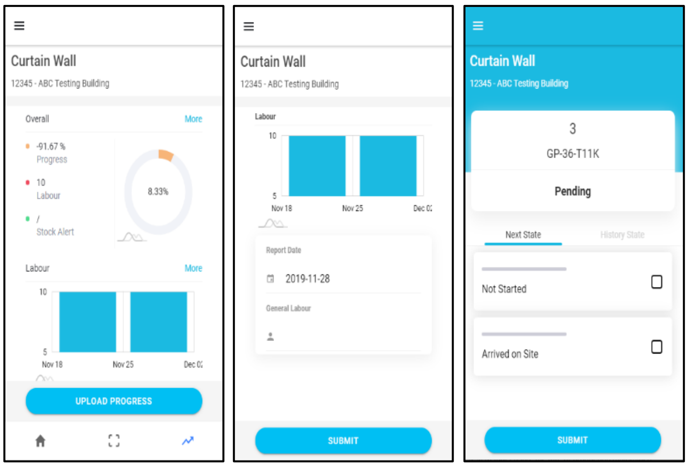


Fig. 17 - Digital Supply Chain Monitoring Platform Enhancing Site Safety by Minimizing Ad hoc Event

Logistics

- With tracking device installation, read time location during the transportation can be monitored.

With the help of Digital Supply Chain Monitoring Platform, the site safety risk can be minimized as the engineers and front-line supervisors can know the exact time the material arrives and have sufficient time to prepare and arrange hoisting or storage for the material. As a result, there will be no more sudden arrangement of hoisting or delivery on site.

A well-managed arrangement for material delivery on site can help to prevent accidents caused by insufficient preparation. Also, the workflow under Digital Supply Chain Monitoring Platform can be streamlined and automated, which can avoid material shortages as the quantity of material can be real-time monitored and the efficiency of the project is enhanced.

2.3 BIM Enabled Construction

BIM was introduced in Hong Kong for more than 10 years. While starting from just clash analysis and manage visual expectation, recently there is a lot more exploration and usage.

Common Data Environment (CDE) is one of the area where Construction Industry Council (CIC) have been continuously driving, from traditional use of visual coordination to data analytic and as a centralize data integration platform. To that end, designers can create a shared virtual building project with integrated information from cradle to grave in a format that models both the structure and the entire timeline of the project. That leads also to further elaboration on digital use for construction project, and different industry stake holders have been exploring the usage of BIM-enabled project to drive further extra value.

According to the McKinsey Buiding Products Survey, 2022, Digital design / building tools (e.g. BIM) are the hottest digital topics that have sighnificant impact on the building products industry in the next 5 to 10 years. The flexibility of using BIM platform can facilitate a lot more further development.

In the context for safety perspective, a good BIM development could facilitate prefabrication decision as well as steering safety at construction stage and fostering future provision of operational and maintenance needs at design stage.

In view of complex geometry in design as well as highly compact space in MEP service corridor, BIM could facilitate discussion on maintenance access as well on the site feasibility check that avoid traditionally decision made by front line workers on changing method statements due to different site constraints.

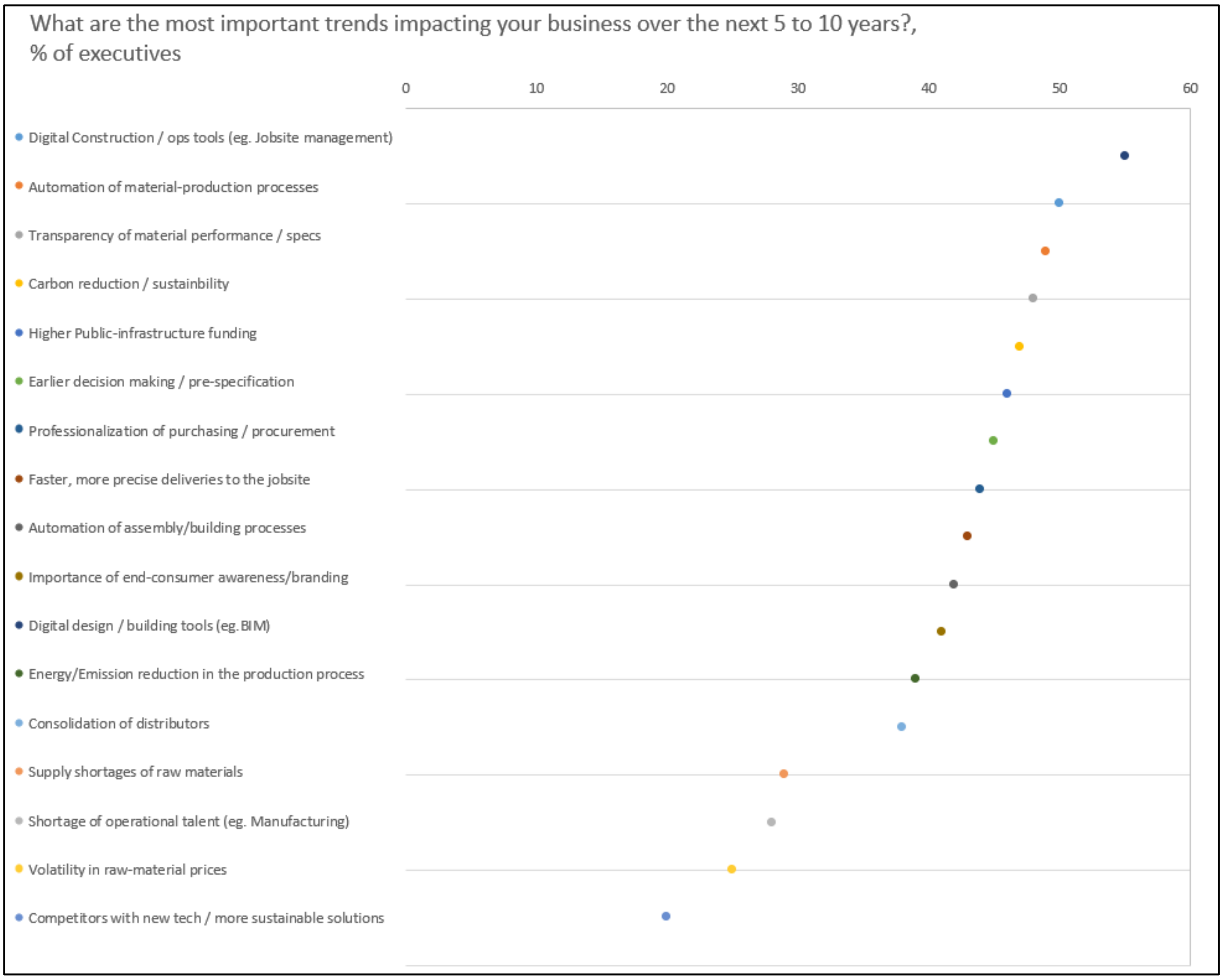


Fig. 18 - Digital Topics Impacting Building Products Industry (Reference to McKinsey Building Products survey, 2022)

Fig. 19 - BIM Environment Facilitating Site Feasibility Check and Maintenance Walkthrough

When assets and different operation and maintenance data input to BIM with clear BIM folder structure, the model further empowered to a ‘digital twin’ where the physical project data can be read in a virtual environment. For example T&C, operational data, maintenance manual, delivery path etc. can all be stored under a single source of truth which also can minimize unnecessary travelling time or high level access or checking upon energized environment to collect necessary operational data. In some projects a BIM model could also correlate with QR codes or RFID tags, which further enhanced the assets management system in keeping up to date building information in order to facilitate correct location identification for complicated field equipment maintainability.

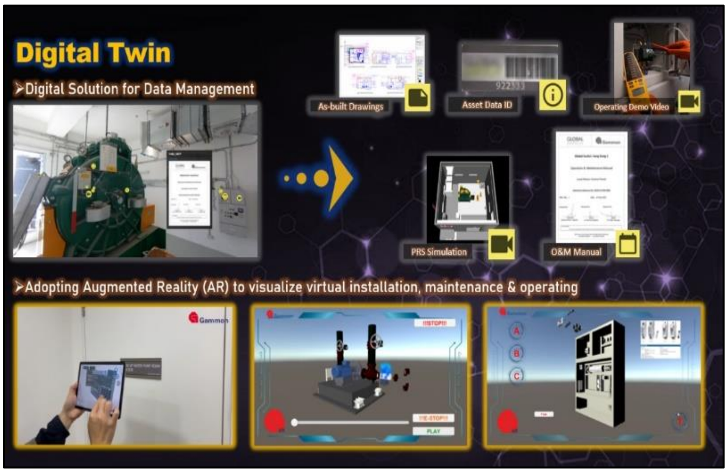


Fig. 20 - Real Life Example of Digital Twin being used in a Project for O&M

2.3.1 BIM enabled method statement

Popularization of 3D modelling has led to the emergence of many third-party software which can be integrated with BIM to create value at all stages of the construction lifecycle. For example, one such cloud-based BIM platform consists of integrated risk identification tool to help design by safety at an early-stage way before actual construction even begins.

Fig. 21 - An Example using 3D Repo for Method Statement Planning to Ensure Workers Location in a Complicated Geometry and Operation of Works

This risk identification tool is able to provide tracking and tagging at each and every stage of the construction sequence. Key risks and mitigation are included in the BIM data for model-based safety planning.

The interface of this software encourages collaboration between stakeholders to resolve these safety risks. The model can be marked up and recorded easily and BIM objects such as heavy plant equipment or personnel can be dragged and dropped as needed to show fatal zones. The entire sequence can then become an animation which will revolutionize the way method statements are prepared in the future.

Currently, many high-profile projects in Hong Kong are already using this third-party software to enhance the capabilities of BIM-enabled construction. The results have been promising, showing time savings through elimination potential complications down the line in the project.

2.4 Off-Site Fabrication

2.4.1 MiC and MiMEP in construction

With the capability of being able to carry out detailed coordination at design stage in a BIM-enabled project, that also unlocked subsequently different variety of off-site fabrication, which greatly enhanced safety and quality of site. Modular Integrated Construction (MiC) or Modular Integrated Mechanical Electrical and Plumbing Installation (MiMEP) become possible when complicated coordination can be done to a stage that could reflect 90% of real site situation. With that introduced, traditional site safety risk like hot work, high level frequent access, falling from height, falling of object can be greatly reduced through engineering design and careful consideration on integrating part or whole of the works in a factory environment with in situ installation. In the context of MiC, free-standing integrated modules (completed with finishes, fixtures and fittings) are manufactured and assembled in a factory where simple structures can be substantially completed off-site. The adverse impacts of weather conditions, scarce labour resources and site constraints can all be substantially reduced. MiC provides a great degree of production quality control, and can improve construction productivity, safety and sustainability.

During the pandemic of COVID-19, MiC became one of the solutions on quickly mobilizing construction project in a massive scale with good safety result. A recent successful MiC example on quarantine center, 707 nos. of MiC units were delivered within 87 days with zero accident. The figure reflected good planning of MiC together with MiMEP could greatly reduce site safety risk and accomplish complicated construction planning on time, in particular with the appreciation and help of different stake holders of a project.

Fig. 22 - MiC Unit at Penny Bay's Quarantine Center, 707 nos. MiC Units Delivered within 87 Days

Fig. 23 - MiMEP Plant Room at Penny Bay

Fig. 24 - Prototypes of MiC Negative Pressure Ward at Zero Carbon Centre

More than that, different engineers in the field are looking into the challenge and complexity of off-site fabrication by uplifting the safety and quality standards, as well as enhancing the functionality of this kind of construction in terms of real application to projects. One of the prototypes at Construction Industry Council (CIC) Zero Carbon Center under exhibition would be a negative pressure ward being constructed with this methodology. The concept of MiC was further elaborated to a complicated plant room with interlocking control on MEP services, which served not only the capability of engineers showcasing their innovative thinking, but also demonstrating to the society the future possibility of modular construction with educational purpose to the public how an isolation ward can work. The project physically was completed within 14 days excluding procurement lead time which is also indicative that most of the work can be carried out in an off-site environment nowadays with good planning achieving zero harm in a construction site even with complicated plant rooms.

Fig. 25 - MiC Negative Pressure Isolation Ward Fully Designed and Manufactured using BIM

Other off site fabrication examples can be MiMEP, which can cater different challenges and safety pain points of a construction site. While removing all the hot work from site in a mega scale chiller plant room can greatly reduce fire risk and high level access. In one example, all hot works were removed out from site by introducing mechanical joint to the whole plant room without welding. Careful planning on BIM by considering the joints and all off site possibilities to tailor made a fit for purpose plant room with zero accident. The whole chiller plant was constructed only within 60 days as compared to traditional method a similar plant room of this scale would require 50-80% more time. It also removed more than 500 nos. of welding joints, and all the pipework were installed with bolts and nuts fixing without any leakage throughout the project and operation life cycle up to date.

Fig. 26 - MiMEP Zero Welding Chiller Plant with Full BIM Implementation

Fig. 27 - Zero Welding Methodology of Pipe

The benefit of offsite fabrication with a BIM-enabled project could also tailor made to cater some of the safety risk. For instance, riser openings become possible to close off together with riser installation in one goal by collaboration of traditional builder's seal up works and MEP installation.

Traditional demarcation with builders sealing off outside the sleeves and MEP sealing inside the sleeves needed a re-think in order to adopt this kind of methodology but could definitely be applied in a real job example by tackling all the riser opening risks. In this real-life example, all risers were completed within a week by a one team strategy together with Main Contractor and MEP Contractor, as well the riser openings were being sealed up immediately by adopting mechanical joints on pipe removing hot work and integrated with floor covering where within short installation period achieving also again zero harm accident record.

Fig. 28 - Example of Riser Module Hoisting

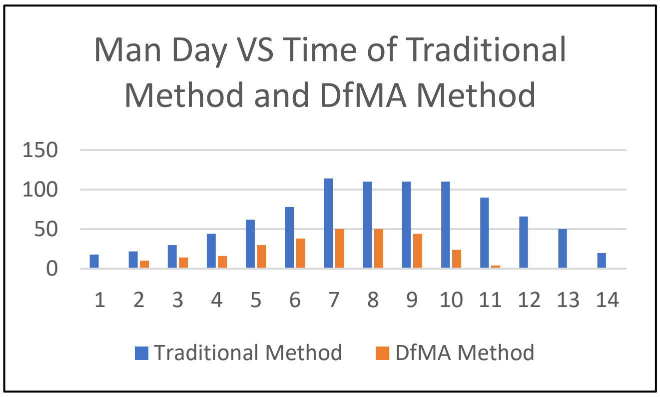
2.4.2 Mega scale tailor made DfMA / MiMEP

DfMA focuses primarily on Design for Manufacture and Design for Assembly. While MiMEP stands for Modular Integrated Mechanical, Electrical and Plumbing installation, Design for Manufacture studies how individual parts of a product can be standardized for easier manufacturing while Design for Assembly examines the ease of putting everything together. The combination of these two concepts improves productivity, quality control and assurance, and safety / environmental performance indicators.

Fig. 29 - Mega Scale Tailor Made DfMA/MiMEP - Thermal Tank in a DfMA Project showcasing Better Safety Performance with Minimized Site Risk

In one of a recent construction project in Hong Kong, all aspects of this design and build project were executed with DfMA / MiMEP and BIM as the major focus. In fact, the prefabrication of the four 175 meters cubed thermal tanks were the best example which showcase DfMA / MiMEP culture. A massive 50-ton thermal tanks had adopted BIM as a critical tool to streamline the entire design process. Structural verification of steel members, baffle plate design with correct temperature profiles, and spatial checking with combined service were all conducted with the use of BIM. This ensured all provisions were coordinated correctly with one goal.

By utilizing off-site prefabrication to manufacture these DfMA / MiMEP thermal tanks, it had provided significant reduction in risks related to high level works and extensive welding. Welding inspection reports show that more than 8000 nos. of welds were moved off site and included in the factory acceptance test.



Estimated On Site Labour (Manday)							
	Qty of Weld	Site Welding		Erect Scaffold		Installation	
1 Tank	>2000	156	0	54	0	120	120
4 Tanks	>8000	625	0	216	0	480	480
		781	0	270	0	600	600

Traditional

DfMA

Fig. 30 - Traditional Method Manpower vs DfMA/MiMEP Method Manpower

Fig. 31 – An Example of a Thermal Tank adopting DfMA Approach from BIM to Final Product

Conventional delivery of these massive DfMA / MiMEP tank by road is feasible but would not be viable if the tight programme schedule was to be achieved. The team studied the different delivery proposals in the BIM model and opted for a more complex solution of shipping by barge oversea, hoisting to land by 750 mobile crane and then hoisting again to the roof by a 500-ton mobile crane. A BIM method statement had been presented to the project team and stakeholders for pre-work briefing to ensure everyone understands the complex procedures clearly. The entire process would take four days, which would not be feasible if the tank was transported by land only with zero incident.

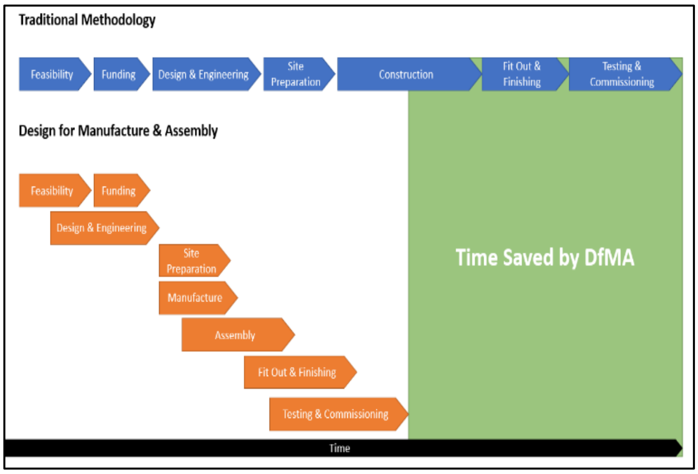


Fig. 32 - Programme Comparison between Traditional Methodology and DfMA / MiMEP

For quality of DfMA / MiMEP, as high as 80% of defects were identified and rectified at the factory. Rectification of these defects was managed through QR-code driven installation checklist with quality hold points. This information was available real time through IoT for all stakeholders at the Hong Kong site office as well as the mainland factory. The remaining 20% of defects resulted during delivery or final installation on site. These were accounted for during on-site installation inspection.

For programme benefits of using DfMA / MiMEP, multiple construction activities could take place concurrently. The thermal tanks were delivered in two batches 2 months apart. Manufacturing of 2 thermal tanks took place at the fabrication yard off-site while the final connection of the other 2 thermal tanks took place on site. This time saving meant testing and commissioning can be started much earlier. The key is that there is no constraint to the sequence of works when compared to traditional construction methodology.

Construction activities can overlap instead of having to strictly wait for the completion of one activity before commencing another.

This example also demonstrates how innovation can improve safety performance by removing hot work and hoisting work off site, to an extent that also showcase DfMA / MiMEP have a high potential with solid figures proving it is safe to transform from typical off-site fabrication into tailor made mega scale unit to tackle different project challenges.

3. CONCLUSION

The digitalization of the construction industry is the general trend. New construction technology such as Smart Construction Site, DWSS, BIM enable construction and DfMA / MiMEP can help improving the work level of construction sites.

Working as safety professionals, we must equip ourselves with the knowledge of traditional site safety management, as well as empower ourselves with an open mind to adopt new technologies that streamline our daily management work. On one hand, there is a challenge to introduce new concepts to the profession, but on the other hand, safety professional nowadays contributes to evolving the traditional construction industry into the digital era and transforming site safety management.

We foresee that the number of construction projects will continue to increase in the future, and how to effectively reduce the number of construction site casualties in the increased construction site relies on the efforts of the newly recruited safety professionals.

4. ACKNOWLEGEMENT

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Paper No. 4

AN EFFECTIVE APPROACH FOR DECARBONISING BUILDINGS - ZERO CARBON, DIGITAL AND ESG

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ABSTRACT

Responding to COP26 held in 2021 and setting a 1.5 Degree Celsius warming limit, countries and territories in Asia have begun setting carbon neutrality targets. In Hong Kong, this target is set to reaching carbon neutrality prior to 2050. With 90 percent of the city's emissions coming from buildings, a robust approach towards carbon reduction in the buildings sector is needed to help reaching this aim. The World Green Building Council (WGBC) has developed a complete whole life-cycle carbon (WLC) approach to assess carbon emissions for buildings. Practitioners within the buildings industry must understand how organisation and operational boundaries can be applied to their corporations and assess how operational and embodied carbon should be assessed on a building level. A roadmap for carbon reductions for building projects and their parent corporations can then be developed. Practitioners must also overcome major challenges in data availability, boundary setting, target setting and monitoring and verification. To allow for a more consolidated and robust approach, Arup has developed a suite of carbon tools to help practitioners to develop WLC assessments for their projects and corporations, including the EA WLC assessment tool and Neuron Carbon. Through the Advancing Net-zero (ANZ) design competition, Arup has also applied WLC reduction in design for existing buildings, highlighting the approaches and benefits to reaching carbon neutrality by 2050 in the buildings industry. With the market transitioning towards becoming more carbon-conscious, Arup will continue to set an example through actions and standard-setting to facilitate the industry's transition towards carbon neutrality.

1. INTRODUCTION

With the dire need to set ambitious carbon reduction targets highlighted in COP26[1], an increasing number of Asian nations and territories have set carbon neutrality targets. In response to the 1.5-degree Celsius limit set in COP26, Hong Kong has set a goal of reaching carbon neutrality before 2050[2]. As shown in Hong Kong's Climate Action Plan 2050 and in many other analyses performed by members of the industry, the primary contributor to Hong Kong's carbon footprint is in buildings, contributing to 90 percent of the city's carbon emissions.[3] In order to reach Hong Kong's committed carbon neutrality goals, the buildings sector must develop a comprehensive approach to decarbonisation, involving all major stakeholders of a building development such as the building owner, designer, contractor and operator.

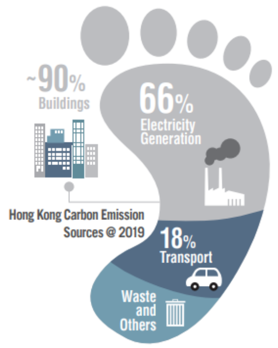

Fig. 1 - Carbon Footprint of Buildings in Hong Kong (from HK Climate Action Plan 2050)[3]

Despite the clear goals set, however, most industry practitioners are still somewhat lost on the concept of carbon and how it relates to their individual expertise. Many consider carbon to be an item directly related to energy efficiency, deeming that selection of efficient equipment is adequate to achieve carbon savings. Others figure that carbon is an item related to operations and policy, determined by how operators use the constructed facilities. These piecemeal views or approaches to carbon showed how difficult it can be to achieve carbon neutrality without a complete understanding of WLC approach to buildings.

Under the WLC approach, carbon savings is related to all stakeholders, from design architects, electrical engineers to facility operators, and covers all aspects of a built project, from efficient design, material and equipment selection to operating procedures or optimisation. All stakeholders must be aware of the contributions they can make towards carbon reductions and how their choices can affect the overall carbon emissions for their development.

[1] UN Climate Change Conference of the Parties (COP26).
[2] From the Chief Executive's 2021 Policy Address.

[3] Hong Kong Climate Action Plan 2050. https://www.climateready.gov.hk/files/pdf/CAP2050_booklet_en.pdf.

2. INTERNATIONAL FRAMEWORKS AND BENCHMARKS

Many internationally recognised institutions have already endorsed the WLC approach for assessing carbon intensity of corporations and buildings. They have developed target-setting and assessment guidelines, as well as introduced how boundary setting should be conducted for projects. Some of the major frameworks, protocols and initiatives to this end are outlined below.

2.1 World Green Building Council WLC Vision

As the leading institution for sustainable building design, the WGBC has developed a comprehensive WLC approach to considering the emissions from any buildings project.

WGBC has set clear definitions, target dates and best practises to achieve set targets under this framework.[4]

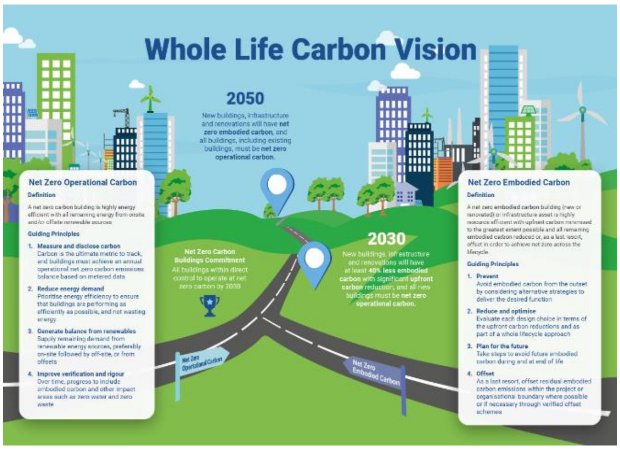

Fig. 2 - WLC vision by WGBC[4]

The key headlines formed under this vision include:

- **Net-zero Operational Carbon** – a highly energy efficient building with all remaining energy from onsite and/or offsite renewable sources.
- **Net-zero Embodied Carbon** – highly resource efficient building with upfront carbon minimized to the greatest extent possible and all remaining embodied carbon reduced, or as a last resort, offset to achieve net-zero through the whole life-cycle.
- **Key Target Dates –**
  - 2030 – All buildings with direct control to operate at net-zero carbon; All new buildings, infrastructure and renovations to have 40% less embodied carbon.
  - 2050 – All new buildings are net-zero embodied carbon. All buildings are net-zero operational carbon.

2.2 Greenhouse Gas Protocol

The Greenhouse Gas ("GHG") Protocol[5] provides relevant standards and guidance for reporting GHG emissions across all industries. It forms the calculation and technical basis from which all other tools and frameworks for assessment of emissions are derived from.

Specifically, the GHG Protocol sets standards for how corporations account for and report emissions, including which gases are included, how boundaries need to be set, data quality and reporting requirements. These form a consolidated and consistent means of reporting emissions for all stakeholders or projects and the basis from which reductions can be made.

2.3 Science-Based Targets Initiative

In recent years, many tools have emerged as means for stakeholders to consider WLC emissions reductions at company levels. Among these, the most prominent includes Science-Based Targets Initiative ("SBTi")[6], which forms a foundation for companies to set reduction targets in their corporate-related emissions and provides detailed pathways and requirements under the 1.5-degree warming limit set out in COP26.

Utilizing in the standardized methodology of the GHG Protocol, the SBTi framework also spells out clear guidance or recommendations on several major aspects of WLC assessment and reduction, including defining various emission types (scopes), boundary setting requirements, target setting requirements and target timeline recommendations. These provide companies with a standardized methodology for setting carbon reductions in alignment with COP26 commitments.

How this translates to real estate and buildings industry, as well as individual building projects, however, requires a deeper understanding of WLC emissions and how it is applied to the industry.

3. WHOLE LIFE-CYCLE CARBON CONCEPT FOR BUILDINGS INDUSTRY

To apply carbon reductions frameworks and strategies to buildings, there must first be an understanding of boundary setting, to follow.

3.1 Boundary Setting

Under the corporate frameworks mentioned previously, boundary setting can be split into **organisational** and **operational** boundaries. Organisational boundaries refer to direct control over emission sources, while

[4] World Green Building Council. *Whole Life Carbon Vision.* *https://www.worldgbc.org/advancing-net-zero/whole-life-carbon-vision*.

[5] The GHG Protocol Corporate Accounting and Reporting Standard. https://ghgprotocol.org/corporate-standard.

[6] Science Based Targets. https://sciencebasedtargets.org/.

operational boundaries include the sources and types of emissions within operations of a building.

Organisational boundary for any building owner will include its building operations. This is because the owner has control over design decisions as well as operational policies of any given development. As such, there is a need for building projects to reduce carbon emissions as a whole.

Operational boundary for developments, like corporations, can be split into 3 main scopes:

- Scope 1 - Direct emissions from building operations
- Scope 2 - Indirect emissions from the generation of purchased electricity, steam, or heating and cooling that is consumed
- Scope 3 - All other upstream and downstream emissions in the value chain and within the assessment scope

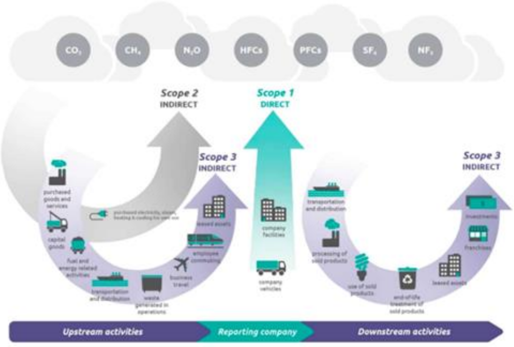

Fig. 3 - Operational Boundary under Scope 3 Guidelines[7]

While a building itself cannot be assessed under corporate carbon assessments and reporting standards listed, the same principles can be applied to reduce the overall carbon footprint of building developments and aid building owners to reduce their carbon emissions and meet their corporate reduction goals.

3.2 Building-level Applications

For buildings, stakeholders may consider a more timeline-related framework for embodied and operational carbon. Using Arup's framework created in collaboration with the World Business Council for Sustainable Development ("WBCSD"), a temporal outline shows how embodied carbon can be separated into both upfront and operational embodied carbon, while operational carbon from energy use is counted as a separate "operational carbon" element.[8]

This framework, based on both the GHG Protocol and WGBC's WLC vision mentioned earlier, shows how the design of any building system or element must consider not only how efficient it is during operations phase (under B6 and B7 categories), but also early on during design phase to include its carbon emissions due to its materiality and construction (A1-A5 categories). Further consideration must also be made for materiality during its lifetime as well as repair, maintenance and decommissioning (B1-B5 and C1-C4).

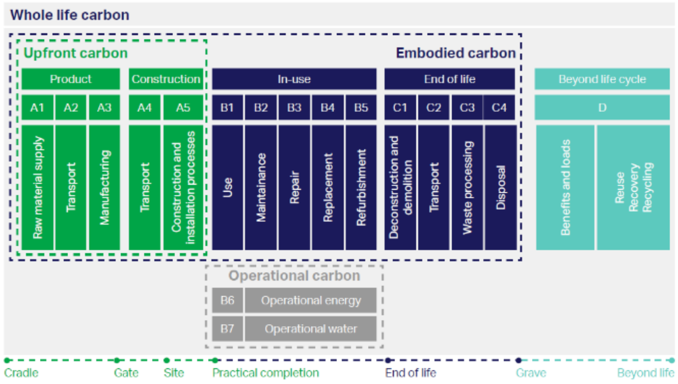

Fig. 4 - Various Scopes and Applications of Embodied Carbon, Upfront Carbon and Operational Carbon as per WBCSD's Report on Net-zero Carbon Buildings[8]

With only 50 percent of emissions attributed to operations during the lifetime of a building, designers must consider an WLC approach to assessing design strategies. As an example, a specific lighting or electrical installation may be energy efficient and save operational carbon, but require significantly more materials or be designed and assembled bespoke from Europe to Asia instead of using locally available suppliers. Under the WLC framework, it is not possible to immediately discern carbon savings possible for this system as while B6 through B7 emissions are saved, there is likely an increase in A1 through A5 and B1 through B5 emissions if this system is designed. Stakeholders for these buildings must undergo a full WLC assessment for this design to consider its effect on overall building carbon emissions.

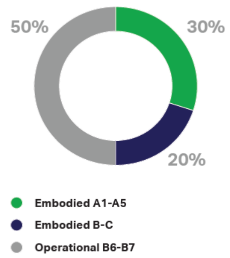

Fig. 5 - Breakdown of Embodied and Operational Carbon throughout Life Time of Building[8]

3.3 Setting a Carbon Reduction Roadmap

Using the corporate frameworks and tools as a guide and considering the vision targeted by WGBC's WLC vision, building designers should develop a roadmap

[7] Corporate Value Chain (Scope 3) Standard, WRI and WBCSD.

[8] World Business Council for Sustainable Development and Ove Arup and Partners Ltd. *Net-zero Buildings: Where do we stand?* p. 11.

and direction for carbon emissions for buildings. This will inform project teams on the amount of focus that needs to be placed on both the embodied and operational carbon aspects of carbon emissions and help the project team select suitable design strategies for the development to undertake.

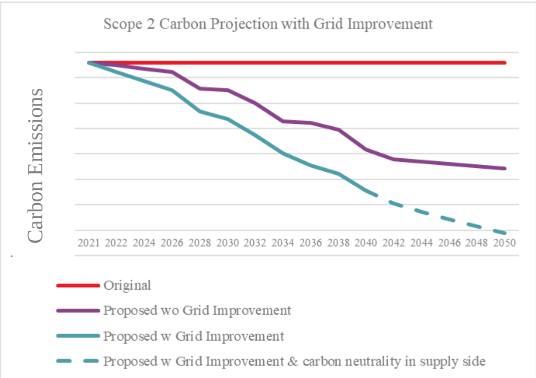

Fig. 6 - Example of Roadmap Setting for a Project or Corporation

4. CHALLENGES

Despite having a thoroughly developed and clear framework for assessment from a corporate to a project-specific level, conducting WLC assessments has challenges that must be overcome. The four major challenges include **data availability**, **boundary setting**, **target setting** and **monitoring and verification**.

Challenge 1: Data Availability

To assess emissions from materials, activities or operations throughout the building life cycle require significant amounts of data and monitoring. Often such data are either unavailable due to lack of measurement devices or inaccessible due to information being proprietary to upstream service or product providers. This often creates difficulties for stakeholders to assess whether their design selections or operational considerations are having a positive carbon impact on the development.

Challenge 2: Boundary Setting

Translating existing boundary setting guidelines under the Greenhouse Gas (GHG) Protocol to common practise is difficult due to the abstract nature of the guideline. Stakeholders often struggle to understand which types of emissions are attributed to the development and which do not have to be attributed under these guidelines. Furthermore, as most guidelines are written under the understanding they will be applied at the corporate level, it is often difficult to translate these into project-specific boundaries.

Challenge 3: Target Setting

Even if stakeholders have access to quality data and understood what can be included and excluded within their boundary setting, target setting is often a problem as stakeholders often do not have the expertise to understand every discipline within the life-cycle of a built project. Targets under existing tools such as SBTi are made for corporate uses, while their percentage reductions do not translate directly to project-specific reductions. These need to be further translated for easier building design optimisation.

Challenge 4: Monitoring and Verification

The final and perhaps the largest challenge is that the industry lacks tools to comprehensively track and monitor progress of carbon emissions in a built project. Even if stakeholders are able to develop and determine WLC emissions for a development project, often it lacks tools to verify, monitor and optimise performance during construction and operations stages of a building's life.

5. ARUP'S WLC ASSESSMENT SUITE

With a relatively complex framework to digest for buildings and several major challenges to overcome to assess carbon emissions for any given development, Arup has developed a tool suite to address WLC emissions for a building. These include the **East Asia WLC Assessment Tool** for buildings and **Neuron Carbon**.

5.1 East Asia WLC Assessment Tool

As the central piece to Arup's carbon assessment suite for buildings, the East Asia WLC Assessment Tool allows building designers to conduct quick analyses of their development or design's whole life-cycle carbon emissions, no matter which stage of the project they are within. The tool capitalizes on Arup's project experience in the built environment, utilizing Arup's expansive database on embodied and operational carbon emissions for all disciplines in the built industry.

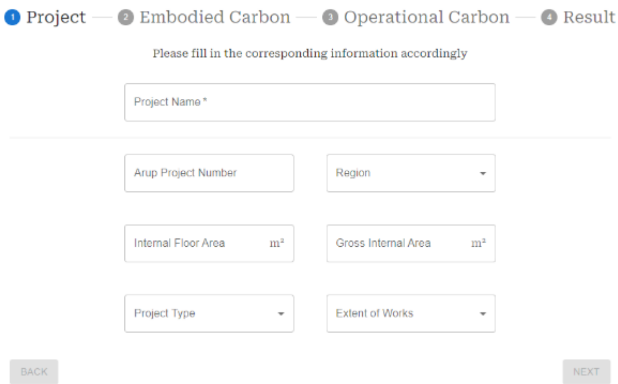

Fig. 7 - Input Page for East Asia WLC Tool

By allowing users to input material quantities for embodied carbon and efficiency levels of equipment and systems for operational carbon, a holistic view of overall carbon emissions for all systems can be generated for all building projects. Practitioners can utilize this tool to configure and optimize their design for embodied and operational carbon reductions.

The intended audience includes not only structural engineers. All other disciplines with a hand in designing building systems can consider optimizing their design for carbon reductions, including design of chiller plant configuration, busbars, cabling and distribution systems, pipework, and other equipment or network design.

With Arup's comprehensive database and tool, the intent is to allow all disciplines the ability to conduct carbon reduction and optimization based on carbon neutrality goals of the future.

5.2 Neuron Carbon

To facilitate performance monitoring, benchmarking and verification, Neuron Carbon offers stakeholders the ability to collect real-time data regarding carbon emissions of a built development, while optimizing for possible emissions reductions strategies through automatic controls or through operational changes.

The software programme intakes operational data from buildings and considers the boundary and scope of emissions from these sources. The software is then capable of benchmarking and reporting emissions from building operations.

The benchmarking function allows teams to compare current month performance with historical data and international benchmarks, allowing teams to gain insight on carbon-intensive items and possible optimization strategies to adopt cost-effective solutions to excessive carbon emissions.

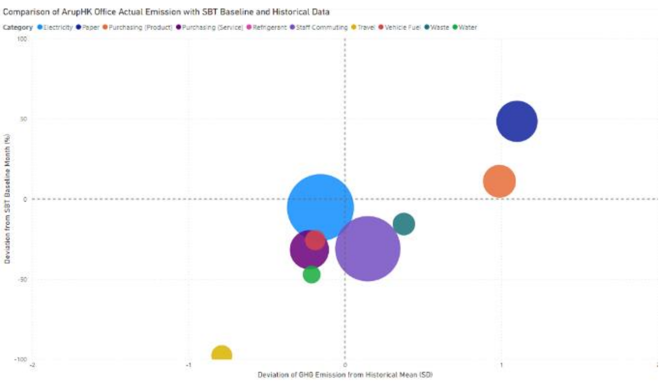

Fig. 8 - Benchmarking Function for Neuron Carbon

Smart reporting functions also allow the presentation of operational-essential data such as carbon reduction strategy effectiveness with relevant key performance indicators (KPIs). KPIs can be referenced from various carbon data disclosure guidelines, such as ESG Reporting Guide from HKEx or SBTi to help teams connect their building's performance with targets at a corporate level.

Fig. 9 - Reporting Function for Neuron Carbon

6. ADVANCING NET-ZERO DESIGN – EXISTING BUILDINGS

To develop a benchmark for ideal design and construction practises to reduce emissions from buildings, Arup participated and won the ANZ competition for Existing Buildings held by the Hong Kong Green Building Council.

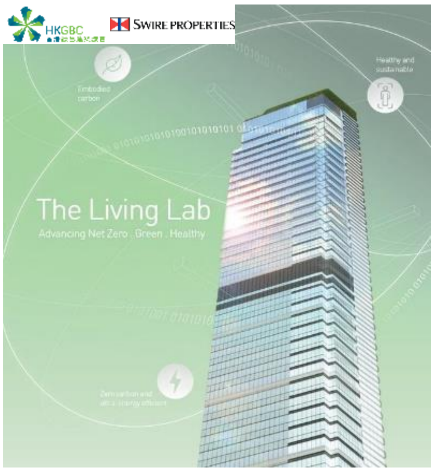

Fig. 10 - Arup's Winning Idea for Existing Buildings Category of the ANZ Competition Hosted by HKGBC

The approach taken considers achieving net-zero through balancing energy reductions while minimising embodied carbon emissions. A Net-zero Design Approach was outlined and followed as shown below.

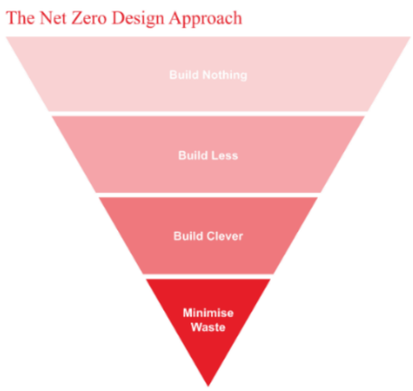

Fig. 11 - Net-zero Design Approach Proposed by Arup under ANZ Competition

6.1 Building Clever

Starting with "building clever," the ANZ existing building design proposed by Arup considers a transition into a Direct Current ("DC") distribution system, where power quality is improved and conversion loss is reduced from renewable energy systems.

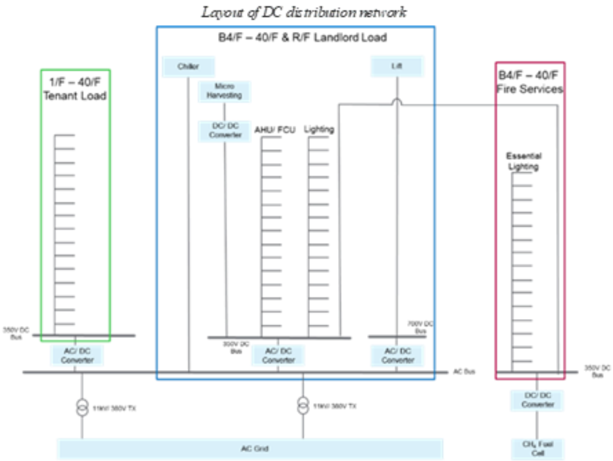

Fig. 12 - Example of How DC Distribution is applied to Buildings

For vertical transportation systems, active design initiatives such as people-flow pattern simulation and application of a dynamic counterweight to lifts allow more efficient operation of such systems in buildings.

6.2 Building Less

To make existing buildings more efficient while building less, use of natural resources such as daylighting and natural ventilation can allow for reduced material or equipment use while achieving the same design outputs.

Daylighting and daylight harvest passive design strategies were introduced into the existing building to achieve the same amount of lighting in interior spaces while using less equipment and materials. This allows similar lux levels to be achieved with significantly less artificial lighting. Use of organic light-emitting diode (OLED) and circadian lighting systems also improve individuals comfort while reducing power consumption from lighting luminaires.

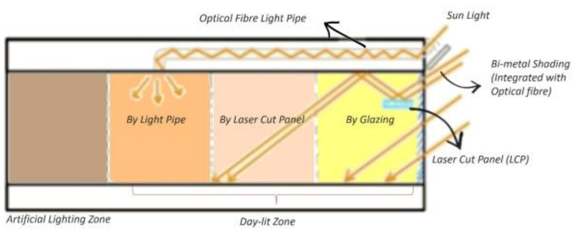

Fig. 13 - Example of Passive Design Utilizing Daylighting

Furthermore, building less and using less material are achieved through introducing circular economy concepts into the existing building or through extending the life of building components through continued use. Modular and flexible interior spaces are an innovative design measure and can reduce embodied carbon through flexible supporting ceilings holding all major mechanical, electrical and plumbing (MEP) system components and branches. These ceilings can then be flexibly connected (i.e. magnetic flexible ducts) with terminal units (e.g. diffusers) and allow for flexible partitioning and application to various fit-out schemes. This enables a reduction of over 50% of waste generated due to fit-out constructions during tenancy changes as tenants can simply apply their fit out to modular panels without creating excessive construction waste.

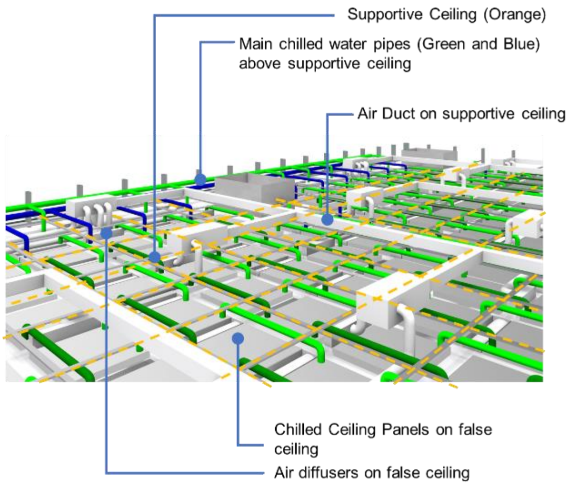

Fig. 14 - Application of Modular Ceilings in Building Design

6.3 Building Nothing

The highest level of achievement in net-zero design approach is building nothing while achieving net-zero energy savings. This is possible through data-driven operations and digital platforms for managing carbon on site.

To reduce embodied carbon and maximise effective lifetime of products, an integrated predictive maintenance platform can help to predict and plan equipment replacement schedules and reduce the need to stock up spare parts or replace components during incorrect times in their life-cycle.

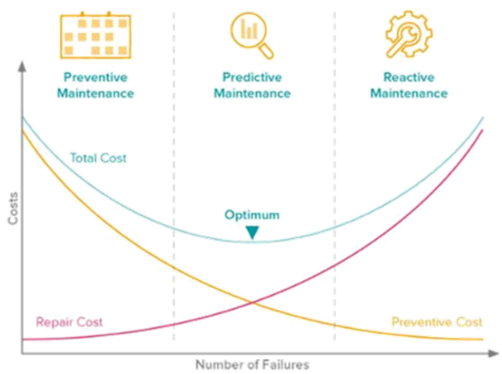

Fig. 15 - Optimizing Embodied Carbon Emissions through Predictive Maintenance

Another option suggested during this design competition was the application of blockchain for low-carbon incentivisation of occupants. Recognition of low-carbon behaviour through blockchain technology can allow users to reduce overall carbon consumption within the building without actual construction of any devices or equipment. Applied with incentivisation, users can be influenced to greatly reduce their carbon footprint through good practice.

7. LOOKING TO THE FUTURE

With commitments already made in COP 26, Arup foresees a significantly greater interest in WLC approach to emissions assessment for all aspects of building design and corporate sustainability. Designers, engineers and all other stakeholders of the buildings industry must fully understand the importance of WLC approaches to assessing their designs, and place effort in including strategies that can reduce WLC emissions for their developments.

Companies and other stakeholders with ownership in the buildings industry will also become evermore keen in reducing their carbon footprint within their portfolio, calling on designers and those partaking in design, construction and operation phases to develop strategies to help reduce their corporate emissions profile. This demand for services is set to increase significantly in the coming years and is a major factor for developing services and associated tools in this area. Hong Kong's building industry should continue to lead through setting an example, creating design standards and producing tools to facilitate the further development of WLC assessment in the engineering field.

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Paper No. 5

TRANSFORMATION INTO A SUSTAINABLE WASTEWATER TREATMENT WORKS: YUEN LONG EFFLUENT POLISHING PLANT

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TRANSFORMATION INTO A SUSTAINABLE WASTEWATER TREATMENT WORKS: YUEN LONG EFFLUENT POLISHING PLANT

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ABSTRACT

Wastewater treatment is an energy-intensive process, and energy consumption increases with wastewater treatment level. The Drainage Services Department (DSD), with a vision "To provide world-class wastewater and stormwater drainage services enabling the sustainable development of Hong Kong", has adopted innovative ways for integrating sustainable development concepts into its new / upgrading sewage treatment works projects, with a view to minimizing energy consumption and increasing renewable energy (RE) generation.

This paper provides an overview of the Yuen Long Sewage Treatment Works (YLSTW) upgrading project (i.e. YLSTW would be upgraded as the Yuen Long Effluent Polishing Plant (YLEPP) after the project), which is one of the DSD's iconic endeavours, to showcase its pursuit in sustainability.

1. INTRODUCTION

Wastewater treatment is crucial in order to protect environment and health of both humans and animals. Existing wastewater treatment plants may be required to be upgraded / expanded as a result of increasingly stringent effluent discharge requirements and insufficient treatment capacity due to increasing flows / loads. Population growth, economic development and rising public aspiration for better quality of life and sustainable development have raised the demand for environmentally friendly and energy efficient wastewater treatment facilities.

In this context, the DSD, with a vision "To provide world-class wastewater and stormwater drainage services enabling the sustainable development of Hong Kong", adopts innovative ways for integrating sustainable development concepts into its new / upgrading sewage treatment works projects, with a view to minimizing energy consumption and increasing RE generation, while in compliance with stringent discharge requirements. The YLEPP, an upgrading to the existing YLSTW, is one of the DSD's iconic projects in the pursuit of sustainable development.

Fig. 1 - Photomontage of YLEPP

2. PROJECT BACKGROUND

The DSD has two major portfolios, viz., on flood prevention and on sewage collection, treatment and disposal. Currently, the DSD is operating 328 sewage treatment facilities, including 69 sewage treatment works and 259 sewage pumping stations. In 2020-21, the DSD treated 1,044 million m^3 of sewage in total. About 2.1% of the sewage received preliminary treatment, 78.6% received chemically-enhanced primary treatment, and 18.9% received secondary treatment. The remaining about 0.4% received primary or tertiary treatments.

The YLSTW, commissioned in 1984, is one of the major secondary sewage treatment works[1] in the DSD, serving Yuen Long Town, Yuen Long Industrial Estate and Kam Tin areas with treatment capacity of 70,000 m^3/day.

To cope with the population growth and development needs, the YLSTW is being upgraded in stages from its treatment capacity of 70,000 m^3/day to 150,000 m^3/day and be transformed into the YLEPP at tertiary treatment[2] level to meet the more stringent discharge requirements, thus minimizing adverse environmental

1 Secondary Treatment - The sewage is purified by means of a biological treatment process after the primary treatment. The organic matter and nutrient in the settled sewage are decomposed by micro-organisms in the biological treatment process. Treated effluent from this process meets 30mg/L TSS and 20mg/L BOD standard.

2 Tertiary Treatment - The highest level of treatment for polishing the treated effluent from secondary treatment process. This process typically comprises a combination of physical and biological processes with the objective of further removing nutrients and suspended solids in the sewage.

impact on the ecological setting of Deep Bay. During the course of the upgrading works, about half of the existing facilities of the YLSTW will be demolished while the other half will remain in operation to maintain the sewage treatment service for the Yuen Long area.

Fig. 2 - Aerial Photo of the Existing YLSTW

Fig. 3 - Construction of YLEPP

3. SUSTAINABLE DESIGN OF YLEPP

Some key considerations have to be made to ensure wastewater treatment plants are constructed in a sustainable and energy efficient manner. In addition to ensuring the compliance with discharge requirements, two major sustainable strategies have been incorporated into the design of YLEPP. On one hand, energy consumption should be minimized. This can be done by adopting various green designs and energy efficient wastewater treatment processes. On the other hand, use of RE / energy recovery from wastewater should be maximized as far as practicable. The following sections outline several pathways taken by the YLEPP in order to reduce energy consumption as well as increase RE production.

3.1 Adoption of Energy Efficient Design

Wastewater treatment is a well-known big energy consuming process worldwide. Many factors affect energy consumption for wastewater treatment, including location, quality of influent wastewater, process configurations, treatment capacity, effluent standards, etc. Energy is used throughout the wastewater treatment process and the majority of energy is consumed for aeration and pumping of sewage and sludge. Wastewater treatment plants should be designed to maximize resource utilization and energy efficiency to ensure long-term operational sustainability. In this connection, the YLEPP has adopted energy-efficient design approaches in order to reduce energy consumption in wastewater treatment, aeration, pumping, building services, etc.

(a) Advanced Wastewater Treatment Process

Selection of an appropriate treatment process is an important issue before designing and implementing wastewater treatment plant. Advanced treatment technologies process can help bring about sustainable development, as well as more resource-efficient (in terms of energy and chemicals), environmentally friendly, compact and robust wastewater treatment undertakings.

Having conducted trials on various technologies that are helpful in improving sewage treatment efficiency, the YLEPP adopts the Aerobic Granular Sludge (AGS) process, which is an advanced technology for biological treatment, allows simultaneous removal of organic carbon, nitrogen, phosphorus and other pollutants in a single treatment reactor. The AGS process closely resembles the operation of Sequencing Batch Reactor (SBR) and each operating cycle of the AGS process will mainly consist of three operations: 1) Fill / Decant, 2) Aeration and 3) Fast Settling and Sludge Wasting.

In the Fill / Decant phase, the system will feed the appropriate portion of the primary effluent into the AGS reactor. As the reactor is equipped with fixed overflow weirs, supernatant is decanted simultaneously into the tertiary system. During the Aeration phase of the operation cycle, the influent no longer enters the reactor, and the aeration system begins delivering oxygen to the reactor. The introduction of oxygen converts the reactor from an anoxic / anaerobic environment to an aerobic environment. In this phase aerobic reactions take place in the outer part of granular biomass while anoxic condition exists in the middle of granular biomass. After Aeration, the reactor enters the Fast Settling and Sludge Wasting phases. In these phases the influent does not enter the reactor. Also, the aeration system is turned off. The absence of flow and aeration activity produces an ideal quiescent environment in the reactor for settling to separate solids from the treated effluent.

Compared with the conventional activated sludge process that relies on suspended biomass for sewage treatment, the AGS process requires less footprint as a result of high reactor biomass concentrations and fast granular sludge settling ability. This is particularly advantageous as it allows the treatment capacity of YLSTW to be upgraded to the YLEPP within its existing footprint without acquiring additional land space. In addition, the AGS is comparatively energy efficient due to the reduced use of mechanical equipment, like mixers, recycle pumps, etc. Moreover, a dedicated AGS controller and batch operation mode allows the AGS system to utilize aeration air more effectively than other conventional systems.

(b) Aeration System

Aeration is typically the largest single energy consuming process in a secondary sewage treatment. Aeration system is the core part while blowers are an integral part of the aeration system. The working principle is that blowers pull in outside air and force it through distribution pipes into aeration basins at a pressure when the shaft turns. Energy consumption of blowers is a function of air flow rate, discharge pressure, and equipment efficiency, while blower efficiency varies with flow rate, pressure, speed, inlet conditions and actual design. Technological advancements in air blowers provide new options for reducing energy consumption. The YLEPP uses high-speed gearless blowers (i.e. magnetic bearing air blowers), which adopts advanced bearing design, operating at higher speeds with less energy input than conventional type air blowers (i.e. single stage integrally geared blower and positive displacement blower) over a wide range of flows, particularly part-load conditions. The impeller shaft in a magnetic bearing design is magnetically levitated to provide friction-free floating of the shaft. The friction-free bearing design, coupled with high-efficiency motors, contributes to the comparative high energy efficiency of these air blowers over conventional types.

(c) Pumping System

Pumping is a significant energy consumer at wastewater treatment plants, being in many cases is the second one after aeration. An energy efficient pumping system has to start with the design of hydraulic system. One of the key design elements in the YLEPP is to employ hydraulic head whenever possible to reduce the need to pump. For instance, an effluent pumping station is provided downstream of ultraviolet (UV) disinfection facilities to discharge effluent to the Shan Pui River. To save energy / cost on pumping, there are two operation modes of effluent discharge. With the optimal hydraulic design, the operation allows the effluent to be discharged to the Shan Pui River mostly by gravity, and the effluent pumping station only operates during extreme weather or normal high tide conditions.

Sewage pumping system is usually a low head pumping system, with static lift usually accounting for the majority part of the total system head. Keeping the entire system's static lift to a minimum is also an important aspect of energy efficiency. The YLEPP uses variable speed drive (VSD) and level sensor to control pump speed in the inlet pumping system and effluent pumping system in order to maintain the water level at the highest acceptable level to reduce static lift, thus saving energy. In addition, the inlet pumping system is designed with multiple pumps: small pumps operate at low flow rate, while large pumps operate at maximum design flow rate. By using this configuration, all the pumps are able to operate near their best efficiency point (BEP).

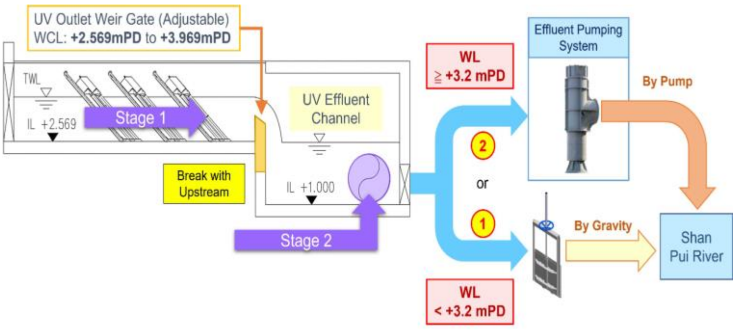

Fig. 4 - Schematic Diagram of Effluent Discharge Modes

(d) Effluent Cooling

Water is a consumable in wastewater treatment process. Effluent reuse is a prominent solution in some tertiary sewage treatment applications to reduce the use of this precious resource. The treated effluent in the YLEPP is used not only for chemical preparation and equipment cleaning, but also serves as a cooling medium for its water-cooled air conditioning (A/C) systems in plant rooms / buildings, which are more energy-efficient than air-cooled A/C units. The concept of effluent cooling can provide favorable conditions for sustainable development and contribute to environmental protection.

(e) Natural Lighting and Cooling in the Building

Use of natural light is one of the prime movers in saving energy. Glazing panel array on building wall allows natural light to transmit and diffuse to building interior as supplemental lighting, thereby reducing the need for artificial lighting and energy consumption of lighting systems. Also, shading created by cantilevered slab extending from all sides of building blocks direct sunlight to the interior and prevents unwarranted heat gain in buildings, thereby reducing the demand for air conditioning.

3.2 Integration with Renewable Energy

The YLEPP has not only been designed to minimize energy consumption, but also has maximized the use of RE to achieve carbon neutrality. In wastewater treatment works, two kinds of RE are usually available; namely, solar energy and biogas.

(a) Extensive Provision of Photovoltaic (PV) Panels

Solar energy is the cleanest and most abundant RE source on earth. The recent development of photovoltaic cells makes it a more practical and financially viable energy source. Over the years, the DSD has endeavoured to make full use of open space in its facilities to capture solar energy to generate electricity for subsequent use as far as practicable. Following the DSD's 1.1MW solar farm commissioned in 2016 at Siu Ho Wan Sewage Treatment Works, the YLEPP was designed to maximize its potential to utilize solar energy by installing more than 5,000 monocrystalline PV panels on rooftops of most of YLEPP buildings for power generation, with a total installed generation capacity of around 2.5MW, operating in on-grid configuration (i.e. connected to operate in parallel with the power supply grid). It can generate as much as 2.5 million kWh of electricity annually, which is equivalent to the annual electricity consumption of 750 three-member families. Annual reduction of carbon dioxide emission can be up to 1,750 tonnes. The electricity generated is supplied to the facilities in the YLEPP for consumption. Upon commissioning in 2027, the YLEPP will be one of the largest solar power generation facilities in Hong Kong.

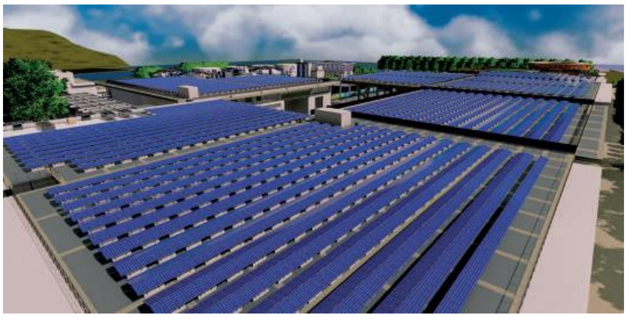

Fig. 5 - Photomontage of PV Installation at YLEPP's Building Roofs

(b) Biogas Utilization

Biogas is one of the by-products in secondary sewage treatment process with anaerobic digestion of sludge. In the anaerobic sludge digestion process, organic matters of the sludge are broken down into less obtrusive inorganic products resulting in the reduction of dry mass of the sludge. At the same time, biogas is produced. The biogas mainly consists of methane (60% to 65% by volume), CO2 (35% to 40% by volume) and other trace amount of gaseous products (e.g. hydrogen sulphide (H2S) and moisture). The heating value (i.e. the heat released when a known quantity of fuel is burned) of the biogas is generally above 22.4 MJ/m^3, which is about 23% higher than the heating value of domestic gas used in Hong Kong.

Biogas generated in sludge digesters is first transferred to and stored in biogas holders. After proper treatment including desulphurization and moisture removal, the treated biogas is fed at a constant pressure into combined heat and power (CHP) generators. The energy stored in the biogas is then converted into thermal energy and mechanical energy which drives a synchronous generator for producing electricity to meet part of the plant's power demand, with the heat recovered from the process for maintaining the proper temperature of the digesters, which is one of the key conditions for the sludge digestion process to proceed, and thus biogas generation.

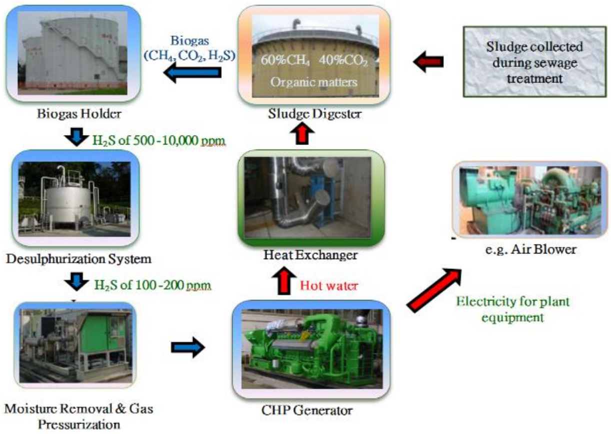

Fig. 6 - CHP Generating System Flow Diagram

More biogas will be produced when the YLEPP is commissioned. There will be three biogas-fuelled CHP generators, each rated at 635kW, generating electricity and heat to support the daily operation of YLEPP. The CHP system, operating in on-grid configuration, can generate 5.4 million kWh of electricity generation annually, which is equivalent to the annual electricity consumption of 1,600 three-member families. Annual reduction of carbon dioxide emission can be up to 3,700 tonnes.

(c) Implementation of Food Waste and Sewage Sludge Co-digestion

The average daily quantity of food waste disposed of at landfills in 2020 is 3,255 tonnes[3], accounting for 30% of the total municipal solid waste in Hong Kong.

Food waste, by virtue of its higher organic contents, has a higher specific energy value than municipal sewage solids. In fact, the average methane gas production rate of food digestion is usually much higher than that of municipal sewage sludge.

In view of the high energy value of food waste, it is considered that if more food waste is delivered to the sludge treatment facilities in sewage treatment works for co-digestion with sewage sludge to generate biogas, the recovery of energy can be remarkably enhanced. It

3 The Hong Kong SAR Government. Monitoring of Solid Waste in Hong Kong - Waste Statistics for 2020

can also help relieve the burden to our landfills arising from food waste dumping to the limited landfill space. More importantly, it has been demonstrated that there is a synergy effect in carrying out co-digestion of food waste and sewage sludge where it can increase biogas production and reduce solid waste more effectively than digestion of the two wastes separately.

Fig. 7 - Co-digestion of Food Waste with Sewage Sludge

In addition to the co-digestion pilot project in the Tai Po Sewage Treatment Works, an area with sufficient footprint has been reserved in the YLEPP for collecting and handling about 260 wet tonnes of pre-treated food waste per day. This will provide the potential for the YLEPP to implement co-digestion of imported food waste with sewage sludge there to boost up biogas production. It is estimated that the co-digestion can nearly triple biogas production when compared to the digestion of sewage sludge alone.

4. CONCLUSION

Population growth as well as economic development of the city generate much more pollution loads, and quality wastewater treatment becomes necessary. But, just making provision of infrastructure in wastewater treatment alone is not enough to achieve sustainable development. Wastewater treatment facilities must be carefully planned and designed. As one of the DSD's major upgrading sewage treatment works projects, the YLEPP exhibits a commitment to sustainable development through various measures including: (1) reducing energy consumption in wastewater treatment process; (2) increasing the energy recovery from internal sources; and (3) adding sufficient external RE sources. The use of green designs and advanced wastewater treatment technologies / equipment can make wastewater treatment more energy efficient. Biogas from sewage sludge is the primary RE source in the DSD's secondary treatment works. The use of biogas-fuelled CHP generators is considered to be one of the most effective approaches to energy recovery. Application of food waste and sewage sludge co-digestion reveals the possibility of increasing the biogas production and reducing the volume of digestate at the same time. In addition to utilizing biogas, solar energy is utilized as RE source to provide electricity to the plant.

Looking ahead, the DSD will keep striving to enhance the total energy management strategy for its facilities and extend the application of RE, whereby providing even more contributions to sustainable development.

Paper No. 6

APPLICATION OF VISUALIZED OVERHEAD LINE REMOTE EARTHING SYSTEM IN MTR

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ABSTRACT

According to the Railway Development Strategy 2014 published by the Government of the HKSAR (the Government), 7 new railway projects are planned to be built by around 2031 in Hong Kong. For railway lines to be extended from or built on existing railway lines operated by the MTR Corporation Limited (the Corporation), modification works of the existing civil structures and E&M systems, especially at the trackside areas, will be inevitable. As many of the modification works will need to be carried out at tracksides during Non-Traffic Hours (NTH) with the overhead line (OHL) de-energized, isolated and earthed to ensure safety, the demand of de-energized possessions will increase significantly.

Currently, NTH in MTR is around 4.5 hours per day but the actual working window to carry out modifications works is only around 2 to 2.5 hours for de-energized possessions as it takes about an hour to set up and restore the possession areas. To shorten the setup and restoration time so as to enlarge the working window to improve efficiency and reduce wastage of valuable resources, a Visualized Overhead Line Remote Earthing System (the System) has been introduced in MTR. To evaluate the safety and effectiveness of the System, the essential parts of the System have been implemented as a trial (the Trial System) on an OHL section of the Airport Express Line (AEL). The trial is also aimed at identifying and implementing any required enhancements on the System and the associated operating procedures to fulfill the requirements stipulated in the Code of Practices for the Electricity (Wiring) Regulations published by the EMSD (the COP) of the Government, as well as the Railway Safety Rules (RSR) and Design Standard Manuals of the Corporation.

This paper describes the architecture and system design of as well as the experiences gained from the Trial System.

1. INTRODUCTION

According to the Railway Safety Rules (RSR) of the Corporation, before any works within the minimum safe distance of the OHL system can be carried out, protection measures have to be set up to safeguard personnel working in proximity of OHL equipment. As such, the designated OHL sections of the working area will need to be de-energized, isolated and earthed prior to site work.

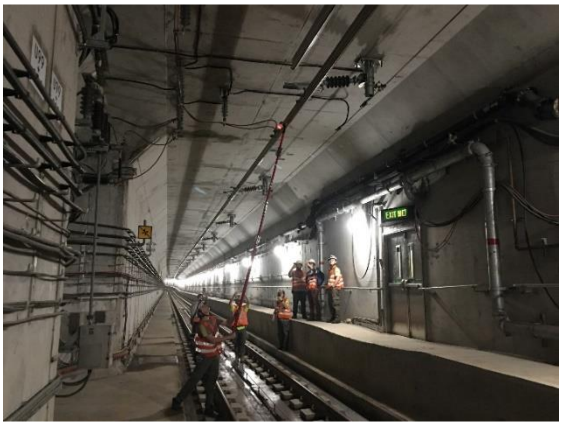

Fig. 1 - Existing Testing and Earthing of OHL

Major steps for setting up the protection measures sanctioned by the RSR for a de-energized possession include:

(a) Opening of designated OHL isolators (to be carried out by the Power System Controller (PSC) at the Operations Control Centre (OCC))
(b) Disabling of remote-control authority of OHL isolators
(c) Testing of OHL line voltage
(d) Applying earthing rods on OHL
(e) Issuance of Permit-to-Work (PTW)

Steps (b) to (e) are executed at trackside by the Authorized Person (AP) on duty as depicted in the RSR.

As a record of the protection setup and authorization, a Permit-to-Work (PTW) will be issued by the AP to each relevant Competent Person (CP) who is responsible for the safety of his working party prior to the commencement of works.

According to the current operating procedures, the AP shall set relevant OHL isolators to local control and apply personal padlock at the OHL isolator control boxes to prevent un-authorized / accidental control of OHL isolators while the PTW is in effect. The AP shall check the position of OHL isolators visually and use live line testers to check line voltage before applying earthing rods to earth the OHL.

The setup of protection is often time-consuming as the AP needs to travel to various locations along the tracks to set up protected working boundaries for the works after the permission of track access has been granted by the Traffic Controller (TC). These procedures reduce the working window available for the working parties during NTH which in turns may result in longer time frame to complete emergency corrective maintenance works. In some situations, these necessary safety procedures would also result in longer rescue time during traffic hours.

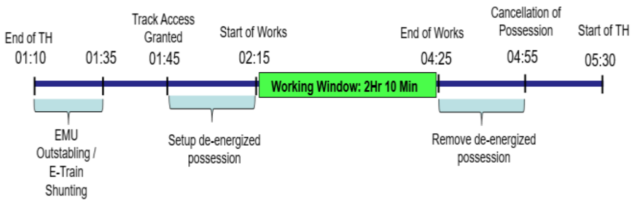

Fig. 2 - Existing Allowable Working Window

Therefore, a system which can test the OHL voltage and connect the OHL to earth remotely to negate the need of manual testing and earthing as well as reduce the setup and restoration time for de-energized possessions to cater for the increasing demand of de-energized possessions is considered necessary.

2. SYSTEM ARCHITECTURE OF VISUALIZED OHL REMOTE EARTHING SYSTEM

Visualized Overhead Line Remote Earthing System (the System) which has been adopted in some of the metro lines in Mainland China is considered feasible to be adopted in MTR network, with enhancements required to suit local requirements, to improve safety and to shorten the preparation and restoration time of a de-energization possession. The System normally adopts a three-layer architecture that is, the Trackside Level, Station Level and OCC Level.

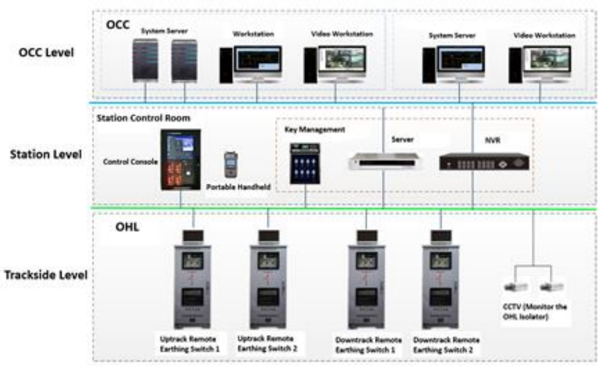

Fig. 3 - System Architecture of Visualized Overhead Line Remote Earthing System

2.1 Trackside Level

The trackside level comprises of the following equipment installed at trackside:

a) Remote Earthing Switch

Remote Earthing Switch, with a weather-proof cubicle housing an earthing isolator, voltage transducers, on-board CCTV as well as a motorized and manual control mechanism, is installed nearby each in-feed OHL isolator at trackside.

The major functions of a Remote Earthing Switch are:

- Make or break the connection between OHL and earth (rail) with an earthing isolator.
- Measure the OHL line voltage with voltage transducers.
- Discharge OHL residue voltage (after the power supply of OHL has been switched off).
- Provide real-time video footage of earthing isolator position via on-board CCTV.

b) OHL Energization Status Display Panels

An OHL energization status display panel is installed nearby each Remote Earthing Switch to indicate the real-time energization status, i.e., energized, power off or earthed, of the associated OHL section.

c) Trackside CCTV

Trackside CCTVs are installed to provide real-time video image of the OHL isolators. This real-time video image allows visual confirmation of the OHL isolator positions by APs who are stationed at the Control Consoles of the System (Station level) installed at stations or traction substations.

2.2 Station Level

Control Consoles, key boxes, portable handheld devices, data transmission devices and video recording equipment of the System are installed at back-of-house areas of selected passenger stations or traction substations. Each Control Console allows for remote control and monitoring of the System's equipment in nearby track sections, as well as the issuing of electronic versions of Permit-to-Work (ePTW) and Sanction-for-test (eSFT) to CPs of associated working parties at site.

2.3 Operations Control Centre (OCC) Level

Workstations and server equipment are installed in OCC, so that all associated equipment of the System in the railway network can be controlled and monitored by the PSC. In addition, provisions are also made available at this level to allow for issuing of ePTW and eSFT to CP of the associated working parties, if needed.

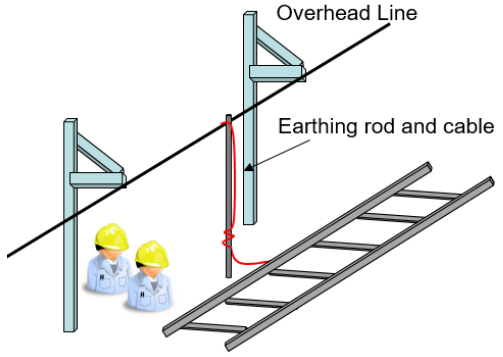

Fig. 4 - Current Practice - Manual Setup of OHL Earthing at Trackside

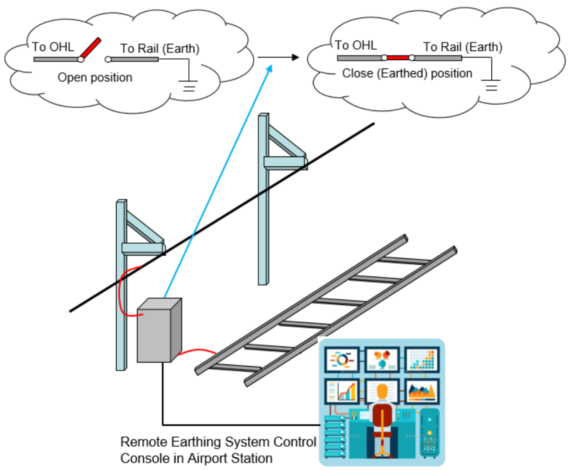

Fig. 5 - Remote Earthing of OHL

3. ADOPTION OF THE SYSTEM IN MTR METRO LINES

To verify the feasibility and confirm the suitability to adopt the System in MTR metro lines (Lines with 1500V d.c. traction power system), a trial of the Visualized Overhead Line Remote Earthing System (the Trial System) has been carried out in an OHL section between Chek Lap Kok Traction Substation (CHT) and Tung Chung Traction Substation (TUT) in the Airport Express Line (AEL).

The primary objectives of the trial were:

- To validate the safety, integrity and reliability of the System
- To analyze the effects on Human Factor issues as compared with the existing isolation and earthing procedures.
- To evaluate the time-saving on setup and removal of de-energized possessions.

3.1 Architecture of the Trial System

To reduce the duration and complexity of the Trial, the Trial System only comprises of the Trackside Level and Station Level. A set of Trackside Level equipment and Station Level equipment have been installed and an electronic permit (ePTW and eSFT) system has been implemented so that the setup of de-energized possession and issuing of safety documents can be remotely performed. The server which originally designed for the OCC Level has been installed at the Station Level.

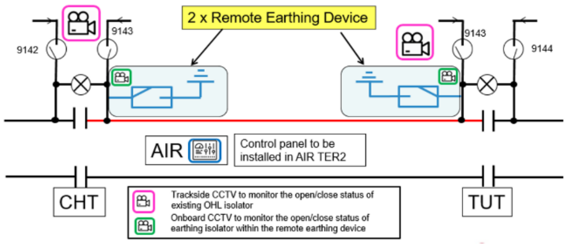

Fig. 6 - Configuration of the Trial of Visualized OHL Remote Earthing System on an OHL Section in AEL

a) Trackside Level

Trackside Remote Earthing Switch

Two Remote Earthing Switches with onboard CCTV have been installed nearby the OHL isolators CHT 9143 and TUT 9143 respectively at the Down Track of the Airport Express Line (east bound for Hong Kong Station).

Fig. 7 - Remote Earthing Switch

Trackside CCTV

Trackside CCTVs have been installed in the proximity of OHL isolators for monitoring the real-time position and status of the OHL isolator heads. These cameras have night-vision functions which support image capturing under a low illumination environment. Time stamps and ID of the OHL isolators are displayed on the video images to facilitate the confirmation of OHL isolator status.

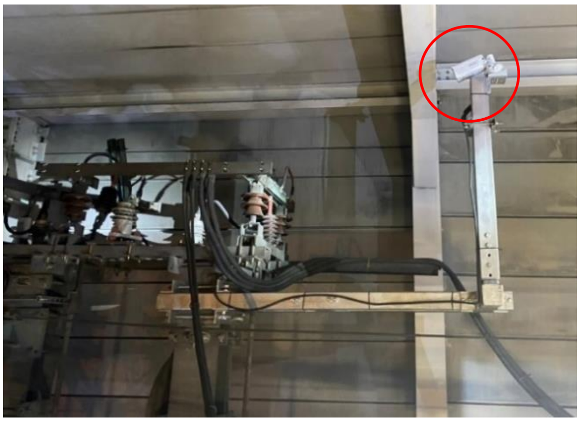

Fig. 8 - Trackside CCTV in the Proximity of OHL Isolator

Electronic Locks

In existing practice, the AP must apply personal padlocks to control boxes of OHL isolators before the issuing of the permits. To eliminate the time required for the AP to apply padlocks on multiple OHL isolators at site, electronic locks have been fitted to the control boxes of OHL infeed and bypass isolators (TUT 9102/9143 & CHT 9102/9143) so that the control boxes can be locked remotely.

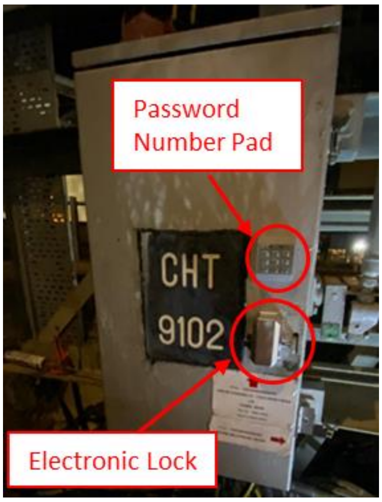

Fig. 9 - Modified OHL Isolator Control Cubicle with Electronic Lock and Password Number Pad

OHL Energization Status Display Panel

An Outdoor LED display panel has been installed nearby the Remote Earthing Switch at CHT and TUT respectively to notify the working party of the real-time OHL energization status.

Fig. 10 - OHL Energization Status Display Panel

Electronic Hazard Warning Notice

In current practice, the AP has to post warning notices on the OHL isolator control boxes before the issuing of the permits. To eliminate the time required for the AP to post the notices on multiple OHL isolators at site, electronic Hazard Warning Notices have been fitted to the control boxes of OHL infeed and bypass isolators (TUT 9102/9143 & CHT 9102/9143) respectively, so that the warning notices can be posted remotely.

Fig. 11 - Electronic Permit-to-Work in Effect

Fig. 12 - Electronic Sanction-For-Test in Effect

b) Station Level

Control Console

A Control Console has been installed in the Telecom Equipment Room of the Airport Station to enable the AP to monitor and control the equipment of the System remotely. The Control Console also allows the AP to issue electronic permits to CPs of the associated working parties.

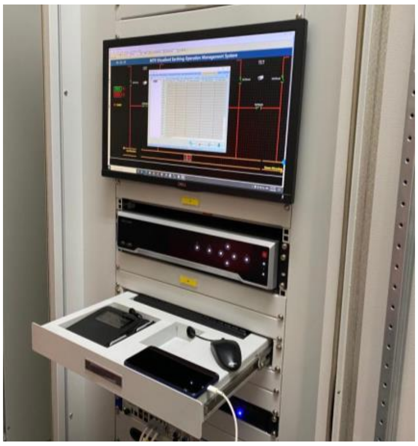

Fig. 13 - Control Console in Airport Station

OCC Level (Equipment Status Monitoring)

Real-time status monitoring function of the Remote Earthing Switches has been provided at the OCC (instead of full feature including remote control), so that the PSC can monitor the status of remote earthing switches and OHL isolators at the exiting MIMIC and HMI workstations. No remote-control function of earthing switch was provided at OCC.

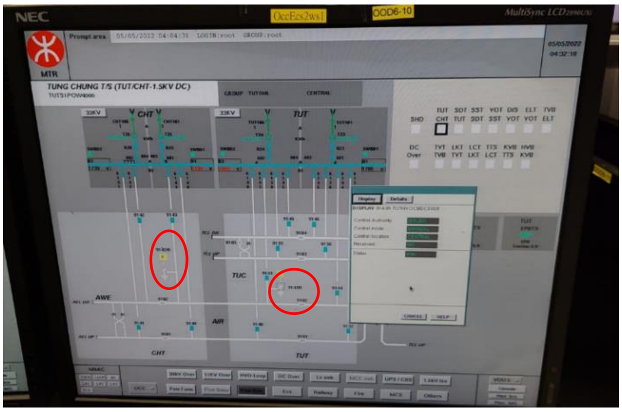

Fig. 14 - Real-time Statuses Monitoring of the Remote Earthing Switches in OCC

Network Architecture

Both SCADA and optical fibre cables are used to transmit data, the statuses of the Remote Earthing Switches and OHL isolators as well as the images captured by the CCTVs, from trackside to the equipment installed in the Station Level. The control commands from the Control Console to the Remote Earthing Switches are also sent through the optical fibre cables. The network architecture is shown in Figure 15 below.

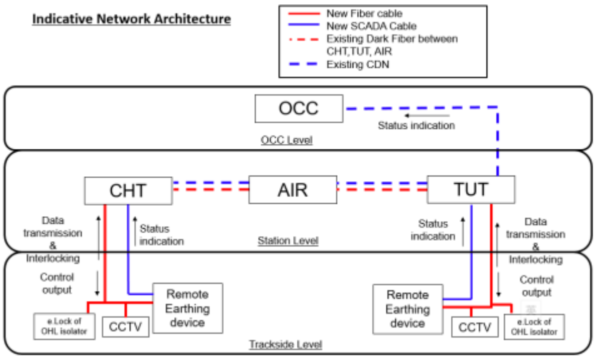

Fig. 15 - Network Architecture

3.2 Electronic Permit-to-Work (ePTW) system

According to the RSR of the Corporation, protection measures must be set up to safeguard personnel working in the proximity of OHL equipment. As a record of the completion of the protection setup and authorization, a PTW shall be issued by the AP to the CP prior to the commencement of any site works.

To negate the need for AP to issue PTWs at site, an electronic Permit-to-Work (ePTW) system has been developed as part of the System, where electronic permits can be issued and sent to the CPs via a wireless network. Specialized portable handheld devices have been provided to the CPs for receiving and reviewing the ePTWs.

Whilst the primary objective of the ePTW system is to reduce the setup time required for de-energized possessions, efforts have also been made during the design of ePTW system, such that its workflow and sequence are as similar as possible to the current PTW system to mitigate the impacts to the RSR currently enforced by the Corporation.

The ePTW system possesses the following functions:

- Preparation of ePTW
- Issuance of ePTW
- Receipt of the ePTW
- Transferal of ePTW
- Declaration of clearance of worksite
- Cancellation of ePTW

3.3 Setup of De-energized Possessions with Remote Earthing and ePTW Systems

The procedures for the setup of de-energized possession and issuing of ePTW using the Trial System are highlighted as follows:

a) Preparation for ePTW

After defining the worksite boundaries in the Trial System (i.e., Points of Isolation & Circuit Main Earth), the System will identify automatically the required Remote Earthing Switches and OHL isolators of concerned in the ePTW.

Fig. 16 - Electronic Permit-to-Work (ePTW) System in the Control Console used by the Authorized Person

b) Opening of OHL Isolator and Validation of Isolator Status

After the preparation of ePTW is completed, the relevant OHL isolators will be opened remotely by the PSC. The statuses of the OHL isolators will be confirmed through both the Trackside CCTVs and the statuses shown on the existing Main Control System (MCS).

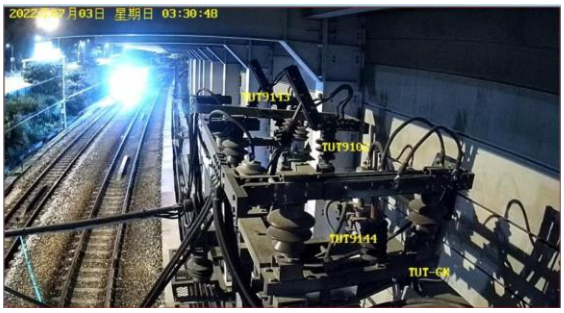

Fig. 17 - Real-time Image from TUT Trackside CCTV for Monitoring OHL Isolator Head Positions at Control Console

c) Application of OHL Earthing via Remote Earthing Switch

When all relevant OHL isolators are opened, the respective OHL section becomes isolated. The relevant Remote Earthing Switches will be closed remotely and their statuses will be validated through the onboard CCTVs and MCS. The OHL section will then be considered successfully isolated and earthed.

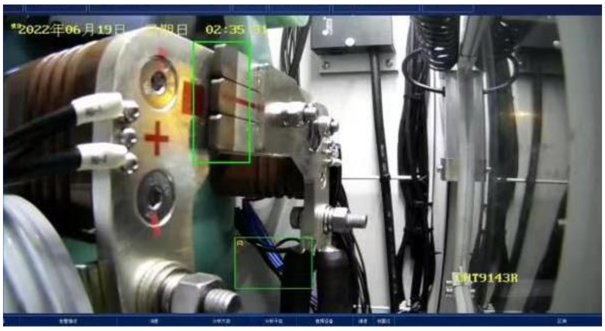

Fig. 18 - Real-time Image from On-board CCTV of Earthing Switch for Monitoring the Earthing Switch in CHT at the Control Console

d) Issuing of ePTW to CP

After the successful completion of OHL isolation and earthing, the AP will issue the ePTW to the CP of the working party at trackside. The ePTW will be transmitted to the CP's portable handheld device via the wireless network.

Similar to the current PTW system, the control of relevant OHL isolators and Remote Earthing Switches lies only on the CPs who receive the permits, with the keys to unlock the OHL isolator control boxes and Remote Earthing Switches being held by the CPs.

However, instead of physical keys adopted in the current PTW system, the ePTW system utilizes electronic keys in the form of One-Time-Password (OTP) which are generated by the Trial System and sent to the CPs' portable handheld devices. Once the ePTW has been issued, the unlock passwords of the electronic locks fitted on the OHL isolator control boxes and Remote Earthing Switches will be updated, and the locks can only be unlocked with the OTP

e) Transfer of Permit and Declare Clearance of Worksite

If the work lasts for a long duration, the CP can stand down and transfer the ePTW to another CP using the portable handheld devices, without the need to cancel and reissue the ePTW again.

After the completion of works, the CP can declare clearance of worksite and send OTP back to the AP via the portable handheld device. When the control authorities of the OHL isolators and Remote Earthing Switches are resumed, the AP can cancel the ePTW, and restore the equipment back to its original positions with the PSC.

4. SAFETY FEATURES AND DESIGN ENHANCEMENTS

4.1 Summary of Design Features

The Trial System has been designed with various safeguards to mitigate potential operational safety risks of the System caused by human errors and / or system failure. With these safeguards, the system has been certified as compliant to Safety Integrity Level 2 (SIL-2) as stated in IEC 61508.

The major design features of the system are listed as follows:

- Redundant Status Monitoring Equipment & Modes
- Hardwire interlock
- Software interlock
- Cybersecurity features

a) Redundant Status Monitoring Equipment & Modes

The following redundant and fail-safe status monitoring techniques have been applied in the Trial System:

Redundant Status Monitoring Modes: Hardwire & Video Recognition

To ensure the reliability and accuracy of status monitoring of the OHL isolators and the earthing isolator inside the Remote Earthing Switches, two monitoring modes are adopted:

Hardware monitoring – Auxiliary contacts are used to indicate the status of isolators which are transmitted to the server of the Trial System through hardwire circuits.

Video recognition – The real-time video images of isolators are transmitted to the server of the Trial System through fibre cables and a video recognition software is used to identify the status of the isolators.

The status of the isolators identified by the two independent methods will be compared. Alarms will be automatically prompted at the Control Console and portable handheld devices notifying the AP and CP if any discrepancies found.

Redundant Voltage Measurement Equipment

To ensure reliability of the OHL voltage measurement, redundant voltage transducers are installed in each Remote Earthing Switch. The voltage data measured by the transducers will be compared. If the delta between the two measured values exceeds a threshold, alarms will be prompted at the Control Console and portable handheld devices.

b) Hardware Interlock

To prevent inadvertent operation, hardwire interlock is installed such that the closure of OHL isolators or earthing isolator inside the Remote Earthing Switches will be prohibited if the defined conditions as stated in Figure 19 below are not fulfilled.

	CHT 9102	CHT 9143	TUT 9102	TUT 9143	ES1	ES2
ES1 is closed	Prohibit to close					
ES2 is closed	Prohibit to close					
CHT 9102 is closed					Prohibit to close	
CHT 9143 is closed					Prohibit to close	
TUT 9102 is closed					Prohibit to close	
TUT 9143 is closed					Prohibit to close	

Remarks: ES1 is the Remote Earthing Switch near CHT
ES2 is the Remote Earthing Switch near TUT

Fig. 19 - Logics for Hardware Interlock

c) Software Interlock

Before the issuance of ePTW, the operator is required to carry out various checking and remote-control operations via the Control Console.

To prevent hazards caused by human errors, the following software interlocks are enforced.

Remote closure of trackside remote earthing switches is prohibited if any of the following scenarios is valid:

- The measured OHL line voltage is higher than 120V (maximum safe voltage as stated in EN50122-1).
- The difference in voltage measured by the transducers is higher than 2%.
- The statuses identified using auxiliary contacts and video recognition do not match with each other.
- Relevant OHL isolators are not opened.
- The Remote Earthing Switches are not stated as the "Circuit Main Earth" in the ePTW.
- Cabinet door of Remote Earthing Switch or control boxes of OHL isolators is opened.
- Communication with any of the relevant trackside equipment is lost.

d) Cybersecurity Features

During the issuing of ePTW / eSFT, the electronic safety documents will be sent from the Control Console to portable handheld devices of the corresponding CPs via a 4G network.

To prevent hazards caused by cyberattacks, the following cybersecurity features are adopted:

- De-militarized Zone (DMZ).
- Private APN Sim Cards used for all Portable Handheld Devices.
- Compliance to Security Level 2 (SL-2) of cybersecurity standard IEC 62443-3.

4.2 Safety Features to Avoid Human Factor Issues

When utilizing the System and the ePTW, the AP needs to confirm the statuses of OHL isolators and earthing isolators inside the Remote Earthing Switches through the Trackside CCTVs and the on-board CCTV respectively.

To avoid wrong judgement of the isolator statuses, the following features have been added on the CCTV images:

- Timestamps for the AP to know if the CCTV image is frozen.
- Isolator ID stamps for AP to distinguish and confirm the identity of isolators easily and accurately.
- Provision of image recognition software to facilitate the AP to double confirm the status of isolators.

4.3 Summary of Safety Enhancements During System Design

As lessons learnt, the following enhancements have been made to the Trial System as part of the trial:

a) Voltage Sensors and Dual Earthing Cables

As the OHL line voltage measured by the Remote Earthing Switch is critical to the remote earthing process, dual voltage sensors are provided for redundancy. In addition, the voltage testing circuits are of failsafe design. When the measured OHL line voltage is 0 V, a secondary voltage of 1 V (instead of 0 V) shall be output from the secondary side of the voltage sensors. If no secondary voltage is detected by the System, both sensors should be considered failed.

Furthermore, two separate cables are used to connect the remote earthing switch to the rail to secure the earthing connection.

b) Stringent Earthing Requirements

Remote Earthing Switches are installed at each end of the OHL section of concern and the earthing isolator inside both Remote Earthing Switches have to be confirmed closed before the ePTW can be issued.

c) Unintended Closing of the Earthing Isolator

To prevent unintended closing of the earthing isolator caused by failure of electronic components of a Remote Earthing Switch, an open contact from a closed OHL isolator is added to the motor control circuit of the earthing isolator to prevent the earthing isolator from closing when the corresponding OHL isolator is still in its closed position.

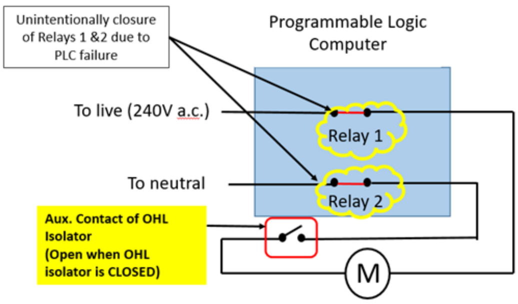

Fig. 20 - Simplified Motor Control Circuit for Earthing Isolator

4.4 Risk Control Procedures

To mitigate the potential risks that might have arose during the implementation of the Trial System to a practicable minimum, the following rick control procedures were implemented:

a) Hazard and Operability Study (HAZOP)

A HAZOP study was carried out, from which a hazard log was developed to identify all design, construction as well as operation and maintenance (O&M) risks and their potential consequences. Relevant safeguards were conceived so that the respective risks could be reduced to an acceptable level. The hazard log was presented to the MTRCL's Risk Control and Analysis Committee (RCAC) for endorsement.

b) Human Factor Analysis

A Human Factor Analysis was carried out from which a Human Factor Issues Register (HFIR) was developed to identify all potential human factor related risks and consequences during the operation of the System. Design and O&M safeguards were conceived so that risks due to human errors could be kept to a practicable minimum. The results of the Human Factor Analysis were presented to the MTRCL's Human Factors Management Committee (HFMC) for endorsement.

c) Change Analysis of Operating Procedures

In light of the remote and automatic nature of the Trial System, there was stark contrast between the existing and the new procedures for OHL isolation and earthing, as well as issuance and cancellation of permits.

As such, a change analysis was carried out to outline all necessary changes to the existing procedures. For every identified change, the new procedures had to be designed such that the purposes / functionalities of the existing procedures are retained. The results were presented to the Corporation's Operations Standards Committee (OPSC) for endorsement.

d) Overall System Safety

In addition to the risk control procedures stated, the overall safety of the Trial System was scrutinized by the Corporation's Safety Technical Committee (SAFTEC). Safety features of the Trial System, as well as the results of the HAZOP, Human Factor Analysis and the proposed operating procedures were all reviewed holistically by the SAFTEC. Approval to commence the Trial System was granted accordingly.

4.5 Results of the Trial

Validation on the Trial System were carried out to confirm if the original objectives could be achieved.

a) To validate the Safety, Integrity and Reliability of the Trial System

Multiple design features were devised to assure the safety, integrity and reliability of the Trial System. Site tests under various failure scenarios were carried out to prove the effectiveness of the design and O&M safeguards. Results of the tests showed that the safety and integrity of the system were still intact in the event of system failures. In addition, it was verified that the new operating procedures for OHL isolation and earthing as well as issuance and cancellation of ePTW could deal with normal system operations and contingencies in the event of system failures.

b) To Analyze the Effectiveness in Human Factor Issues as compared with the Existing Isolation and Earthing Procedures

The Trial System had been incorporated with multiple software and hardwire interlocks to safeguard maloperations and incidents due to human errors during manual earthing of the OHL.

The safety features were proved to be effective in safeguarding the following human errors:

- Incorrect identification of Isolator positions.
- Application of earthing rods when OHL is still live.
- Apply earthing rods at the incorrect OHL sections.

c) To Evaluate the Time-saving on Setup and Removal of De-energized Possessions

Trials were carried out to record the time required to set up a de-energized OHL possession between TUT and CHT at AEL Down Track. The comparison of the times for setup and removal of possessions by using the existing procedures and equipment and that of the Trial System was presented as follows:

Time Comparison	Existing (min)	Trial System (min)
Set up de-energized possessions	25	5
Remove de-energized possessions	20	3

The results of the tests on the Trial System revealed that all objectives set were achieved and the trial project was considered successful.

5. CONCLUSION

To cope with the anticipated surging demand in de-energized possessions during the implementation of the new railway projects in existing network, the Corporation has been seeking new initiatives by adopting latest technologies such as the Visualized Overhead Line Remote Earthing System to enlarge the working window of de-energized possessions which in turns reduce the wastage of valuable resources and enhance safety by mitigating potential risks due to human errors.

To adopt the System in the MTR network, design enhancements need to be made to the original design by others so that the safety and reliability assurances as required by the Corporation and relevant statutory authorities in Hong Kong can be fulfilled. Using the current Railway Safety Rules as the framework, the impacts of the new operating procedures to the operations of the existing railways can be kept to a minimum.

The Trial System implemented in the Airport Express Line (AEL) served to verify the improvements in safety as well as the resource saving in setup and restoration time of de-energized possessions. The trial results demonstrated that the risks of incidents due to human errors happened during testing OHL voltage and earthing OHL can be mitigated and the saving in time is significant for NTH which is a demanding asset for the Corporation.

The Corporation endeavors to deliver new railway projects safely and timely. The encouraging results of the trial project has paved the way for the Corporation to plan for the full implementation of the System with enhancements in existing 1500V d.c. metro lines and future railway extensions to provide safer working environment and more valuable times for works requiring de-energized possession.

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Paper No. 7

AMMONIA FUEL CELL & ITS APPLICATIONS TO ELECTRIC VEHICLES

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ABSTRACT

The paper describes the recent development of an ammonia-powered electric vehicle. The issues of the Li-ion battery as the main energy storage in an electric vehicle are discussed. Hydrogen fuel is now being promoted worldwide, but the handling of hydrogen is not simple. It suffers from the high cost of manufacturing, high handling cost and high safety standards. On the other hand, ammonia fuel is an excellent alternative because its cost is low, and its handling is simple. The operational pressure is low. A full study of ammonia for electric vehicle fuel is presented, and a prototype has been examined and presented in this paper.

1. INTRODUCTION

The conventional electric vehicle is based on battery energy storage. With the emergence of Li-ion batteries, the electric vehicle now becomes successful electric transportation. Li-ion battery has a high energy content. It has been proven to be excellent energy storage with high efficiency and a long lifetime. It earned the 2019 Nobel Prize in Chemistry. The common Lithium Iron Phosphate has a specific energy of at least 140 Wh/kg, and the NMC battery has an energy density of 200 Wh/kg. Therefore the present EV is able to provide a 300-500 km range of traveling per charge.

The battery however has an aging issue. The present battery has a lifetime of 7 to 8 years, and the state of health (SoH) will drop to 70-80%. The recycling of batteries is difficult; Lithium, cobalt, manganese and nickel are expensive metals; they have bonded to the electrode and also dissolved in the electrolyte and the process to extract them is very expensive, and it is usually at least five times more than making a new battery cell. The Li-ion batteries eventually rest in the landfill. The carbon footprint of Li-ion battery production is enormous. The processing of the lithium requires over 800 °C. The mining of lithium to battery materials produces over 20 times of CO2 in weight. Therefore Li-ion battery is not environmentally friendly energy storage.

A battery electric vehicle produces CO2 because lithium production and electricity generation are not renewable. Presently most counties or regions may still use coal fire, natural gas, nuclear and renewable energy. The electric vehicle, even without considering the battery's carbon footprint, can only reduce CO2 emission to 25% as compared with gasoline vehicles. It is interesting to see how many km an EV is needed to travel in order to offset CO2 emissions as compared with a gasoline vehicle. Table 1 shows the analysis using vehicles that have an average traveling of 20,000 km per year. It can be seen that if an EV has a large battery pack which is a common design for vehicles to travel long ranges over 500km and high acceleration, the km equivalent of traveling to save the CO2 is also very large. It takes 2.7 years of driving to save CO2 production during battery manufacturing. For a small private car, it still needs 1.1 years of driving to save CO2 production during battery manufacturing. Therefore a small battery vehicle can claim itself environmentally friendly only after 1.1 years. In the future, if all electricity is purely derived from renewable energy, the 1.1 years can be reduced to 0.8 year.

Battery size	100 kWh	60 kWh	40kWh
CO2 production during manufacturing	7.5 tons	4.5 tons	3.0 tons
km equivalent to saving CO2	54,000 km	32,000 km	21,000 km
Years of driving to save CO2	2.7 years	1.6 years	1.1 years
If use renewables purely to generate electricity	2.0 years	1.2 years	0.8 years

Table 1 - CO2 Production of Battery EV

The present electric vehicle penetration is only 2-3 % in most of the major countries. With the recent banning of the licensing of gasoline vehicles from the major European and Asian countries, most gasoline vehicles will be discontinued in the market in around 2025-2040. The remaining gasoline engine will be gradually aged, and perhaps they will retire by 2050, which may match with the global target of Carbon Neutrality 2050. With the recent demand for alternative fuels for electric vehicles, the use of hydrogen is now a trend of possible electric vehicle development. The main reason to consider hydrogen as a future electric vehicle fuel is because of the elimination or reduction of the use of batteries in an EV. A hydrogen vehicle is usually using a fuel cell, which basically only produces water / steam as a side product that is not greenhouse gas. The efficiency of fuel cells is around 45% to 50%, much higher than internal combustion engine (ICE), which is only 15-20%. However, hydrogen may suffer from other issues and hindrances such as high operation, installation and production cost, safety and human psychological mindset. Perhaps other alternative fuels should also be considered. Although methanol, alcohol, and other hydrocarbon fuels have been considered for hydrogen generation using a reformer for implementation in an EV, these fuels still have the content of carbon, and they still emit carbon into the atmosphere. They may be suitable for power generation in a factory in which the CO2 are captured and sealed; however, they may not be suitable for electric mobility.

This paper is to propose a zero-carbon fuel which is ammonia. An ammonia-based electric vehicle has been designed and developed. Ammonia has been discussed by the literature [1] for its prominent feature in energy storage. However, the application to an electric vehicle has not been developed, and the present research so far examined the use of ammonia to power [2] and biomass to ammonia [3]. The feature of the ammonia fuel-powered vehicle is described, and its advantages against conventional fuel and also battery electric vehicles are discussed in this paper. The ammonia fuel-powered electric vehicle is the world's first vehicle development programme and will be fully discussed.

2. BATTERY ISSUES

The use of hydrogen fuel cell is now a trend for green vehicles. The concept of using hydrogen as energy storage is to reduce CO2 emission during manufacturing and reduce the consumption of battery materials, including Lithium, Cobalt, Nickel and Manganese. It is known that the world's resources of metal are limited. Although they are not rare earth materials, their resources are not high. The world production [4] of metal is tabulated in Table 2, and it can be seen that the four primary metals used in Lithium batteries, especially Cobalt and Lithium, are low in production ranking.

Metal	Rank in metal production	Ranking in minerals production
Iron	1	3
Aluminum	2	4
Chromium	3	13
Copper	6	18
Manganese	7	19
Zinc	8	21
Lead	10	26
Nickel	11	30
Cobalt	17	45
Lithium	18	47
Vanadium	20	49
Silver	21	53
Cadmium	22	54
Mercury	23	56
Gold	25	57

Table 2 – World's Metal and Minerals Production

The battery is not only applied in electric vehicles; electric vessels, building energy storage, power distribution, entertainment, and renewable energy storage are all demanding lithium batteries. Therefore it is evident that Lithium-ion batteries will suffer from a shortage or expensive trend in the near future.

Figure 1 shows the commodity price of the two major metals, Lithium and Cobalt, in the market [5] [6]. Lithium is traded in the form of Lithium Carbonate. It can be seen that during COVID-19 or around the year 2000, the prices dropped. However, in recent years, both metals prices have risen rapidly because of the world's demand for battery materials. It is expected that the price may continually grow in the next few years.

The Li-ion battery has a minor concern of safety due to its high specific energy. It also has stranded energy that may reignite even after it has been extinguished for a day. Therefore the fire precaution or rescue of Li-ion battery vehicles imposes certain difficulties. The common method to extinguish a firing vehicle is to use plenty of water to cool down the battery. The unfavorable smoke and emission also during fire accidents pollute the environment seriously.

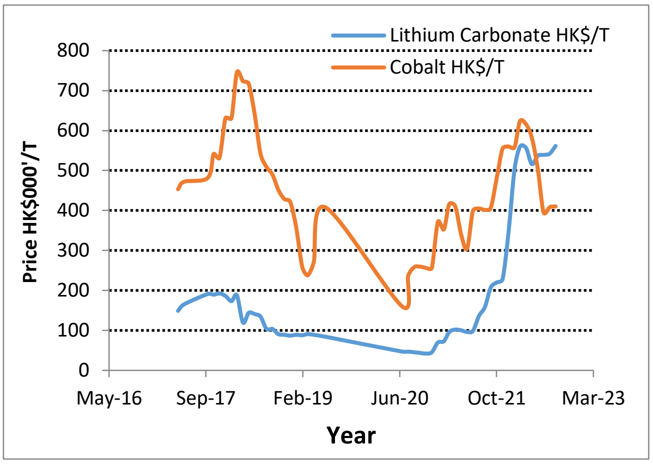

Fig. 1 - Battery Metal Price in the Recent 5 Years

3. HYDROGEN FUEL CELL

To address the shortcoming of the Li-ion battery, researchers propose the hydrogen fuel cell-based electric vehicle that is a good alternative. The energy storage is the hydrogen fuel which is zero-emission fuel. Hydrogen is also one of the most abundant elements on the earth, and there is no issue of resources. Recycling is not a concern because the end product of the fuel cell is water.

3.1 Green Hydrogen

Hydrogen can be classified into a number of hydrogen types that depends on its method of manufacturing.

Green Hydrogen is produced by the green method and has no carbon dioxide emission. The common method is to use renewable energy to electrolyze the water to produce hydrogen. This method does not produce any greenhouse gas and is the most favorable method. However, green hydrogen is expensive. Its cost is relatively fixed as it solely depends on the renewable energy cost which is independent of oil price.

3.2 Blue Hydrogen

The hydrogen can be produced by steam reforming. Hydrocarbon or natural gas, including methane, can be cracked with a catalyst to produce hydrogen in the following two stages of reforming.

$$CH_4 + H_2O \rightarrow 3H_2 + CO \quad (1)$$
$$CO + H_2O \rightarrow CO_2 + H_2 \quad (2)$$

The side product CO2 is captured and does not allow to emit into the environment. It is usually stored permanently underground or uses another chemical method to recycle the CO2. This method is greener, but the process is relatively costly. The cost of hydrogen depends on the natural gas price.

3.3 Grey Hydrogen

The production of hydrogen is the same as blue hydrogen, but the CO2 is allowed to be released into the atmosphere. The method is not favorable, but it significantly reduces the cost of production. The cost of grey hydrogen also depends on the natural gas price.

3.4 Brown Hydrogen

Solid fuel such as brown coal is firstly converted to fuel gas through gasification and then to produce hydrogen using the cracking method. This is also a common method to produce hydrogen, and it is of low cost. CO2 is emitted into the atmosphere during this process.

Only green hydrogen should be considered for EVs in order to uphold the green vehicle concept. At the moment, the green hydrogen production cost is around HK$50 per kg [8]. The sale price is much higher than that.

3.5 Hydrogen Storage

The present hydrogen is stored at high pressure in order to produce sufficient density to drive an EV. One kg of hydrogen is considered to have 33.6kWh, whereas the diesel is 10.5kWh/kg, given that the energy content varies with the quality of diesel. With the density of diesel of 0.85 kg/litre, the energy content of 1kg of hydrogen is equivalent to 1 gallon of diesel. Hydrogen cars usually use equivalent mpg, which is referred to as miles per kg.

Under normal atmospheric pressure, it is equivalent to 0.083 g/litre, which is too low for electric vehicles. The most method is to increase its storage pressure to 700 bars or 350 bars. For one 25kg gas tank, it is around 100kg in weight because a strong material is needed to ensure safety under high pressure.

The boiling point of hydrogen is -253ºC. The evaporation rate of the liquified hydrogen must be taken into account for its leakage. For long-term storage and transportation, the actual storage in weight W_n after n days is estimated to be:

$$w_n = w_0(1-k)^n \quad (3)$$

where W_o is the initial weight and k is the leakage in percentage per day. A typical system may have a loss of 0.1%/day, and therefore, the actual weight after 30 days is only 97% of the original amount. Additional energy is also needed to keep the pressurized or liquified condition which is estimated to be respectively 15% or 30% of the energy storage by the hydrogen [9].

3.6 The Fuel Cell

The hydrogen fuel cell is a mature technology, and there are hydrogen Fuel Cell Electric Vehicles (FCEV) available in the market. Table 3 shows three recent models of FCEV. Its fuel consumption [10] as compared to the typical gasoline car Corolla is shown. The three FCEV Mirai, Nexo and Clarity all have around double the traveling performance in terms of the common index mpg. The fuel cell efficiency is around 45-55%, and the motor efficiency is about 95%; therefore, the overall efficiency of FCEV is much higher than diesel or gasoline vehicles.

	City (km/kg)	City (km/gal)	Highway (km/kg)	Highway (km/gal)	Power (kW)
Toyota Mirai	122		114		136
Hyundai Nexo	105		93		120
Honda Clarity FC	109		108		130
Toyota Corolla		53		61	104

Table 3 - Comparison of FCEV Energy Consumption with a Gasoline Car

3.7 Summary and Discussion

The existing issues of FCEV can be summarized as follows:

- High green and blue hydrogen price.
- Grey and brown hydrogen are not environmentally friendly.
- The hydrogen vehicle faces the challenge of safety because of high storage pressure and fire hazard. FCEV cannot be used in tunnels and bridges.
- Hydrogen is odorless and colorless. Its sensors are more expensive. In case of leakage, it is not easier to be detected.
- A hydrogen station is not safe for installation in the city center or inside a building because of fire and high-pressure hazards.
- The operation of hydrogen is different from gasoline or Liquified Petroleum Gas (LPG). The old gasoline or LPG station cannot be converted into a hydrogen station.

4. AMMONIA

4.1 Ammonia Fuel

Ammonia is one of the gases that has zero emission when connected to a fuel cell reformer system. Most of the fuel gas used in the reformer fuel cell is hydrocarbon which after the operation of reforming, there is an emission of CO2. Therefore the methane or alcohol fuel cell is not the ultimate solution for zero-emission vehicles. Ammonia's chemical formula is NH3, which means that one mole of NH3 has 50% more hydrogen than 1 mole of hydrogen gas. Ammonia turns into liquid at -33ºC at atmospheric pressure or under 7.5 to 8 bars and room temperature. It is a preferred carrier [1] of hydrogen because its storage pressure is only 8 bars which is easy to manage and has a low cost of operation. The storage tank using a standard steel tank is sufficient. The density is only 600kg/$m^{3,}$ which is less than that of water, which is 1000 kg/m^3.

4.2 Ammonia Energy Converter

The ammonia cracker is to convert the ammonia in the storage tank to hydrogen. Figure 2 shows the schematic. The storage ammonia is released to the cracker through a flow control unit. The cracker is to use high temperatures with the assistance of catalysis to decompose the ammonia into hydrogen and nitrogen.

$$2NH_3 \rightarrow N_2 + 3H_2 \qquad (4)$$

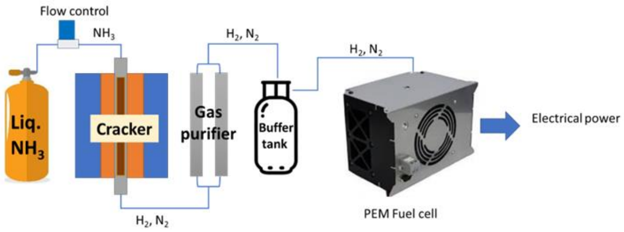

Fig. 2 - Ammonia Converter Schematic

A gas purifier is to eliminate any residue of ammonia. The present development of the proposed ammonia-powered EV can convert 99.99% of ammonia to hydrogen. Therefore the purifier is not heavily loaded. A small buffer tank is connected between the purifier and the fuel cell, which provides a stable hydrogen source. The fuel cell is a conventional PEM fuel cell.

The catalysis can be selected from a wide range of chemicals. For example, ferrite oxide is a common one. The operational temperature is between 400°C to 700°C.

4.3 Source of Ammonia

The ammonia can be obtained from the fertilizer farm, which has high resources of low cost and an enormous supply of ammonia. It is widely available in South China and Malaysia, Indonesia, and Singapore. The ammonia can be easily stored in around 8 bars, and therefore, the storage tank is not expensive. The operation cost is also very low.

The conventional facility of the LPG station is also operated under similar gaseous pressure. Therefore the LPG station can be easily replaced by an ammonia station. The gas station can be operated safer using ammonia as it is utilized in low pressure as LPG. The fire hazard concern is much lower than hydrogen.

Alternatively, the technology to combine nitrogen and hydrogen into ammonia using renewable energy has been reported [11].

$$N_2 + 3H_2 \rightarrow 2NH_3 \qquad (5)$$

The reaction is exothermic, and energy is released. Using NH3 to store renewable energy is an alternative method. Although the overall efficiency of storing energy cannot be as high as the battery, it is a recyclable gas, whereas a Li-ion battery is not.

Figure 3 shows the well-known Harber-Bosch process [7] that earned the 1918 Nobel Prize in Chemistry to generate ammonia from hydrogen.

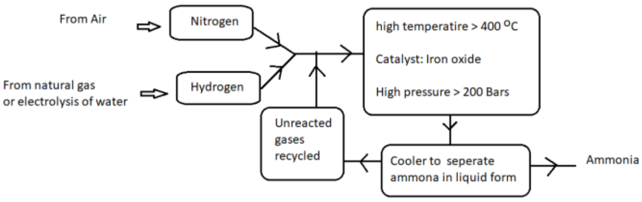

Fig. 3 - Harber-Bosch Process for the Production of Ammonia

5. AMMONIA POWERED EV

5.1 The Design

The ammonia cracker is simply added to an electric vehicle, and an ammonia-powered EV is realized. The concept of the ammonia EV is simple as it is merely system integration of the ammonia cracker to hydrogen fuel cell EV. By using an ammonia cracker which provides an uninterruptible hydrogen fuel source, the hydrogen tank can be eliminated or much reduced in size. Therefore the issues of hydrogen mentioned before are eliminated.

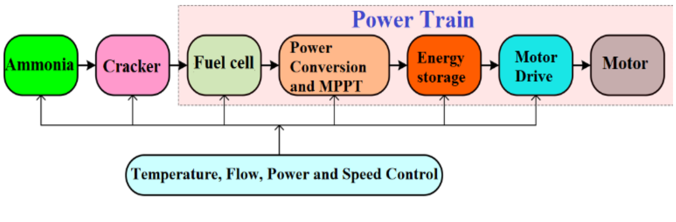

Fig. 4 - Power Train and the Ammonia Cracker for the NH3 EV

5.2 Advantage

The ammonia-powered EV can be constructed using a retrofitting of an EV or an FCEV. The facility related to high-pressure hydrogen can be eliminated. The overall cost of the hydrogen station, storage tank and sensors is reduced. Ammonia is a cheap gas and can be obtained easily from the fertilizer farm. Many adsorption techniques of ammonia have been reported [12]. It is obvious that the ammonia-powered EV is easier to handle as compared with the hydrogen EV. It has high energy content as compared with hydrogen. The safety and handling with respect to pressure are moderate in ammonia.

5.3 The Energy Content of Ammonia

In order to increase the energy density of the storage of ammonia or hydrogen, the liquified state may be used. The melting point of ammonia is -77.7 ºC and that of hydrogen is -259.1 ºC. On the other hand, the density of ammonia and hydrogen is 70.8 g/100L and 8.3 g/100L respectively [13]. For compressed hydrogen, it is only 4.2 kg/100L. Therefore using ammonia as a fuel is more favourable. Ammonia and oxygen can be combusted directly as fuels and do not produce carbon dioxide:

$$4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O \quad (6)$$

The heating value of fuels is classified into higher heating value (HHV) which includes the latent heat, and lower heating value (LHV) which excludes the latent heat, respectively. The gravimetric energy density and volumetric energy density of liquid Ammonia in LHV are 18.6 MJ/kg and 12.7 MJ/kg respectively, whereas the gravimetric energy density and volumetric energy density in LHV of compressed hydrogen are 120 MJ/kg and 4.5 MJ/kg respectively. For liquid hydrogen, the volumetric energy density is 8.49 MJ/L [14].

The gravimetric energy density of ammonia is lower than that of hydrogen, but it is less critical because the overall energy density of both of them is very high as compared to the battery.

Also, because of the high-pressure requirement, the weight of the gas tank of hydrogen is much higher than that of the ammonia tank. In terms of the energy content, the volumetric energy density is more important. The liquid ammonia is nearly three times the compressed hydrogen. Compressed hydrogen only contains very little energy because its density is 42 kg/m^3 whereas liquid ammonia is 600 kg/m^3.

The maximum energy that can be released from ammonia is 5.16 kWh/kg. After the discount of the energy 0.5 kWh/kg needed to extract hydrogen, fuel cell efficiency of H2 output at 75% concentration, and loss, the actual energy is around at least 1.4 kWh / kg, which is ten times of a Li-ion battery.

5.4 Colour of Ammonia

Similar to the colour of hydrogen, there are also green, blue, and grey ammonia based on the same definition as hydrogen. There are numerous green and blue ammonia plants being built. Indonesia is now building a large plant [15]. Norway, Japan and Singapore have industrial work in ammonia production.

5.5 World's First Ammonia-Powered EV

The world's first electric vehicle using ammonia power has been developed in June 2021. Figure 5 shows the prototype. The technology has been firstly implemented in a light vehicle which is a golf cart. The ammonia tank, ammonia converter, purifier, buffer and fuel cell are as presented in Figure 3.

Fig. 5 - World's First Ammonia-Powered Electric Vehicle

For 5 kg of ammonia gas storage, a light vehicle can travel over 200km. For a design of a private or minibus, a typical gas tank is 22.7kg. In terms of ammonia, it represents a volume of 37.8L. The maximum energy content is then 117 kWh. If the same volume is used to contain the compressed hydrogen, it can only fill up 1.59kg. The associated maximum energy content is then 53 kWh. The compressed hydrogen needs the additional weight of the strong gas tank, whereas ammonia does not.

Although ammonia storage has been reported by literature in the past, the system integration of ammonia power and electric vehicles require an interdisciplinary development of chemical engineering, applied physics and electrical engineering, and electric vehicle expertise. This challenge and technology are not easy to be secured in a single institution.

6. CONCLUSION

This paper presents the ammonia-powered electric vehicle development programme. The vehicle is based on ammonia fuel and is more user-friendly as it does not require handling high pressure. The facility, including the storage, connection, filling station, and transportation, is simple. The potential of using ammonia is high as it has been a good hydrogen carrier in the past. Ammonia to power an EV is a good alternative; thus, the large hazardous amount of hydrogen storage can be eliminated from the EV, and also the problematic hydrogen facilities installation in a city is eliminated. The expected cost of ammonia gas in all aspects is lower than that of hydrogen. The associated facility is also simple and easy to handle.

Ammonia represents a future ammonia economy and is a strong alternative to a hydrogen economy. Ammonia can be generated from fertilizer farms or by renewable energy synthesis from nitrogen and hydrogen. The proposed technology for ammonia applied in EVs has been fully demonstrated. The next step is to apply to a minibus or large vehicle.

ACKNOWLEDGMENT

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Paper No. 8

DESIGN OF AN INNOVATIVE IN-WHEEL MOTOR FOR ELECTRIC DRIVE AXLE OF A 12-METER COMMERCIAL BUS

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Green Mobility Innovations Ltd.

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ABSTRACT

With the electrification of different types of vehicles, electric drive axle solution has been applied in commercial vehicle electrification for some time, especially for high power multi-megawatt mining trucks. The design of in-wheel motor for electric drive axle is a substantial challenge, as it has to integrate the drive motor, gearbox and transmission as a single assembly within the wheel, with only a limited space. This paper introduces an innovative design for an in-wheel motor for the electric axle of a 12-meter commercial bus.

1. INTRODUCTION

Electric axle is a compact, cost-effective electric drive solution for applications in battery-electric and hybrid vehicles. The electric motor, power electronics and transmission are combined in a compact unit directly powering the vehicle's axle. This simplifies the electric drive assembly and also enables the powertrain to become cheaper, more compact and more efficient.

The AVE electric portal axle is produced by ZF from 90er, perfectly applicable to various drive concepts for city buses: whether as a serial hybrid or all-electric drive powered by fuel cell or battery, or from trolley wire. Lane-independent, zero-emission driving is now also achievable in the city. This enormously increases cost-effectiveness and availability for use. Each wheel is driven by a compact, high-speed, liquid-cooled asynchronous motor, keeping the weight of the axle together with the integrated motors low. As no separate engine nor propeller shaft is required, this reduces the overall vehicle weight and the amount of space required. The extra space makes room for a more powerful battery pack or an improvement in payload or passenger carrying capacity. No special wheel components are required with the AVE. The tire-rim combination used in normal buses as well as the standard disk brakes can both be retained. The brakes are fitted in the same low-maintenance position as with standard axles.

As the next generation electric axle, SAIETTA developed a unique electric in-wheel powertrain technology which offers direct drive power. Sophistication of the drivetrain is the simplicity; only a bare minimum of components is required to achieve high efficiency. However, requirement of a super single wheel hub and a heavy and expensive driving motor limits its application.

In order to resolve the above problems, this paper introduces an innovative in-wheel motor design for 12m commercial bus, which uses a standard hub and tire, and integrated gearbox motor.

2. STRUCTURE OF AN INNOVATIVE IN-WHEEL MOTOR OF AN ELECTRIC DRIVE AXLE

Figure 1 introduces the structure of the electric axle with the innovative in-wheel motor design for application in a 12-meter electric commercial bus.

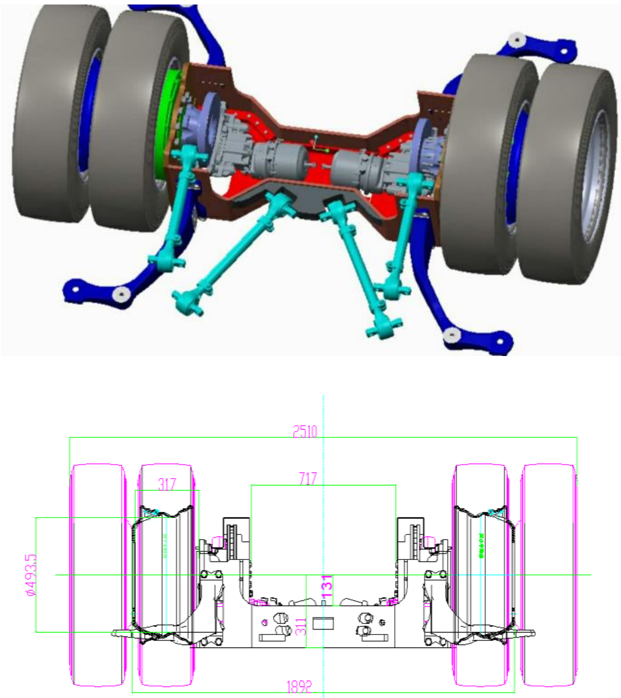

Fig. 1 - Structure of Electric Axle with an In-wheel Motor

The electric axle is designed for a 13,000 kg laden and 8,000 kg unladen axle. Standard tire of 275 / 70R22.5, standard aluminum hub of 22.5×8.25, standard brake disc, caliper, brake chamber and WABCO ABS system are used. It has a maximum torque output of 16,630 Nm and a rated output of 6,630 Nm, optimal for application for a 12-meter commercial bus. The axle has two planetary gear boxes with an overall ratio of 10.8.

Figure 2 shows the structure of the in-wheel motor with water cooling system in the stator housing. The steel stator housing is connected to axle side frame by the motor end cap. The first planetary gear box uses rotor inner space. Two ball bearings on the housing of the first stage planetary gearbox are applied to fix the steel frame with rotor sheet. The first stage planet gearbox housing has the same water cooling of motor housing. The design spares the space along the axial direction of the first stage gearbox. Although the system structure becomes more complicated, the integration of two stages gearboxes in a limited space of a standard wheel hub to achieve the maximum torque output becomes viable.

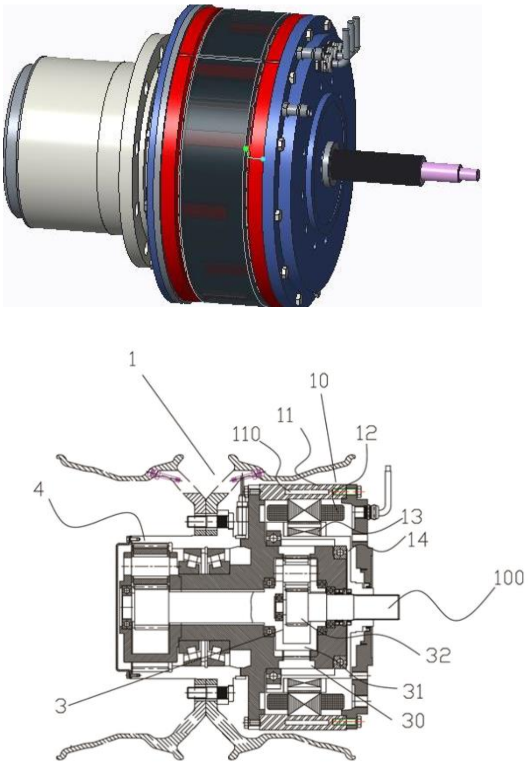

Fig. 2 - Structure of In-wheel Motor with Two Stage Planetary Gearboxes

In order to understand the structure better, Figures 3 and 4 show the built rotor sheet and the first stage planetary gearbox. Rotor sheet has a big inner diameter providing enough space for the gearbox.

Fig. 3 - Rotor sheet

Fig. 4 - The First Stage Planetary Gearbox

The first stage gearbox is connected on the motor end cap. Due to the high surrounding temperature inside rotor, the housing of the gearbox has the same water cooling from the motor housing. Braking system is connected to rotor torque input axis.

Different from the first stage gearbox, the torque output of the second stage planetary gearbox uses ring gear connected to hub as in Figure 5.

Fig. 5 - The Second Stage Planetary Gearbox

3. CHARACTERISTICS COMPARING WITH ZF AND SAIETTA ELECTRIC AXLES

Figure 6 describes the ZF AVE electric axle. Each wheel is driven by a compact, high-speed, liquid-cooled asynchronous motor to keep the axle weight including the integrated motors low. But different from our in-wheel motor solution, powertrain components of ZF electric axle including driving motor and gearbox are still integrated in the axle case. The mechanical case and powertrain components are not completely independent. A better design, as with the current electric axle development, powertrain and axle mechanical case are independent with modular design.

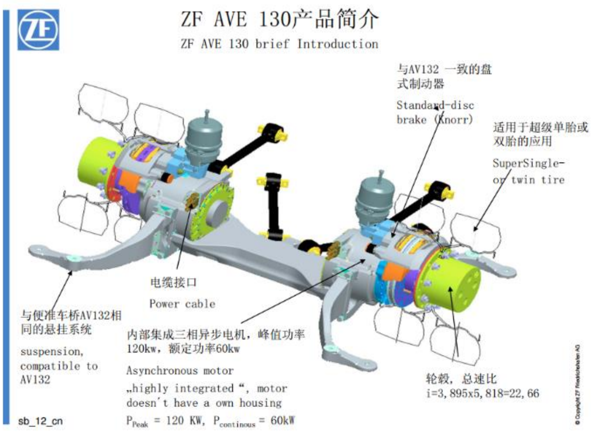

Fig. 6 - ZF AVE 130 Electric Axle

Figure 7 describes the SAIETTA powertrain solution using in-wheel motor. Application of a permanent magnet (PM) in-wheel motor without gearboxes greatly improves the driving efficiency to eliminate efficiency loss on other transmission components. The disadvantage are the heavy motor weight and the high cost of motor and the unique super single hub. This is the reason why the solution does not have a wide application in commercial buses in the market.

Fig. 7 - SAIETTA Electric Axle

To summarize, our in-wheel motor design enjoys the following advantages:

Comparing with ZF electric axle, powertrain components of our in-wheel motor is completely independent of the mechanical axle case. Permanent magnet motor application will also increase driving efficiency.

Comparing with SAIETTA in-wheel motor, our design has significant cost and weight advantages; the in-wheel motor with planetary gearboxes will be much more economical to be applied in customer market. Below is the weight comparison of three electric axles:

ZF: 1,110 kg
SAIETTA: over 1,500 kg
Our electric axle: 1,200 kg

4. SIMULATION OF DRIVING PM MOTOR

An PM in-wheel motor is designed with the following specifications:

Maximal torque	770 Nm
Rated torque	307 Nm
Maximal power	100 kW
Rated power	70 kW
Maximal speed	4300 rpm
Rated DC voltage	650 V
Highest efficiency	96%
Cooling	water
Rated current	106 A
Maximal current	376 A (30s)
Pole pair numbers	6

Firstly, a finite element analysis (FEA) calculation for no load condition is done. Figure 8 shows the magnetic flux distribution for no load. The air gap magnetic flux density analysis is shown in Figure 9, the first harmonics magnetic flux is 0.748 T.

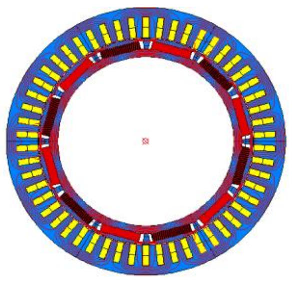

Fig. 8 - Magnetic Flux Distribution of No Load Condition

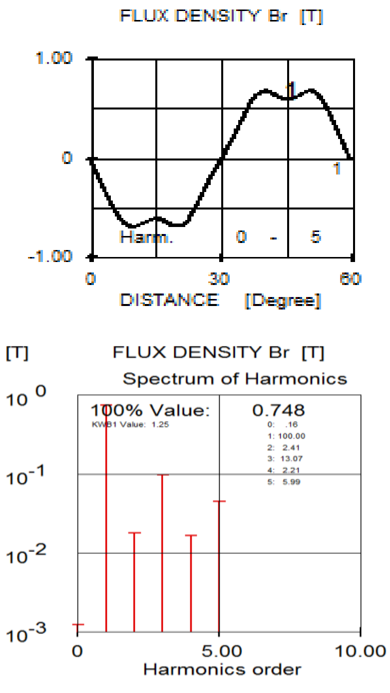

Fig. 9 - Magnetic Flux Density Analysis of Air Gap

An FEA for maximum load condition is then made. Figure 10 shows the magnetic flux distribution for full load. The air gap magnetic flux density analysis is shown in Figure 11, the first harmonics magnetic flux is 1.1 T.

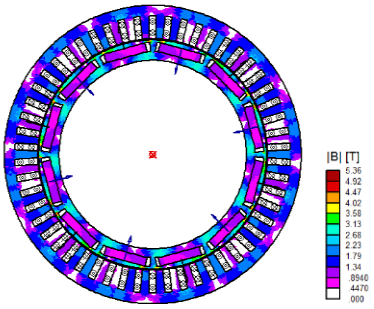

Fig. 10 - Magnetic Flux Density Distribution of Maximal Load

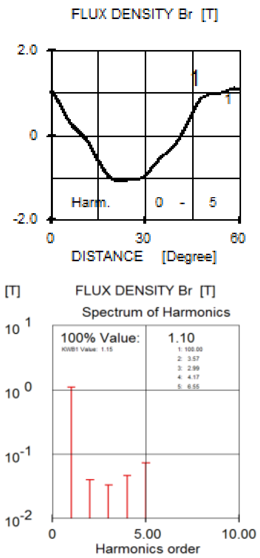

Fig. 11 - Magnetic Flux Density Analysis of Air Gap with Maximal Load

5. PROTYPE PRODUCTION AND TEST

A protype electric axle with the in-wheel motor is built, as shown in Figure 12. The production cost is only about 30% of SAIETTA electric axle, but with a higher efficiency than the ZF electric axle based on the application of PM motor.

Fig. 12 - Prototype of Electric Axle with the In-wheel Motor

Figure 13 shows the structure of the second stage planetary gearbox with maximum output torque to 15000 Nm by the ring gear.

Fig. 13 - Ring Gear of the Second Stage Planetary Gearbox

After a type test on test-bench, it was fitted to a 12m electric bus for the next 10,000 km test.

Fig. 14 - Prototype Bus for 10,000 km Test

6. CONCLUSION

On the development of electric drive axles, this paper introduces an innovative design and a solution for in-wheel electric drive axle for application on 12m electric battery buses. The design overcomes the biggest challenge to integrate the drive motor, gearbox and other transmission components in the limited space of a standard wheel hub. Comparing with ZF electric axle and SAIETTA in-wheel electric axle, the design achieves benefits not only in higher efficiency of the application of an in-wheel motor PM motor, but also provides a product with competitive price and weight. A prototype was produced and the type test was successfully completed. A 10,000 km test is now in progress with a prototype 12m EV bus.

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Paper No. 9

SMART METER DATA-DRIVEN INCIPIENT FAULT DETECTION

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SMART METER DATA-DRIVEN INCIPIENT FAULT DETECTION

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ABSTRACT

To offer customers with innovative digitalised services and a range of energy saving and demand side management solutions, CLP Power Hong Kong Limited (CLP Power) launched a massive programme since late 2018 to progressively replace electro-mechanical (E&M) meters to smart meters. This not only offers smarter customer service experience but also drastically enhances the low voltage (LV) network visibility.

As telemetry facilities are not widely deployed to monitor system performance of a conventional LV network, it is challenging to identify the incipient fault in the massive LV network. With the advancement of Smart Grid technologies, Advanced Metering Infrastructure (AMI) platform can monitor the LV network performance by collecting the smart meter data and analysing the current and voltage profiles to detect abnormalities. To detect potential LV network incipient fault, a Proof-of-Concept project was completed. With reference to the data collected in the AMI platform, the theoretic calculation as well as the data analytic methodology, potential LV incipient faults can be screened out and located in the Geographical Information System (GIS). It can substantially reduce the lead-time required by frontline staff to dispatch on site for fault pinpointing, diagnosis and repair. With a promising result observed, the new approach has improved the supply reliability, safety and customer satisfaction.

In this paper, we summarise a theoretical approach and data analytics methodology adopted in detecting LV network incipient fault and findings from case studies.

1. INTRODUCTION

To offer customers with innovative digitalised services and a range of energy saving and demand side management solutions, CLP Power rolled out a massive installation programme since late 2018 to progressively replace electro-mechanical (E&M) meters to smart meters for over 2.6 million customers. With smart meters and its Mobile App, our customers can keep track on their hourly electricity consumption data, act smarter on energy management and energy conservation.

In addition to the digital customer services, CLP Power is also keen to extend the meter data applications beyond their primary function of billing. To further enhance the supply reliability to our customers, a proof-of-concept data-driven project entitled “LV incipient fault detection by smart meter data” was completed with a promising result. Leverage on the data analytic and digitalisation technologies, the smart meter data including the current, voltage profiles and abnormal voltage events were analysed to detect and pinpoint LV incipient faults.

1.1 Existing Practice of Handling LV Fault in Distribution Network

In conventional LV network with E&M meters installed, the visibility of the LV network operational parameters is very limited. The detection of LV incipient fault seems impossible to achieve. The abnormalities of the LV network can only be made known by an outage call or unstable electricity supply call from the affected customer after the impact of the fault is developed. System operator will then dispatch the emergency crew for investigation and power restoration. The whole process is passive and time consuming.

1.2 Digitalisation Challenges on Revealing the Abnormality from Massive Smart Meter Data

In a conventional metering process, to prepare electricity bills for customers, E&M meter readings are manually taken monthly or bi-monthly. With the massive deployment of the smart meters, most meter data can now be captured by the AMI platform automatically in every thirty-minute. These smart meter data of 2.6 million customers collected in the AMI platform would occupy around 60 Gigabytes of data storage space per day. Such huge-sized raw data files cannot be directly retrieved by spreadsheet software in a desktop computer. Moreover, the raw data format is also not readily available for data analysis and fault diagnosis, thus, processing a huge volume of raw data is considered as a major challenge of digitalisation.

To efficiently manage and analyse these huge volume of data, cloud computing solutions including the data lake and data pipelines were deployed. The data lake acts as a centralised repository to store unstructured raw datasets. The data pipelines can make use of cloud-based computational power to re-engineer raw meter data files at thirty-minute intervals to structured time-based meter data and to store it in a high-performance database.

1.3 The Latest Fault Detection Techniques by Smart Meter Data Analytic

In recent years, academies and industries have adopted different data analytic approaches to detect faults in the LV distribution network with smart meter data. Machine learning technique was proposed by a Spanish utility to analyse smart meter voltage alarms [1]. An automatic learning system is adopted to group and sort the alarms, which can narrow down the number of potential fault locations for on-site inspection.

Large volume of actual and simulated cases are required to train those machine learning models offline. In practice, as telemetry facilities are not widely deployed in the LV distribution network, power utilities do not have sufficient voltage and current data of actual LV fault cases to support the machine learning process. Researchers in the industry presented a GIS-based fault location system for a LV distribution network. With the LV circuit layout and the support of simulated fault cases, the fault location and smart meter data, such as voltage sag and the event of meter power-off, can be correlated in the GIS platform and the fault location can be narrowed down [2].

In this paper, the data-driven approach is demonstrated to detect and locate the LV incipient faults. Initial screening of potential faults and desktop fault analysis are carried out with the use of over-voltage events and the thirty-minute root-mean-square voltage (VRMS) readings generated from smart meters. Eventually, the abnormal voltage data are visualised in the GIS platform and the fault location can be narrowed down for site verification. This can minimise the effort of on-site fault pinpointing.

In Section 1, we have briefly discussed the existing practice of LV fault handling, digitalisation challenges and the latest fault detection techniques by data analytic. The rest parts of this paper are comprised of three sections. In Section 2, the threshold voltage-based fault detection algorithm is demonstrated, which is developed in according to the theoretical analysis on Negative Sequence Component (NSC) of abnormal supply voltage. Two typical fault types, neutral fault and high impedance fault, are examined theoretically. In Section 3, abnormal supply voltage datasets of the smart meters are crowdsourced in GIS. The visualisation can facilitate the tracking of the network abnormality and the fault location can be narrowed down eventually. Conclusions are made in Section 4.

2. THEORETICAL ANALYSIS ON LV ABNORMAL VOLTAGE

This section is divided into two parts: (1) Develop the threshold voltage-based fault detection algorithm, and (2) Case studies on detection of neutral fault and high impedance fault in the LV circuit with Photovoltaic (PV) connection.

2.1 Negative Sequence Component of Abnormal Supply Voltage

In an unsymmetrical fault, the associated voltage and current are not balanced in different phases. The fault introduces NSC of voltage and current in the LV power system [3] [4]. Principle of Symmetrical Components is commonly used to conduct a power system fault analysis. Supply phase voltages and currents of the three-phase power system can be decomposed into positive, negative and zero sequence components respectively. A transformation between three-phase supply voltages and sequence components is shown in Equation (1) [3].

$$\begin{bmatrix} V_0 \\ V_1 \\ V_2 \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & h & h^2 \\ 1 & h^2 & h \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad \text{Equation (1)}$$

Remark:

$h = e^{\frac{2\pi}{3}},\ V_a = V_{L1},\ V_b = h^2 V_{L2},\ V_c = hV_{L3},$

V_0, V_1, V_2 are Zero, Positive and Negative Sequence Component of Voltage.
V_a, V_b, V_c are Supply Phase Voltage Vectors.
V_{L1}, V_{L2}, V_{L3} are magnitudes of Supply Phase Voltage.

Positive (V_1) and Negative (V_2) sequence voltage equations are shown in Equation (2) and (3) respectively. Positive Sequence Component (PSC) is presented in symmetrical and unsymmetrical faults, whereas NSC is only dominant in all unsymmetrical faults [3]. Based on that, an unbalance index is proposed to determine likelihood of unsymmetrical fault occurrence [4]. The Voltage Unbalance Factor (VUF) is the ratio of Negative (V_2) to Positive (V_1) Sequence Voltage Components in terms of phase voltage. It can also be used to evaluate the degree of three-phase voltage unbalance.

$$V_1 = \frac{1}{3}(V_{L1} + V_{L2} + V_{L3}) \qquad \text{Equation (2)}$$

$$V_2 = \frac{1}{3}(V_{L1} + hV_{L2} + h^2V_{L3}) \qquad \text{Equation (3)}$$

Equation (4) is further derived, so that the VUF is only in relation to the supply phase voltage (V_{L1}, V_{L2}, V_{L3}). The supply phase voltage can be captured from smart meter directly.

$$\left|\frac{V_2}{V_1}\right| = \frac{\sqrt{(V_{L1}^2+V_{L2}^2+V_{L3}^2-V_{L1}V_{L2}-V_{L1}V_{L3}-V_{L2}V_{L3})/9}}{(V_{L1}+V_{L2}+V_{L3})/3} \qquad \text{Equation (4)}$$

In a three-phase voltage balanced circuit, the VUF approaches zero, since V_{L1}, V_{L2} and V_{L3} are approximately the same. On the contrary, the VUF will be increased when the divergence of phase voltages is significant to induce NSC in an unbalanced voltage circuit. According to IEEE Std. 1159-1995, the VUF should be below 2%.

Apart from LV fault scenarios, unbalanced voltage in the LV network can be caused by other reasons. One of the major reasons is an uneven distribution of single-phase loads – the unbalanced currents are drawn from the source. Another one is the proliferation of Distributed Energy Resources (DER), especially for single-phase PV system. In order to differentiate the genuine LV fault from the circuit with relatively high VUF, it is crucial to set a threshold limit for the over-voltage data. This helps the initial screening of the possible LV faults and the detailed analysis. For example, threshold can be set at equal to or above the upper supply voltage limit. This approach increases the accuracy of the LV fault detection, as well as reduces the computational power required. This is particularly important when conducting data analytics for large volume of meter data.

In the early stage of LV fault (e.g. neutral fault), the occurrence of the over-voltage is intermittent and in a short duration. It is difficult to reveal the abnormality by on-site voltage measurement. By making use of over-voltage event of the smart meters, it is more effective to capture the intermittent nature of LV fault in the initial stage. When the LV fault is further developed, the VUF will get worse and the thirty-minute VRMS will be distorted substantially, in which the fault can be easily revealed by on-site measurement.

2.2 Case Studies

To verify the effectiveness of the above-mentioned algorithm, a proof-of-concept project is initiated. The over-voltage events and thirty-minute VRMS are collected from smart meters for further analysis. Two major typical LV faults can be identified: 1) High impedance fault in the LV circuit with PV connection, and 2) Neutral fault at the riser of the high-rise building.

<u>(1) High impedance fault in the LV circuit with PV connection</u>

For a conventional LV circuit without DER, the voltage gradually drops along a circuit feeder. The power flow from the grid to the circuit end is unidirectional. In recent years, DER, such as PV systems, has been proliferated in the LV distribution network. The power flow is bi-directional in daytime. A typical LV radial-feed circuit with PV generation is shown in Figure 1.

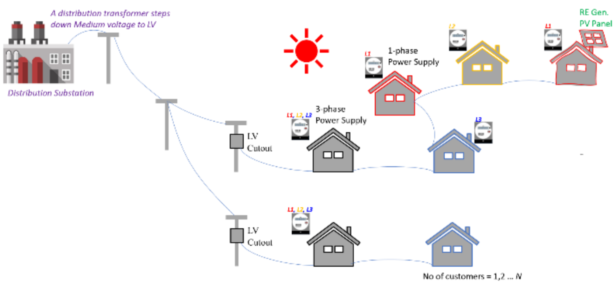

Fig. 1 - Typical LV Radial-feed Circuit with PV Generation

The voltage characteristic of a radial-feed circuit with PV connection is illustrated by a single-phase circuit model as shown in Figure 2.

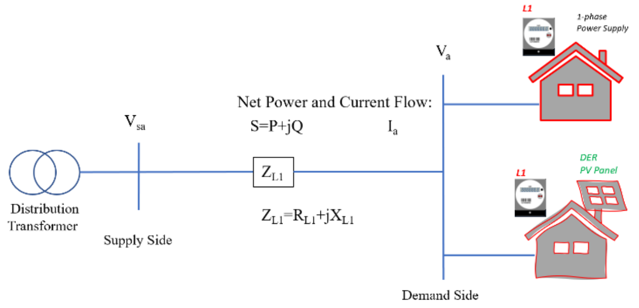

Fig. 2 - A Single-phase Circuit Model for a Radial-feed Circuit with PV System

The voltage difference between the supply and demand side is expressed in Equation (5) and the vector diagram in Figure 3.

$$\Delta V = V_{sa} - V_a = I_a Z_{L1}$$

$$\Delta V = \frac{PR_{L1}+QX_{L1}}{V_{sa}} + j\frac{PX_{L1}-QR_{L1}}{V_{sa}} \qquad \text{Equation (5)}$$

Remark: $I_a = \left(\frac{P+jQ}{V_{sa}}\right)^*$

V_{sa} and V_a are Phase A Voltage at supply and demand side respectively.
Z_{L1}, R_{L1} and X_{L1} are line impedance, resistance and reactance.
P, Q and I_a are active, reactive power and current flow between the supply and demand side respectively.

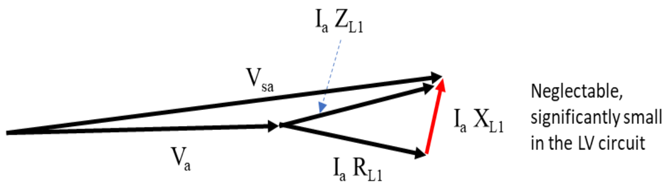

Fig. 3 - Vector Diagram to show the Voltage Difference between the Supply and Demand Side

In LV circuit, the line resistance is much larger than its reactance (i.e. R>>X). The voltage difference can be approximated in Equation (6) since an imaginary part in Equation (5) is significantly small and neglectable.

$$\Delta V \approx \frac{PR_{L1}+QX_{L1}}{V_{sa}} \qquad \text{Equation (6)}$$

In principle, the voltage difference is linearly proportional to line resistance, reactance, and the active and reactive power flow between the supply side and demand side. In practice, as the power factor at the demand side is normally greater than 0.85, the active power is much larger than the reactive power. As a result, active power consumption and line resistance can be considered as major contributors of the voltage drop or rise in the radial-feed circuit.

In daytime, PV systems generate the three-phase balanced active power at its peak, whilst the residential load is at trough period. Thus, a net power flow from the demand side to the supply side is expected. The LV network will have voltage rise phenomenon according to Equation (6) at the high side but still within the supply voltage limit of 1.06pu. If there is a high impedance fault along the path from customer's PV to the supply source, over-voltage will occur. As shown in Figures 4 and 5, the worst voltage has reached 1.1pu of the nominal supply voltage, whilst the VUF is around 2.5% to 3%.

By setting the threshold limit at 1.09pu, we can initially screen the potential high impedance LV fault circuits out for further analysis.

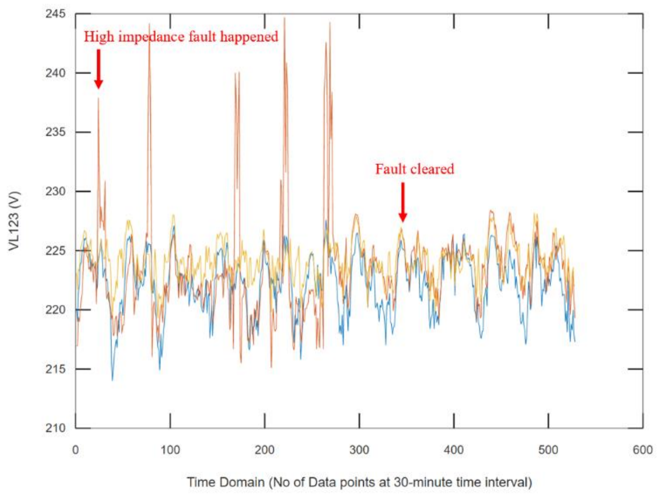

Fig. 4 - Occurrence of Over-voltage for a High Impedance Fault in a LV Network with PV Connection

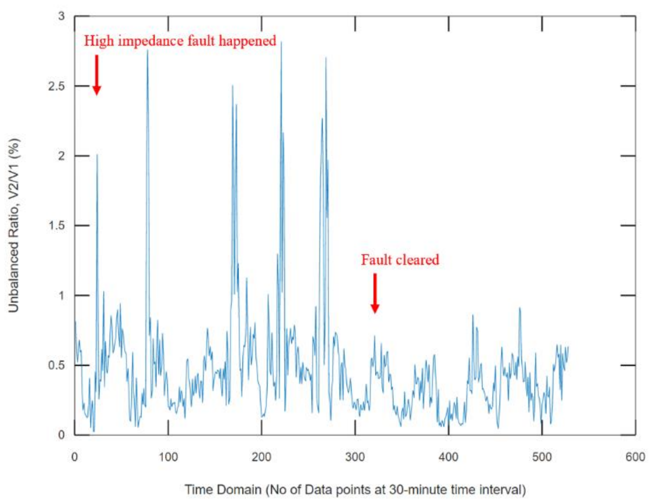

Fig. 5 - VUF Fluctuates during High Impedance Fault Period

2) Neutral fault in high-rise building

In a high-rise building, the distribution transformer at a customer substation is connected in delta-star configuration. At LV side, the three-phase power supplies to the customers are connected via a customer owned rising main with a configuration of three-phase four-wires. The schematic diagram in Figure 6 illustrates and analyses the characteristic of neutral fault. In the event of loosen, oxidised, or broken neutral conductor, unbalanced three-phase current returns to the supply source through the neutral wire, as neutral current. As such, an observable neutral voltage will be induced if both magnitudes of neutral current and impedance are significant.

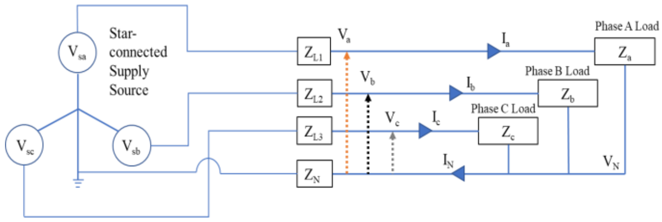

Fig. 6 - A Schematic Diagram of a Star-connected Supply Source with a Three-phase Load

Z_a, Z_b, Z_c are load impedances.
Z_{L1}, Z_{L2} and Z_{L3} are line impedances, which are neglectable in general.
V_{sa}, V_{sb}, V_{sc}, are three-phase voltages at the supply
V_a, V_b, V_c, I_a, I_b and I_c are supply phase voltage and current respectively which can be measured by a smart meter
V_N, I_N, Z_N are neutral voltage, current and impedance at load side respectively

As Kirchhoff's Current Law is applied at a neutral node of load side (V_N), I_N is shown in Equation (7).

$$I_N = I_a + I_b + I_c \qquad \text{Equation (7)}$$

The circuit in Figure (6) can also be modelled in Equation (8).

$$\frac{V_N}{Z_N} = \frac{V_a}{Z_a} + \frac{V_b}{Z_b} + \frac{V_c}{Z_c} \qquad \text{Equation (8)}$$

Given $V_a = V_{sa} - V_N,\ V_b = V_{sb} - V_N,\ V_c = V_{sc} - V_N$
The voltage at this neutral (V_N) can also be expressed in Equation (9).

$$V_N = \left(\frac{V_{sa}}{Z_a} + \frac{V_{sb}}{Z_b} + \frac{V_{sc}}{Z_c}\right) \times Z_{bal} \qquad \text{Equation (9)}$$

$$Z_{bal} = \left(\frac{1}{Z_a} + \frac{1}{Z_b} + \frac{1}{Z_c} + \frac{1}{Z_N}\right)^{-1} \qquad \text{Equation (10)}$$

The graphical solution of Equation (9) is shown in Figure (7). If the neutral wire is in bad contact or broken, the neutral point will be drifted according to the unbalanced load impedances among three phases (Z_a, Z_b, Z_c). As a result, the phase voltage will fluctuate and cause voltage sag and swell.

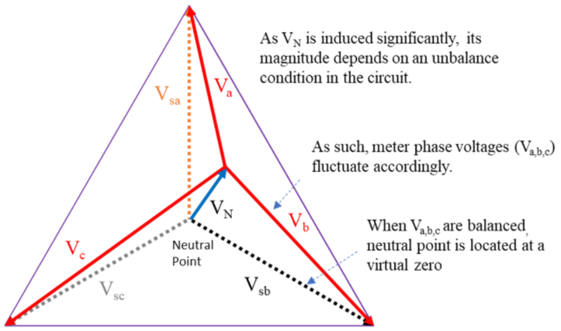

Fig. 7 - Neutral Voltage Drifts in a High Impedance Neutral Circuit under the Condition of Unbalanced Load

During the proof of concept stage, one successful case of detecting the neutral fault at the tee-off point of the riser main was captured. The VRMS waveform captured by a group of three-phase smart meters beyond the neutral fault point is shown in Figure 8.

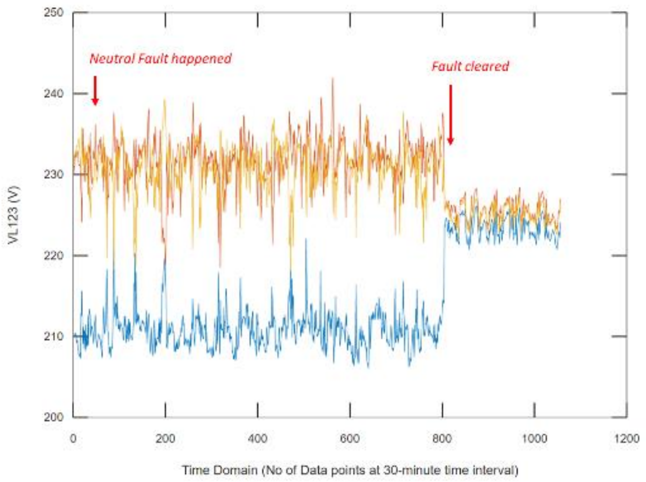

Fig. 8 - The Abnormal Voltage Waveform was Captured by the Smart Meter during the Occurrence of a Neutral Fault

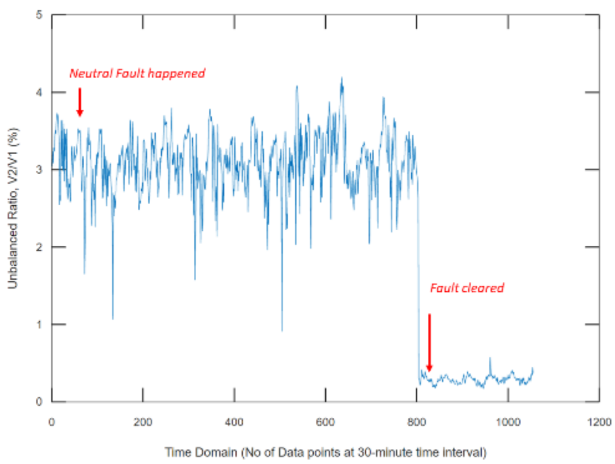

Fig. 9 - The VUF Changes during the Neutral Fault Period

Significant voltage sag and swell across different phases was clearly observed. The VUF shown in Figure 9 was around 3%, implying the occurrence of an unsymmetrical fault.

Subsequent to the initial fault finding after examining the smart meter data, further desktop study was required to pinpoint the location of the fault. It could be done by comparing the VRMS waveforms from different floors of the building.

It was revealed that a group of eight smart meters with abnormal VRMS waveforms were located at the same floor, as shown in Figure 12, while the voltage waveforms and VUF in other floors were normal, as shown in Figure 10 and Figure 11.

From the above examination sequence, we successfully confined the fault point at the tee-off part of the riser main at the floor with abnormal voltage readings.

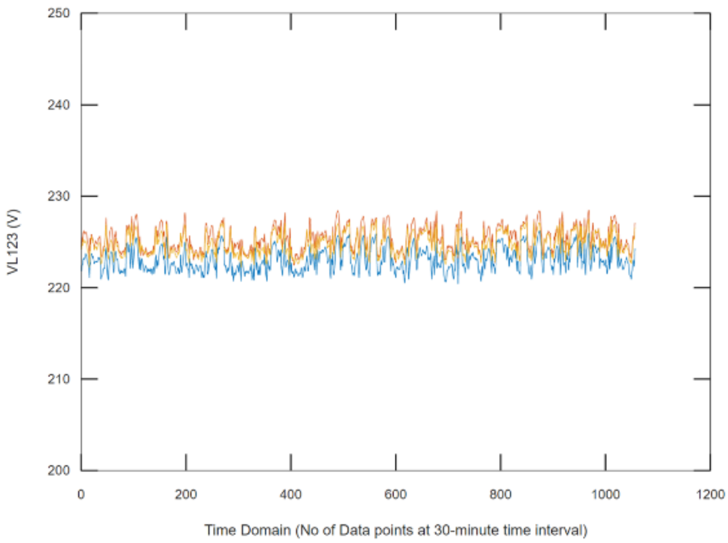

Fig. 10 - The VRMS Waveform was Normal at the Floors without Abnormal Voltage Alarm

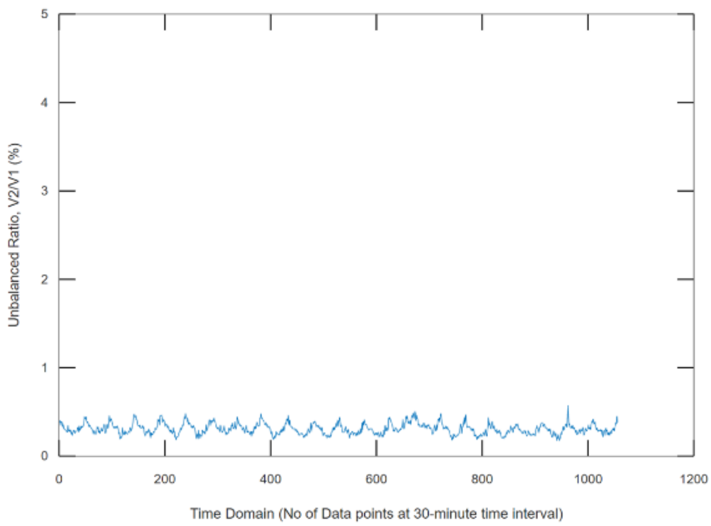

Fig. 11 - The VUF was Normal at the Floors without Abnormal Voltage Alarms

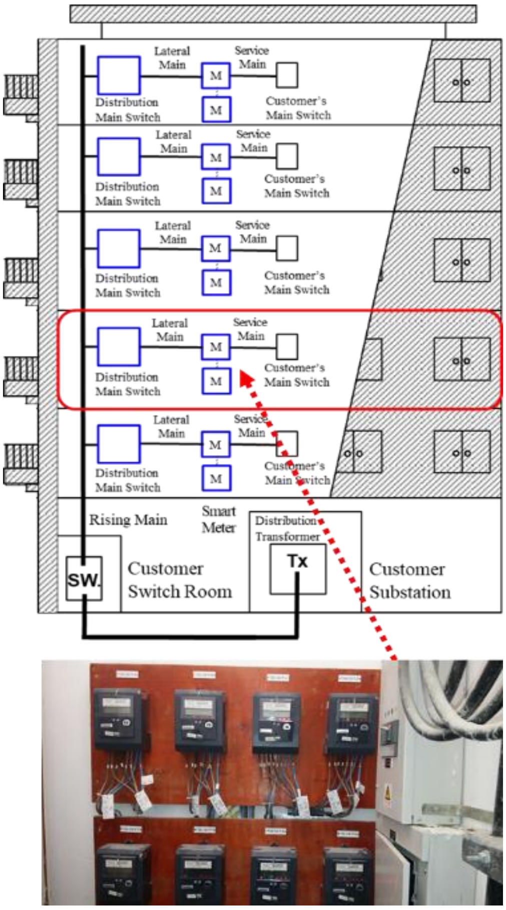

Fig. 12 - A Group of Eight Smart Meters with Over-voltage Alarms at the Same Floor is Identified in the Desktop Study

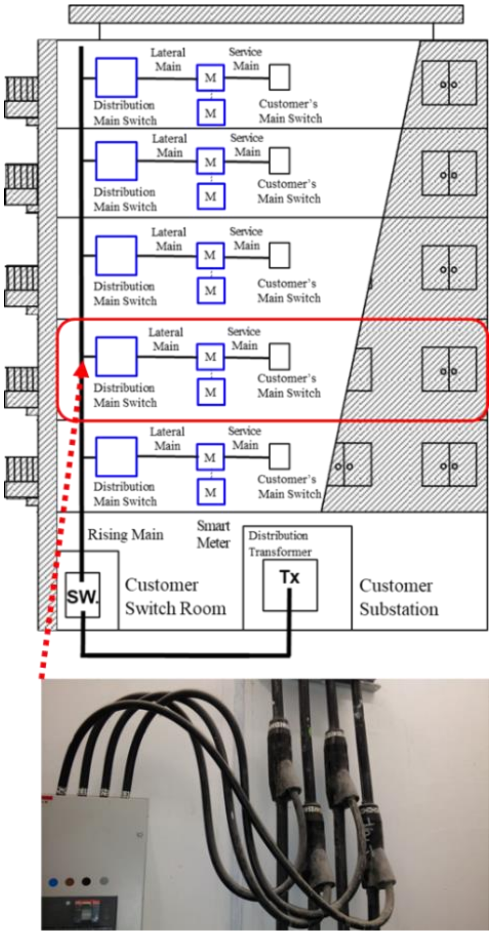

Fig. 14 - The Customer Rising Main Tee-off was found Faulty

Subsequent site inspection by Installation Inspector confirmed the above finding with faulty neutral component revealed at rising main tee-off circuit. Figure 13 and Figure 14 refer. After the fault component was replaced by Building Management Office, the voltage readings were back to normal.

L1-N : 213.8V L2-N : 234.1V L3-N : 231.5V

Fig. 13 - Voltage Readings are Verified during a Meter Inspection to ensure Proper Meter Operations

3. VISUALIZATION OF ABNORMAL SUPPLY VOLTAGE

In previous sections, we demonstrated how to narrow down a potential fault location in a high-rise building by carrying out a grouping analysis in the desktop study. With the same principle, it is also practical to determine the potential fault location with the visualisation support of the over-voltage VRMS and over-voltage events in GIS for geo-spatial analysis.

In the proof-of-concept stage, the meters with over-voltage VRMS and over-voltage events have been visualised in the LV circuit layer of a GIS platform with the location information, the worst voltage and occurrence counted. In principle, for a radial-fed LV circuit, smart meters at the downstream of the fault location can capture the fault related abnormal voltage fluctuation. As a result, the fault location can be preliminary identified.

To cite an example, a high impedance neutral fault is shown in Figure 15, in which the smart meters with over-voltage are visualised by yellow dots and are traceable along the LV circuit. By preliminary analysis, the fault location is most probably situated at the LV pole (black dotted circle) and emergency crew is dispatched to conduct investigation. Eventually, an oxidised neutral conductor of a LV cut-out is found at the predicted location as shown in Figure 16.

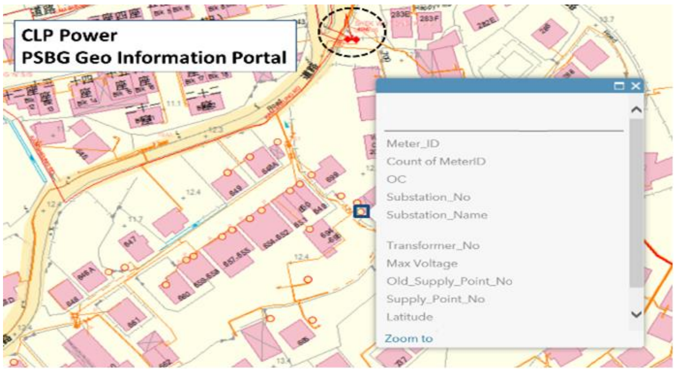

Fig. 15 - Visualisation of Over-Voltage Events on the GIS Platform. LV Network Layout (Orange line), Over-Voltage Smart Meters (Yellow dot), Predicted Fault Location (Black-dot circle)

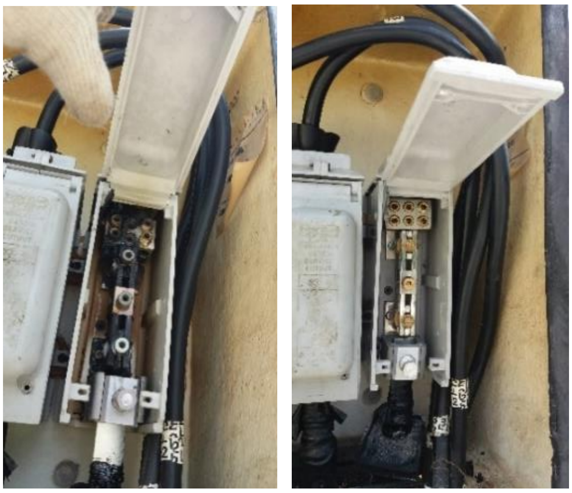

Fig. 16 - Oxidised Neutral Link of a LV Cut-out (Left photo). Replacement Work has been done (Right photo)

4. CONCLUSION

From the proof-of-concept stage, it is proven that two types of LV incipient faults (i.e. neutral fault and high line impedance fault) can be identified by the use of smart meter data and the calculation of VUF. By identifying the failure before it is developed into a permanent fault, the planned repair work can be done to prevent the unplanned interruption and the damage to customer's electrical appliances by the fault. Besides, by visualising the over-voltage VRMS and the events to the GIS platform, it can assist the pinpointing of failure location. This can reduce the efforts of subsequent site investigation.

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Paper No. 10

COMMISSIONING OF THE FIRST F-CLASS COMBINED CYCLE GAS TURBINE (CCGT) UNIT EQUIPPED WITH SELECTIVE CATALYTIC REDUCTION (SCR) SYSTEM IN HONG KONG

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ABSTRACT

In February 2020, HK Electric successfully commissioned its Unit L10 Combined Cycle Gas Turbine (CCGT) Unit utilising F-Class gas turbine technology at Lamma Power Station (LPS). It is the first CCGT unit in Hong Kong equipped with Selective Catalytic Reduction (SCR) System. The SCR System is specially designed to drastically reduce the Nitrogen Oxides (NO_X) emission so as to satisfy the stringent hourly NO_X Emission Limit Value (ELV) of 5 mg/Nm^3 imposed by the local Authority. Upon the successful on-load operation of L10, it has been proven that the adoption of SCR System in conjunction with thermal decomposition of the associated Urea-to-Ammonia Conversion (UTAC) System to break down the urea solution into ammonia for catalytic reaction is a practical solution to achieve the superior environmental performance in a reliable manner.

It is also a statutory requirement from the local Authority that a Continuous Emission Monitoring System (CEMS) has to be installed for the CCGT unit to continuously measure and record the levels of air pollutants (including NOx and ammonia) in the flue gas emitted. The CEMS should comply with all the regulatory requirements and endorsement should be obtained from the local Authority before installation. The CEMS should be commissioned in accordance with EU Directives and European Standard EN 14181. Since this is the first CEMS at LPS measuring such low NOx concentration, the selection and commissioning process was demanding yet valuable for the installation of similar CEMS in future CCGT units.

Being the first F-Class CCGT unit equipped with UTAC / SCR System and CEMS for extremely low NOx measurement in Hong Kong, unexpected and challenging technical issues were encountered during the commissioning of the abovementioned systems including the urea solution production plant. With tremendous efforts spent and unfailing supports contributed by various parties, the technical issues were satisfactorily resolved without sacrificing operational reliability and availability of L10.

This paper serves to share HK Electric's experiences in the suitability evaluation, commissioning and trouble-shooting of Unit L10, its UTAC / SCR Systems and CEMS, together with the way forward of implementing necessary improvement measures for other upcoming new CCGT units.

1. INTRODUCTION

In order to tackle air pollution issues and maintain good air quality in Hong Kong, the first set of Air Quality Objectives was established by the Environmental Protection Department (EPD) of the Government of Hong Kong Special Administrative Region (HKSAR) early in 1987. Since then, a wide range of measures controlling emissions from power plants have been regularly implemented and revised by the EPD to achieve a long-term goal of fostering sustainable environment not only in Hong Kong, but also the Pearl River Delta region of Mainland China. A pledge to reduce nitrogen oxides (NO_X) by 20 – 30 % by 2020 compared with 2010 as benchmark had been made by the Government of HKSAR in 2012 so as to meet the environmental target for 2020.

Fig. 1 - Lamma Power Station

As a result, HK Electric, being one of the two major power utilities in Hong Kong and having the solely-owned Lamma Power Station as shown in Figure 1 with currently installed capacity of about 3,652 MW (including the newly commissioned L10 & L11 and excluding recently decommissioned GT57), was granted approval by the Government of HKSAR of constructing three 380-MW class combined cycle gas turbine (CCGT) units, namely, L10, L11 and L12, at the Lamma Power Station Extension (LMX) to support the aforesaid environmental emission target with the associated commissioning year of L10, L11 and L12 scheduled for 2020, 2022 and 2023 respectively. The hourly average of NO_X emissions for these three units is limited at 5 mg/Nm^3 at 70% loading or above by the EPD in its published “A Guidance Note on Best Practicable Means (BPM) for Electricity Works 2018” [1]. Such NO_X emission limit of 5 mg/Nm^3 is considered extremely challenging and cannot be solely achieved by applying even the most advanced combustion system of gas turbine under the current technological level.

The most advanced combustion technology in relation to the Dry Low NO_X (DLN) burners has been employed by M701F4 gas turbine manufactured by Mitsubishi Heavy Industries, Ltd. (MHI) of Japan, for L10, L11 and L12 in order to optimise the air-to-fuel ratio so as to control NO_X formations during the combustion process under extreme and dynamic operating conditions. Considering the typical 30 mg/Nm^3 as the NO_X emission level that can only be achieved by the advanced M701F4 gas turbine, the adoption of post-combustion NO_X abatement facilities including the SCR and UTAC technologies is deemed necessary for L10, L11 and L12 in order to further reduce the total NO_X level down to below 5 mg/Nm^3 prior to discharging the flue gas to open atmosphere.

The EPD also requires HK Electric to have Continuous Emission Monitoring System (CEMS) installed at the chimney of L10, L11 and L12 to continuously measure and record the levels of air pollutants (including NO_X) in the flue gas. The CEMS shall comply with all the regulatory requirements and endorsement should be obtained from the EPD before installation. The measured data shall be telemetered to the EPD in real time. A series of testing, commissioning and quality assurance procedures have to be implemented in the CEMS.

2. CONFIGURATION OF SELECTIVE CATALYTIC REDUCTION (SCR) & UREA-TO-AMMONIA CONVERSION (UTAC) SYSTEMS IN L10

By considering the flue gas temperature of around 600 - 650 ºC at the inlet of the Heat Recovery Steam Generator (HRSG) for CCGT design utilizing M701F4 gas turbine technology, the SCR System has been designed for installation at the immediate downstream of the tube bundles of High Pressure Evaporator (HP EVA) in the HRSG to serve as a post-combustion means for reducing NO_X emissions in the exhaust gas. NO_X in the flue gas is converted into nitrogen and water vapour by reacting with aqueous ammonia (NH_3) which is evenly distributed in the flue gas by the Ammonia Injection Grid (AIG) comprising thousands of ammonia injection nozzles installed across the flue gas path.

The SCR catalyst modules with NO_X removal efficiency of 95%, composed of ceramic in the form of titanium dioxide and tungsten trioxide, are installed at downstream of AIG to stimulate the chemical reactions between NOx and NH_3 as follows:-

$$4\,NO + 4\,NH_3 + O_2 \rightarrow 4\,N_2 + 6\,H_2O$$
$$2\,NO_2 + 4\,NH_3 + O_2 \rightarrow 3\,N_2 + 6\,H_2O$$
$$NO + NO_2 + 2\,NH_3 \rightarrow 2\,N_2 + 3\,H_2O$$

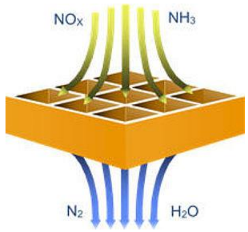

Fig. 2 - SCR Process happened in Catalyst Module [2]

Continuous supply of NH_3 is of utmost importance in a SCR system as well as the operation of L10 as regulated by the Specified Process (SP) Licence issued by the EPD under the Air Pollution Control Ordinance (APCO), Cap. 311 of HK Law. The SP Licence mandates the use of SCR for continuous operation except for special occasions such as unit start-up, shutdown, flame stabilization, emergency fuel changeover, etc. [3]

NH_3 is classified as Dangerous Goods (DG) in Hong Kong [4] and hence the risk associated with the adoption including the handling and storage of NH_3 could not be underestimated. Based on our feasibility study to evaluate alternative approaches to support continuous supply of NH_3 to SCR system for the planned CCGT units, urea - which is a naturally safe chemical widely used as fertiliser - has been considered suitable to be used as reagent feedstock for conversion into NH_3 in LMX on an as-need basis [5].

The UTAC process applying thermal decomposition technology has been finally adopted in L10 given that the complicated licencing is not required as compared with the alternative hydrolyser technology involving storage of NH_3 under certain pressure which must necessitate special licences under the Boilers and Pressure Vessels Ordinance (Cap. 56 of HK Law) as well as Dangerous Goods Ordinance (Cap. 295 of HK Law). After ignition of gas turbine, the high temperature flue gas is extracted by the Tapping Flue Gas Fans of 2 x 100 % duty and then heated up by the Tapping Flue Gas Electric Heaters of 2 x 100 % duty whenever necessary to achieve the sufficiently high temperature for the thermal decomposition of urea. Dilute ammonia gas under low pressure is produced through the pyrolysis reaction by controlled injection of urea solution into the Decomposition Chamber of vertical cylindrical shape at temperature of around 315 – 590 °C. The reaction products comprising NH_3, carbon dioxide and water vapour would be directed together with the extracted hot flue gas to the AIG for ammonia injection into the flue gas path as follows:-

NH_2CONH_2 (urea) + $H_2O \rightarrow NH_3$ + HNCO (isocyanic acid)
HNCO (isocyanic acid) + $H_2O \rightarrow NH_3 + CO_2$

The overall SCR and UTAC systems of L10 is shown below:-

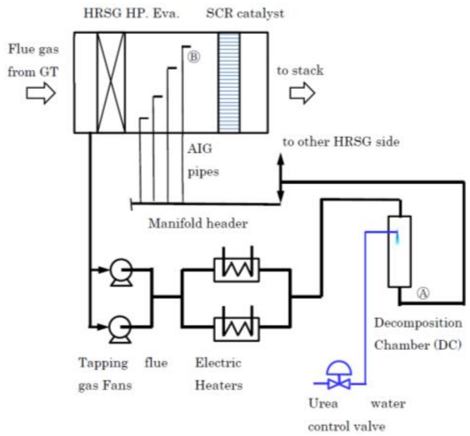

Fig. 3 - Brief Schematic of SCR & UTAC System [6]

Fig. 4 - Complete Installation of L10 UTAC System

3. REQUIREMENTS AND SELECTION OF L10 CEMS

The CEMS installed shall have type approval or certification at the appropriate measuring range(s) for the specific measurements by recognised international or national certification body, such as MCERTS in the UK, TUV in Germany or other body acceptable to the EPD.

The CEMS shall meet the measurement uncertainty requirements as specified in the "Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control)" of the European Union (EU) or other equivalent requirements acceptable to the EPD. A quality assurance plan shall also be developed and implemented to the CEMS.

The certification procedure shall refer to the European Standard EN 14181 - Quality Assurance of Automated Measuring Systems and EN 15267 - Air quality - Certification of automated measuring systems. The standards define the performance criteria and test procedures covering the Quality Assurance Level 1 (QAL1) requirements. According to the standard, the maximum certified measuring range of CEMS for power plant which is categorised as large combustion plant shall not be greater than 2.5 times of the ELV [7].

EU Directive 2010/75/EU states that the CEMS shall meet the requirement on measurement uncertainty, which shall not exceed 20% of the emission limit values at 95% confidence level. This requirement can be validated by performing the QAL2 test procedure of EN 14181.

At the time of selection of CEMS vendor, it was recognised that the minimum certified measuring range of NO_X for most of the commercially available MCERTS certified CEMS was 0 - 50 mg/Nm^3. The certified range was 10 times of the NO_X ELV (5 mg/Nm^3) for L10 and could not meet the requirement of the QAL1 (maximum certification range shall be within 2.5 times of the ELV (i.e. 12.5 mg/Nm^3)).

Certified CEMS with two common measurement principles for NO_X are available in the market. The first one uses Non-dispersive Infrared for NO_X measurement, which measured the amount of absorbed infrared at certain level of wavelength to calculate the NO_X concentration. The second one measured the NO_X concentration by Chemiluminescence, which calculated the NO_X concentration by detecting the light energy released during the reaction between NO and Ozone. Ozone is combined with NO to form NO_2 in an activated state. The activated NO_2 luminesces as it reverts to a lower energy state and a photomultiplier counts the photons that are proportional to the NO concentration. The block diagram of Chemiluminescence is shown in Figure 5.

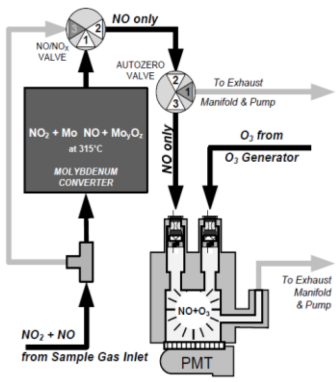

Fig. 5 - Block Diagram of Chemiluminescence Method to Detect NOx

The main contractor of L10, MHI, recommended a Stack Gas Analyser from a manufacturer (Model A), for installation at L10. This Gas Analyser is designed with ultimate sensitivity to continuously measure extremely low concentration of NO_X under 5 ppm (10 mg/Nm^3) at stack. It adopts Chemiluminescence, which is a United States Environmental Protection Agency (USEPA) approved method for accurate measurement of low NO_X concentration at ambient level. The selection of Model A Stack Gas Analyser was proposed to the EPD for their endorsement. However, due to the absence of required type approval or certification at the measuring range by recognised body, the EPD rejected the proposal of using this analyser to be the CEMS of L10.

MHI subsequently recommended another Stack Gas Analyser, from another manufacturer (Model B). This analyser is a MCERTS and TUV certified product to EN 15267, and also compliant with USEPA. Although the certified measuring range of the analyser is 0 - 20 mg/Nm^3 for NO_X measurement, such range is in fact the lowest QAL1 certification range among the certified CEMS in the global market. Same as Model A, Model B also adopts Chemiluminescence to measure the NO_X concentration. The selection of Model B was then proposed to the EPD for endorsement. Eventually, the EPD accepted the proposal to install Model B Stack Gas Analyser as the CEMS for L10 provided that it could meet the QAL2 requirements of EN 14181.

4. COMMISSIONING OF L10 CEMS

The CEMS was installed at the stack of L10 by MHI and satisfactorily passed the Site Acceptance Test (SAT). The CEMS was commissioned by the equipment manufacturer in accordance to the SAT Procedure of CEMS prepared by manufacturer and agreed by MHI and HK Electric. The SAT Procedure details the commissioning procedure for CEMS and confirms if the CEMS is installed and functioning properly. The SAT Procedure, which includes four test items, are presented in Table 1.

For measurement of NO_X emission of L10, EN 14181 specifies procedures for establishing quality assurance levels (QAL) for CEMS installed at industrial plants for determination of flue gas components [8]. QAL2 test is a procedure to calibrate the CEMS and determine the variability of the measured values obtained by it, so as to demonstrate the suitability of the CEMS for its application, following its installation. A calibration function is established from the results of a number of parallel measurements performed with the standard reference method (SRM).

In general, the QAL2 test covers the following items:

1. Functional test of the CEMS including check of correct installation.
2. Parallel measurements with the SRM.
3. Data evaluation.
4. Determination of the calibration function of the CEMS and its range of validity.
5. Calculation of variability of the CEMS measured values.
6. Test of variability of the CEMS measured values.
7. Reporting.

Commissioning works with reference to the Site Acceptance Test procedure confirmed that the L10 CEMS was correctly installed and commissioned. The L10 CEMS passed the EN 14181 QAL2 test and hence fulfilled the requirement on 20% measurement uncertainty for NO_X as required by the EPD.

Installation conformity check	• Mechanical installation • Electrical supply and installation • Instrument air supply and connection • Availability of span gas cylinders • Connection of DCS interface
Commissioning	• Functionality check of CEMS cabinet • Supply of instrument air • Operation check of CEMS cabinet air conditioning • Temperature regulation of heated lines and sampling probes • Operation check of CEMS
Calibration of CEMS	• Zero/Span gas check • Zero/Span gas adjustment
DCS communication test	• ADAM module digital output simulation and DCS input • DCS digital output simulation and ADAM module input • DCS analog output simulation and DCS analog input check

Table 1 - Test Items of Site Acceptance Test (SAT) Procedure of L10 CEMS

5. CHALLENGES ENCOUNTERED DURING TESTING AND COMMISSIONING OF SYSTEMS

In end 2019, HK Electric completed the installation, testing and commissioning of L10 UTAC/SCR system which has been introduced to the Lamma Power Station the first time ever in HK Electric's history. Due to the lack of real-life experience in adopting similar systems for high temperature application of around 600 ^oC in previous projects for Lamma Power Station, our project team has encountered various problems during the course of commissioning which – after spending extended efforts in carrying out the detailed investigation as well as root cause analysis and formulating reliable remedial measures through repetitive verifications under hot condition – have been satisfactorily resolved.

5.1 High Vibration of Tapping Flue Gas Fans

Even though the performance of the two Tapping Flue Gas Fans 10A and 10B (Fans 10A and 10B) of UTAC

System had been confirmed acceptable under room temperature environment in the client's witness inspection at shop before ex-factory, the fans continuously demonstrated certain deficiencies at site since initial trial run when operating under hot condition after tapping in hot flue gas from L10 HRSG exhaust starting from late 2019.

During the initial trial run, abnormal rubbing noise was observed in both Fans 10A and 10B. With the aid of the manufacturer's technical advisor dispatched on-site, improper clearance between the fan wheel and fan housing under hot condition was identified after open-up inspection which was finally resolved by inserting additional spacer to keep the required clearance of 10 mm to avoid rubbing.

Not long after the settlement of above issue, vibration level in the range of 4.0 mm/s to 7.00 mm/s (R.M.S.) was identified in the subsequent trial runs of these fans, which was unacceptably high when compared against acceptable level of less than 2.8 mm/s for medium-sized machines (i.e. 15 kW to 75 kW) resting on rigid foundations as defined in relevant ISO 10816-3 standard providing requirement on vibration level of industries machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15,000 r/min [9]. Nevertheless, the fan bearing of Fan 10A was found damaged in the follow-up investigation. After the replacement of fan bearing, the vibration level reduced to the relatively acceptable range of 0.9 to 3.5 mm/s (R.M.S.). However, vibration level of the two fans was found unstable intermittently whereas Fan 10A even went up to 18 mm/s requiring immediate fan trip to prevent catastrophic damage to the nearby equipment and personnel.

In order to tackle the occasionally high vibration issue endangering the unit reliability of L10, the following remedial measures were finally concluded for field implementation after confirming that there was no potential misalignment nor undesirable wear and looseness in the fans:-

1. Field balancing work of fan shaft / impeller to ensure good dynamic balancing.
2. Concrete grouting and / or installation of jack bolts at the pedestal so as to increase the support's rigidity.
3. Replacement of the nearby expansion joints from metallic to fabric type and addition of fixed support point for air ducts so as to eliminate the thermal expansion of the air ducts which might abnormally push the fan casing.

Even with the above efforts spent, the vibration problem could only be temporarily resolved, and the high vibration was observed again after operation for certain period of time - suggesting that there were design issues in the original fan thus making these fans in their current design / configuration not suitable for reliable operation under high temperature environment which had finally been revealed as the most challenging design requirement. In order to bring a close end to this long dragging problem, a decision was made calling for replacing the original fans with new fans supplied by another manufacturer and equipped with the following salient features which would make them to operate reliably under high temperature environment:-

1. Fan housing is separated from the fan pedestal in order to isolate heat conduction to the pedestal during operation (whereas integrated configuration is adopted in the original fan design).
2. Water-cooled bearings are adopted in the new fan design for more effective heat dissipation (whereas natural air circulation is adopted in the original fan design).
3. Coupling in terms of flanged connection is adopted in the new fan design for maintaining the coupling alignment in more reliable manner under continuous high temperature application (whereas flexible wire connection is used in the original fan design).
4. Fan impeller fabricated from molybdenum-containing grade stainless steel SUS317 is adopted in the new fan design thus offering better performance of creep strength, tensile strength and stress-to-rupture behaviour at elevated temperature (whereas SUS309 is used in the original fan design).

Though the replacement of Tapping Flue Gas Fans would require re-construction of concrete foundations supporting the new fans and installation of additional cooling water pipeline, the replacement work was planned to be carried out during the three-month unit outage period starting from December 2020.

Fig. 6 - Complete Installation of New Tapping Flue Gas Fans

With the tremendous efforts contributed by different parties, the new fans were successfully installed, tested and commissioned in mid-February 2021 and L10's operation was timely resumed in early March 2021 as scheduled. Since then, the new fans have been operating smoothly with acceptable vibration level.

5.2 Overheating of Tapping Flue Gas Electric Heater

Not only high temperature of about 200 °C was found on the surface cladding of both Tapping Flue Gas Electric Heater 10A and 10B after operation for half year, leakage of hot flue gas was also identified at the flange of Heater 10B whereas some electrical cables were found damaged inside the termination box located right above the Heater 10B. As this shortcoming had posed a serious threat to the personnel's health and safety, the Heater 10B had to be isolated from the system for follow-up investigation. As a result of comprehensive root cause analysis conducted against the aforesaid observations, the possible design defects / shortfalls had been identified as follows:-

1. The thermal insulation made of calcium silicate with thickness of 125 mm was found inadequate, coupled with poor workmanship observed for installation of thermal insulation at shop thus creating air gaps in between the insulation board, which as a whole had made it impossible to keep the surface temperature under 55 °C as per originally designed.
2. The gaskets with design temperature of 454 °C were mistakenly used in the inlet flange of the Tapping Flue Gas Electric Heaters with design temperature of 593 °C.
3. Some of the electrical cables were only rated for 90 °C which were found not in line with the design temperature of the termination box of 120 °C.

Fig. 7 - Complete Installation of Tapping Flue Gas Electric Heater

In order to completely eliminate the aforesaid defective issues, total replacement of Heaters 10A and 10B was arranged by using the new heaters originally planned for L11 during the three-month unit outage period of L10 in early 2021 with the following modification works included:-

1. Covering the external surface by the new thermal insulation of ceramics (Si, Ca & Mg based) with lower thermal conductivity and thickness of 200 mm.
2. Adoption of new gasket suitable for application at 1000 °C.
3. Provision of thermal resistant power cables with temperature rating of 200 °C

The overheating problem has been satisfactorily resolved since March 2021.

5.3 Slow Heating of AIG During Unit Start Up

Due to the stringent requirement set out in Specified Processes Licence issued by EPD under APCO, the urea injection must be operated at above 182 MW loading in order to secure the low NO_X emission. On the other hand, the UTAC's OEM has set out the required minimum temperature of 218 °C at the metal surface of AIG as the prerequisite for the urea injection in order to ensure no unwanted solidification of NH_3 solution and in turns to eliminate the chance of AIG piping blockage. Therefore, the time spent on the heating up of AIG after ignition of Gas Turbine would determine the overall start-up time for L10 to achieve full load.

Since the commercial operation of L10, the slow heating of AIG has been identified which has prolonged the time required for L10 to start loading up from 182 MW. During a hot start-up of L10 in mid-December 2019, it took about 117 minutes which was 37 minutes more than the standard requirement of 80 minutes and was highly unfavourable. In order to resolve this unsatisfactory slow heating phenomenon, the project team had once explored the implementation of early start-up of Tapping Flue Gas Fans and Electric Heaters at some 10 - 15 minutes prior to Gas Turbine's spin start which, however, was considered not acceptable due to the fact that the heating up of the residual gas containing combustible gases in HRSG might pose undesirable risk to L10 operation. Alternatively, MHI had performed the computational thermal analysis of NH_3 piping in between the outlet of Decomposition Chamber and AIG and it was finally concluded that the adopted piping's surface thermal insulation of calcium silicate with thermal conductivity of 0.095 W/mK at 400 °C was not sufficiently low enough to prevent the heat energy of urea solution from leaking to the surrounding. As a result, the existing thermal insulation was replaced with the new insulation of ceramics (Si, Ca & Mg based) with lower thermal conductivity of 0.08 W/mK at 400 °C during the three-month unit outage starting in early December 2020.

Together with the aforesaid replacement of Tapping Flue Gas Fans and Electric Heaters, the slow heating of the metal temperature of AIG was reasonably resolved and the unit start-up time could finally achieve the design requirement since March 2021.

6. CONCLUSION

In support of the Government's policy to increase the proportion of using natural gas for power generation and provide better air quality in Hong Kong and nearby region, HK Electric has taken an active role to plan, design, install, commission, test and operate the first ever F-class CCGT unit L10 equipped with UTAC /

SCR system in Hong Kong. The UTAC / SCR system installed in L10 has been proved to be highly effective in removing over 90 % of NO_X from the exhaust gas of gas turbine and capable in dealing with the very stringent NO_X emission limit of 5 mg/Nm^3 imposed by the local Authority.

It was also a challenge for us to source for a suitable CEMS, which could fulfil all the regulatory requirements of the local Authority for installation at L10. A series of back and forth discussion with the Authority was conducted to review and select the CEMS. A Stack Gas Analyser with the lowest certified measuring range in the market was subsequently endorsed by the EPD to be the CEMS of L10. A series of commissioning tests in accordance with international standards were conducted to confirm the acceptance of the system.

Based on the knowledge and experiences gained in dealing with the challenges and difficulties encountered during L10 commissioning as discussed above, HK Electric is determined to devote continuous efforts in order to further improve the overall performance of the L11 and L12 as well as to continue its commitment in providing safe, reliable, environmentally friendly and affordable power supply to the community and building a low carbon society in the future.

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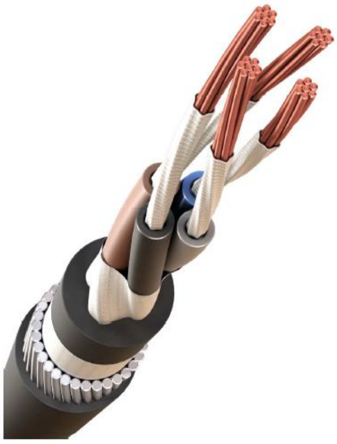

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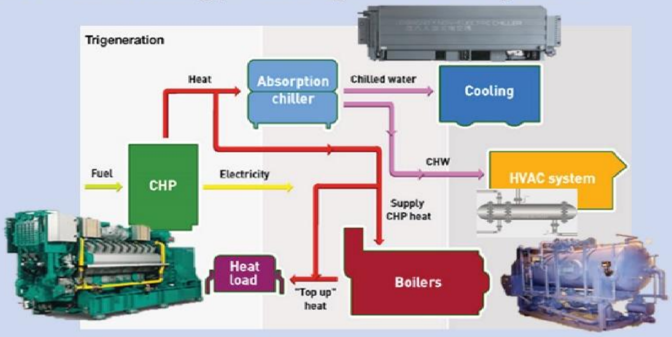

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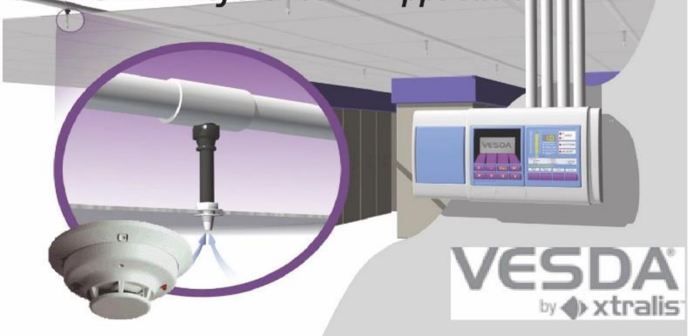

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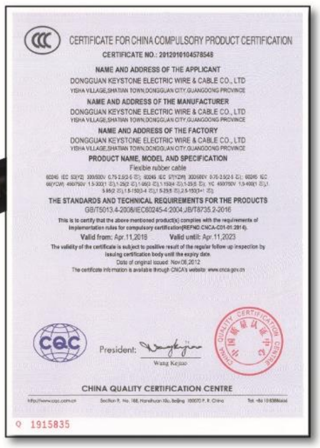

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FR30 - BS 7846
BS 8491 120M
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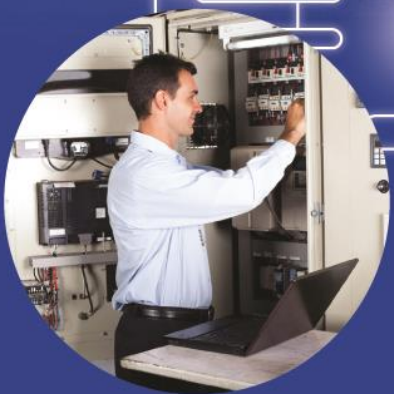

BUILDING WIRES

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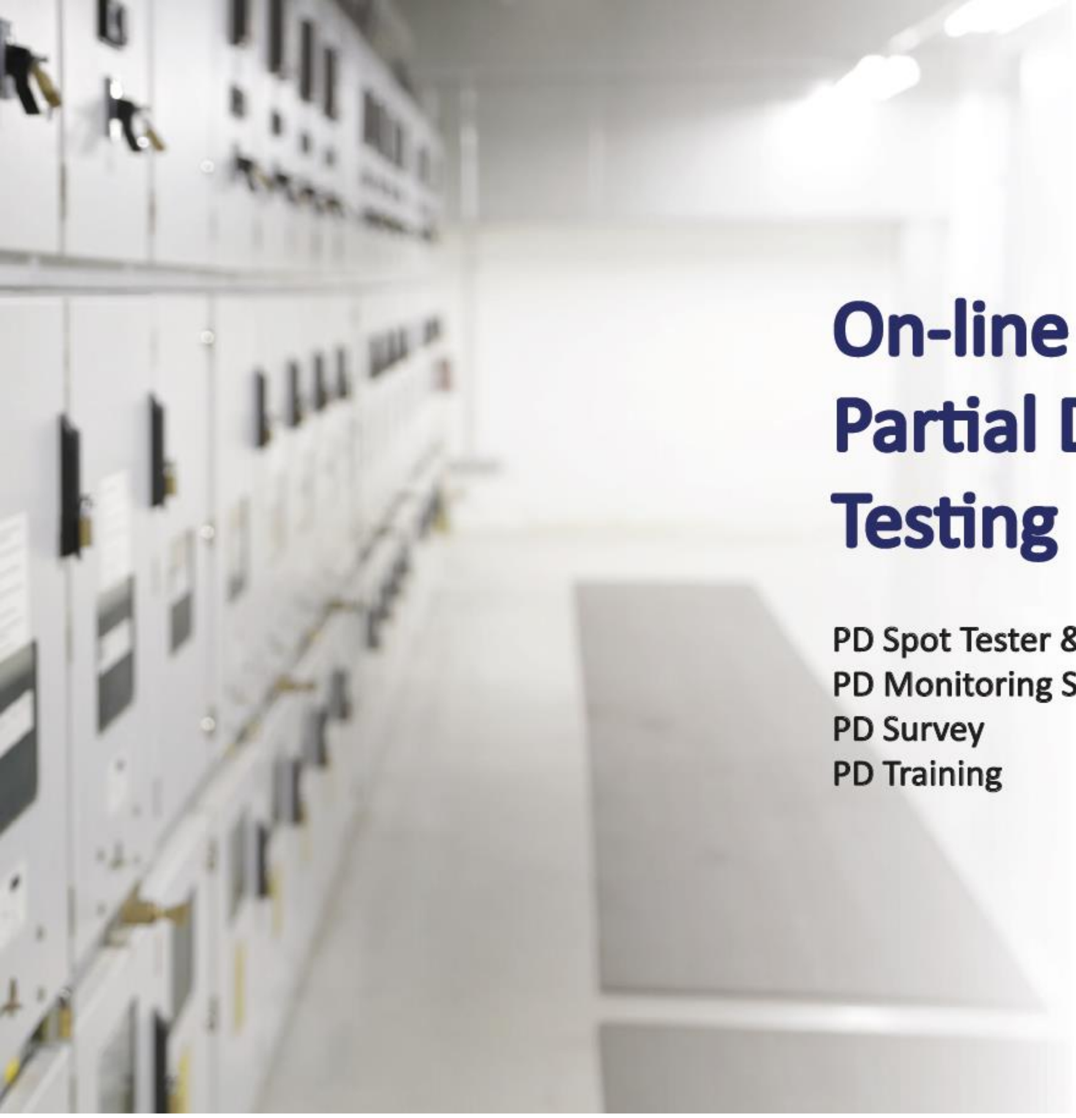


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