THE HONG KONG
INSTITUTION OF ENGINEERS
ELECTRICAL DIVISION

The 36th Annual Symposium
Tuesday
23rd October 2018

ELECTRICAL ENGINEERING DIGITALIZATION – A, B & C

(A, B & C stand for Artificial Intelligence, Big Data & Cloud Services)

at

Ballroom
Sheraton Hotel
Nathan Road
Kowloon
Hong Kong

SYMPOSIUM PROGRAMME

08.30 Registration and Coffee

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

09.05 Opening Address
- Ir Thomas K.C. Chan
  Immediate Past President, The HKIE

09.10 Keynote Speech
- Mr Donald C.K. Mak
  Assistant Government Chief Information Officer
  Innovation and Technology Bureau
  The Government of the HKSAR

1. Digital Grid

09.40 Airbone LiDAR Scanning for Overhead Line Vegetation Management
- Ir Brian C.F. Tsui, Deputy Director, Asset Development
- Mr Chris C.K. Cheung, Asset Development Engineer
- Mr K.L. Chan, Engineer I
  CLP Power Hong Kong Limited

10.00 Digital Grid – Power Asset Management
- Mr Norbert Kaiser, Senior Asset Management Consultant
  Siemens AG, Germany
- Mr Keith T.M. Wong, Digitalization Manager
  Siemens Ltd., Hong Kong

10.20 Discussion

10.40 Coffee Break

2. Smart Transportation

11.10 Use of Bluetooth and Wifi for Monitoring Traffic and Pedestrian
- Professor Edward C.S. Chung
  Professor
  Department of Electrical Engineering
  Hong Kong Polytechnic University

11.30 Smart Railway
- Ir C.L. Leung, Head of E&M Construction
- Ir Sha Wong, Head of E&M Engineering
  MTR Corporation Ltd.

11.50 Development of Elevator Drives

- Ir Dr Albert T.P. So, Honorary Lecturer
- Ir Dr Bryan M.H. Pong, Associate Professor
- Ir W.K. Lee, Principal Lecturer
- Dr K.H. Lam, Lecturer

Department of Electrical & Electronic Engineering
University of Hong Kong

12.10 Discussion

12.30 Lunch

3. <u>Digitalization</u>

14.15 BIM in respect of Digitalization

- Ir C.K. Lee, Chief Engineer
- Ir Steve H.Y. Chan, Senior Engineer
- Ir Christy C.Y. Poon, Engineer
- Ir Grace K.M. Yip, Engineer
- Mr Francis P.H. Yuen, Assistant Engineer

Electrical & Mechanical Services Department
The Government of the HKSAR

14.35 Embrace the Power of Digitalization for a Sustainable Hyper-Scale Data Centre

- Ir George K.C. Or, Director, Infrastructure Development
- Mr Dikson Choi, Technical Manager

Data Centre Business
NTT Com Asia Limited

14.55 Discussion

15.15 Coffee Break

4. <u>Machine Intelligence & Data Mining</u>

15.45 Deep Learning Technology & Applications with Big Data

- Professor Francis Y.L. Chin
  Emeritus Professor & Honorary Professor
- Dr Bethany M.Y. Chan
  Honorary Associate Professor
  Department of Computer Science
  University of Hong Kong

16.05 Preventive Maintenance by using Connected IoT Devices in Electrical System

- Mr Markus Hirschbold
  EcoStruxure Power L&C Future Offer Director
  Strategy and Innovation, Building & IT Business
  Schneider Electric Ltd.
- Ir Ian Y.L. Lee
  Solution Director
  Schneider Electric (HK) Ltd.

16.25 Discussion

16.45 Summing Up

- Ir Dr Edward W.C. Lo
  Symposium Chairman
  Electrical Division, The HKIE

Closing Address

- Ir Professor Christopher Y.H. Chao
  Dean
  Faculty of Engineering
  University of Hong Kong

Acknowledgement

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Speakers/Authors

Mr Donald C.K. Mak
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Mr Chris C.K. Cheung
Mr K.L. Chan
Mr Norbert Kaiser
Mr Keith T.M. Wong
Prof. Edward C.S. Chung
Ir C.L. Leung
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Ir Ian Y.L. Lee

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Hong Kong Electrical Contractors' Association Ltd.

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Paper No. 1

AIRBORNE LiDAR SCANNING FOR OVERHEAD LINE VEGETATION MANAGEMENT

Speakers: Ir Brian C.F. Tsui, Deputy Director, Asset Development
Mr Chris C.K. Cheung, Asset Development Engineer
Mr K.L. Chan, Engineer I
CLP Power Hong Kong Limited

AIRBORNE LiDAR SCANNING FOR OVERHEAD LINE VEGETATION MANAGEMENT

Ir Brian C.F. Tsui, Deputy Director, Asset Development
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Mr K.L. Chan, Engineer I
CLP Power Hong Kong Limited

ABSTRACT

CLP Power Hong Kong Limited (CLP Power) operates a transmission network consisting of 400kV and 132kV overhead line and cable which transmit electricity from power stations to the bulk substations in the company's service area. Vegetation interference to overhead line is a major cause of unplanned outages for the overhead line system. It is therefore crucial to maintain effective overhead line vegetation management in order to ensure highly reliable electricity supply to customers.

The traditional overhead line vegetation inspection and patrol are conducted by human visual observation. However, there are certain limitations of this ground-based and labour-intensive inspection method, such as potential risks for patrolling at mountainous areas and difficult terrain, as well as low accuracy of vegetation clearance measurement due to blockage of visibility by massive vegetation. With the objective to perform proactive vegetation management planning, CLP Power initiated a pilot project to assess the airborne remote sensing technique and application on the vegetation management to accurately evaluate the clearance between overhead line conductors and nearby vegetation, thus to enhance safety, efficiency and effectiveness of vegetation inspection and management. The key deliverables include vegetation risk identification; accurate 3D spatial information of overhead line structures and the surroundings; implementation of Vegetation Management System to visualise 3D models of the overhead line system and the surrounding terrains.

This paper shares CLP Power's experience of the first Airborne LiDAR Scanning for transmission overhead line vegetation management, which covers the project approach, deliverables and benefits, and the way forward to facilitate future regular scanning for transmission overhead line to further enhance the electricity supply reliability.

1. INTRODUCTION

CLP Power has been serving Hong Kong for over 116 years. It operates a vertically integrated electricity supply business in Hong Kong, and provides a highly reliable supply of electricity and excellent customer services to six million people in its supply area.

LiDAR, which stands for Light Detection and Ranging, is a remote aerial laser survey technology using remote sensing technique based on light detection and ranging measurements for collecting data to create 3D models and maps of objects and environments. Airborne scanning is commonly used for acquiring LiDAR data. Onboard sensors can capture accurate positions and orientation from the Global Navigation Satellite System while measurements are taken from an Inertial Measurement Unit (IMU). The resultant data is a collection of point cloud LiDAR measurements which provide accurate spatial data for the transmission overhead line network and its surroundings. These data would help display a precise overview of the assets of the overhead line network with a terrain view using accurate Digital Elevation Models (DEM), Digital Surface Model (DSM), and Digital Object Models (DOM).

The LiDAR data can be used for vegetation encroachment analysis and assist in determining tree trimming requirements based on the blowout or grow-in conditions. It also allows operators to measure ground to line safety clearances based on terrain data, and analyse high risk overhead line sections susceptible to high temperatures and strong winds.

Fig. 1 – Airborne LiDAR Scanning Point Cloud Model

2. THE LiDAR CONCEPT

LiDAR is an optical remote-sensing technique that uses laser light to obtain accurate data of the surface terrain and ground objects such as buildings, roads, electrical tower structures and overhead line. During data collection, each data point has a GPS coordinate measurement tag to indicate location. For the airborne

LiDAR approach, the data accuracy was further enhanced by combining with information obtained from the synchronous observation survey points which work concurrently at ground level during the airborne scanning operations. The measurements then go through a data analytics process and are summarized in a database under different layers to distinguish them into data classifications such as conductor, tower, and buildings for user visualization.

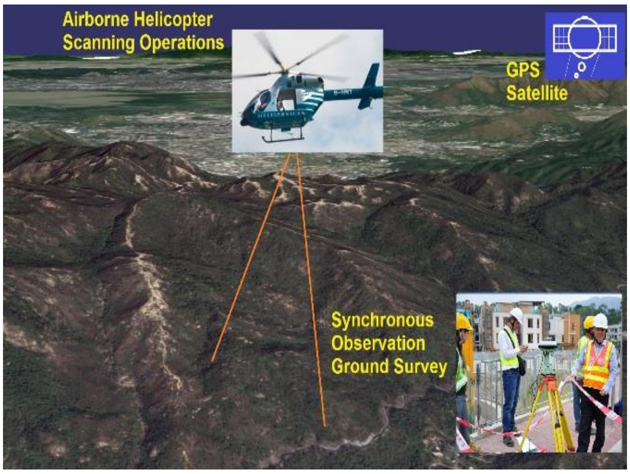

Fig. 2 – Airborne LiDAR Scanning with Synchronous Observation Ground Survey

3. ISSUES ON THE OVERHEAD LINE NETWORK

One common cause of unplanned outages on overhead line system is interference by overgrown trees or vegetation. Thus, effective overhead line vegetation management is crucial to ensure highly reliable electricity supply, as well as to maintain the upkeep of vegetation nearby. The current overhead line vegetation inspection and patrol require human visual observation which is labour-intensive. Some overhead lines are located in remote areas of difficult terrain that are hard to access. In addition, the accuracy of the vegetation clearance measurements will be affected by different factors such as poor weather conditions and blocked visibility due to overgrown vegetation.

Airborne LiDAR scanning can improve the efficiency of line inspection while reducing the risks involved and virtually eliminates tower climbing. The 3D geospatial models generated from LiDAR sensing results would facilitate better decision making and optimise of human resources allocation for site inspections. With the help of the LiDAR data, vegetation management teams could accurately locate areas with vegetation risks in the overhead line system and develop a time schedule for vegetation management that could maintain the compliance for clearance requirements and upkeep of surrounding vegetations. In November 2017, CLP Power commenced a pilot project to assess the LiDAR technology.

4. AIRBORNE LiDAR APPROACH

This project involved several challenges including meeting a tight schedule, achieving quality standards, whilst fulfilling flight operation requirements by the Civil Aviation Department (CAD). The project sought a balance among resources allocation, quality control and project costs and time management. Execution strategies which incorporated written plans to determine flight routes, ground survey methods, and verification of data quality were well defined beforehand with the service provider. Regular feedbacks from frontline staff and business intelligence were also collected and relayed to the project team for continuous improvement.

Fig. 3 – LiDAR Scanning Equipment Attached to the Helicopter

The project work comprised of three main components: Helicopter Flight Operations, Data Processing and Analysis, and Data Visualisation.

4.1 Flight Operations Plan

Prior to the commencement of airborne scanning, a Flight Plan was developed to map out an efficient helicopter route. The main concern was the reliability of the collected data due to its dependence on whether the existing Hong Kong Continuously Operating Reference Stations (CORS) ground base station signal is interrupted and reliance on static Ground Control Points (GCP) to provide backup coverage. Other external factors that needed to be considered include sensitive flight areas and No-Fly-Zones defined by the CAD; as well as changes in weather conditions that might hamper flight progress, such as thunderstorms, haze, and high wind speeds.

To ensure the survey coverage was sufficient, the LiDAR operator determined a number of tailor-made specifications for the airborne survey, which include the output of two sets of coordinated data (WGS84 and HK80), a targeted point cloud density level of 65 points per square metre (ppsm), and the minimum horizontal and vertical point cloud accuracy requirements. The actual point density achieved was higher than specified at approximately 125 ppsm. A fixed transmission corridor width for the aerial survey was also specified.

For the pilot project implementation, a corridor width of 50m and 36m (with a 10m margin on both sides) was specified for the 400kV and 132kV transmission lines respectively. The captured LiDAR aerial images with an orthophotography resolution of 2.6cm were then embedded onto this corridor section at the DOM layer. The entire flight plan took a total of 37 hours of actual flight time to complete.

4.2 Data Processing and Analysis

Data processing is comprised of three main sub-processes: (1) Data Layer Classification, (2) Danger and Crossing Points, and (3) Data Analytics and Results.

(1) Data Layer Classification
The point cloud data is classified into specific layers in the system for calculations and data analysis. For this project, the vegetation management system requires classification of the point cloud data into different layers such as overhead wires, structures, roads, buildings, vegetation, railways, rivers etc. After the primary classification, some data will be further categorised into sublayers, for example, roads would be divided into highway, driveways, and walkways.

(2) Danger Point and Crossing Points
This part refers to determining which classified point cloud data indicates significant risk to vegetation management operators. The concerned data is categorised into two different types: (a) vegetation danger points, and (b) object crossing points.

Vegetation danger points indicate areas of vegetation which are deemed to be within proximity from the safety clearances of the overhead line system. This information is important to a network operator as it helps prioritise tree trimming works. The 3D visual interface allows a network operator to very quickly determine the areas of higher vegetation risks before site inspection, and allocate vegetation management resources more efficiently.

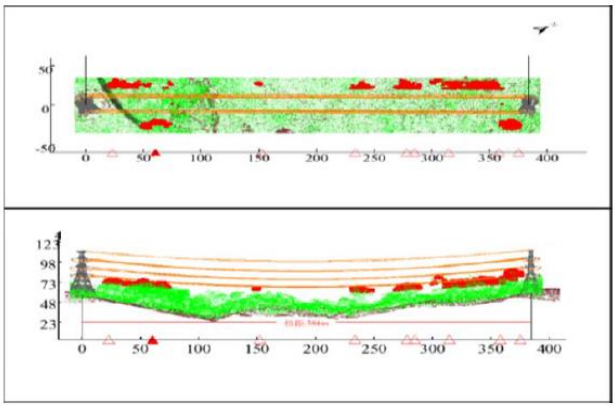

Fig. 4 – Line Profile Analysis for 400kV Overhead Line

The object crossing points refer to LiDAR data points indicating objects directly underneath the overhead line and deemed to be within minimum clearance requirements. The analysis involves an investigation of all crossing points showed in the model to calculate the vertical distances between the object and the overhead line. This database of crossing points can be used to identify those potential risk points with insufficient clearance and enable better overhead line corridor management.

(3) Data Analytics and Results
After data collection and processing, in-depth analysis was performed on the data set to obtain a summary of the results in the form of inspection reports. The result findings provide critical information and valuable insight, such as the location of vegetation danger points and crossing points, to assist vegetation operators in making decisions for remedial action. There are seven types of inspection data available:

a. *Object Safety Distance* provides a summary of the vegetation danger points and clearance information.
b. *Falling Tree Safety Distance* provides a summary of clearances for anticipated fallen tree objects.
c. *Cross-over* provides a summary of clearances and information of objects which cross underneath the overhead line.
d. *Tower/Pole Inclination* is a summary of the transmission tower conditions on site, showing details regarding tower tilt/gradient and bearing of the inclination.
e. *Safe Distance under High Temperature Simulated Conditions* provides a summary of increased conductor sag due to high temperature.
f. *Safe Distance under High Load Simulated Conditions* provides a summary of increased conductor sag due to high load.
g. *Safe Distance under High Wind Simulated Conditions* provides a summary of conductor swing due to high wind conditions.

The inspection data provides detailed information on point cloud data clearances of vegetation danger points and crossing points, location coordinates of asset structures, as well as a ranking of hazard levels. The results from the data analytics enable operators to better understand site conditions prior to allocating site resources and assist in vegetation management.

4.3 Data Visualization

Upon completion of the data processing and analysis phase, the classification layers for point cloud data, danger points and crossing points are assembled and distributed to the three separated platforms, namely the Client Server, the Browser Server and the Mobile Server, of the vegetation management system (VMS).

(1) Client Server
The Client Server (C/S) can display point cloud and geographic data in KML format in a 3D panorama, perform data query functions, and generate clearance

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statistics. It retains its own data set including point cloud data and KML models, DEM, image tiles, and video files. Access to the VMS interface is performed locally, with local administrative control. The user can perform functions such as danger point and crossing point analysis, horizontal, vertical and spatial measurements, and locate tower and pole structures with navigation tools. The C/S platform has advantages in processing speed with its inherent local retention of data, but lacks an online access portal.

Fig. 5 – Client Server (C/S) Vegetation Management System

(2) Browser Server
Browser Server (B/S) operates as a client-to-host platform and supports multiple clients access at the same time. The functions and features of B/S are basically similar to that of the C/S. The major difference is that B/S operates online through the web. The Server runs Microsoft Windows Server 2016 Standard and is linked with a SQL database server. The B/S vegetation management system then accesses this database for displaying the point cloud and KML data.

The advantages of the B/S platform are that multiple users can simultaneously access a same set of data (from Server), and updates to the data set are completed once at a centralised location. However, the operation speed of the software platform might be constrained by the bandwidth of online connection speeds, in particular during periods of heavy user congestion. A high level of administrative control is also required to meet cyber security requirements.

(3) Mobile Server
Mobile Server (M/S) is a portable application that runs on the mobile iOS operating system. The application is not as powerful as C/S and B/S due to limited CPU speeds. Although the M/S platform can display 3D KML models and generate danger point and crossing point statistics, it cannot show point cloud data nor allow users to measure horizontal, vertical, or spatial distances. However, the M/S has other special features including live photo capturing and real-time upload to a Picture Server. It provides frontline staff with a tool to capture maintenance related conditions on tower and pole structures. The portable mapping function and navigation tools of the M/S would help frontline staff to find the travel routes and access to structures.

5. BENEFITS OF THE LiDAR TECHNOLOGY

The introduction of LiDAR technology to the vegetation management system brings direct benefits to power system operators and the customers through improving power system reliability, enhancing customer services, and streamlining internal processes. There were several tangible benefits realised upon completion of the project.

5.1 Accurate Geospatial Information

As part of the project deliverables, the set of reports generated by the vegetation management system can highlight clearance from objects, crossover of objects (such as line-object, line-line), tree to line clearances, and safe clearance distances based on conductor working conditions under high temperature, high load, or high wind. These functions, which once required lengthy site visits and cumbersome calculations, can now be performed very quickly on the VMS interface on a desktop computer.

Mitigating risks such as outages caused by vegetation interference is a key benefit of the project which provides up-to-date geospatial information of the surrounding environment of the overhead line system. These information and data enable the operator to conduct vegetation management with enhanced efficiency and reduced risks.

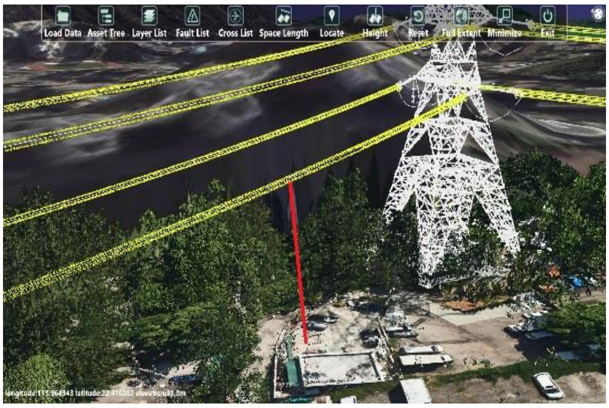

Fig. 6 – Overhead Line Safety Clearance Analysis

5.2 Identify Vegetation Risks

Overgrown vegetation is a major cause of unplanned overhead line outages that undermine power quality. The LiDAR data helps operators to make more effective plans for line inspection and improve resources utilisation for vegetation clearance by prioritising tree trimming according to the risk levels. This results in fewer line outages caused by overgrown trees and falling branches, and a direct reduction in overall network downtime.

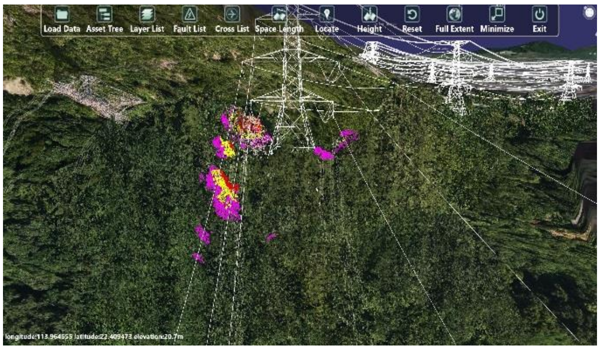

Fig. 7 – Identification of Vegetation Risks or "Danger Points"

A particular area of the project with development potential is the ability to monitor trends in vegetation growth and forecast hazards ahead of time. This can be achieved by categorising areas of particular tree species with similar growth rates to project the growing trends for formulating pro-active vegetation management plan and optimise work packages. This application of the technology will facilitate smart and efficient vegetation management.

5.3 Improved Safety and Sustainable Vegetation Management

The project has a direct impact on improving personnel safety as airborne scanning enable faster and safer inspections for crews by greatly reduce the need for unnecessary line patrols, in particular in areas with potential hazards and risks. The scanning results enable operators to better manage the allocation of human resources for efficient and sustainable vegetation management and minimise environmental harm.

6. POTENTIAL APPLICATIONS

The results and findings from the pilot project have opened the door for other potential applications.

6.1 Geological Hazard Analysis

With the LiDAR data, the vegetation management system enables operators to conduct analysis on slope stability and how it may affect transmission tower foundations. For example, the high-resolution photos taken by airborne scanning can be used for detailed analysis of geotechnical related issues such as landslides, soil erosion, or failure of the ground surface.

Fig. 8 – Geological Hazard Analysis - Landslide

6.2 Overhead Line (OHL) Corridor and Asset Condition Assessment

After completion of data analysis and processing, the system generates a suite of geospatial models and a comprehensive asset database with high-resolution photos. This enables the user to view and manage individual structures and line circuits, as well as track the locate assets according to the GPS coordinate system on a 3-D platform. The high-resolution photos enable operators to conduct quick corridor inspections, as well as identifying missing or broken insulators, or damaged equipment on the overhead line and tower structures.

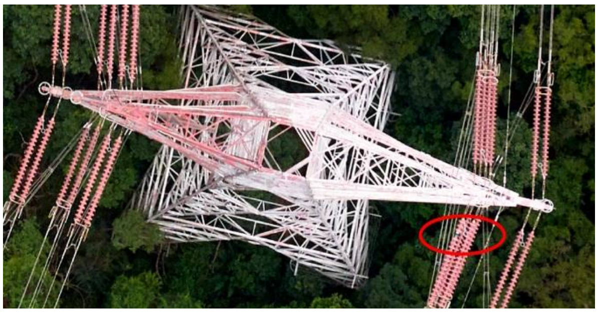

Fig. 9 – Insulator Condition Assessment – Broken Insulator Identified

6.3 Route Planning for Line Patrol

One critical element in the vegetation management life cycle is the ability for the operator to conduct route planning for line patrol staff. While previously, vegetation management teams would rely on 2D topographic maps and site experiences to plan their line visits; the LiDAR scanning results produce a thorough and 3-D view of the terrain which assists site staff to plan and allocate their resources more efficiently. The navigation feature of the Mobile Server (M/S) platform interface allows users to plot and generate travel routes. In the future, CLP Power plans to further develop the mobile app together with the existing company's Geo Information Portal (PGIP) hiking trail to provide a more efficient path for vegetation management teams to plan their travel routes.

7. THE WAY FORWARD

It is with no doubt that collecting accurate data on vegetation clearances forms a critical part of the overall vegetation management strategy. Without an intelligent solution such as LiDAR to collect accurate information, a considerable amount of resource is needed for planning and execution of vegetation management tasks. Looking ahead, there is a need to review possible options for conducting regular remote aerial scanning in the future. CLP Power is exploring several technologies including Unmanned Aerial Vehicles (UAVs) to conduct airborne scanning, data collection by photogrammetric methods, and the use of satellite imagery.

7.1 Unmanned Aerial Vehicles (UAV)

Unmanned Aerial Vehicles (UAV) is an emerging trend of airborne scanning as a cost-effective way to supplement LiDAR scanning conducted by helicopter. UAVs, which are able to hover in close proximity to the electrical assets, can obtain high resolution photos and data on overhead lines and structures with significantly lower cost when compares to helicopters. Although application of UAVs is limited to localised inspections, UAVs can be dispatched to no-fly-zones and locations that are not traversable by helicopters. The UAVs can obtain detailed asset information from these areas and provide a more intricate view of structure components which require special attention. Additionally, the advancements in drone technologies in recent years have seen the battery life extended well enough for industrial applications requiring robust performance including the monitoring of power assets [1].

7.2 Photogrammetry

Photogrammetric method provides permanent, accurate and measurable photographic records of the site conditions for clearance measurements and analyses. This method is also attractive as the existing DEM and topographic data developed from the first LiDAR scanning may be reused, resulting in both work and cost savings.

7.3 Satellite Imagery

Satellite data collection inherently has a time delay and do not provide the level of details which LiDAR scanning can capture because satellite data is only 2D and does not support measurement of clearances. Satellite imagery however, does provide a good overview of the surrounding environment around the electrical power assets. The satellite imagery method uses short-wave infra-red bands that can detect objects even obstructed by cloud cover and water vapor. The latest commercial satellites also provide automatic correction for environmental interferences such as clouds, aerosols, water vapor, ice and snow [2]. This technology can obtain good resolution images in all weather conditions with a relatively lower cost, and can provide an overview of the overhead line network quickly and efficiently.

8. CONCLUSION

Overall, the result from the first LiDAR airborne scanning project has provided an excellent database for CLP Power to further improve the existing vegetation management practices. The project is also a big step forward towards building a complete 3D asset management system that incorporates geospatial models for CLP Power's overhead line network. There is a need to review the current data attained from the project and determine which parts could be reused for future scanning. This will ensure best use of resources for effective vegetation management and facilitate a pro-active approach for vegetation management planning.

REFERENCES

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2. "DigitalGlobe – WorldView-3" website
   Web link: http://worldview3.digitalglobe.com/

Paper No. 2

DIGITAL GRID – POWER ASSET MANAGEMENT

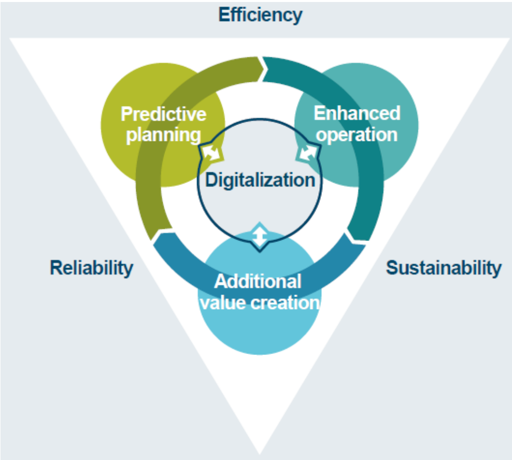
Speakers: Mr Norbert Kaiser, Senior Asset Management Consultant
Siemens AG, Germany
Mr Keith T.M. Wong, Digitalization Manager
Siemens Ltd., Hong Kong

DIGITAL GRID – POWER ASSET MANAGEMENT

Mr Norbert Kaiser, Senior Asset Management Consultant
Siemens AG, Germany
Mr Keith T.M. Wong, Digitalization Manager
Siemens Ltd., Hong Kong

ABSTRACT

Digitalization is the use of digital technologies to change business models and to lever value-producing opportunities, which usually also implies a wide use of data. The modern digital substations will provide a dramatically increasing amount of data (huge amount of data), once new intelligent electronic devices and sensors will be added to substation automation system which ideally designed with an open architecture. Benefits in reliability, efficiency and sustainability can be taken from these data.



Typically, one of the core elements for the electrical grid – the substation, consists of various complex assets – things that may be connected to the Internet of Things (IoT). Important use cases, including the connectivity, lie in the field of the management of these assets including visualization of analytics results e.g. on importance for the grid and consequence of failures. A general distinction needs to be made between primary assets (i.e. transformers, gas-insulated switchgears, circuit breakers, overhead lines, cables, surge arresters, …) and secondary assets (i.e. electronic components like protection relays, bay controllers, merging units, RTUs, switches, routers, computers, including the software components running on these devices).

In this paper, we deal with the subject of assessing the condition of a given asset by gathering and interpreting data derived from the digital systems. We also discuss how this data can be converted to information and used together with other operational parameters – like the above mentioned importance – to provide actionable asset management recommendations on asset as well as on grid level.

1. DIGITAL SUBSTATION

Electrical Substations are one of the core elements in power grids. Its operational efficiency includes the tasks of maintenance, service restoration and asset productivity. And the core mission of the Utilities is to ensure the availability and reliability of the power grid in their geographical area of responsibility. To achieve these missions, other than conventional time based maintenance, the operator shall apply digital and sensing technology to assess the asset performance and condition to enable an improvement of the efficiency, in-service life and to minimize both planned and unplanned outages.

Substations with the digitalized station level have been introduced far more than one decade, In general, a digital substation usually refers to the implementation of substation automation system, including protection relays, bay controllers, remote terminal units (RTUs) and substation controllers, which all usually named as Intelligent Electronic Devices (IED), whereas the data exchange through an Ethernet-based, digital station bus, commonly Modbus TCP/IP and IEC 61850 has become the interoperable worldwide substation automation communication standard. The IEC61850 commun-ication protocol, in addition to the vertical communication for monitoring and control, supports also communication between bay devices on the same level and enables flexible solutions. These devices allow the implementation of individual continuous function charts (CFCs) and the availability of data in the digital station bus enable distributed logics throughout devices and bays. And the latest generation of devices applied the more recent innovations in this field include modularity and scalability throughout their lifetime and the more advanced dissociation of the device hardware and its firmware (i.e. functionality). Extension modules enabling for instance new communication possibilities can be added to existing devices even years after commissioning. Using new protection functions in an existing relay is just a question of configuration. And powerful automation devices may host de-centralized, evolving applications that help to master complex challenges in a dynamically changing environment.

Nowadays, in addition to the digitalization in station level, the industry is also implementing the digitalization in process level. The concept of a fully digitalized process level includes so-called non-conventional instrument transformers (NCITs) that replace conventional current transformers (CTs) and

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voltage transformers (VTs), using new, low-power measurement principles that are illustrated in Figure 1.

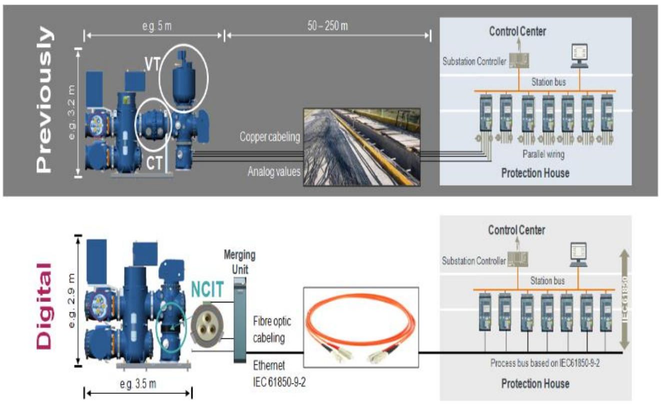

Fig. 1 – Digitalization in Process Level

The NCITs show an improved measurement performance, namely avoiding ferro-resonance effects and cover a very wide measuring range, as there is no ratio to be considered. This innovation also significantly reduces the size and weight compared with conventional CTs and VTs.

On the secondary side, the Merging Units (MU) are installed very close to the switchyard and transform the output signals of (depending on their type conventional or dedicated non-conventional) CTs and VTs into digital data points, so called sampled measured values (SMVs). The measurements are thus available – practically from the switchyard on – in a digital format. This reduces cost-ineffective hardwiring significantly, especially in the substations with long distances. Safety is improved, as NCIT sensors provide low-power signals and the risk of an internal arc is minimized. The sampled measured values that are provided by the Merging Unit according to IEC 61850-9-2 in the process bus can be used by IEDs of different vendors for various applications, such as different protection functions/relays and metering. One protection relay is not necessarily linked to only one measuring point. This provides many functional possibilities and a maximum of flexibility and scalability.

These digital technologies involve real expenses and modifications as well as established procedures in the design, engineering, operation and maintenance of the critical power transmission grid. The IEDs and NCITs are usually equipped with multi-functioning, such as condition monitoring of circuit breakers by contact wearing and/or integrated temperature sensor to further lever tangible benefits. The technologies enable Integrated Substation Condition Monitoring (ISCM). By using an integrated data model for primary and secondary engineering, device and software configuration and testing, the level of automation throughout this value chain, can be significantly increased, and will lead to important time and quality improvements. By maintaining this data model throughout the substation life time, also later adaptations or enhancements of the existing system are easily made possible.

2. INTEGRATED SUBSTATION CONDITION MONITORING

Monitoring (e.g. temperature at transformers) is known for more than decades; however, monitoring has become increasingly more advanced over the years. The development of condition monitoring took place for each type of asset on its own. This resulted in no or limited synergy at condition monitoring. With Integrated Substation Condition Monitoring a leading role has been taken to establish a platform which is suitable for connecting different types of T&D monitoring systems. With this platform standard modules can be offered very efficiently and are proven in the market. On the other hand, the platform is open to customer specific solutions for optimal integration.

The Integrated Substation Condition Monitoring is a modularized approach, surveying all relevant Substation components. It can be implemented in the existing substation communication and visualization infrastructure. Starting from simple asset embedded value monitors up to fully integrated condition monitoring – with generation of recommendations. It includes

- One central system (single platform)
- One look and feel
- Implementation in Central Monitoring System (SCADA likes)
- Asset specific “Knowledge Modules”
- Available for various standards (e.g. IEC, ANSI)
- Sensors for all types of monitored assets

Nowadays, Utilities face a number of unique challenges: expenditure is being cut, knowledge and expertise is being lost when people retire or through downsizing. Furthermore, operating aging equipment at higher levels impacts on lifespan and reliability. Yet, utilities are expected to maintain continually levels of performance. Application of Condition Monitoring can provide answers. It is an important element of both asset management and operation support providing recommendations based diagnostics of measured values. The implementation of Digital Substation technology can provide the visibility of primary equipment like circuit breaker in terms of condition and power quality. The additional condition monitoring modules such as partial discharge and gas purity have to be implemented in a way that complete asset-related condition information is available to the operator and the asset manager in a common format.

The ISCM is based on expert knowledge modules for every asset family. By carrying unique competence and manufacturer experience, the sophisticated modeling techniques, Knowledge Modules, cover all primary asset types, and each module focuses on improving the reliability of the equipment as well as on the reduction of unscheduled downtime by monitoring and predicting equipment health. A typical knowledge module for a circuit breaker monitoring is shown in Figure 2. The data acquisition units or IEDs for the standard available modules are predefined. Knowledge modules diagnose and evaluate condition information for visualization and furthermore for recommendations. The availability of asset condition status is the prerequisite for generation of actionable recommendations. The knowledge modules are hosted in a ‘software frame’ which is designed to communicate system internally via data-interfaces protocol with the ISCM HMI (Human Machine Interface) or Central Monitoring system.

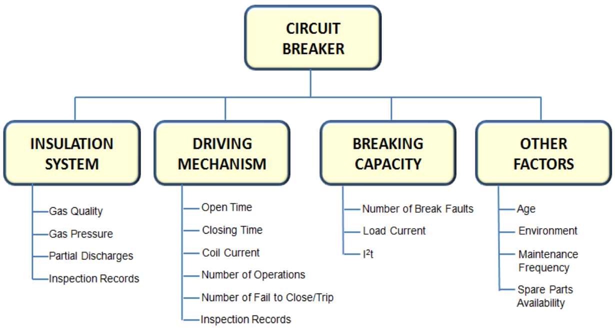

Fig. 2 – Typical Knowledge Module for a Circuit Breaker Monitoring

The knowledge modules are independent from an existing hardware platform and can be implemented in the different Condition Monitoring level from substation control system up to the Central Data Acquisition Units or to the Control Center. For some monitoring modules a selection can be made between different kinds of knowledge modules. The knowledge modules, and thereby their evaluation, vary due to different norms (e.g. IEC / ANSI), standards or used best practices (e.g. Manufacturer’s experience). The different modules offer different information of all the various important network assets. The customer decides which knowledge module to implement. Diagnosis and prognosis is an essential need for Operators and Asset Managers of complex systems to optimize equipment performance and to reduce unscheduled downtime. With predefined data acquisition units, Utilities save engineering costs, deliver well proved units and minimize customer specific solution with their relatively high maintenance costs.

Another innovation of Integrated Substation Condition Monitoring is the evaluation of the logged data with centrally administrated knowledge modules on substation or preferably control centre level. Centrally, with one look and feel for the user. This means that the visualization and operation of transformer monitoring is aligned (e.g. alarm levels) with high voltage monitoring modules. The HMI can be installed at substation level, control center level or at company level.

The ISCM is NOT a new Condition Monitoring System; it is an approach which enables Utilities to supervise various condition monitoring systems for an integrated substation approach for substation’s primary asset types including connections with overhead lines, cables and Balance of Plant assets. It offers internal synergies, significant price/cost reduction potential if more asset / asset clusters (e.g. Transformers and Gas Insulated Switchgear) are implemented. Connecting the ISCM at company level, with integration in the business architecture with Reliability Centered Asset Management (RCAM) suite, which will be discussed in next Section, is the ‘on top’ solution from sensor up to ERP, i.e. enterprise resource planning systems, provides reliable information about the health and ageing state of the devices in operation. The RCAM suite supplies a consistent asset data model, where all commercial, technical and geographical figures are persistently stored. The information analyses functions support the decision making process for the asset manager (replace, repair and invest). It is a modular and SOA-based solution, boosting the efficiency, transparency, and flexibility of grid asset management, and helps to control risks and balances technical necessities and economic feasibility. The combination of these systems, within a Smart Grid structure, helps to minimize downtimes, maximize asset performance through integrated maintenance planning and pave the way for reduced lifecycle costs and an extended service life of the assets.

3. RELIABILITY CENTERED ASSET MANAGEMENT

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

This Section describes a modular approach for a Reliability Centered Asset Management process. Figure 3 gives an overview of the modular structure of the RCAM process. The goal of this process is to analyze and evaluate relevant technical and economical aspects of network operation, and to derive improved asset management strategies for the considered component classes – i.e. strategies for both content and time intervals of preventive maintenance actions, as well as for the technical lifetime specification. The technical and economical effects of such measures are very complex and even temporally decoupled, but can be bridged by the use of innovative Asset Management methodologies.

In the definition of the component classes (e.g. only one class switchgear, or separated into circuit breakers / isolators / other), the benefit of more detailed results has to be weighed against the availability of suitable input data and against the increasing effort of data acquisition.

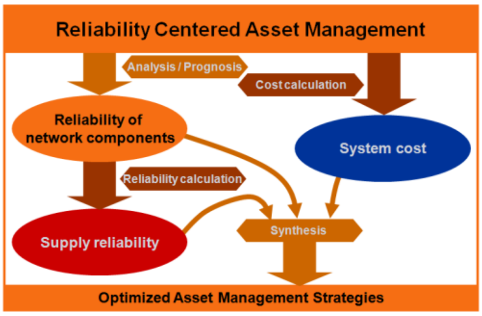

Fig. 3 – Reliability Centered Asset Management Process

The RCAM process is structured into three basic steps:

1) Analysis the current asset reliability of network components

The asset condition parameter values can be collected from online and offline information such as maintenance and operational records, sensor signals. As mentioned in the previous Section, the ISCM allows a comprehensive way to collect and diagnosis the data to useful information via the knowledge modules. The reliability of components, both in the present and projected into the future can be estimated from the diagnosis results. A simple and effective way to manage this complexity is the use of a composite indicator generally known as Condition Index or, more commonly, Health Index (HI).

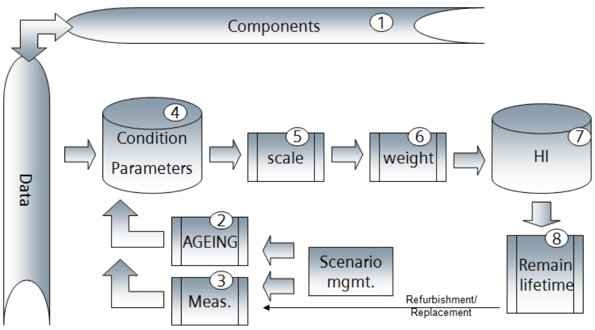

Fig. 4 – Generic Workflow to determine Health Index

The HI is a numerical representation of the estimated condition of a given asset. In principle, HI should: i) be indicative of the suitability of the asset for continued service, ii) contain objective and verifiable measures of asset condition, iii) be understandable, iv) be readily interpreted, and v) be correlated with the asset risk of failure and remaining useful life. The development of the Health Index metric is quite a complex matter, as it is usually customized (tailor made) for every asset type and for every system/utility.

Figure 4 shows the generic work flow of how HI determined.

2) Systematic analysis of the network (Criticality and Risk Assessment)

The second element required for the determination of effective asset management strategies is the importance of the assets. Importance can be measured in terms of Importance Indices, Criticality Indices, and/or probabilistic assumptions like 'Energy not supplied in time'. Importance is brought together with asset condition to generate actionable recommendations on the individual asset level. Importance indices can be qualitative or quantitative. Quantitative methods are: i) the use of Failure Modes and Effects Analysis (FMEA) and/or Failure Mode, Effects, and Criticality Analyses (FMECA) to obtain e.g. a Risk Priority Number (RPN) and a Criticality Index, and/or, ii) power system simulations. RPN and Criticality Indices can be used as a numerical estimate of asset importance, and contingency analysis, as part of system simulations, could reveal how important an asset is from the standpoint of network operation and/or reliability.

The risk associated with an asset is the sum of all the consequences of potential/future outages, usually expressed in monetary terms. The risk is linked to a failure rate or failure frequency, which is assumed to be affected by the asset condition. Figure 5 shows the typical factors that are considered in the estimation of the asset risks. These factors are combined together to derive a Criticality (or Importance) Index. Monetary cost of failure of an asset encompasses OpEx and CapEx for foreseen interventions besides expenditure estimates for each of the factors listed in Figure 5.

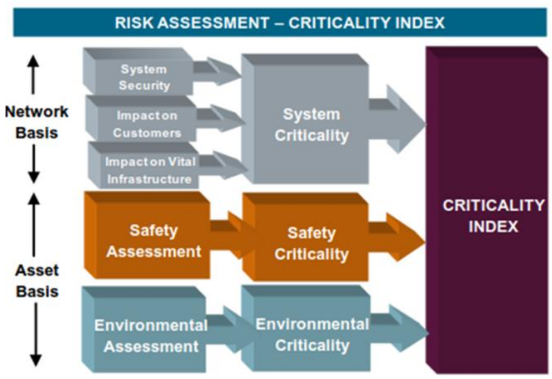

Fig. 5 – Typical Factors are considered in the Estimation of the Asset Risks

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3) Synthesis of optimized asset management strategies

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

Reliability Centered Asset Management (RCAM®) is a proven Siemens methodology for linking asset condition (in terms of Health Indices which are based on aging, deterioration, wear and tear) and asset importance (priority in the grid, usually obtained from FMEA analysis or system simulations) to develop, continuously improve, and optimize operational maintenance strategies. The RCAM methodology includes a Condition-Importance diagram where the Condition is based on the HI and Importance is classified according to the necessity of the asset towards an effective, reliable and safe grid operation.

Based on such a diagram shown in Figure 6, optimized maintenance strategies can be charted out combining corrective and condition based maintenance ranging from extended time interval to OEM interval to annual or periodic monthly inspections.

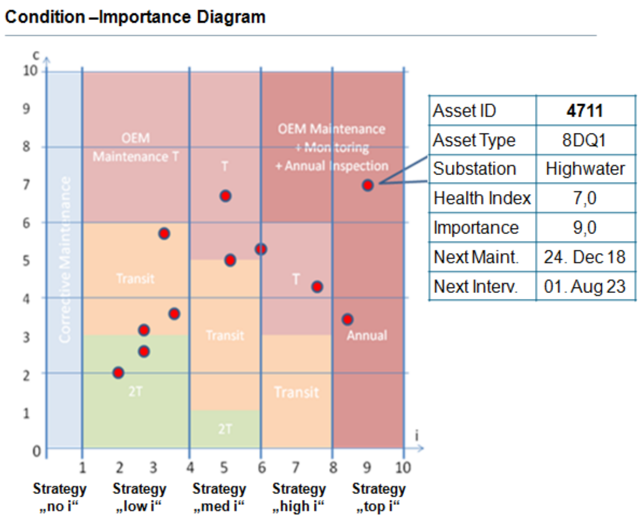

Fig. 6 – Condition – Importance Diagram

One of the main goals of the RCAM methodology is also to find the strategic intervention type and moment in time that minimizes the Present Value of the sum of Risk and Intervention costs.

Figure 7 generically shows the recommended times for refurbishment and for replacement over the asset lifecycle while maintaining a permissible health index.

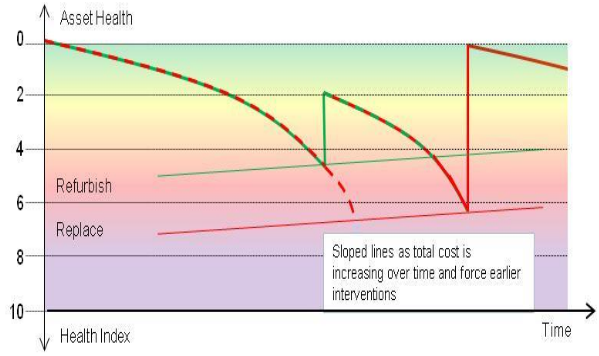

Fig. 7 – Intervention Type and Time along Asset Life-cycle

The analytical approach of such an 'Optimal Intervention' search which results in a recommended action is shown in Figure 8.

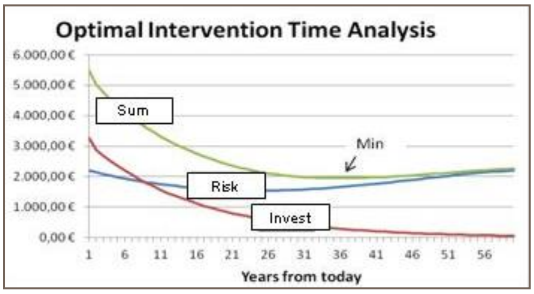

Fig. 8 – Optimal Intervention Analysis

It is clear that asset management strategies can be improved by leveraging the "power of data," that is, by capturing, processing, analyzing, and ultimately acting upon information about the assets themselves as well as about their function within the system these assets are embedded in, in order to estimate future risks and prepare a plan for optimal asset management, where the trade-offs between risks and the cost of asset intervention are most appropriate. This model must be correlated with the health index forecast through the relationship between the health index and the failure rate/frequency. This is the concept behind the advanced asset management approaches sometimes known as Asset Performance Management (APM) strategies, operation and maintenance actions are determined by considering, among other parameters, the condition of the assets and the risks associated with asset failure.

4. MOVING FORWARD

Digital asset management is not an isolated technical task, but the findings from technical asset management (e.g. about the residual life time of a transformer resulting from the asset performance management application) are of high interest to commercial enterprise resource planning (ERP) system, into which asset management systems can be integrated.

The potential benefits of applying digitalization for substation asset management are numerous: The efficiency of operational maintenance of the power assets can be significantly improved. Investments into new primary assets can be made at the right and probably later point of time, considering their actual heath status and their strategic relevance. Unplanned downtimes can be avoided, with a positive effect on grid availability and asset productivity.

The big data analytics capabilities of industrial IoT platforms increase the value that may be generated from this centrally captured asset data along with self-learning algorithms in future, beyond operational tasks. In addition to the asset management applications, the information shall be linked and shared across various enterprise systems via Common Information Model (CIM). The centralized platform, e.g. energy information cloud can correlate the acquired data with other sources (e.g. historical data, weather data, age of the assets, etc.). Decisions can be made more consciously, better and faster, and the Utilities can benefit from the newly developed cloud applications, such as Visual Analytic (see Figure 9) to decide the most economical point to perform a smart and just-in-time action considering best the future impact in some years from now.

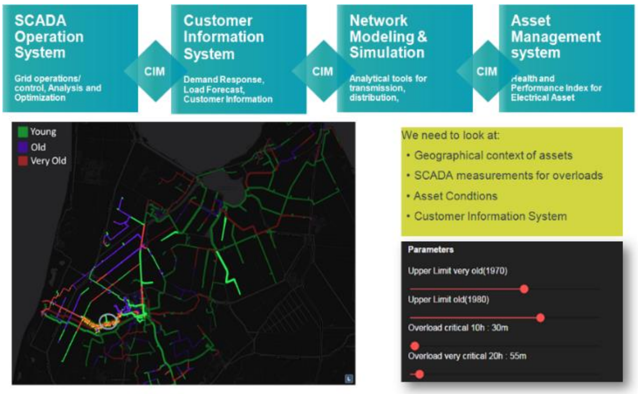

Fig. 9 – Illustration Examples of Cloud Applications Visual Analytic

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Paper No. 3

USE OF BLUETOOTH & WIFI FOR MONITORING TRAFFIC AND PEDESTRIAN

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USE OF BLUETOOTH & WIFI FOR MONITORING TRAFFIC AND PEDESTRIAN†

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ABSTRACT

This paper presents a review of the research on the use of Bluetooth and Wifi for monitoring traffic and pedestrian movement. This in an excerpt of the past publications of the author and his co-authors. For details of past research, readers are recommended to read references [2-4, 9-13, 21, 29, 37-38].

1. INTRODUCTION

Transport agencies collect data to monitor, manage and control traffic, and to plan for future infrastructure. There are two broad categories of sensors used in these data collection. Fixed sensors such as loop detectors that provide traffic information at the location where the sensors are installed and mobile sensors such as GPS equipped vehicles that provide data for the entire journey of the vehicle equipped with such sensors.

In early 2000, researchers explored the use of Bluetooth (BT) technology for the automotive industry. Nusser and Plez (2000) presented the architecture of the Bluetooth network as an integral part of in-car communication and information systems. Researchers (Sawant et al., 2004, Murphy et al., 2002 , Pasolini and Verdone, 2002) have tested the proof-of-concept for the use of BT for Intelligent Transport System services, and have verified that the BT equipped devices in moving vehicles could be discovered.

Recently, there has been significant interest from transport agencies in exploiting the Bluetooth Media Access Control Scanner (BMS) as a complementary transport data source. The concept behind BMS is rather simple. A BMS scanner has a communication range (say around 100 meters in radius) that we term as zone. The zone is scanned to read the Media Access Control addresses (MAC-ID) of the discoverable BT devices transiting within the zone.

The MAC-ID is a unique, alpha-numeric string, that is communicated by the discoverable BT device. According to ABI Research, in 2018, 86% of all new vehicles will include Bluetooth connectivity (Bluetooth SIG, 2018). Bluetooth is behind in-car infotainment systems that enable hands-free calling and audio streaming.

2. THE BIRTH OF THE BLUETOOTH TRAFFIC DATA SENSING

The usage of Bluetooth in transport has passed its first decade, and though it has come a long way, its full potential is still to be explored. In the early days, Murphy et al. (2002) investigated the utilization of Bluetooth for short-term ad hoc connections between moving vehicles, while it was still a new wireless technology. The findings were promising. They showed that even fast vehicles - driving 100 km/h – could be detected by a Class 1 (20dB) Bluetooth. Although the experiments were performed for vehicle-to-vehicle communication, the same issues apply to monitoring traffic through Bluetooth scanners. In the same year, Sergio Luciani, submitted an application to the United States Patent office that described, though as a fall back option, exactly that: The usage of Bluetooth scanners for traffic monitoring. In his application, Luciani (2003) described that tracking the MAC address of a device along the road through matching sighting with paths through the road network, one would be able to determine travel times that, when compared to a baseline, could be used to determine the traffic state of the road. The patent was issued one year later in 2003. While the described setup is similar to what is used today, it took years to see it established on the road. Though the idea of using Bluetooth, among other mobile sensors, for traffic monitoring manifested itself in various sensor network based traffic information service systems (SNTISS), such as the three-tiered architecture proposed by Zhang et al. (2005). By that time it was clear that intelligent transport systems (ITS) would require networks of smart sensors embedded in the traffic area, performing automated continual and pervasive monitoring to enhance the quality of traffic information collection and services.

It took another three years before Ahmed et al. (2008) introduced a prototypical implementation and test deployment of a Bluetooth and wireless mesh networks platform for traffic network monitoring. The platform used cars as mobile sensors and used wireless municipal mesh networks to transport the sensed data. The assumption was that drivers carry mobile devices equipped with the widely adopted low-cost Bluetooth wireless technology. The platform was able to track cars travelling at speeds of 0 to 70 km/hour. In addition to tracking vehicles, the study was able to approximate car

† This paper is an excerpt of published papers by the author.

speeds with an accuracy of ± 15%. A similar study was performed by Mohan, et al. (2008) who suggested the system as a cost effective solution for developing countries. One year later, and with large sample sizes of 5% to 7% of the overall traffic stream, Tarnoff et al. (2009) introduced a system claiming accurate measurement of travel times as well as origin-destination data for freeway and arterial roadway networks. The paper points out that the major benefits are that the cost of Bluetooth scanning are a factor of 100 less than equivalent floating car runs, and that privacy is less of an issue with the Bluetooth equipment due to the absence of databases that can relate addresses to specific individuals (owners). Another system was developed to ease the path for road authorities to enter the travel time measurement market by Puckett and Vickich (2010), who took a practitioners' approach. The accuracy of travel time measurement, and the ease on the privacy issue, that made the usage of mobile phone data nearly impossible, might have been the turning point, as from then on Bluetooth gained a lot more interest from the research community.

3. EXPERIENCES AND CASE STUDIES

Over the past few years, the Bluetooth data source has been used for large-scale behaviour studies, across different domains. It has been used to characterize pedestrian environments and walking behaviour, by using the distributions of device type, dwell time and travel time (Delafontaine et al., 2012; Malinovskiy and Wang, 2012). These endeavours have been directed towards the analysis of the effect of the environment on the signal strength of the scanners, and the relationship between the signal strength and type and frequency of detection road users such as walkers, runners and cyclists (Abedi et al., 2013). Recently, researchers have used the Bluetooth-based tracking strategy to measure the time it takes for passengers to move through the various airport areas (Bullock et al., 2010). Currently, Bluetooth finds its widest application within the Intelligent Transport System and Road Management domains. Here, the Bluetooth data are often fused with other data sources – such as WiFi, GPS and loop detectors (Abbott-Jard et al., 2013) – in order to enhance the estimation of the traffic state or to identify the causes of congestion outbreaks (Nantes et al., 2013). Finally, the Bluetooth technology has also been recently employed for improving the estimation of Origin-Destination patterns (Barceló et al., 2013) and route choice analysis (Hainen et al., 2011; Carpenter et al., 2012).

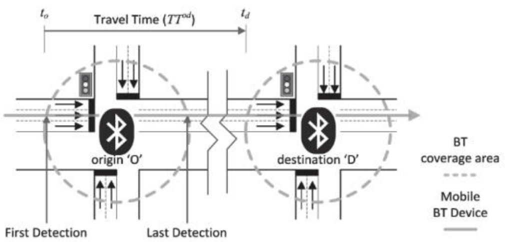

Fig. 1 – Travel Time Estimation Mechanism

4. THE BLUETOOTH-BASED ESTIMATION OF TRAVEL TIME

The Travel Time is an important traffic indicator of the status of the network and may be used to minimize the level of congestion. It has long been a topic of research and numerous models have been proposed for both motorways (Bhaskar et al. 2014; Khoei et al., 2013; van Lint, 2008; Li and Rose, 2011; Fei et al., 2011; Khosravi et al., 2011) and arterial (Bhaskar et al. 2009, 2010, 2011, 2012) networks. The relationship between the level of congestion and travel time has been studied theoretically by a number of researchers (Tsubota et al., 2011, 2013) and has led to the conclusion that, if the vast majority of drivers were informed on the actual travel time for their trips, congestion would be reduced significantly, provided that these drivers made the right decision at the right time, in a cooperative fashion (Monteil et al., 2012).

It is one thing, however, to assume that the output from a traffic simulator is realistic, and quite another thing trying to determine how realistic this output is, when the parameters of the simulator are numerous and the data available for validation are very limited and noisy. A very important validation data seemed to become available at a low cost when it was shown by Murphy et al. (2002) that pairing Bluetooth sensors together could produce travel time data. Simply put, given a pair of locations, O and D, both covered by Bluetooth scanners, the time it takes for a Bluetooth discoverable traveller to go from O to D is given by the time difference between the matching identifiers (Figure 1). Therefore, if a vehicle is first detected at O at time t_{O}, and later at D at time t_{D}, the travel time (O, D) for this device will simply be

$$(O, D) = t_{\mathrm{D}} - t_{\mathrm{O}} \tag{1}$$

By plotting these values over some period of time (Figure 2, left), the travel time stands out, from what is seems like feeble background noise. Since the early promising reports on the use of the Bluetooth technology for traffic monitoring, researchers and practitioners have been debating about the actual value of this relatively new data source.

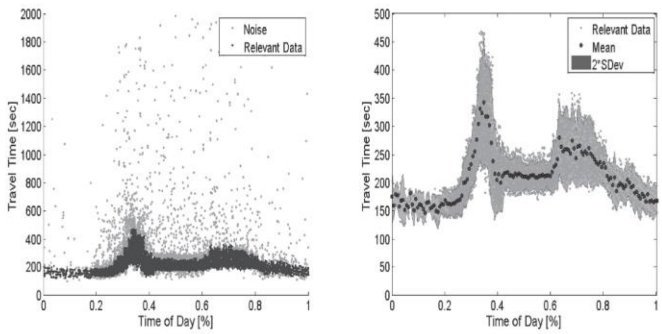

Fig. 2 – Travel Time De-noising and Parameterization

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Strictly speaking, although the mechanisms for measuring the travel time seems simple and does produce large datasets, it is still not clear how much noise is actually 'lurking' in the data and how this noise ought to be isolated and reduced.

Common travel time measures for a corridor are produced from the aggregation of per-vehicle travel times over a given time window, e.g. 1 day (left). Data cleansing is often achieved by separating high-density regions from the regions of low density. From the cleansed data (black region on the left picture), sufficient statistics (e.g. mean and standard deviation) are computed and used as indicators of road performance (right). The filtered data in this example was clustered into 144 time bins of equal length. Mean and standard deviation were then computed for each time bin. In the graph on the left, the grey region indicates the $\pm 2 \cdot$ sdev (standard deviation) interval around the mean.

5. MONITORING PEDESTRIAN AND CYCLISTS

Monitoring, simulating and predicting human's dynamic patterns of movement through space is becoming an increasingly important target of urban and transport planners interested in designing effective urban spaces for pedestrians (Batty, 2003). It is also an interesting area for studying and understanding human behaviour in terms of moving through pedestrian pathway environments such as corridors, urban and bridge pathways. However, such research and pattern extraction are complex due to a large number of variables related to pedestrian, situations and environments.

Analysis of massive distributed movement data has been recently presented by new technologies as the popularity of using mobile devices has been increased (Jankowski et al., 2010, Andrienko and Andrienko, 2007). Tracking mobile-devices and intercoms has motivated researches and scientist to collect movement information from individuals. Recent research has been focused on the analysis of individuals' travelling behaviour in various applications such as the tourism industry (Jankowski et al., 2010), public transport utilisation in Graz, movement behaviour assessment in shared areas (Abedi, 2014) and shopping malls and pedestrian's density distribution during seasons. Discovering Bluetooth enabled-devices has recently become an effective tool for human's movement monitoring purposes (Stange et al., 2011). Some research has been done on recording flows movements using Bluetooth and WiFi in outdoors and indoors. Pels et al. (2005) implemented various BMSs at Dutch train stations in order to track transit travellers. Weinzerl and Hagemann (2007) collected information from transit travellers and also tracked public transport busses by locating sensors inside buses. Abedi et al. (2014) analysed human behaviour in terms of shared space utilisation based on MAC address data. They presented MAC address data as effective information to extract features from human's spatio-temporal movement such as time spending, frequency of utilisation and group gathering.

6. CONCLUSION

BMS is an inexpensive sources of data and has the potential for providing rich information for area-wide traffic monitoring such as "live reporting" of the travel activity of the road users who carry BT-equipped devices.

After matching and filtering the BT data points, a good graphical representation of travel time patterns can be easily visualised. However, utilising the travel time estimates for real time applications such as signal control and traveller information system, should consider the accuracy and reliability of the estimates.

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Paper No. 4

SMART RAILWAY

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SMART RAILWAY

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ABSTRACT
The extension of existing lines and opening of new rail lines will be knitted together to form a more superior railway network that will provide enhanced connectivity and accessibility to more areas. Major upgrades of infrastructure and facilities are underway alongside the new lines in order to construct a better railway network. A more caring and personalized experience can be provided by continuously enhancing various functions which provides a new customer experience.

With the Internet of Things (IoT) and industrial digitalization, the existing asset management capability can be changed and improved, as well as to shape future direction. This paper will introduce new technologies adopted/to-be adopted in MTR including asset condition monitoring systems, new generation train to track communication, whole-life/system cost efficiency and optimisation and other various innovative systems to enhance safety and customer experience.

1. INTRODUCTION

With the extension of the Island Line to the Western District, the extension of the Kwun Tong Line to Ho Man Tin and Whampoa, the opening of the South Island Line and Express Rail Link, and the upcoming Shatin to Central Link, the existing and new rail lines will be knitted together to form a more superior railway network that will provide enhanced connectivity and accessibility to more areas and additional cross-harbour options.

Major upgrades of infrastructure and facilities are underway alongside the new lines in order to construct a better railway network for our future. Overall customer experience will be improved through the provision of new trains and new light rail vehicles, conversion of the West Rail and Ma On Shan Lines from seven-car into eight-car trains and from four-car into eight-car trains, and an upgrading of the signalling system and station facilities, such as installation of automatic platform gates, station modification works at major interchange stations, and the replacement of air-cooled chillers.

Meanwhile, it is hope that a more caring and personalized experience can be provide to customers by continuously enhancing MTR Mobile functions under the initiatives of Rail Gen 2.0.

2. RAIL GEN 2.0

2.1 Challenges

After operating for 30 some years, a good portion of MTR railway assets is now up for replacement. The upgrading of the existing E&M systems for many of the operating rail lines is now in full swing. Upgrading of the assets under day-to-day operation is no easier than carrying out immensely complex and technical neurosurgery. In order not to affect normal passenger service and nearby residents, whilst routine maintenance works are still required, the project teams could only share the use of the few hours after train services to conduct the upgrade works, whilst it is critical to minimise the impact on the passengers.

2.2 Objectives & Key Focuses

Whilst it is very challenging to replace the railway assets with minimum impact to daily operations, these major replacements do actually provide opportunities to change and improve the railway capability.

Under the Rail Gen 2.0 initiatives, there is strategy focusing on effectiveness and efficiency enhancements, for instance asset management optimization, maintenance efficiency, operational efficiency, and safety and better customer experiences. A few innovative technologies adopted or to-be adopted will be briefly described in this Paper as demonstration of transformation for Smart Railway.

3. INNOVATION TECHNOLOGIES

3.1 Safety Enhancement

The rail network in Hong Kong is regarded as one of the world's leading railways for safety, reliability, customer service and cost efficiency. Safety is the first priority of operating railway, it is important to explore various technologies to continuously enhance railway safety.

3.1.1 Fallen tree detection system (FTDS)

In sections with open area, there were reported cases of trees falling onto EAL (**Ea**st Rail **L**ine) tracks, a FTDS will thus be helpful to mitigate the risk.

After studies and trials on a number of technologies, it is found that the fallen tree detection by laser scanning technology provides the most optimal result so far. LASER scanners can detect objects and measure their sizes and distances by continuously emitting LASER beams and monitoring the reflections. Measurement profiles can be plotted according to the reflected LASER beams (Figure 1) and software detection algorithms can then be developed to identify the target objects. The technology allows flexibility to re-define the detection areas through software configurations. A trial project was conducted to investigate the feasibility of using the technology for fallen tree detections.

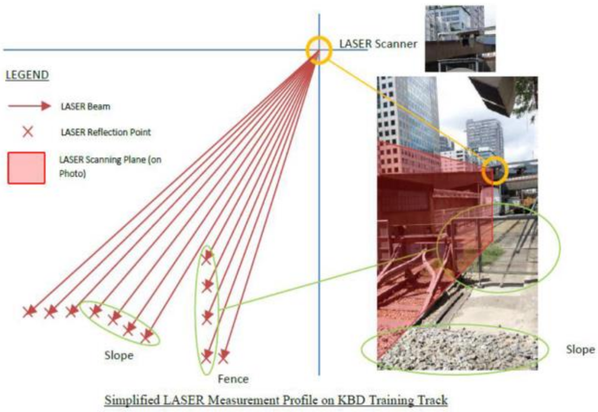

Fig. 1 – Typical LASER Measurement Plot by a Vertical LASER Scanning Plan

LASER scanners with sufficiently strong LASER beams were selected to enhance detection accuracy and achieve reasonable detection range. At least 5 consecutive reflections from the target object were taken to confirm its existence so as to get rid of false detection due to rain drops while maintaining the detection accuracy. Generally, rain drops will not give consecutive reflections at the same point, see Figure 2.

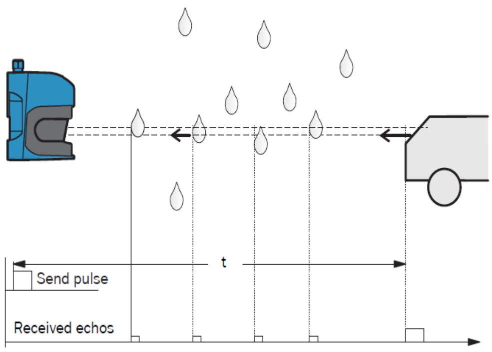

Fig. 2 – True Object is confirmed by having received the 5th Echo

Through repeated site tests and refinement on system design, the latest trial setup using LASER technology can achieve a successful detection rate of >99.9% in dry conditions and >98% in wet conditions respectively, with a reliable detection range of 30m per LASER scanner-pair.

Fig. 3 – Fallen Tree Sample was detected by the LASER Detection Setup under Simulated Rains

Apart from detection accuracy, the suppression of nuisance alarms is also critical because it will adversely affect train operation. The trial system achieved a false detection rate (alarms triggered by nuisance objects such as flying newspapers and plastic bags) of <0.1% both in dry and wet conditions, in both temporary testing setup in Kowloon Bay Depot and 1-year trial testing near University Station.

However, LASER scanning cannot provide real-time images of the track sections and need relatively great software programming effort to set up initially to simulate sufficient detection scenarios.

3.2 Customer Experience Improvement

Lifts form part of the integrated pedestrian network of all-weather walkways. Lifts and escalators are considered as community facilities built especially in the West Island Line project, which has the first station in the rail network to feature "Lift-only-Entrances". For future deep stations requiring lifts as the only means of vertical transportation serving between platform and concourse, rapid transfer of a group of passengers from the platform level to the concourse is crucial to station operation and customer satisfaction.

3.2.1 Crowd control by using CCTV

By using Video Content Analysis (VCA) built into the CCTV system, the number of passengers and the crowd flow direction can be detected and analyzed and hence the flow and volume of the crowds are heading to the lift lobby can be made known, in a recent study. With proper modifications on the system, appropriate number of lifts can then be automatically assigned to arrive at the platform level, depending on the crowd size, to serve passengers hence reduce the lift waiting time. Footages of existing long adits were used for the preliminary study of the application. Two methods of passenger counting were adopted:

a) Accumulation of crowd in the defined boundary and assign appropriate number of lifts based on the length of the queue
b) Counting of passenger flow within a defined boundary and assign appropriate number of lifts before passengers arrive at the lift lobby

VCA is considered as an appropriate technology to detect incoming passengers and number of serving lifts can then be assigned automatically to relieve the traffic demand.

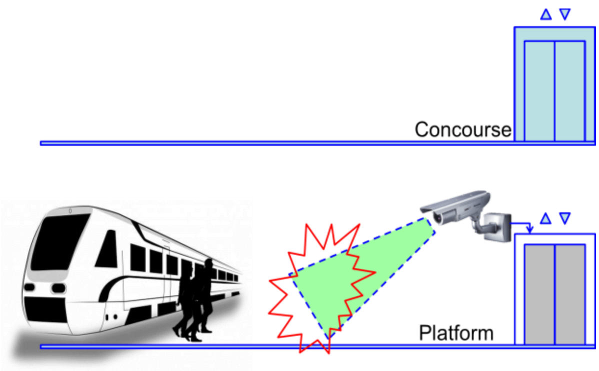

Fig. 4 – Working Mechanism of CCTV VCA

Station crowd management is vital for big interchange station. Based on the queuing platform captured from the CCTV cameras and the newly installed cameras at platform levels, divert passenger queuing can fully utilize the platform space. Inflow control action applied to selected stations for slowing down passengers going down to platform.

3.3 Asset Condition Monitoring

The existing railway network in Hong Kong has a total route length of over 256 kilometres, MTR trains run about 19 hours a day, 7 days a week, from early morning to 1:00 am the next morning. There is only limited time after services operation for maintenance works. After rail and overhead line inspection, there are labour intensive follow up works for handling tremendous data and post inspection recording. Therefore, there is a real urge to automate the rail and overhead line inspection works as much as possible during normal travel hours in order to allow flexibility in optimizing the use of non-traffic hours for tasks with urgent needs.

3.3.1 Onboard Railway Inspection System (ORIS)

ORIS is a system previously designed to be installed on maintenance vehicles with technical personnel, its analysing algorithm caters for off-line analysis and little project application for real time application until it was firstly installed by MTR on passenger trains as an automation rail inspection / monitoring system. Images of rail could be captured by high-speed line scan camera, with measurement with laser and algorithm to recognise defects in mainline.

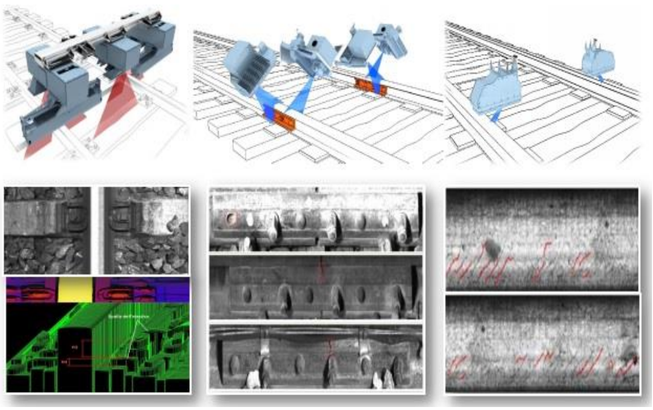

Fig. 5 – High-speed Line Scan Cameras installed at Underframe/Bogie and Samples of Rail Images

Different types of rail failures can be recognised, including:

a) Shelling
b) Squats and wheel burn
c) Rolling contact fatigue/ spalling
d) Rail corrugation
e) Missing fasteners/ bolts
f) Broken rail

These are common rail failures on the rail network and detecting them could fit general rail maintenance purposes.

ORIS is a mature technology, whilst there is customisation for MTR – categorising rail failures based on necessary action to be taken, for example send alarm for urgent inspection, send email with photo to alert potential issue of concern, or keep in log as minor anomalies.

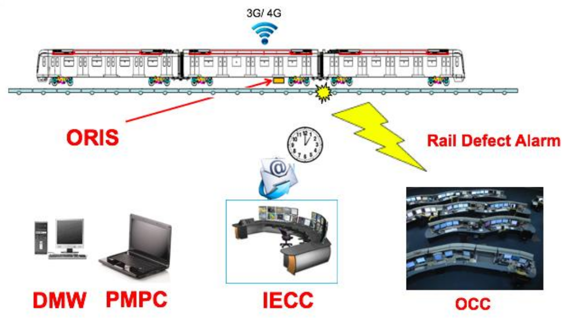

Fig. 6 – Configuration of ORIS

Apart from transmission of the real time alarm and defect information, the system also provides full details of track condition data for maintenance staff and regular backend review. This could not only facilitate the existing manual work of rail inspection, but also as a tool to enhance the analysis of rail fault development and prediction in future. However, effort is still required to reduce the level of nuisance alarm for a more efficient and effective system, which involves the use of data analytic and machine learning techniques.

3.3.2 Overhead Line Inspection System

Likewise, study has been done to automate the inspection of overhead line system on passenger train. Combination of technologies such as laser technology, infrared thermography and image processing technology with data analytics, the system could monitor deviation and staggering of contact wires, detect high temperature point, arcing and defect on catenary, and compare the contact wire geometry and shifting of hanger wire. Different technologies in the market was evaluated with support from professional industry experts, integrated solution which could suit MTR's operation is developed so as to achieve real-time overhead line condition monitoring.

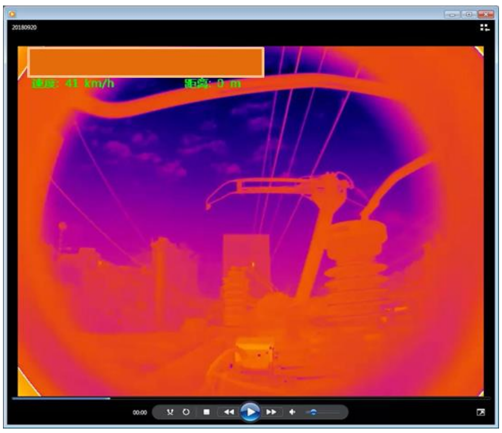

Fig. 7 – OHL Condition Monitoring using Passenger Train Rooftop Equipment

3.3.3 Mobile Apps

Customers are looking for not only accurate and comprehensive information, but also integrated and personalized service experience. "Next Train" was one of the first Apps in MTR that provides real-time update of train information, with ability to display the estimated arrival time of next 4 trains. With the enhanced "Traffic News" function, new "In-station Finder" as well as "Fast Exit" functions, MTR Mobile provides comprehensive information for better planning of your journey.

Fig. 8 – Intelligent Mobile Apps

4. CONCLUSION

Safety and reliability are vital to the railway in Hong Kong as the system is carrying an average weekday patronage of about 5.8 million passengers. MTR is striving to enhance the existing railway network to Rail Gen 2.0, a new generation rail that brings superior connectivity, better facilities and enhanced services to the general public.

Exploration on Big Data Analysis is also triggered. Combining various innovative applications going through Cloud computing or any analytics platform can provide meaningful traffic information and analyse impacts of system changes with simulations. More effective and efficient ways are required to maintain the assets by adopting different innovation technologies. Instead of focusing on one single technology, integration of various systems with support of digitalization could not only enhance the predictive and preventive maintenance, but also improve the response and recovery during service disruption. It enables us to make E&M systems and infrastructure more intelligent, increase value sustainably over the entire lifecycle as well as enhance passenger experience.

Paper No. 5

DEVELOPMENT OF ELEVATOR DRIVES

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DEVELOPMENT OF ELEVATOR DRIVES

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ABSTRACT

According to the Skyscraper Center, Hong Kong is ranked the champion around the world in terms of the highest number of skyscrapers with a height of at least 150 m. All skyscrapers must be served by elevators. Conventionally, induction motors driven by ACVV and ACVVVF technologies account for the standard drives of elevators. As buildings are getting taller, say 400 m or higher, the power-to-weight ratio of such induction motors is no longer adequate when the rated speed goes beyond 10 m/s. Permanent magnet synchronous motors thus become the appropriate candidate. In this paper, a review of the development of elevator drives is made. Two issues are addressed, namely a big wastage of space to have only one car in the hoistway, and the requirement of both vertical and horizontal movement of the car for tall and wide buildings. Both issues for the application of ropeless elevators driven by linear permanent magnet synchronous motors. In this paper, a review on the development of such technology in elevator systems is also made. Potential problems with these two types of motors are also highlighted.

1. INTRODUCTION

The Hong Kong Special Administrative Region has over 7,840 high-rise buildings, 1,303 of which are skyscrapers standing taller than 100 m (328 ft) with 316 buildings over 150 m (492 ft). The tallest building in Hong Kong is the 108-storey International Commerce Centre, which stands 484 m (1,588 ft) and is currently the ninth tallest building in the world. The total built-up height (combined heights) of these skyscrapers is approximately 333.8 km (207 miles), making Hong Kong the world's tallest urban agglomeration. By the way, Hong Kong has more inhabitants living at the 15th floor or higher, and more buildings of at least 100 m (328 ft) and 150 m (492 ft) in height, than any other city in the world.

First of all, let us look at a list of super high-rise buildings around the world [1]. By the turn of the century, the Petronas Towers at Kuala Lumpur, Malaysia was considered "The World's Tallest" with a height of 452 m. Then, in 2004, the Taipei 101 at Taipei, Taiwan became the tallest with a height of 508 m. In 2009, the champion went to Burj Khalifa at Dubai, United Arab Emirates with a height of 830 m. The next world record may go to the Jeddah Tower (previously named Kingdom Tower) at Jeddah, Saudi Arabia, which is still under construction. As planned, if it can be completed by the year 2020, it may reach a height of 1,600 m (almost 1 mile), thus named the Mile-High Tower in the past. Besides these world records, others at the top of the 2020 list may include Wuhan Greenland Center at Wuhan, China to be completed next year with a height of 636 m, Shanghai Tower at Shanghai, China with a height of 632 m, the Makkah Royal Clock Tower at Mecca, Saudi Arabia with a height of 601 m, and the Ping An Finance Center at Shenzhen, China with a height of 599 m. It can be seen that each of the top five by the year of 2020 is at least 600 m tall or higher. At the same time, the world's biggest building, called the New Century Global Center (500 m (L) x 400 m (W) x 100 m (H)) was opened in Chengdu, China in 2013. All these buildings demand a very efficient elevator system where the drive is one key component.

2. THE HISTORY OF ELEVATOR DRIVES [2]

More than half a century ago, there were basically two types of elevator drives, namely the AC-2 (AC 2 speed) for low speed operation and the DC-WL (DC Ward Leonard) for high speed operation. An AC-2 drive motor consists of two sets of windings with different pole numbers, the 4-6 poles for normal speed operation and the 16-24 poles for maintenance speed operation and leveling. It is well known that the rated speed of an AC motor is inversely proportional to the number of poles. The DC-WL drive consists of a 3-phase induction motor mechanically driving a DC generator which further energizes a DC motor which is mechanically coupled with the brake and sheave for ropes. A DC motor has much higher start-up torque and good speed regulation, thus employed for high-speed elevators. At that time, 1.5 m/s - 2 m/s was already considered high speed operation.

In the 70's of the last century, AC-2 drives were replaced by ACVV (variable voltage) drives while DC-WL drives were replaced by DC-TL (thyristor Leonard) drives for better speed control. There is no speed control of AC-2 drives while ACVV drives could provide limited speed control, still for relatively low speed operation. By DC-TL drives, the motor-generator set was replaced by a power electronic thyristor based AC-DC converter. Similar to the DC generator in the DC-WL drive, variable DC voltage could be produced by the converter to control the motor speed. In building applications like pumps, fans and compressors etc., motors always rotate in the same direction under a more or less constant speed. But in an elevator system, the direction of rotation has to be changed from time to time. For ACVV drives, a change in direction can be realized by swapping two phases while for DC-WL or DC-TL drives, a change in direction can be realized by changing the direction of the field current while maintaining the same polarity of the armature current.

3. THE POPULARITY OF ACVVVF DRIVES

ACVV drives are not energy efficient [3] and owing to the energy crisis of the 70's of the last century, energy efficient drives became demanding. At the same time, good speed control of elevator drive was also imperative due to the comfort requirements of passengers. In the 80's, ACVVVF (variable voltage and variable frequency) drives were developed and became popular in the early 90's of the last century.

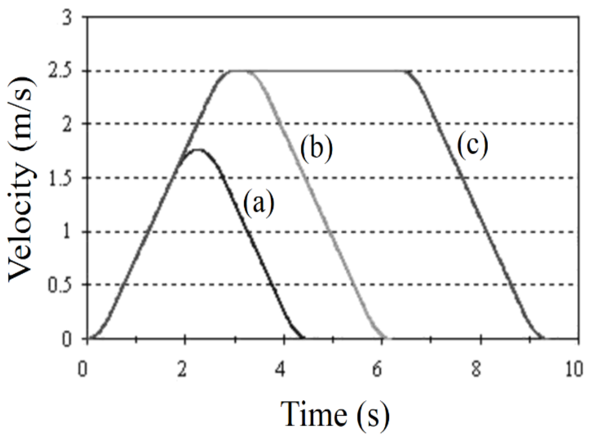

Fig. 1 – Typical Elevator Velocity-Time Profiles for (a) 1-floor jump, (b) 2-floor jump and (c) 4-floor jump [4]

As discussed in the last section, frequent changes in the direction of rotation is one distinct feature of elevator drives versus other drives used in buildings. Furthermore, the emphasis is on rated speed operation for most motor drives in buildings whereas the acceleration/deceleration profiles of elevator drives draw much attention in operational control. In a typical brake-to-brake journey, the kinematics [4,5] of the elevator car must obey some rules as shown in Figure 1 and equation set (1).

$$v = \frac{dx}{dt} \quad ; \quad a = \frac{dv}{dt} = \pm A \quad ; \quad j = \frac{da}{dt} = \pm J \qquad (1)$$

It can be seen that the rated speed may not be achieved for short jumps, like 1-floor jump. And the control of every step, namely jerk (j), acceleration (a), jerk (-j), rated speed operation (v), jerk (-j), deceleration (-a), and jerk (j), throughout the journey must be precise for high quality passenger comfort. Equation set (1) shows the requirements. Normally, jerk is limited to around 1.5 - 2.0 m/s^3 and acceleration or deceleration is limited to around 1.0 - 1.5 m/s^2 which is around one sixth of the gravitational constant.

The rated speed is given by V, rated acceleration or deceleration given by $\pm A$, rated jerk given by $\pm J$. Then, for a long jump, i.e. rated speed achieved, the total time to travel a whole journey with a distance, D, is given by equation (2) while the validity of such equation is given by the constraint in equation (3).

$$\text{Total time to travel a distance } (D) = \frac{D}{V} + \frac{A}{J} + \frac{V}{A} \qquad (2)$$

$$\frac{D}{V} \geq \frac{V}{A} + \frac{A}{J} \Rightarrow D \geq \frac{V^2 J + A^2 V}{AJ} \qquad (3)$$

In order to accomplish such precise speed control, ACVVVF drives were developed because the torque / speed control was much better than the ACVV drives while energy consumption was much lower. There were basically two kinds of ACVVVF drives in elevator systems, the scalar type and the vectored type.

The scalar type is working on the standard T-equivalent circuit of an AC induction motor. The standard torque-speed curve of an AC induction motor provides a fixed torque-slip relationship around the operating point when the slip, s, is less than 10%. A speed encoder attached to the motor shaft is used to measure the instantaneous speed of the motor, ω_r, which is added to the slip frequency command (i.e.

from the torque command) based on a constant *V*/*F* relationship to produce the desirable and instantaneous synchronous speed, ω_s. On the other hand, the desirable torque command governs the desirable rotor current as reflected to the stator circuit, I_r, because the driving torque, T_d, is given by equation (4) and R_r is the rotor resistance as reflected to the stator circuit.

$$T_d = \frac{3R_r|I_r|^2}{s\omega_s} \qquad (4)$$

By adding the desirable I_r to the desirable magnetising current, I_m, through the magnetizing branch, the desirable stator current, I_s, is obtained. An *I*/*V* converter is used to produce the desirable voltage, *V*. With *V* and ω_s in hand, the 3-phase inverter bridge can be controlled accordingly. The desirable T_d is first obtained by equation (5) where T_L is the load torque including friction and total weight of the car and ropes etc. and *J* is the moment of inertia of the whole system. And T_L is obtained by a strain gauge or linear transformer attached between the elevator car cage and the sling which is attached to hoisting ropes.

$$T_d - T_L = J\frac{d\omega_r}{dt} \qquad (5)$$

Although the torque-speed control and energy performance of scalar control are not bad, the dynamic transient performance is unsatisfactory. Therefore, in the mid 90's of the last century, vectored control was developed for elevator drives [6].

By vectored control, the stationery three phase components, *a*, *b*, *c* (*b* leading *a* and *c* leading *b*, and *a* is at 0°) are converted into stationery components, α and β (β leading α and α is also at 0°), which are further converted into rotating components, *d* and *q* (*q* leading *d*) while *d* is making an instantaneous angle $+\theta(t)$ with α where the sinusoidal feature, ωt, is absorbed into $\theta(t)$. The conversion is shown in equation set (6) where *g* could generally mean *v* (voltage), *i* (current), ψ (flux) or anything.

$$\begin{pmatrix} g_\alpha \\ g_\beta \end{pmatrix} = \frac{2}{3}\begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix}\begin{pmatrix} g_a \\ g_b \\ g_c \end{pmatrix} \qquad (6)$$

$$\begin{pmatrix} g_d \\ g_q \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}\begin{pmatrix} g_\alpha \\ g_\beta \end{pmatrix}$$

For vectored control applied to an induction motor, only two of the three phase currents, i_a and i_b, are monitored and converted to i_d and i_q, according to equation (7) because $i_c = - i_a - i_b$.

$$\begin{pmatrix} i_d \\ i_q \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{3}}\sin\theta + \cos\theta & \frac{2}{\sqrt{3}}\sin\theta \\ -\sin\theta + \frac{1}{\sqrt{3}}\cos\theta & \frac{2}{\sqrt{3}}\cos\theta \end{pmatrix}\begin{pmatrix} i_a \\ i_b \end{pmatrix} \qquad (7)$$

i_d is related to the magnetizing current of the T-equivalent circuit of the induction motor while i_q is related to the torque, i.e. I_r of equation (4). Two ACRs (automatic current regulators) are used to control i_d by v_d and i_q by v_q accordingly because the two are de-coupled by such conversion. Similar to scalar control, the instantaneous motor speed, ω_r, is measured and added to the desirable slip frequency based on the desirable torque to produce the desirable synchronous speed ω_s*. At the same time, the desirable torque is used to estimate the desirable current, i_q* and further the desirable v_q*. The desirable magnetizing current, i_d*, is more or less maintained constant by the associated v_d*. Together with the ω_s*, the 3-phase inverter bridge is switched by means of the space vector method.

Each of the three phases of the inverter bridge has two switches, normally in the form of IGBTs (insulated gate bipolar transistors) in elevator application. The one attached to the positive line is denoted by "1" while the other attached to the negative line is denoted by "0". "1" means the upper switch is "on" while "0" means the lower switch is "on". There are six modes of operation, namely $\mathbf{a}^+$, $\mathbf{a}^-$, $\mathbf{b}^+$, $\mathbf{b}^-$, $\mathbf{c}^+$, $\mathbf{c}^-$. $\mathbf{a}^+$ is actually (1 0 0), $\mathbf{b}^+$ (0 1 0), $\mathbf{c}^+$(0 0 1), $\mathbf{a}^-$ (0 1 1), $\mathbf{b}^-$ (1 0 1) and $\mathbf{c}^-$ (1 1 0). There is a zero vector **0** represented by either (0 0 0) or (1 1 1) where no current is fed to the motor. From v_d* and v_q*, two parameters can be obtained, *V** and δ*, which resemble a rotating vector with variable magnitude, phase angle and speed ω_s*. The circular path of the rotating vector is created by sequentially switching between the six modes, e.g. from $\mathbf{b}^+$ to $\mathbf{c}^-$ to $\mathbf{b}^+$ etc. The dynamic response is acceptable while the magnitude of the voltage is realized by proper pulse width modulation.

4. UTILIZATION of PERMANENT MAGNETS

Induction motors had been used in the elevator industry for decades because they are almost maintenance free and robust in nature. However, the torque-to-size ratio or power-to-weight ratio is relatively small. Also, the dynamic response is not desirable enough when dealing with high speed high capacity elevators. The motor used in Taipei 101 for the two 1010 m/min elevators has a rating of 650 kW [7]. By the turn of the current century, research and development on the utilization of permanent magnet synchronous motors (PMSMs) was actively conducted in the elevator industry. PMSMs are famous of their high torque-to-size or torque-to-weight ratios. Traditionally, synchronous motors have not been used in elevator drives as they are not robust enough and they need an additional controllable DC supply at the rotor to produce the rotor magnetic field.

In a PMSM, no additional DC supply is needed as the rotor magnetic flux is automatically produced by the permanent magnets. Again, like the normal vectored control of induction motors, current control is executed in the rotor *d-q* reference frame. In this frame, the armature inductances and magnetic flux linkage are constant if the back EMF and variation of inductances are sinusoidal [8]. The motor used to drive the 1010 m/min elevator at Taipei 101 is a PMSM. In the *d-q* reference frame, the equivalent circuits between the *d*-axis and the *q*-axis are de-coupled from one another and the following equation set (8) is valid. Here, L is the leakage inductance of the stator winding, R_s the resistance of the stator winding, p the number of pole pairs, ψ the flux linkage, ψ_f the magnetic flux linkage produced by the permanent magnets, v the stator voltage, i the stator current, T the electromechanical torque, and ω_r the rotor speed.

$$\begin{aligned}
\psi_d &= L_d i_d + \psi_f \\
\psi_q &= L_q i_q \\
v_d &= R_s i_d + \frac{d\psi_d}{dt} - \omega_r \psi_q \\
v_q &= R_s i_q + \frac{d\psi_q}{dt} + \omega_r \psi_d \\
T &= \frac{3}{2} p\left(\psi_d i_q - \psi_q i_d\right)
\end{aligned} \tag{8}$$

Let ψ_s be the resultant of ψ_d and ψ_q and δ be the angle between ψ_s and ψ_d, the torque equation can be expressed by equation set (9) when there is no saliency between the stator and the rotor, i.e. $L_d = L_q = L_s$.

$$\begin{aligned}
\sin\delta &= \frac{\psi_q}{|\psi_s|} \\
T &= \frac{3}{2}\frac{1}{L_s} p|\psi_s||\psi_f|\sin\delta
\end{aligned} \tag{9}$$

Since ψ_f is constant as it is produced by the permanent magnets, the torque can be solely controlled by varying ψ_q which is produced by i_q. In section 3 of this paper when vectored control of induction motors was discussed, i_d needs to be controlled as it represents the magnetizing current. Now, only i_q needs to be controlled in order to control the torque, more convenient and quick. It should be noted that the final production of the voltage waveform is still according to the space vector method discussed in section 3 with the consideration of ω_s* as well.

5. UTILIZATION OF LINEAR PMSMs

As buildings are getting taller and taller, wider and wider, as mentioned in the introduction of this paper. it is a big wastage of the hoistway space by allowing only one elevator car to occupy the whole hoistway all the time. It is analogous to running just one train on a railway tens or hundreds of km long. One solution is to put more hoistways in one building. However, tall buildings tend to be slim. The existence of too many hoistways means the majority of the footprint is occupied by the elevator system, which is unreasonable and not practical. Double decker elevators and TWIN™ of the German manufacturer's, Thyssekkrupp, elevators allow up to two cars move along the hoistway all the time, the former one dependent of while the latter one independent of one another. That is still a wastage. To serve a building hundreds of metres tall, as many elevator cars as possible should be allowed to run in the same hoistway. Conventional systems, even the machine roomless, rely on the hoisting ropes to suspend the cars, which at the same time prevent too many cars to run in the same hoistway.

The technology of ropeless elevators is certainly the trend to go. Ropeless elevators also allow an elevator system to be upgraded from 1-dimensional to 2-dimensional so that both tall and wide buildings can be served appropriately [9]. The drive of such ropeless elevators has to be changed from the rotary PMSMs to linear PMSMs.

Conceptually, it is straight forward to imagine cutting the stator of a rotary PMSM along the axle and flattening it into a planar shape. The rotary rotor is manipulated by the same way to make it planar. Most electromagnetic equations can be reused with minor modification. The same *d-q* reference frame is used but ω_r is changed into linear velocity, v_s with the consideration of pole pitch, τ, as shown in equation set (10) [10].

$$\psi_d = L_d i_d + \psi_f$$
$$\psi_q = L_q i_q$$
$$v_d = R_s i_d + \frac{d\psi_d}{dt} - \frac{\pi}{\tau} v_s \psi_q \qquad (10)$$
$$v_q = R_s i_q + \frac{d\psi_q}{dt} + \frac{\pi}{\tau} v_s \psi_d$$
$$P = \frac{3}{2}\frac{\pi}{\tau} v_s \left(\psi_d i_q - \psi_q i_d\right)$$
$$F = \frac{3}{2} p \frac{\pi}{\tau}\left[\psi_f + \left(L_d - L_q\right) i_d\right] i_q$$
$$= \frac{3}{4} p \frac{\pi}{\tau} \frac{1}{L_d L_q} |\psi_s| \left[2\psi_f L_q \sin\delta - |\psi_s| (L_d - L_q) \sin 2\delta\right]$$

Here, F is the linear force exerted on the rotor from the stator, and p is also the number of pole pairs. Again, if no saliency is involved, $L_d = L_q = L_s$, F is directly controlled by i_q or ψ_q.

The world's first 2-dimensional elevator system driven by linear PMSMs was developed by Thyssenkrupp, called MULTI™ [11]. The linear rotor is attached to the back of the elevator car and it can be rotated 90° to make it move either vertically and horizontally. Since the car is physically detached from the building, the only points of contact being between the rollers and the guide rails, it is expected that the permanent magnets are on the car side while the coils that are to be energized from time to time are on the guide rail side. In a super-tall building, the hoistway will be in the form of a closed loop. One side of the loop is for upward movement while the other side is for downward movement. In this way, tens of elevator cars can move around the loop to serve passengers, like the Ferris wheel in an amusement park.

6. WHAT'S NEXT?

It is for certain that 2-dimensional elevators utilizing linear PMSMs will become more and more popular in the near future once the real installation of MULTI™ is completed hopefully in 2018. However, since the whole installation is ropeless, stationery braking and the triggering of the safety gear are to be further developed for 100% risk-free safety.

Another consideration is with the permanent magnets. It is well aware that permanent magnets are artificially produced, which are gradually demagnetized and have a limited life. Furthermore, the production of high quality permanent magnets relies on the adequate supply of rare earthed materials which are also limited in supply.

Some researchers are looking into the development of linear reluctance motors for use by such 2-dimensional elevators so that no permanent magnet is needed [12]. However, the adequacy of torque is still an issue.

Finally, conventionally, the power consumed inside the elevator car, including lighting, ventilation, display, control and door operation etc., is fed via travelling cables. In the case of ropeless elevators, travelling cables certainly do not exist. The effective way to energize the elevator car has to be studied and such power must be available for certain time after a full power breakdown of the building throughout the rescuing process.

7. CONCLUSION

The global trend of the construction of super-tall and super-wide buildings was first highlighted in the introduction. And it was argued that all these buildings need an advanced and efficient elevator system. Conventional drives of elevator systems were briefly reviewed in this paper. The modern trend of applying permanent magnet synchronous motors was discussed, involving both rotary PMSMs and linear PMSMs. The discussion led to the view that linear PMSMs would dominate the elevator industry where a 2-dimensional design will certainly be the norm. Further development would be in the direction of perfecting the safety features and less reliance on the supply of permanent magnets.

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Paper No. 6

BIM IN RESPECT OF DIGITALIZATION

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ABSTRACT

The Smart City Blueprint for Hong Kong was released in December 2017 with the vision to transform Hong Kong into a world class 'smart' cosmopolitan city. To embrace the new era of innovation and technology in this highly dense 'concrete jungle', digitalized E&M engineering solutions play a significant role towards smart buildings. Electrical and Mechanical Services Department (EMSD) is responsible for managing substantial amount of E&M assets in more than 8,000 government buildings. EMSD has developed a BIM-AM System which integrated Building Information Modelling (BIM) and the digitalized E&M asset management (AM) towards smart operation and maintenance (O&M) workflow. To ensure smooth handover of as-built BIM models for digitalized asset management, EMSD launched BIM-AM Standards and Guidelines in November 2017. Our development on integrated building management system (iBMS), Internet of Things (IoT) Hubs and the possible applications leveraging data analytics will be discussed in this paper with a view to achieving intelligent E&M asset management to support Government's initiative of transforming Hong Kong into a Smart City.

1. INTRODUCTION

Hong Kong is a densely populated city in which the urbanized areas take a significant portion. The city is characterized by sophisticated infrastructure systems and high-rise buildings, both of which rely on reliable operation of electrical and mechanical (E&M) systems. EMSD provides operation and maintenance engineering services for massive amounts of E&M systems in thousands of government venues and public transport infrastructures.

Nowadays, it is an era of rapid advancement of Innovation and Technology (I&T), many new technologies are available for managing the building E&M systems. That not only helps improve the E&M system availability and reliability, but also leads to transform Hong Kong into a smart city. It is an echo in the Smart City Blueprint for Hong Kong launched in last year and this paper will illustrate how EMSD, as a promotor and facilitator, utilizes the I&T technologies in our E&M asset management and the potential benefits.

2. BUILDING INFORMATION MODELLING FOR ASSET MANAGEMENT (BIM-AM)

To streamline and enhance fault localization workflow during corrective maintenance, EMSD has developed a novel architecture of an integrated BIM-AM System for asset management. The system offers smart O&M working tools for providing an intuitive way to access heterogeneous assets information such as photos, attributes, equipment relationships, manuals, e-forms, drawings, maintenance records, live view of Closed Circuit Television (CCTV) System, real-time sensing data from Building Management System (BMS) and wireless ad-hoc sensors, as well as location information of moving asset from a Real Time Location System (RTLS) in one single integrated mobile platform (see Figure 1 for the BIM-AM System architecture). All the information is readily accessible simply by asset repository, manoeuvring throughout a BIM model, or even triggered from a handheld Radio Frequency Identification (RFID) scanning tool [1].

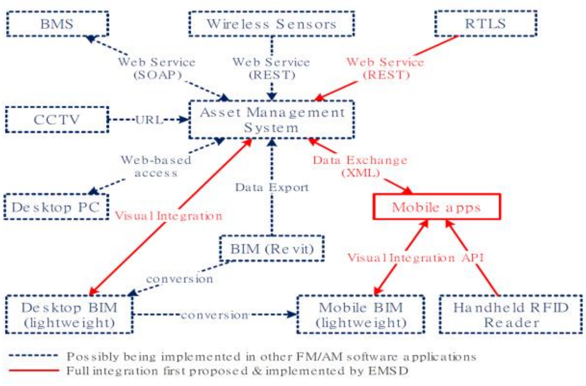

Fig. 1 - The Novel Architecture for BIM-AM System

EMSD started a pilot project at its Headquarters in 2014 and it demonstrated BIM-AM System has great benefits and long-term cost savings in the O&M building lifecycle.

The BIM-AM system can be further explored for the handover of E&M systems before the project completion. It can provide a single online platform for document and workflow management, handover of O&M as well as reporting defects with proper track record.

3. BUILDING INFORMATION MODELLING FOR ASSET MANAGEMENT (BIM-AM) – STANDARDS & GUIDELINES

To ensure smooth handover of as-built BIM models for digitalized asset management, the BIM-AM Standards and Guidelines was officially launched on 24 November 2017 and uploaded to the EMSD Internet webpage (see QR code) for reference by the trade. The standard covers three major aspects including (i) modelling requirement, (ii) asset information requirement and (iii) interfacing requirement.

3.1 Modelling Requirement

The guideline is based on the asset templates developed by EMSD, which is a summary of information requirement for more than 19 types of E&M systems. Building individual BIM model for each E&M system in separate file is required for the ease of operation. The requirement on asset naming convention and RFID coding is also elaborated in the guideline that is crucial in data migration between BIM models and AM system.

3.2 Asset Information Requirement

Asset information requirement is the key of BIM-AM System. In the massive amount of E&M assets, detailed asset information of over 230 types of important assets is identified to be input to BIM models for O&M. For the sake of easy understanding, each important asset is assigned with an Asset Data Template (ADT), which explicitly tabulates the information requirement of that particular asset.

Asset information is divided into two categories which are (i) general information and (ii) equipment specific information. For the general information, it is common for all E&M assets, for example, asset code, warranty, make, model, asset relationship, and documentation link (to O&M manual), etc. For the equipment specific information, it covers equipment operational data, for example, flow rate, set point, efficiency, power, etc.

Another important informative feature of BIM-AM System is the display of “System Topology” which can be interpreted as “E&M asset relationship diagram” for visualising the relationships between assets within a particular system and for cross-referencing among assets. Figure 2 shows a graphical view of the asset relationships of an air-handling unit (AHU). A logical parent-child relationship is represented by a “dependent” arrow pointing from a parent asset to its child asset whereas a logical associated relationship is represented by an “associated” arrow pointing from an asset to its associated asset, indicating that an asset relates to its associated asset but has no dependence on it. This System Topology is found useful and effective for fault locating.

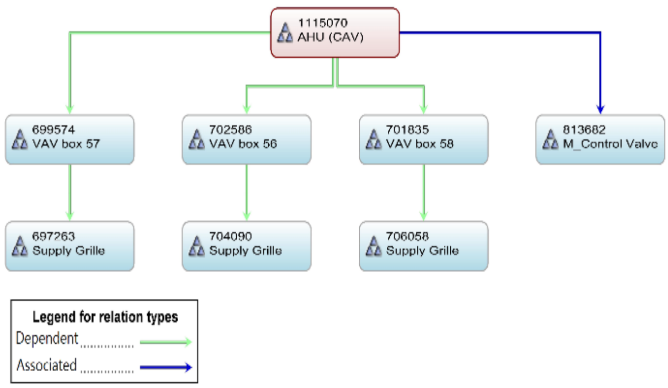

Fig. 2 – System Topology of AHU

3.3 Interface and Integration Requirement of Electronic Systems to BIM-AM System

Technical requirement on system interface between BIM-AM System and other electronic systems is explicitly elaborated in the guideline. The interface of BIM-AM with real time systems should be by means of web links (e.g. for CCTV cameras) or web services (e.g. for BMS) which are accessible by iOS and / or Android browser.

For the RFID scanning system, each major E&M equipment should be provided with RFID asset tag. Whilst other E&M assets with massive numbers of quantity, such as lighting fixtures and cameras etc., a single zone tag by means of QR codes could be assigned to a group of assets based on their spatial proximity (e.g. zone, area or room). Figure 3 illustrates the examples of the installation of RFID asset tag and zonal QR codes.

Fig. 3 – Examples of the Installation of RFID Asset Tag and Zonal QR Code

4. E&M DIGITALIZATION

Apart from the BIM-AM System, EMSD has formed a number of working groups to develop digitalized E&M asset management solutions in order to enhance operational efficiency through real-time monitoring and data analysis.

4.1 Internet of Things (IoT) Hubs

As mentioned in Section 3.3, the interface between BIM-AM System and real time BMS is by means of web services, such as SOAP and RESTful protocols. It may be costly and time consuming to implement the interfacing works at individual sites with different protocols of BMS, including BACnet, Modbus and Dry Contact. Thus, a "universal BMS Adaptor", namely IoT Hub, is established in EMSD Headquarters for further interfacing with the AM system. Figure 4 illustrates the IoT Hub System architecture.

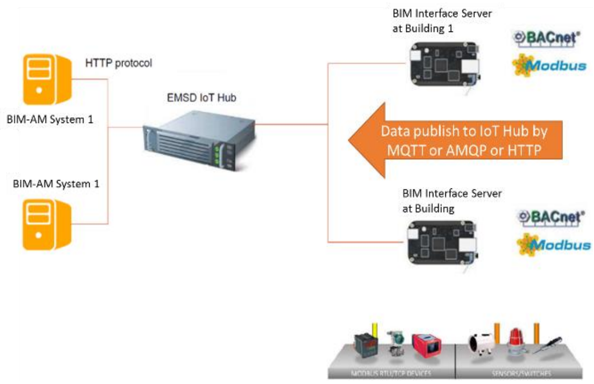

Fig. 4 – IoT Hub System Architecture

Figure 5 shows that the IoT Hub acts as a "message broker" which sends and receives messages from/to BMS Interface Servers. The IoT Hub is capable to support several message protocols, including web services (e.g. SOAP / RESTful), message queue telemetry transport (MQTT) and Advanced Message Queuing Protocol (AMQP) in order to provide BIM-AM System a standardized interface to communicate with BMS Interface Servers in different buildings.

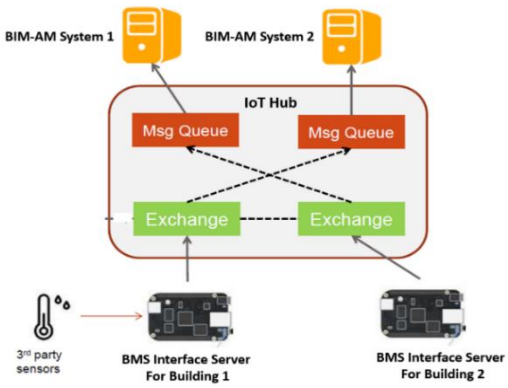

Fig. 5 – The Functions of IoT Hub

4.1.1 The features of IoT Hub

(a) The IoT Hub runs on "Server Cluster" which is a group of independent servers working together for storing messages received from BMS Interface Servers to provide auto-failover and increased availability of application by avoiding message loss due to singe server failure.

(b) Each IoT Hub server can support more than 20 remote sites. With the cluster feature, the IoT Hub is scalable to support more than 8,000 site locations in which at least 3,000 BMS input / output points can be supported for each site.

(c) The IoT Hub is designed to monitor the healthiness of remote sites such as data link connectivity, data throughput, alarms and heartbeat to be sent from the remote sites.

4.1.2 The interface of IoT Hub and BIM-AM System

Through this unified interface platform, BIM-AM System supports visualizing BMS sensor values by colour overlay on the BIM model and plot change in sensor values. The System is also able to monitor and control the set points of BMS via the mobile BIM-AM platform.

4.2 The Integrated Building Management System (iBMS)

In addition to the IoT Hub, EMSD also developed an integrated BMS (iBMS) in order to enhance the efficiency of O&M work as well as to relieve staff work load. The iBMS is also capable to monitor and control the E&M systems of multiple buildings via a single

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platform using either computer, tablet, smart phone at any locations. The central iBMS server with the connections to the BMSs has been established in 2015. With the smart city initiatives, the iBMS is currently integrated with a geographic information system (GIS) platform for map-based asset management.

4.2.1 The integration with iBMS and GIS

Live equipment status from iBMS is now integrated under a single GIS platform. Different types of systems or infrastructures are displayed in different layers of the GIS. Staff responsible for a specific system can select the individual layer of interest, while management staff or staff in the fault call centre can select multiple layers for territory-wide overview of the infrastructure conditions. The integrated platform enables real time monitoring of system healthiness, and sending pre-fault alerts to maintenance staff. All these help reduce the fault response time and fault rectification time, and improve the reliability of critical infrastructure systems [2].

4.2.2 The proven benefits of iBMS

Since the implementation of iBMS, the operation and maintenance work has become more effective. As the control and monitoring of the E&M equipment can be carried out through one central console, it minimises the need for maintenance team to travel between buildings. Manpower is saved and staff can carry out maintenance work more efficiently and effectively.

Fault alarms are now not only shown in iBMS, but also sent to management staff and maintenance team via SMS that saves a lot of reporting time and leads to a faster response to equipment faults[2].

5. E&M DIGITALIZATION APPLICATION

With the E&M digitalization, system operational and maintenance data can be properly recorded and kept track in the central service centre for data analysis that turns data into actions.

5.1 Data Analysis for Enhanced Maintenance Performance

5.1.1 From scheduled preventive maintenance to predictive maintenance

The system performance and the associated energy consumption can be kept track in the central console. Any abnormal energy consumption, such as improper energy usage pattern, caused by faulty equipment could be easily identified. The analysis of historical and real time data leads to the next level of maintenance model for "predictive maintenance". For example, the maintenance agent may adjust the preventive maintenance schedule for checking the high-risk equipment with an abnormal profile at a higher frequency to suit the actual system needs [3].

5.1.2 Off-site pre-diagnosis

The application of BIM for asset management allows the maintenance team to carry out pre-diagnosis of the root cause remotely and to streamline the fault location process before attendance on-site [4]. We can further complement the visualization and communication element of BIM with Augmented Reality. For complex incident, maintenance staff can call and virtually share the live situation with the off-site experts for step-by-step assistance, adding a new dimension of mobility and agility to maintenance work [5].

5.1.3 Prioritization of massive maintenance works

The remote monitoring provided by the iBMS facilitates the routine or ad-hoc maintenance management. With the data of the system performance, management team can suitably mobilize the workforce and prioritize the work in a more efficient manner.

5.2 Data Analysis for Energy Optimization

E&M digitalization helps in energy saving. With the iBMS, energy consumption is monitored and recorded in real time. The trend analysis provides data-driven insight to optimize E&M system operation. On the other hand, the energy consumption data can help identify abnormal energy consumption pattern due to equipment failure, e.g., a faulty control valve which cannot be properly closed wastes energy and causes overcooling.

5.2.1 Energy benchmarking

With the exponential growth of O&M data collected, operational data analysis not only helps diagnose anomalies, but also helps benchmark the energy efficiency across the same type of plant, equipment or even similar types of buildings. The maintenance team can easily unveil hidden energy patterns and unseen equipment faults, and rank the recommendations on energy cost saving opportunities [5].

5.2.2 Optimized operation based on building and occupant behaviour

The building operational data can help conduct occupant behaviour analysis which can quantify the impact of occupant behaviour on building energy performance. With big data analytics, machine learning can be adopted to learn the historical data and the underlying correlation between the occupant behaviour and total building energy consumption for the prediction of optimal setting to achieve energy saving.

6. CONCLUSION

E&M digitalization brings I&T to E&M systems with a view to achieving high building performance. It has brought drastic changes from traditional preventive maintenance and post-fault rectification to predictive maintenance and pre-fault rectification. The iBMS enables the maintenance staff to monitor and control the E&M systems anytime, anywhere. With the application of big data analytics, building energy performance can be visualized in real-time, energy end-used data can be audited efficiently, and E&M systems can continuously be operated at optimal condition.

To implement the smart O&M workflow in buildings, BIM-AM System provides a single platform to centralize all the building information and manage E&M assets effectively.

With the collaboration of all stakeholders towards E&M digitalization, smart building solutions will be the trend to transform Hong Kong into a Smart City.

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Paper No. 7

EMBRACE THE POWER OF DIGITALIZATION FOR A SUSTAINABLE HYPER-SCALE DATA CENTER

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EMBRACE THE POWER OF DIGITALIZATION FOR A SUSTAINABLE HYPER-SCALE DATA CENTER

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Data Center Business
NTT Com Asia Limited

ABSTRACT

The modern IT environment is constantly evolving, as IT infrastructure rapidly expands in pace with cloud computing, big data, AI, and other new digital technologies. The ever shifting infrastructure landscape drives enterprises to revolutionize their data center strategy, transforming their digital ecosystem.

Demand for digital transformation is constantly on the rise, and data centers must operate at the hyper-scale to stay competitive. Implementing a hyper-scale data center is one of the most critical success factors to economizing digital resources. Supporting massively scalable computing architectures is crucial to optimization and automated delivery. Designing a hyper-scale data center that is sustainable is equally critical; designed to be energy efficient, it reduces of energy consumption and the carbon footprint, minimizing environmental impact and lowering TCO. Adopting a hyper-scale data center enables enterprises to embrace digital transformation and deliver business success.

This paper shares the experiences and insights NTT Communications has had in embracing the power of digitalization to achieve sustainability that meets the LEED-CS 2009 (Platinum Grading) standard. It focuses on how NTT Communications has spearheaded the development of digital infrastructure in its hyper-scale data center in Hong Kong, pioneering a world-class infrastructure across the digital lifecycle from design, to construction, and to operation.

1. INTRODUCTION

The digital economy has changed the structure of industries and how we model our businesses. Uber, the world's largest taxi company, owns no vehicles. Facebook creates no content. Alibaba has no inventory. Airbnb owns no real estate. Nevertheless, all those companies own a lot of customer's data, including behaviors, preferences, activities, and more.

Most companies turn to dedicated service providers to manage growing data and execute sophisticated algorithms in the back-end – so they can be free to focus on their core business. The demand for hyper-scale data center services providing co-location, hosting, cloud computing, Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS), and Infrastructure-as-a-Service (IaaS) therefore will continue to increase.

Creating a hyper-scale data center is one of the most critical factors to successfully economizing digital resources. Building a sustainable hyper-scale data center is equally critical; designed to be energy efficient, a sustainable data center reduces energy consumption and its carbon footprint, minimizing environmental impact and lowering the total cost of ownership (TCO). A hyper-scale data center enables enterprises to embrace digital transformation and deliver business success.

This paper shares NTT Communications' experiences in embracing the power of digitalization to achieve sustainability that meets the LEED-CS 2009 (Platinum Grading) standard [1] and the insights we have gained in our journey. It focuses on how our Hong Kong hyper-scale digital data center has been a leader in digital infrastructure development, pioneering world-class infrastructure across the digital lifecycle, from design, to construction, and to operation.

2. BACKGROUND OF NTT COMMUNICATIONS HONG KONG FDC2 HYPER-SCALE DATA CENTER

Data centers are power-hungry facilities, due primarily to the large number of servers running around the clock, all in need of constant cooling. Hong Kong has a scarcity of land, and data centers generally are designed with high-power densities at an exceptional level – reliable cooling is therefore a challenge.

Businesses demand state-of-the-art IT infrastructure performance and technology that can continuously evolve to meet rising demand. These demands only increase as new technologies emerge. As a result, new cooling system designs are playing an increasingly critical role in ensuring the reliability of high-density IT equipment. Equally important is that the design to be able to deliver enough space, power, and cooling – and be cost effective – all while providing the flexibility needed to meet current and future IT requirements.

Financial services, IT, e-Commerce, and other sectors typically use High Performance Computing (HPC) to satisfy their speed and performance needs. HPCs are denser than standard IT hardware, placing added importance on suppling the higher density power and efficiently needed to cool HPC systems. The cooling system must also be able to meet peak cooling demands while performing under lower average loads efficiently. Traditional cooling systems are not well suited to meet these challenges, so a modern data center must incorporate leading-edge technologies to overcome the limits of older conventional designs. These requirements increase the need for best-in-class data center design, flexibility, and ample capacity to meet business growth.

Fig. 1 – A Practical Example of Cooling Battery System

Imagine an energy heat map of Hong Kong. Parts of Hong Kong would certainly be swathed in red. NTT Communications' Financial Data Center Tower 2 (FDC2) however contributes a large green swath, the first data center in Hong Kong as well as greater China to achieve LEED2009 for Core and Shell Development (LEED-CS 2009) certification at the highest level, platinum, a demonstration of its sustainable design. It uses green engineering measures, in particular those related to reducing energy consumption, environmental impact, and carbon footprint. FDC2 is also the first data center in Hong Kong as well as greater China to have achieved the highest Platinum level under LEED-CS 2009, accomplished through a balanced approach using sustainable design and best practices without compromising operations or reliability.

FDC2's cooling wall and cooling battery – first among Hong Kong data centers – are two remarkable designs enabling it to meet the Tier IV Standard Continuous Cooling requirement as defined by the Uptime Institute [2]. They have the ability to increase energy efficiency by more than 20% compared with traditional data center cooling systems.

3. HYPER-SCALE DATA CENTERS

Hyper-scale data centers are massively scalable computer architectures. They optimize server use, energy efficiency, cooling, and their space footprint through the economy of scale to meet their demanding scale and density needs.

Hyper-scale data centers need to support a hundred thousand physical servers and millions of virtual machines. Ever-rising computing loads demand increased IT hardware to meet their needs, and we have seen power requirements increased significantly overall in recent years. Each generation of IT hardware delivers increase, resulting in a corresponding rise in heat density. This engenders more concerns over how flexibly data centers can adjust power, as well as the optimization of cooling systems – both resulting in long-term power savings.

NTT's hyper-scale data centers optimize server use, energy efficiency, cooling, and space footprints to meet their scale and density requirements.

4. INNOVATIVE DESIGN

4.1 New High Density Design Standard

Data center TCO is comprised of many factors, which can be categorized into upfront capital investment – land, building shell, and facility infrastructure equipment – and recurring operating costs. While there are many operating cost factors including energy, equipment maintenance, and labor, a substantial portion of TCO is energy usage and power costs.

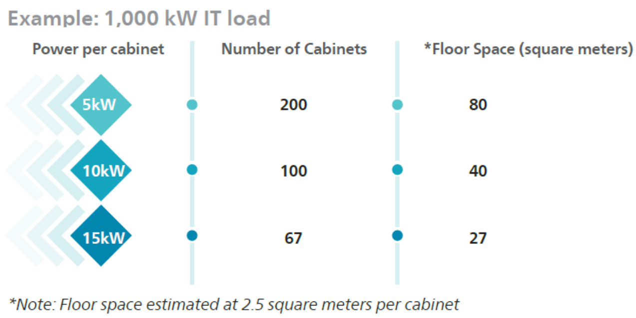

Fig. 2 – Benefit of High Density Design with TCO Optimization [3]

Compact cities such as Hong Kong, Singapore, and Tokyo have high building costs, and density also becomes a significant part of TCO. To maximize the use of space, NTT's Hong Kong hyper-scale data center FDC2 is a multi-story building. This lowered the initial land acquisition cost and optimized the number of cabinets per square metre. Financial services, IT, and e-Commerce have an insatiable need for power, and generally adopt High Performance Computing (HPC) requiring less consumption of floor space. FDC2 therefore packs a power density of more than 100MW within a 15,000 sqm site. It also can accommodate ultra-high power density, up to 24 kVA per IT cabinet, which are ultra-tall racks 54U high.

In 2007, the Green Grid Association released the Power Usage Effectiveness (PUE) energy efficiency metric [4]. PUE is measured by dividing the amount of power entering a data center by the power used to run its IT infrastructure. It is expressed as a ratio, with overall efficiency improving as it approaches one. Hyper-scale data centers are designed for improved PUE, but supporting higher densities requires special focus on making cooling energy optimized and efficient. A lower PUE results in lower initial capital investment and operating costs per kilowatt of IT payload by improving and optimizing cooling efficiency for higher density racks and reducing recurring energy costs.

4.2 Cooling Wall

Cooling systems represent the largest facility-related energy use in a data center. Optimizing efficiency while operating effectively under a range of conditions is therefore key for hyper-scale data centers.

Fig. 3 – Cooling Wall

Traditional down-flow cooling designs are limited in how sufficient of air flow they can provide to high power density racks, and they cause excessive energy loss due to pressure drops at raised floor plenum and air tiles. NTT Communications therefore partnered with Vertiv (formerly Emerson Network Power) to develop a new type of front-flow cooling method with hot aisle containment. We call it the Cooling Wall.

The Cooling Wall has multiple benefits. Its design for laminar airflow, ensuring equal supply distribution to every rack from top to bottom. Compared to the more common 42U racks, it effectively uses space as its lower raised floor allows effective use of vertical space and is able to accommodate more IT equipment in ultra-tall 54U racks. It also provides cooling of up to 24kVA per rack, all while preventing overcooling of low-density racks.

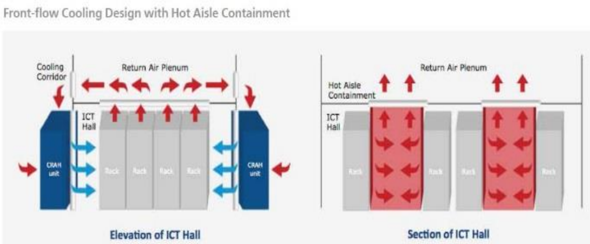

Fig. 4 – Front Flow Cooling System [3]

Its ventilation fans are controlled to maintain a slight positive static pressure, ensuring ample airflow to every IT intake regardless of load condition. The low fan speeds are coupled with low static pressure as the room itself is the plenum, significantly reducing fan power needs. The custom control system regulates computer air room handler (CRAH) supply temperatures by measuring temperatures in cold aisles, ensuring proper and stable environmental conditions, even with mixed rack densities. This sophisticated combination of design factors meets the cooling challenges of modern and future IT hardware and delivers substantial improvement in energy efficiency.

4.3 Cooling Battery

Continuous cooling is crucial to enable the thermal environment bridge to remain stable until the cooling system resumes full normal condition. Maintaining a stable thermal environment using continuous cooling helps mitigate elevation in temperatures within the data center, which could damage IT hardware or critical equipment, and provides thermal stability to IT environments during interruptions in the cooling system, such as the transition to a diesel generator during an outage.

FDC2 has constructed the first stratified thermal energy storage system in Hong Kong, termed the Cooling Battery. It contains 3,600,000 litres of chilled water held in two 25m high concrete cylinders with well thermal insulation for 42 mins backup time, and its Continuous Cooling features override up to six cycles of chiller system restart due to utility power unitability. Water density is inversely proportional to temperature, so the chilled water is fully separated from the hotter water which rises to the top on a thermocline. The chilled water temperature and volume can be secured during operation at all times and scenarios to feed the data center cooling system, while the return hot water is trapped in the upper layer.

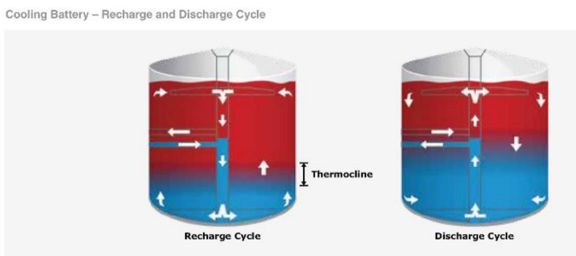

Fig. 5 – Cooling Battery [3]

This is an essential feature enabling FDC2 to meet the continuous cooling requirements of the Uptime Institute's Tier IV design parameters. It also allows FDC2 to achieve better cooling performance by leveraging the potential of server room temperature elevation, all without excessive waste of cooling energy to overcool the temperature in the server room.

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4.4 Traditional 2N UPS Redundancy Design

The average higher tier data center often prefers dual-bus (2N) redundancy as it meets two criteria: 1) concurrent maintainability, and 2) fault tolerance. 2N redundancy traditionally features redundant utility feeds, generators, uninterruptable power supply (UPS) systems, and power distribution systems supporting dual-powered IT hardware, all while eliminating the single points of failure in the critical power system.

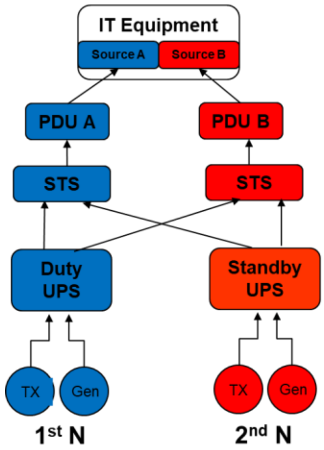

Fig. 6 – Traditional 2N UPS Redundancy Design

The initial floor space requirements and investment costs of 2N redundancy are also relevantly expensive and demanding. Further, to ensure safe operating conditions when one bus is carrying the full load, 2N power system components have a low use rate, with a maximum of 50% in normal operation conditions. This can lead to reduced system efficiency.

The majority of UPS systems operate most efficiently at utilization rates above 30%. Efficiency however begins to drop at 20% utilization (Figure 7).

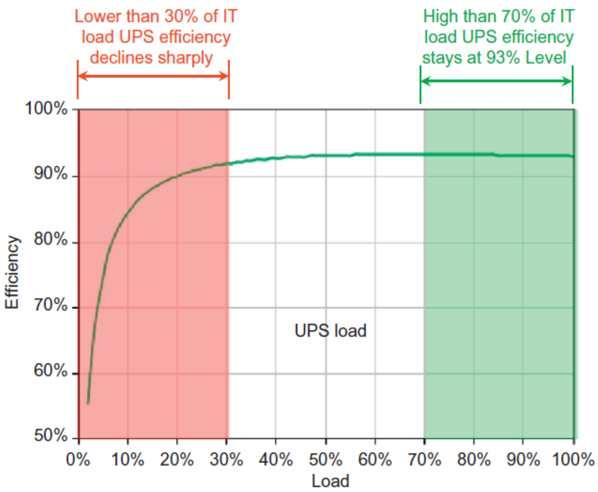

Fig. 7 – UPS Efficiency versus Load

This may not be a serious concern for small-scale data centers (i.e., those at <1MW capacity). Power system losses account for a relatively small percentage of data center power use and achieving a 2% increase in UPS efficiency by operating at higher utilization rates is not enough of an incentive to outweigh the other benefits of the 2N redundancy. But when hyper-scale data centers (i.e., those at >10MW capacity) adopt 2N designs, the low level of utilization inherent in traditional 2N redundancy has a larger impact on operating costs.

4.5 Block Redundancy Critical Power System

As a result, a new architecture of block redundancy design has emerged for hyper-scale data centers that preserves the maintainability and fault tolerance of 2N redundancy while increasing system energy efficiency and reducing TCO, both in terms of capital and operation expenditures, and maintain similar levels of reliability.

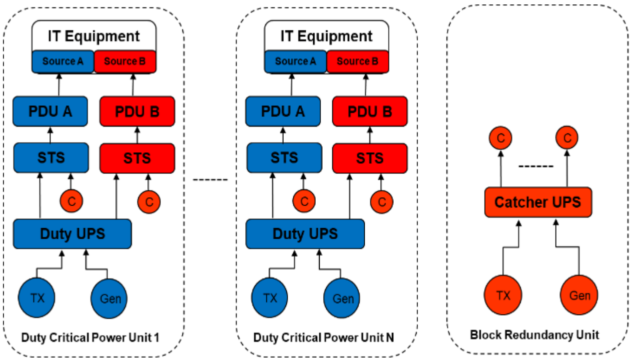

Fig. 8 – Block Redundancy Critical Power System

Block redundancy design essentially creates an N+1 redundancy within the UPS component level in terms of capacity and maintains fault tolerance and concurrent maintainability using static transfer switches (STS). STS allows a redundant UPS system to be brought online to pick up the load from online UPS systems in the event of failure or maintenance. Upstream from the STS units, IT hardware power distribution system is maintained as 2N redundancy to maximize its resiliency level.

This arrangement allows FDC2's duty UPS system to operate at full utilization rates of 100% in normal operation conditions – much higher than traditional 2N redundancy design with only 50% utilization. This lean design represents a viable high-performance value to support latest hyper-scale data center demand.

5. DIGITAL TRANSFORMATION FOR DATA CENTER LIFE-CYCLE MANAGEMENT

Life-cycle management is well recognized as critical to ensure the long-term quality operation performance of a

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data center. NTT created NTT Communications' data center infrastructure management (DCIM), its own digitization platform, for end-to-end visibility management, integrating digital construction, digital operation, and digital service.

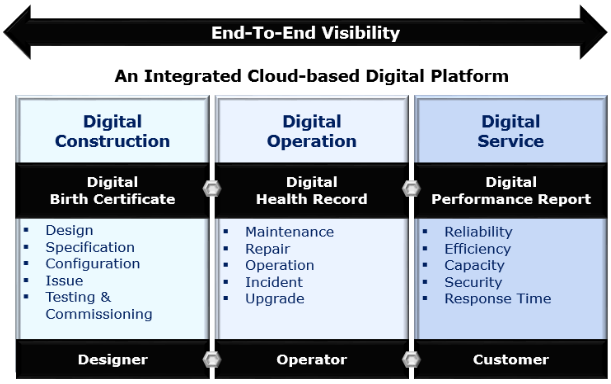

Fig. 9 – Integrated Cloud-based Digital Platform

End-to-end visibility adds value in four areas:

- Faster, enhanced communication between the operator, designer, construction team, suppliers, and clients;
- Faster, enhanced decision-making processes using big data and advanced analysis techniques;
- Automation of manual tasks through technology; and
- Eliminating human error through technology.

Thanks to careful planning of system integration, workflow, and data requirements, FDC2's integrated digital platform has successfully integrated building information modelling (BIM), data center infrastructure management (DCIM), and facility systems (e.g. building management systems, CCTV, security) with its internal workflow, performance analytics, and fault prediction framework.

NTT Communications' DCIM enables performance tracking of all critical system data throughout the life cycle, from design, construction, commissioning, transition, operation, maintenance, improvement, to disposal. This end-to-end visibility is crucial to enable the data center team to continuously improve FDC2's performance, including in energy efficiency, reliability, security, and response time.

5.1 Digital Construction

Building information modelling (BIM) involves the generation and management of digital representations of the physical and functional characteristics of a build asset at the design stage. A BIM model contains information on design, construction, logistics, equipment's technical data, and more. The data in a BIM enables richer analysis, and it has the potential to integrate large quantities of data across several disciplines throughout the building's lifecycle.

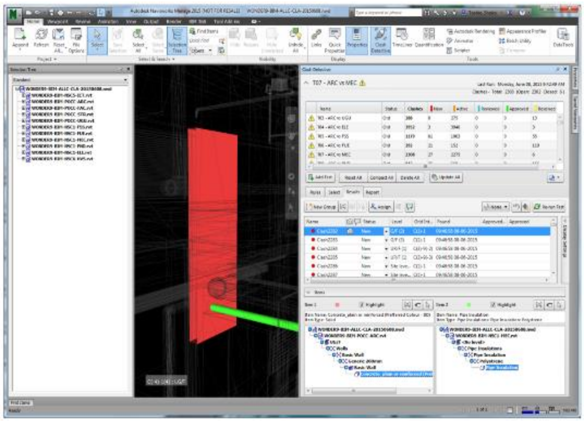

Fig. 10 – Digital Construction by BIM

NTT Communications has deployed BIM for mechanical, electrical, and plumbing (MEP) detail design, clash detection, multi-disciplines coordination, and quality control since 2014. With the help of BIM 360 Field and BIM 360 Glue, NTT Communications and contractors can use 3D models to coordinate construction works and perform quality checking on-site, effectively reducing abortive works and cost overruns.

All design information and hardware data from BIM are exported to NTT Communications' DCIM seamlessly without duplicate data entry.

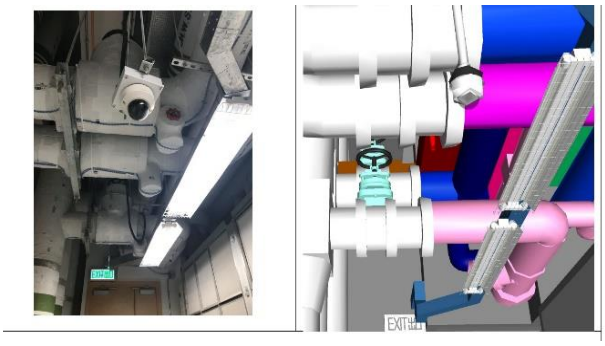

Fig. 11 – Enhanced Construction QA/QC by BIM

5.2 Digital Operation

NTT Communications' DCIM services enhance system operations and reduce operation workload. The customer can monitor the data center system operation status as well as manage the equipment and wiring seamlessly, all from NTT Communications' Nexcenter client portal. Clients can visualize the real-time status of server room temperature and humidity, hardware status, power use, and air-conditioning workload. In the event of any trouble, clients and data center staff can monitor the same screen, enabling swift and smooth resolution of the issue.

DCIM will be a strong part of the software-defined operational and services strategy envisaged by NTT Communications. Deploying DCIM enables NTT Communications to tightly couple demand for virtualized resources at the top layer of its digital stack – IT and networking – with its underlying physical datacenter resource supply – power, cooling, and space. This results in cost efficiencies and reduces the risk of service interruptions due to under-provisioning. By integrating data from DCIM with a range of other management systems, NTT Communications can make more informed decisions around best-execution venues, both internally and for client, all while taking into account the cost and availability of IT, connectivity, and data center resources.

The new dimension of visibility from accurate, transparent, and responsive data provides a better guarantee and increases confidence in the commitment of service-level agreements (SLAs) and service quality. This helps clients reduce risk through informative decision-making, and it enables effective IT infrastructure planning in the long run. DCIM collects, normalizes, and reports data about NTT Communications' data center operating status. Included in the report are power use, availability, redundancy, and quality, as well as environmental conditions such as temperature, humidity, and airflow pressure. Data is pulled from a variety of sources within NTT Communications' data centers, including sensors, power metres and clamps, branch circuits, batteries, and UPSs, as well as hardware ranging from generators and chillers to power distribution units and cooling systems.

The data streams are normalized into standard formats so they can be readily analyzed and made available to end-user clients where applicable. Customizable reports plot data over time, such as power consumption and operating environments at the room, row, and rack level. Configurable alerts notify our operator when preset thresholds are exceeded, and alerts are prioritized for those needing an immediate response, such as an issue in power quality or supply, or hot spots in the data hall.

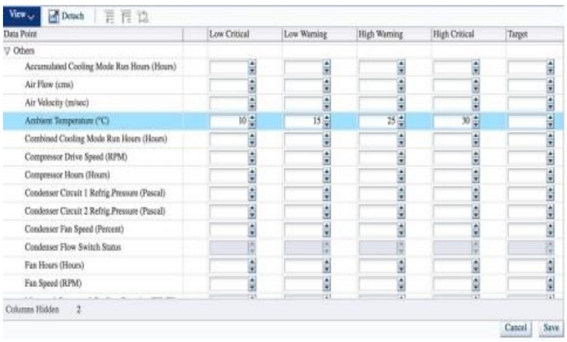

Fig. 12 – NTT DCIM – Configurable Alert Setting

Real-time alarms empower the end-user to proactively manage and mitigate risks by avoiding issues before they happen. Enabling new efficiencies is also a key part of DCIM's value proposition. By identifying stranded capacity, such as power, cooling, or space, NTT Communications has been able to adjust its data centers' layouts to enhance the use of key resources. DCIM also provides the insight needed to better manage and plan data center capacity overall.

Fig. 13 – NTT DCIM – Asset Capacity for Better Business Planning

5.3 Next Step: Automation

NTT Communications' DCIM acts as a middle point to convert protocols between hardware and data collection, and it supports distributed real-time (or near real-time) control. The second phase, pending deployment, will use DCIM to control devices and systems, including power systems and cooling units. NTT Communications aims to replace the traditional building management systems (BMS) functionality in its data centers with DCIM.

BMS commonly are used for environmental control in data centers and tend to be a data center's the largest proprietary control system. There are overlaps between a BMS and DCIM, especially with monitoring. However, BMS are not intended to measure moving workloads or heat loads or make sense of them, nor do they link IT operating information.

By standardizing DCIM and develop its own internet-of-things platform, NTT Communications streamlines monitoring by eliminating duplicate functionality and enables more granular monitoring, including tracking temperatures at a local level and tracking IT power consumption. We envisage adopting DCIM to manage key data center devices and systems in real-time on a standard web browser. Select data will also be available to data center staff via an HTML5 version of DCIM for mobile devices.

The third phase aims to exploit the software as the real-time control and automation framework for NTT Communications' data centers. At the heart of this effort will be deep analysis of an array of data from various sources, such as weather conditions and power costs. Using historical data, DCIM will enable predictive forecasting and scenario planning for IT moves, adds, and changes, and machine-learning algorithms will facilitate cost-optimized operations. For example, NTT

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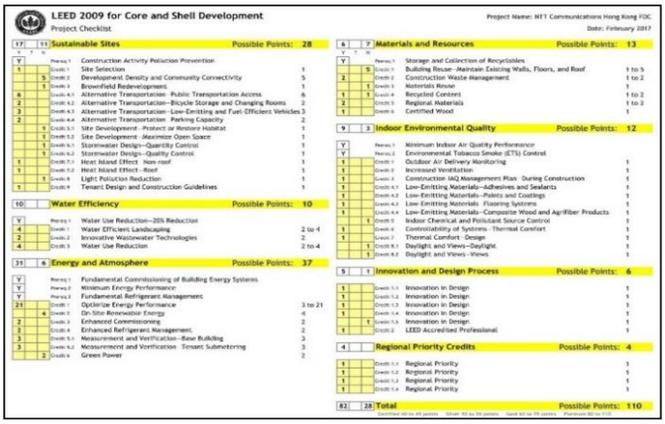
Communications aims to use DCIM for machine-learning-driven automation of its data center cooling equipment. When conditions are optimal, as determined by DCIM and a combination of other data, the set-point temperature and fan speeds on cooling units will automatically adjust. In time, DCIM may enable NTT Communications' data centers to be operated closer to their design peaks, augmenting facility use and, ultimately, enabling substantial cost savings.

5.4 First LEED Platinum for Best Sustainability

FDC2 showcases green engineering excellence in design, construction, and operation. FDC2 is the first data center in Hong Kong as well as greater China to achieve LEED2009 for Core and Shell Development (LEED-CS 2009) certification at the highest level, platinum, and its roadmap to achieve this rating was borne with pioneering digital transformation as the driving force behind data center and sustainable development best practices.

According to USGBC LEED-2009 Rating System Selection Guidance [5], LEED 2009 for Core and Shell Development (LEED-CS 2009) addresses the design and construction activities for projects. As such, LEED-CS 2009 is the most appropriate for the LEED certification of FDC2, addressing seven categories: Sustainable Sites (max 28 points), Water Efficiency (max 10 points), Energy and Atmosphere (max 37 points), Materials and Resources (max 13 points), Indoor Environmental Quality (max 12 points), Innovation in Design (max 6 points), and Regional Priority (max 4 points).

LEED-CS 2009 certifications are awarded according to the following benchmarks: Certified: 40 to 49 points; Silver: 50 to 59 points; Gold: 60 to 79 points; Platinum: 80 points and above. In February 2017, USGBC announced that FDC2 attained an overall 82 points under the LEED-CS 2009 system, ranking it at Platinum level – the **FIRST** in Hong Kong. FDC2's evaluation score is displayed below.


LEED 2009 for Core and Shell Development
Project Checklist

Project Name: NTT Communications Hong Kong FDC
Date: February 2017

Y	?	N			
17		11		**Sustainable Sites**	Possible Points: 28
Y			Prereq 1	Construction Activity Pollution Prevention	
1			Credit 1	Site Selection	1
		5	Credit 2	Development Density and Community Connectivity	5
		1	Credit 3	Brownfield Redevelopment	1
6			Credit 4.1	Alternative Transportation—Public Transportation Access	6
2			Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	2
3			Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3
2			Credit 4.4	Alternative Transportation—Parking Capacity	2
		1	Credit 5.1	Site Development—Protect or Restore Habitat	1
		1	Credit 5.2	Site Development—Maximize Open Space	1
		1	Credit 6.1	Stormwater Design—Quantity Control	1
		1	Credit 6.2	Stormwater Design—Quality Control	1
1			Credit 7.1	Heat Island Effect—Non-roof	1
1			Credit 7.2	Heat Island Effect—Roof	1
		1	Credit 8	Light Pollution Reduction	1
1			Credit 9	Tenant Design and Construction Guidelines	1
10				**Water Efficiency**	Possible Points: 10
Y			Prereq 1	Water Use Reduction—20% Reduction	
4			Credit 1	Water Efficient Landscaping	2 to 4
2			Credit 2	Innovative Wastewater Technologies	2
4			Credit 3	Water Use Reduction	2 to 4
31		6		**Energy and Atmosphere**	Possible Points: 37
Y			Prereq 1	Fundamental Commissioning of Building Energy Systems	
Y			Prereq 2	Minimum Energy Performance	
Y			Prereq 3	Fundamental Refrigerant Management	
21			Credit 1	Optimize Energy Performance	3 to 21
		4	Credit 2	On-Site Renewable Energy	4
2			Credit 3	Enhanced Commissioning	2
2			Credit 4	Enhanced Refrigerant Management	2
3			Credit 5.1	Measurement and Verification—Base Building	3
3			Credit 5.2	Measurement and Verification—Tenant Submetering	3
		2	Credit 6	Green Power	2
6		7		**Materials and Resources**	Possible Points: 13
Y			Prereq 1	Storage and Collection of Recyclables	
		5	Credit 1	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 5
2			Credit 2	Construction Waste Management	1 to 2
		1	Credit 3	Materials Reuse	1
1		1	Credit 4	Recycled Content	1 to 2
2			Credit 5	Regional Materials	1 to 2
1			Credit 6	Certified Wood	1
9		3		**Indoor Environmental Quality**	Possible Points: 12
Y			Prereq 1	Minimum Indoor Air Quality Performance	
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	
1			Credit 1	Outdoor Air Delivery Monitoring	1
1			Credit 2	Increased Ventilation	1
1			Credit 3	Construction IAQ Management Plan—During Construction	1
1			Credit 4.1	Low-Emitting Materials—Adhesives and Sealants	1
1			Credit 4.2	Low-Emitting Materials—Paints and Coatings	1
1			Credit 4.3	Low-Emitting Materials—Flooring Systems	1
1			Credit 4.4	Low-Emitting Materials—Composite Wood and Agrifiber Products	1
		1	Credit 5	Indoor Chemical and Pollutant Source Control	1
1			Credit 6	Controllability of Systems—Thermal Comfort	1
1			Credit 7	Thermal Comfort—Design	1
		1	Credit 8.1	Daylight and Views—Daylight	1
		1	Credit 8.2	Daylight and Views—Views	1
5		1		**Innovation and Design Process**	Possible Points: 6
1			Credit 1.1	Innovation in Design	1
1			Credit 1.2	Innovation in Design	1
1			Credit 1.3	Innovation in Design	1
1			Credit 1.4	Innovation in Design	1
		1	Credit 1.5	Innovation in Design	1
1			Credit 2	LEED Accredited Professional	1
4				**Regional Priority Credits**	Possible Points: 4
1			Credit 1.1	Regional Priority	1
1			Credit 1.2	Regional Priority	1
1			Credit 1.3	Regional Priority	1
1			Credit 1.4	Regional Priority	1
82		28		**Total**	Possible Points: 110

Fig. 14 – NTT FDC2 Evaluation Score – LEED 2009 Core and Shell Development

The FDC2's LEED-CS 2009 score distribution across is illustrated in Figure 15, which shows the score in each individual category. It demonstrates that FDC2 has comprehensively complied with LEED-CS 2009, a benchmark of environmentally sustainable building performance:

- **Sustainable Sites**: 17 out of 28 points (61%)
- **Water Efficiency**: 10 out of 10 points (100%)
- **Energy and Atmosphere**: 31 out of 37 points (84%)
- **Materials and Resources**: 6 out of 13 points (46%)
- **Indoor Environmental Quality**: 9 out of 12 points (75%)
- **Innovation in Design**: 5 out of 6 points (83%)
- **Regional Priority**: 4 out of 4 points (100%)

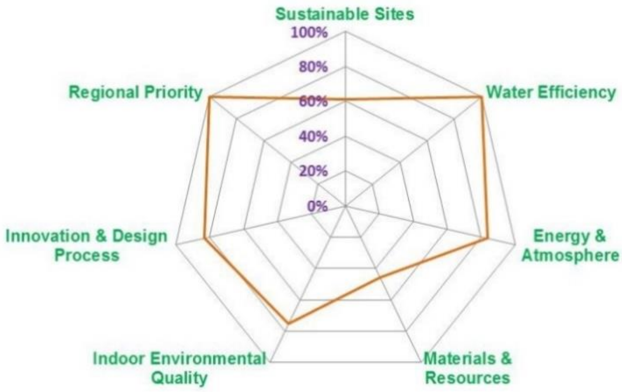


Fig. 15 - NTT FDC2 The spider diagram of LEED-CS 2009 among various categories of credits

The categories with the most outstanding environmental performance are Water Efficiency, Energy and Atmosphere, Indoor Environmental Quality, Innovation in Design, and Regional Priority. FDC2 in particular successfully obtaining the full 21 points under Optimize Energy Performance, a subcategory of Energy and Atmosphere, demonstrating the excellence in its innovative Cooling Wall, Cooling Battery and effective Block Redundancy Critical Power System designs as well as our digitalization operation.

FDC2 is a world-class green data center, and its sustainable operation will continue its pioneering, innovative, and excellent environmental performance to contribute to improve the environment. In this, FDC2 will serve as a role model for sustainable development in data center and IT.

6. CONCLUSION

The digitalization of the new economy drives continuous advancement in hardware technology, which is refreshed every 3-5 years. As a result, the physical structure and critical infrastructure supporting this new economy must be flexible enough to remain technically viable and cost effective for 12-15 years or more. Businesses can no longer afford the power density restrictions of older designs that represented the status quo of the past decade, much less the previous half century. Going forward, they must be able to deliver high efficiency and levels of availability under virtually any operating conditions while providing low TCO. Ultimately, hyper-scale data centers must become an extension of the evolving IT philosophy – supporting change and not being a limit to future innovation.

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Paper No. 8

DEEP LEARNING TECHNOLOGY & APPLICATIONS WITH BIG DATA

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ABSTRACT

In this paper, we walk through the development of Deep Learning and Neural Networks. The success of Deep Learning technology has relied very much on having a large amount of training data (Big Data), which allows the capturing of hidden information in the data (through embeddings or deep representations). Natural Language Processing (NLP) and Image Processing are two applications discussed as examples for Deep Learning with Big Data.

1. INTRODUCTION

Over the past few years, Google and many major IT companies have invested significantly in Machine Learning technology, in particular, so-called "Deep Learning" using very-large-scale multi-layer neural networks, in order to enhance their services with, for example, better image searching and machine translation capabilities. Deep Learning has already demonstrated great success in applications across many domains such as object detection, image classification, speech recognition, natural language and text processing, and medical diagnosis and drug discovery. We envision that Deep Learning will have great potential in many other areas of research and applications.

2. ARTIFICIAL INTELLIGENCE, MACHINE LEARNING, DEEP LEARNING: PROGRESS THROUGH TIME

What is Deep Learning? Within the field of computer science, there is an area called Artificial Intelligence (AI), which began in the 1950s when Alan Turing wrote the paper titled "Computing machinery and intelligence" [1] in which he introduced the famous Turing Test (sometimes referred to as the "Imitation Game" [2]). The Turing Test was essentially a test of whether a computer could fool a person, over the course of a conversation between the person and the computer, into believing it was a human being. Passing the Turing Test would be evidence that a computer could exhibit human intelligence. The human intelligence that a computer was capable of exhibiting was "artificial intelligence".

Whilst pioneering Artificial Intelligence (and indeed Computing), Alan Turing made an important observation: "*Instead of trying to produce a programme to simulate the adult mind, why not rather try to produce one which simulates the child's? If this were then subjected to an appropriate course of education one would obtain the adult brain.*" The implication of his observation was that learning (a course of education) was the basis of intelligence. Some 30 years later, Machine Learning – the idea of learning from past experience or data to make accurate predictions – became the focus of Artificial Intelligence, and Deep Learning followed some 20 years later.

Why did it take so long to get to where we are now? The journey toward Deep Learning was affected by the stalled development of the Artificial Neural Network (NN). The Perceptron [3], the building block of the NN, was inspired by neurobiology and was invented in the 1950's as a tool for learning. In the late 1960s, Marvin Minsky, an MIT professor, published a very influential book, *Perceptrons* [4], which discredited the capabilities of the NN, and this caused a significant decline in research funding for NN for many years. So it was not until the 1980s that interest in NN research resurged on the back of promising experimental results which showed the multi-layer NN's ability to compute any logical function and approximate any function using nonlinear activation functions.

In recent years, we have had the benefit of more and more data – to the point of having Big Data – to learn from, and this has affected the way in which Machine Learning could be accomplished. New techniques for learning from Big Data have resulted in Deep Learning, where very-large-scale multi-layer neural networks are used to learn from plentiful raw data.

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To be fair, Big Data was not the only factor to spur the progress in Deep Learning. What really pushed Machine Learning to new heights in the 2000s came from what we call the "A, B, C, D's" of Deep Learning: (1) the introduction of faster and effective **A**lgorithms, especially an efficient backpropagation learning mechanism, (2) the availability of large volumes of training data, i.e. **B**ig data, (3) faster computing and larger memory resources made available via the **C**loud computing environment, and (4) hefty **D**ollar investment from major companies such as Google, Microsoft, SAS, Amazon, eBay, Facebook, Alibaba, Baidu, Huawei and Tencent.

3. IMITATING HUMAN LEARNING

Alan Turing introduced us to the Imitation Game where the goal of artificial intelligence was to be able to imitate humans.

One important aspect of Deep Learning is that the learning can be from raw data, rather than from features of the data which have been pre-identified by humans as useful. To understand this aspect, consider how children learn. After showing a child many pictures of a cat, it is possible for the child to learn the concept of a cat without being told specifically that a cat has a tail, whiskers and fur (features). Deep Learning imitates this kind of human learning.

In fact, both Machine Learning and Deep Learning take their cues from human learning, particular in the classroom. The notion of "Supervised Learning" in Machine/Deep Learning is the familiar concept of learning from a teacher who knows the correct answers to problems. In the human classroom learning scenario, we learn from the questions and answers given to us by the teacher, we fine-tuned our learning when we take mock examinations, and our learning is tested by the final examination. For Machine/Deep Learning, there is analogous idea of learning from training data (classroom questions and answers) and validation data (mock exams) and being evaluated on test data (final exams). Much progress on Machine/Deep Learning has been made under the Supervised Learning scenario.

4. WHAT IS NEURAL NETWORK (NN)?

The perceptron (single layer NN) is the basic component of NN, which consists of a number of input neurons $\{x_1, x_2, \ldots x_p\}$, a weight for each input neuron $\{w_1, w_2, \ldots w_p\}$, and a summation function that computes $y = \Sigma w_i x_i$ the weighted sum of the inputs, and an activation function h that takes y as input and computes h(y) (as shown in Figure 1). Often the two functions (the summation function and the activation function) are combined into one summation-activation function neuron (orange circle) in diagrams that depict multi-layer NNs.

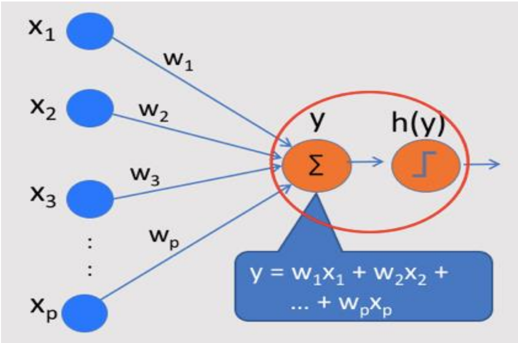

Fig. 1 – Perceptron – Basic Component of NN

A Deep Learning NN consists of many layers with many (summation-activation) neurons in each layer (Figure 2). The layers between the input layer and the output layer are called "hidden layers". Given values for the weights, the NN can compute a prediction y from inputs $\{x_1, x_2, \ldots x_p\}$, by applying the summation-activation functions layer by layer (feed-forward).

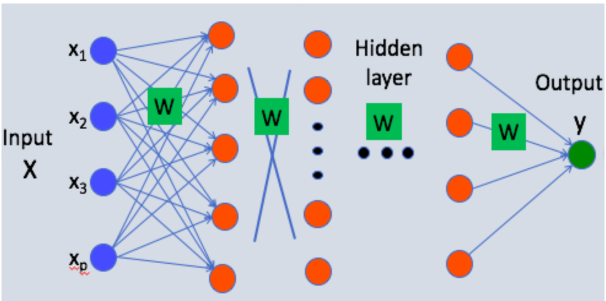

Fig. 2 – A Deep Learning NN

In Supervised Learning, the training data would consist of many inputs with their corresponding correct answers. During the training phase, the NN-computed prediction y of each input would be compared with its corresponding answer, and the weights in the NN would be adjusted to minimize the difference between the answer and the prediction (back-propagation). Thus, NN learning is basically the process of adjusting the weights of the NN so as to minimize the difference between the computed prediction and the corresponding answer for each input instance.

Depending on the application and the amount of training data, the architecture (i.e. the number of layers, the number of neurons at each layer, and the connectivity of the neurons between layers) of the NN may be different.

Usually, more data will allow a NN to yield better predictions. However, more layers and more neurons might not ensure better performance because of the problem of overfitting (i.e. getting very accurate predictions for the training data but very inaccurate predictions on the test data because of a certain degree of "memorization" of answers during the training stage). Larger networks also take more time to train. In the following we shall present two most common types of NN, each of which can serve different applications.

5. CONVOLUTIONAL NEURAL NETWORKS (CNN) & IMAGE PROCESSING

Convolutional Neural Networks (CNN) (Figure 3) are special kinds of NNs, particularly well-suited for image processing. Images are usually stored as 2D pixels (usually of a large size with neighboring pixels being related). To cater for image data, the CNN has two types of hidden layers: convolutional and pooling. The *convolutional* layer applies small-size "masks" or "filters" (these are the weights to be learned) to the whole image to capture different local features of the image, such as lines, corners, small/larger objects (for higher layers), while the *pooling* layer reduces the size of data or compresses the data using the maximum or average of neighboring pixels to represent a patch of the image.

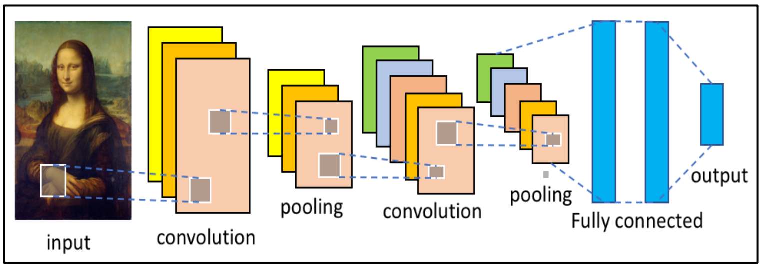

Fig. 3 – Convolutional Neural Networks

We mentioned Supervised Learning earlier. The bottleneck with Supervised Learning is the need to have the "correct answers". The boost to progress in image processing came from ImageNet's huge database of around 15 million labeled high-resolution images collected from internet and its annual competition on image classification [5]. Fifteen million images are unremarkable by themselves, but the fact that they were labeled into roughly 22,000 categories was.

In 2012, there was a breakthrough when AlexNet [6], a 7-layer CNN, won the competition by a wide margin. In the successive years, deeper and deeper CNNs entered the competition, and by 2015, super-human performance for image classification was achieved by a 152-layer CNN.

The development of CNNs for image processing led to new discoveries. Researchers were interested in what was happening in the hidden layers (in between the input layer and the output layer) of the CNNs and discovered that the hidden layers were capturing features from the image, i.e. feature learning. Researchers then began to realize that the CNNs, which had achieved super-human performance in image classification, may be mapping images into some kind of meaningful deep representation (aka embedding) of the image and that this meaningful embedding could be used as the starting input for other image processing applications (other than image classification), such as image captioning, image segmentation and even the generation of new images by making small changes to an embedding of an image.

6. RECURRENT NEURAL NETWOKS (RNN) & NATURAL LANGUAGE PROCESSING

Recurrent Neural Networks (RNN) (Figure 4) are special kinds of NN, particularly well-suited for sequences of data such as texts and speech.

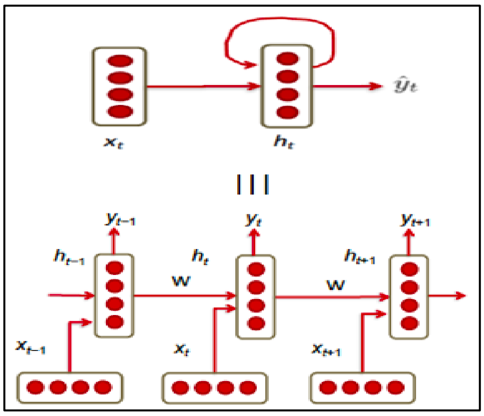

Fig. 4 – Recurrent Neural Networks

The data for language processing is usually represented by a sequence of input data, which is 1-D (and tends to be relatively much smaller in size than image data which is 2-D). However, the sequences can be long and each input in the sequence is related to its neighboring input. A RNN consists of a hidden layer representing the state of the RNN when processing the sequence of input data. Conceptually, the number of hidden layers (states) equals to the length of the sequence and each state depends on its previous state as modified by each input data in the sequence. As the sequence can be long, there are intrinsic problems with RNN, e.g., the output can be

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related to an input processed many time steps earlier, so mechanisms, such as Long Short Term Memory (LSTM) and attention, have been devised to handle this problem, which is called the "vanishing gradient" problem.

Just as the concept of embedding arose with image processing, the concept of embedding also arose in the Natural Language Processing (NLP). The mapping of words to vectors that somehow captures the meaning of the word was made possible through two clever algorithms, one of which is known as Continuous Bag of Words (CBOW) [7]. The principle behind CBOW was an observation made (again) in the 1950s: "You shall know a word by the company it keeps." [8] In solving the task of predicting a word when given the words surrounding it, the NN's hidden layer effectively give a very good embedding of the word.

7. CONCLUDING – BIG DATA or NOT?

Much of the public interest in Deep Learning arose from AlphaGo [9], Google Mind's Deep Learning programme which beat human champion players of Go. AlphaGo trained on 30 million board positions taken from Go games played by human experts. We have mentioned the importance of Big Data for the training of Deep Learning NNs. However, there is now a new piece to the story: the creators of AlphaGo created another version of AlphaGo called AlphaGo Zero [10].

What is significant about AlphaGo Zero is that it was trained without any human data! AlphaGo Zero lends support to *tabula rasa* – the idea that people are born without any built-in mental content and all knowledge has to be learnt from scratch. In commenting on AlphaGo Zero, David Silver (one of AlphaGo and AlphaGo Zero's key developers) posed an important question: Is data really important in learning? Before AlphaGo Zero, the answer was clearly "yes". But after AlphaGo Zero, we are not so sure. Time will tell us more.

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Paper No. 9

PREVENTIVE MAINTENANCE BY USING CONNECTED IoT DEVICES IN ELECTRICAL SYSTEM

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ABSTRACT
Proven technologies exist today that can fully digitize the electrical distribution infrastructure of large and critical buildings and facilities. These are helping improve safety for people and assets, increase power reliability and business continuity, optimize operational and energy efficiency, achieve sustainability goals, and meet regulatory compliance. Yet, most organizations are still not taking advantage of these latest advances in power distribution connectivity and intelligence, some of which may already be in place in their facilities. Without this crucial last step, facility teams are working blind, unaware of many hidden risks and opportunities.

1. INTRODUCTION

The pressures on organizations have never been greater. Businesses routinely face tough competition, while the boards of businesses and institutions are expecting improvements in efficiency – often with fewer resources – to help reduce costs and protect profits. At the core of keeping operations running smoothly is a steady flow of electrical energy, the most important input to critical operations.

This is why operations and maintenance teams of large and critical power facilities – such as hospitals, data centers, and continuous industrial processes – have four primary goals regarding their electrical infrastructure: safety, reliability, efficiency, and compliance. Each of these goals continues to present serious challenges as well as great opportunities:

- **Risks to safety:** Electrical system issues are recognized as the cause of 22% of workplace fires [1], while an estimated 25% of electrical failures are attributed to loose or faulty connections, according to a major insurance carrier [2]. This points to a need for more vigilance in finding sources of overheating. And while today's breakers reliably protect from overloads and short circuit conditions, hospital operating theatres are particularly sensitive to insulation faults, which can put lives at risk. Finally, if a facility-wide or localized outage occurs, it's crucial that power be restored immediately to ensure the safety of occupants, as well as re-establishing operations.

- **Risks to uptime:** Studies have shown that 30 to 40% of business downtime is caused by power quality disturbances, and that 70% of those disturbances originate within the premises [3]. Any amount of power interruption can be devastating to an organization's operations. Given that the average outage in mission critical facilities lasts 90 minutes [4], these incidents represent a massive cost to businesses and institutions. Beyond lost productivity is the cost of replacing expensive equipment such as a failed transformer. To put this in perspective, a study by Lawrence Berkeley National Laboratory found that power interruptions cost the US economy approximately $59 billion in 2015, which was an increase of more than 68% since an earlier 2004 study. Commercial and industrial businesses account for more than 97% of these costs [5]. Preventing downtime requires 'seeing into the future', or rather being able to identify when conditions on your power network are deviating outside of safe parameters, or when protection settings have deviated from their original design.

- **Risks to energy efficiency:** Beyond the costs of power-related interruptions, there are also the economic costs of inefficiency. The US Department of Energy estimates that "with the application of new and existing technologies, buildings can be made up to 80 percent more efficient or even become 'net zero' energy buildings with the incorporation of on-site renewable generation." [6] This is a huge opportunity for organizations to reduce energy consumption, which for data centers and industrial processes can represent a large percentage of operating costs. Doing so requires gaining visibility into every aspect of energy, from billing, to consumption, to onsite energy production.

- **Risks to operational efficiency:** Another big part of operational costs is the time and money facility teams spend maintaining power and buildings systems, often with limited staff. Maintenance represents 35% of a building's lifetime costs (IFMA, 2009) [7], so any improvements to team efficiency and equipment lifespan can represent a significant bottom line savings. In fact, another Department of Energy study revealed that by implementing a programme of condition-based predictive maintenance, a building can save up to 20% per year on maintenance and energy costs, while increasing the projected lifetime of the building by several years [8]. However, predictive maintenance requires a new level of analytic capabilities that can help predict equipment needs and enable collaboration with experts when needed.

- **Risks to compliance:** Emissions regulations are becoming common in most countries, while many corporations are implementing their own sustainability goals. Meeting these objectives is challenging without the necessary energy consumption data. Regarding maintaining reliability, healthcare facilities are often required to regularly test backup power systems. It's also important to ensure energy providers are complying with power quality requirements of energy contracts. These processes can be onerous without the appropriate analysis and reporting tools. Finally, to acquire the data necessary to manage electrical safety, reliability, and efficiency means depending more on connected systems. This brings more risk of cyber-attacks, requiring cybersecurity best practices to be adhered to.

This is a demanding set of challenges. What is even more concerning is that facility management teams in most large buildings and plants are still unaware of these risks and opportunities. The reason: a lack of visibility to enterprise-wide power and equipment conditions. Though the consequences of a power outage are severe, and the costs of energy and maintenance are high, most new and legacy facilities still use only a rudimentary level of technology to help prevent power system failures and minimize operational costs. When problems arise, the response is usually on a reactive rather than proactive basis.

CASE STUDY 1:
Wastewater plant averts disaster

One of the largest wastewater treatment plants in the world was in the process of expanding their power management system. When the final metering devices were connected, the system immediately detected a serious problem. At one of the main substations feeding the plant, the tie breaker between the two incoming transmission lines was unexpectedly closed. Worse, a fuse was blown on one of the incomers, meaning dual incomer redundancy was lost. If there had been a grid outage on the remaining incomer, an entire section of the plant could have experienced a disastrous failure. Fortunately, this risk was detected and corrected, highlighting the critical importance of 24/7 electrical system monitoring.

Fig. 1 – Facility Teams for Large and Critical Buildings need to Maintain the Safety, Reliability, Efficiency, and Compliance of their Electrical Infrastructures

1.1 Intelligent Power has Arrived

Facility teams should be taking full advantage of the many applications and benefits that digitization now enables. Without a fully connected and intelligent power management system, facility teams are 'working blind,' unaware of the many risks that may be threatening business continuity and efficiency. And risks progressively increase as new loads are added that could affect power quality, especially non-linear loads often used to improve energy efficiency such as LED lighting, VSDs, switching power supplies, etc.

Like advances in vehicle-based intelligence in the automotive industry, power distribution systems now include a complete network of smart, connected devices. These deliver timely, actionable information to facility teams through powerful software applications, either at the desktop or on their mobile devices anywhere they are. The newest tools are making it simpler than ever to understand power and energy conditions and manage complex power systems. The steps to implementing such a solution can be extremely cost-effective considering all the dimensions of ROI that can be achieved in a very short payback period. Many of the pieces may already be in place in most facilities, such as smart meters and breakers. Once connected, facility teams will immediately benefit from:

1. early warning of risks

2. faster recovery from problems

3. time and cost-saving opportunities being revealed

4. streamlined maintenance

5. enhanced equipment performance and lifespan

This paper will show how a nominal investment in a digitized electrical distribution infrastructure can help large and critical facilities to more easily meet core operational, sustainability, and regulatory goals while gaining additional unexpected benefits.

Fig. 2 – Smart, Connected Devices are the First Step in a Completely Digitalized Power Distribution System

2. THE DIGITIZATION OF POWER DISTRIBUTION

Digitization is all around us. Consider the automotive industry. Cars today are some of the most digitized machines in our lives, yet we all take for granted the incredible advances that have taken place in recent years.

Every aspect of operation is monitored, displayed, and, in some cases, controlled automatically. These capabilities have vastly improved the safety, reliability, efficiency, and compliance of every kind of vehicle, while improving ease-of-use and driving experience for owners. For example, vehicles routinely provide:

- Oil pressure, temperature, battery voltage, fuel level, coolant level, etc. sensors: make sure you are alerted in case of any malfunction before you get stranded on the side of the road.
- Anti-lock braking system (ABS): prevent un-controlled skidding.
- Stability controls: prevent loss of traction (by sharing the same brake actuator and sensors with ABS).
- Automatic air bags: to protect driver and passengers in the event of a collision.
- Emission sensing and control: to meet regulatory standards.

More advanced capabilities might include:

- Tire pressure monitoring sensors: improve fuel economy and alerting the driver to a potential flat.
- Backup cameras with proximity sensors: guide the driver into a parking spot.
- Blind-spot monitoring: increase safety of lane changes.
- Lane departure warning: help avoid collisions due to driver error, distractions, and drowsiness.
- Look-ahead radar: starts braking before a collision can occur.

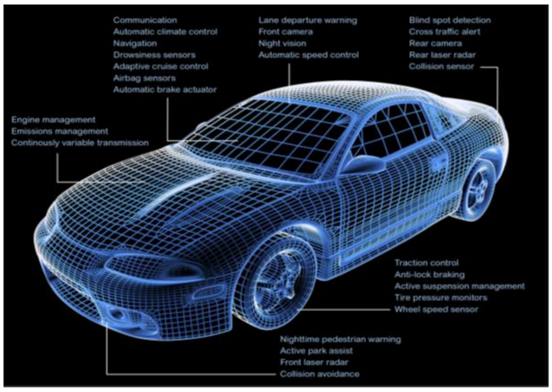

Fig. 3 – Advancements in Automobile Technology provide as Standard Equipment a Vast Array of Sensors and Intelligence in Every Vehicle

2.1 Smarter Power Distribution

It is now unthinkable to deal with the extreme complexity found in cars without sophisticated digitization. Imagine being an auto mechanic and having to troubleshoot a modern car without a diagnostic scanner.

The same is true for modern electrical distribution systems. Systems are larger and typically evolve over time to accommodate more loads, many of which are increasingly power sensitive (e.g. automation systems). Many types of loads, such as variable speed drives, can also be the source of potential power quality (PQ) issues. Beyond energy-consuming loads, larger sites will often include onsite generation and storage, either for power backup, ‘peak shaving’ to avoid demand penalties, or to consume self-generated renewable energy when it’s most economical.

As the complexity and sophistication of our electrical distribution infrastructure increases, it becomes more important to have the appropriate digital sensors, advanced controls, and analytic capabilities to detect, diagnose, and correct issues before they cause mission-critical systems to fail. Touching every corner of a facility’s electrical network, the latest ‘edge control’ software and mobile apps connect to smart devices to keep facility teams informed and reveal deep insights.

Like digitized vehicles, digitized power distribution optimizes safety for people and assets, while improving reliability and business continuity. It provides the data that is converted by analytic software to actionable information to help facility teams maximize energy efficiency as well as life cycle efficiency. As an alternative to interval-based maintenance, digitization enables condition-based maintenance, enabling equipment servicing to be performed at the right times to improve reliability and avoid unnecessary time and costs.

A digitized power network also simplifies energy and emissions tracking and reporting for regulatory compliance, to support participation in carbon markets, or to publicly showcase energy performance.

Finally, data from distributed devices can be automatically and continuously uploaded to cloud-based platforms, enabling 24-hour support from expert services. This can be especially valuable for facilities that do not have adequate in-house resources or expertise.

CASE STUDY 2:
University improves safety and reliability

For a large university, unpredicted power outages carry a high cost, both financially and potentially in lost lives at its medical center. After suffering a major transformer failure, the university built its own substation and installed a complete power management system.

The intelligent power quality meters and analytic software perform automated alarm monitoring, breaker status monitoring and control, and transformer temperature monitoring.

The system helps schedule preventative maintenance, correct transient anomalies, and enables quick response to emergencies such as power outages and weather-related incidents.

3. SIMPLE STEPS TO GETTING CONNECTED

Unlike today's vehicles, power distribution systems do not come 'stock' with complete digitization. However, the technology is available, proven, and operating successfully in thousands of facilities worldwide.

Currently, the required devices, communication networking, and software applications need to be specified. It is expected that in future all of this will become a standard and ubiquitous part of every power distribution installation.

The good news is that most newer power distribution systems may already have the connectivity available but may not have it implemented yet. Installed devices simply need to be networked together. Even legacy systems have simple retrofit possibilities to add the appropriate devices and sensors. These upgrades are extremely cost-effective when considering the long list of benefits to the facility and the organization.

Let's take a look at the type of devices, communications, and architectures that make a digitized power distribution system possible.

3.1 Smart, Connected Devices

Digitization of power distribution has been enabled by the increasing connectivity of devices, aided by the global trend in the Internet-of-Things (IoT). More and more devices and sensors are becoming digitized, with new kinds being introduced all the time. Table 1 lists some common types.

Device / Equipment	**Data / control provided**
Protection devices	
Circuit breakers	Trip units with embedded power and energy metering, breaker condition monitoring, diagnostics, alarms, data logs
Protective relays	Trip units with diagnostics, network status, alarms, data Logs
Meters, monitors, sensors	
Energy meters	Basic single or multiphase energy consumption, data logs
Power quality monitors	Energy, power, demand, advanced power quality capture and analysis, equipment status, alarms, data and event logs
Environmental sensors	Temperature, humidity, gas, and pollution (e.g. to help avoid corrosion, reduced performance, etc.)
Arc-flash sensors and relays	Alarm on arcing condition
Vibration sensors	Vibration readings
Voltage, current sensors	Single measurements on each phase
Busbar temperature sensors	Temperature, alarm on exceeding threshold
Embedded equipment sensors, controllers	
UPSs, DC inverters, battery chargers	UPS status, battery levels, control functions
Gensets	Genset status, voltage, current, power, fuel level, temperature, control functions
Transformers	Temperature sensors, voltage, current
Automatic Transfer Switch	Switch status, control functions
Automation equipment	
PLC	Data from connected devices, control functions
RTU	Analog and digital input measurements

Table 1 - Typical Types of Smart, Connected Devices within a Power Distribution System

Devices can be integrated into a communications network in several ways. Wireless can be used for ease of installation, especially for simpler measurement or sensing requirements. Serial communications can make a good choice in some cases, especially as serial ports are common on many types of devices. Ethernet is the best choice where large amount of data and fast data transfer are requirements, such as for more advanced power quality monitors and for communications hubs that aggregate data from many downstream devices.

Standards, such as the IEC61850 standard, and communications data models are emerging for more effective universal and non-proprietary communi-cations. Most smart devices offer a choice of communication protocols for system compatibility, while some provide modular hardware designs that enable communication ports to be installed in the field for devices not already connected. Some more advanced devices also offer modular firmware architectures that allow functionality to be customized. This kind of flexibility allows devices to adapt to current and future needs.

IoT-enablement means smart devices can upload data directly to Cloud-based data storage and applications, making for simpler data sharing and collaboration across one or more facility's operations and maintenance teams. Many devices also offer direct browser-based access to real-time and logged data using mobile devices.

An example of what an IoT-enabled electrical distribution architecture can look like is shown in Figure 4. This illustrates a simplified architecture for a hospital, highlighting devices at the medium voltage, low voltage, and final distribution levels.

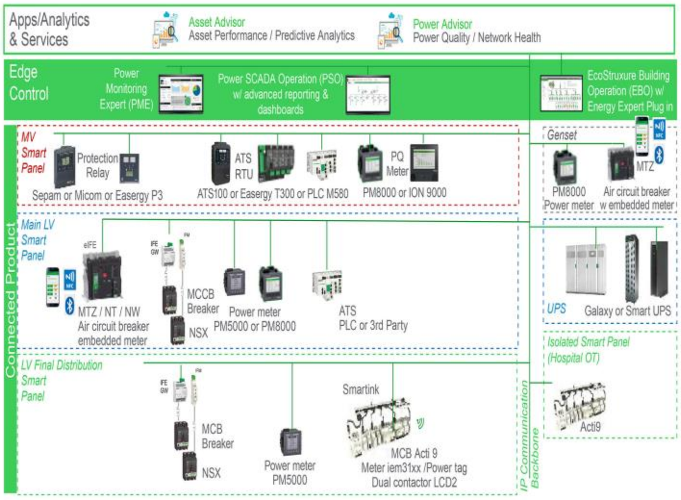

Fig. 4 – A Typical Digitalized Power Distribution Monitoring Network showing Smart Devices located at Each Level of the Electrical System

3.2 Powerful Supervisory Applications

In a digitized power distribution system, a software application acts as the central collection point where all digital real-time and historical data is aggregated and made available to all stakeholders that oversee the electrical infrastructure.

The combination of software and device network is often referred to as an energy and power monitoring systems (EPMS). For large and mission-critical systems, supervisory control and data acquisition (SCADA) systems designed for power distribution are available. These have built-in redundancy that supports fail-safe operation, reliable control actions, and highest-accuracy timing.

With central software, the benefits of digitization come to fruition. Using connectivity to all the devices and equipment mentioned previously, the software makes it possible to supervise electrical processes such as power transfers and network automation. This is commonly done with the help of 'single-line' diagrams that display power and energy conditions throughout the facility, as well as equipment status (Figure 5).

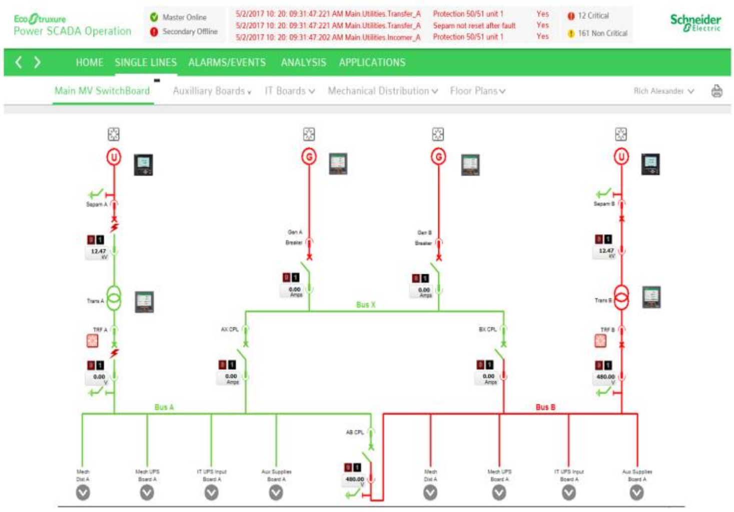

Fig. 5 – A Typical 'One-Line' Diagram showing Electrical Conditions and Equipment Status throughout a Power Distribution System

Event data is captured and stored on board each device with precise timestamping, then automatically uploaded to the software. The software sends automatic email or SMS notifications for alarms and events to designated recipients. It will also provide extensive analytic capabilities to help diagnose and isolate sources of problems, as well as reveal opportunities to improve power, energy, and equipment performance. The next sections describe how these tools simplify each process.

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3.3 Power Management Made Easy

With a fully digitized power system, facility teams can take advantage of a vast number of applications to help meet safety, reliability, efficiency, and compliance goals. Desktop edge-control software and mobile apps enable access to devices distributed across the entire electrical infrastructure, while analytic tools make it simpler than ever to gain deep insights, enable decisions, reduce response time, and make operations and maintenance workflows more efficient. Further, cloudbased advisor services, with experts helping perform analytic and advisory functions, can take the burden off the onsite facility team by assisting with preventive or predictive maintenance.

However, it is important to make sure the data received by analytic applications is accurate and reliable. Experience has shown that many systems are prone to wiring, configuration, and commissioning mistakes. It is vital to have an error checking algorithm that detects all of these errors so they can be eliminated. Without this important step, incorrect decisions can result from unreliable data.

CASE STUDY 3:
Soap factory solves production stoppages

A soap making factory was experiencing mysterious production line stoppages about once a month. Each caused a four to eight-hour delay costing $20,000 (USD) per hour and $120,000 (USD) every month.

A networked power management system was installed. Smart power quality meters and analytic software determined the problem was power sags, swells, and transients coming from the utility grid.

The utility determined the problem was coming from a heavy equipment operator close by that was generating disturbances back onto the grid. The utility installed new lines that isolated the plant from the problem, which resolved the downtime issue.

3.4 Optimizing Safety

Preventing electrical fires: Up to now, electrical fire prevention has involved using infrared (IR) scanning. An IR camera is used to detect hot spots in busbar junctions, transformer connections, or breaker contacts. This procedure is quite expensive and, therefore, is only performed at specific intervals, from twice a year to once every two years. The problem is that electrical fires are often caused by incorrectly performed maintenance procedures; therefore, the issue can be missed if the maintenance is done after the regular IR scanning has been performed.

Fortunately, digitization brings a more sophisticated and continuous approach to thermal monitoring. Wireless sensors installed in strategic locations detect abnormal temperature rises due to high impedance connections on busbars or in conductors, transformers, or breakers. Temperature data is wirelessly transmitted to the software or to an asset monitoring service bureau. This allows for near real-time alarming in case of a thermal problem before it results in an electrical fire destroying equipment or injuring people. Thermal monitoring is effective at the medium voltage and low voltage levels. Specifically, it also brings great value in busway applications to detect improperly tightened junctions.

Preventing electrical shock: Operating rooms and intensive care units in hospitals rely on isolated power to keep patients safe. Sensors in isolated power panels are connected to the power management network so that electricians can be remotely alerted to an insulation failure and, in turn, provide immediate assistance to surgical staff.

Recovering fast from outages: Responding effectively to an outage requires access to the right information when and where it is needed. In a digitized power network, an intelligent relay or circuit breaker trip unit delivers this information directly to mobile smart devices. Mobile devices can also be used to perform remote breaker control to restore power safely from a distance.

At a workstation, sophisticated software tools allow for advanced power forensics, speeding up the diagnosis of power incidents. Due to the high accuracy time-stamping of events that occurs onboard smart devices – e.g. distributed meters, relays, data loggers, etc. – a visual timeline can be automatically created that shows related events, waveforms, and trends (Figure 6). Custom filters can be used to show only what is most relevant.

Additionally, a patented diagnostic capability from Schneider Electric named Disturbance Direction Detection makes it easier than ever before to determine where disturbances are coming from. Power meters automatically analyze every captured waveform, indicating the direction that a disturbance was travelling. With many meters connected to central power management software, it is possible to see how a disturbance flowed through the electrical distribution system, revealing if it was coming into a facility from the grid or originating from inside the building. This capability saves a tremendous amount of time in diagnosing problems.

Precise time synchronization, cross-system correlation, and Disturbance Direction Detection all help to reconstruct event sequences before, during, and after an incident. This helps operations personnel gain an understanding of how incidents cascaded through the system, quickly find the root cause of the event, and enable steps to be taken to restore power speedily.

Analytic results can be annotated and saved for later consideration.

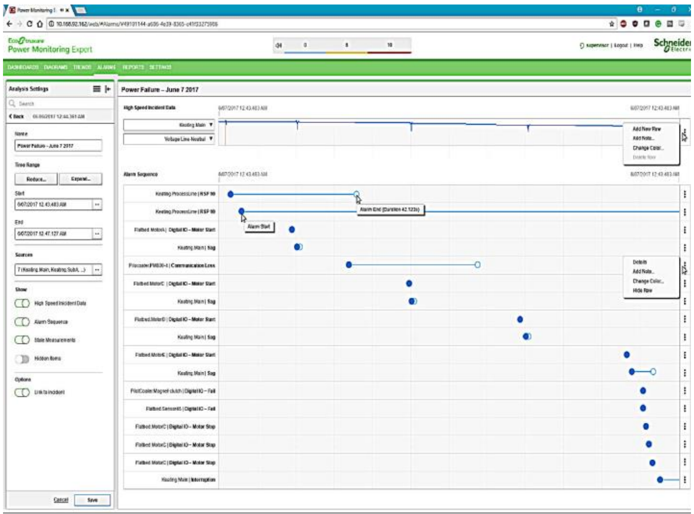

Fig. 6 – Advanced Event Analysis shows Related Incidents on a Visual Timeline, Revealing How an Event Cascades through the System and Enabling the Facility Team to Quickly Isolate the Source of the Problem

3.5 Improving Reliability

Avoiding downtime: By staying connected 24/7 to every point in the electrical distribution network, the real-time state and conditions of the network can be monitored for any deviations from normal operating conditions. If this occurs, the right people can be notified automatically, who will have detailed alarm data to determine the problem and respond before an outage can occur. Chronic power system events can be analyzed using the root cause analysis tools mentioned above, to help in preventing future occurrences.

By constantly monitoring load trends through a facility, active load management can be used to prevent overloads and, in turn, business disruptions. This information can also be used to uncover unused capacity and for capacity planning for new facility expansions, avoiding overbuilding and minimizing CAPEX.

CASE STUDY 4:
Airport maximizes use of infrastructure

A large international airport digitized their electrical distribution system with automatic data collection from key points throughout. The goal was to improve the overall reliability and efficiency.

The system identified peak loading on all distribution equipment, as well as helping determine when non-critical loads could be shed, helping avoid overloading that could cause outages and equipment damage.

Trending capabilities also helped maximize equipment utilization by identifying areas of excess capacity.

Large and critical facilities have a hierarchy of protective devices, typically starting with molded case circuit breakers at the medium voltage level, then compact circuit breakers at the final distribution level. To properly isolate faults it is important that a circuit breaker trips just upstream of a fault. This is referred to as breaker selectivity or co-ordination. During the commissioning of a facility, a co-ordination specialist makes sure that all breakers are configured such that a downstream breaker always operates before an upstream breaker. This minimizes the impact of a fault on the overall electrical system.

In recently commissioned facilities, breaker co-ordination is typically intact and configured as designed. However, over the life of a facility electricians and operators tend to ‘tinker’ with breaker settings in response to nuisance trips or expansion of loads. This compromises selectivity and can result in trips for a much larger part of the network than intended. Thanks to digitization and connectivity to edge-control software or cloud-based analytics, it is now possible to dynamically and continuously analyze breaker co-ordination, generating an alarm in case of any co-ordination violations. A ‘digital twin’ captures and stores the original co-ordination settings of each breaker, detecting any deviation that will result in undesired consequences. This added level of intelligence will help maximize breaker performance and reliability of the overall electrical system over the longer term.

Increasing asset reliability and lifespan: A recent trend in facilities has been the replacement of linear electrical loads with non-linear loads such as LED lighting, variable speed drives, and switching power supplies. This is typically done to conserve energy. However, non-linear loads introduce harmonics that can affect sensitive electrical equipment. As a facility starts to transition to these alternatives they may not, at first, appear to be causing any problems. But, as the number of non-linear devices increases, the level of harmonics can get to a point where sensitive equipment is being affected.

This situation is typical of most power quality problems. Many facility managers may be heard saying, “We have never had problems with harmonics or power quality. It is not something we are concerned about.” Then, one day, their mission critical machine starts to fail.

Having all the relevant information needed to identify power quality issues will help manage their impact and keep them from disrupting business operations or damaging critical loads and equipment. Sensitive equipment needs to be protected from issues such as harmonics, voltage sags and swells, flicker, transient voltages, or brief interruptions. A fully digitized power distribution system helps prevent these by providing early detection of conditions before they exceed levels that harm equipment.

Another threat to reliability is high temperatures and humidity. These can prematurely age the components in power distribution switchgear, especially when operating in extreme or outdoor environments, and when pollutants are present such as salt. Compact, affordable sensors are now available that measure both temperature and relative humidity [9]. Sensors are battery-operated and transmit data wirelessly to the analytic software for analysis. If environmental conditions exceed defined thresholds and durations, maintenance teams can perform required maintenance to help avoid corrosion, equipment failure, and downtime.

Depending on available in-house skills, temperature, humidity, and power quality issues can be analyzed and evaluated on-site by the local facility team. Alternatively, this can be outsourced to a cloud-based advisory service.

CASE STUDY 5:
Hospital reveals source of dialysis machine failures

A large hospital was experiencing failures of their blood dialysis machines due to an unknown source.

A power management system was installed and used to analyzing system-wide power quality. It was determined that the dialysis machines were sensitive to an increased level of harmonics in the electrical system, coincident with the recent installation of variable frequency drives.

Appropriate harmonic filtering was installed which solved the problem.

3.6 Boosting Efficiency

Managing energy consumption and costs: Since energy represents a significant line item for any facility, especially energy-intensive ones like data centers, finding ways to reduce energy spend can make a big impact on the corporate bottom line. The first step that can achieve a massive payback, is to use accurate 'shadow metering' and energy analytics to verify that a facility's utility bill is accurate, both from a metering and bill calculation perspective.

The next step is to encourage energy efficient behavior and support cost accounting by accurately allocating direct and indirect energy costs to departments or processes. Software can also be used to benchmark and compare the energy usage across buildings, plants, or process lines to uncover inefficiency and waste. The energy performance of a facility or building can be analyzed against a modeled baseline which considers relevant energy drivers, such as weather, production levels, etc. (Figure 7)

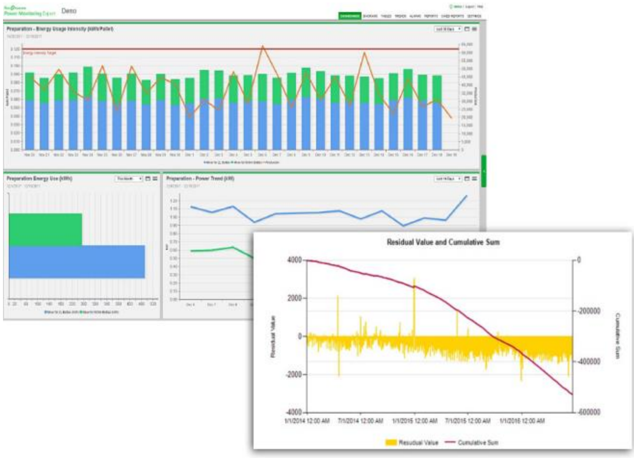

Fig. 7 – Energy Analysis Tools allow Import of Contextual Data (e.g. weather) for Tracking Energy Performance, Conducting Energy Analysis and Calculating Important KPIs. Analytics clearly reveal the Difference between Modelled (pre-retrofit) and Actual (post-retrofit) Data, Helping Weigh the Results of Energy Conservation Measures against Targets

Then, drilling down to see how much energy is consumed by the various load types and/or areas in a facility will help to determine where to focus energy conservation initiatives. Before and after analysis will help verify the energy savings from an energy retrofit or energy savings programme. Some of these initiatives might include eliminating power factor penalties (e.g. by installing appropriate PF management equipment) and, as noted previously, avoiding demand penalties using peak shaving or active load management.

CASE STUDY 6:
Children's hospital uncovers energy saving opportunities

With an intelligent power and energy management system in place, a hospital was able to allocate energy costs to different sections, with alarms set for excessive consumption.

The system analyzes consumption patterns for individual equipment. This supports load-shedding operations to avoid peak demand penalties, and load management to reduce base energy costs. This has also identified areas to improve energy efficiency.

Managing multiple energy sources: A digitized power distribution system helps leverage onsite energy production and consumption to boost energy cost savings and uptime. Energy sources might include solar, combined heat and power system, or gas or diesel-fueled backup generators. It could also include an energy storage system. Such integrated systems are typically referred to as microgrids. They can be operated in parallel with the main utility grid or can sometimes be operated in an off-grid islanded mode in the case of a grid blackout.

Digitization also enables access to value-added services on the 'smart grid', helping a facility team optimize when to consume, store, or to sell back energy to the grid. Advanced onsite or cloud-based microgrid control systems can provide predictive source management with inputs such as weather, energy cost, and other parameters to drive energy source control decisions. Many solutions are modular in design, offering scalability to manage smaller commercial microgrids up to large-scale, islanding-capable systems.

Optimizing maintenance: A digitized electrical network gives a voice to critical energy assets. It enables equipment to provide the relevant condition-based information to maintenance teams to identify when they require servicing. This is a more proactive approach, in contrast to servicing only at regular intervals, which can save time and money while also catching risk conditions that might otherwise be missed.

An example of condition-based monitoring is breaker aging analysis. This is an innovative new capability provided by some of the most advanced circuit breakers and power management software. Breakers report on the condition of their contacts, as well as many other operational parameters, while other sensor inputs report on environmental conditions that can affect breaker health, such as temperature, humidity, and corrosive gases. In combination, a more accurate picture of the aging of a breaker can be determined to help drive the appropriate maintenance protocol. This can help enhance the performance, reliability, and lifespan of each breaker.

Outsourcing facility management functions: Today, many facilities are struggling with the 'brain drain' dilemma when experienced electrical engineers and electricians are retiring and it is difficult to find new young talent. It is becoming more and more common for facilities to outsource some or all their facility management tasks.

Digitization is a wonderful enabler for this, since it enables third party facility management companies to offer competitive analytic and advisory services, including monitoring multiple facilities from a central operations center. Many of the newest cloud-based power and energy management solutions allow for data sharing with outsourced expert services. These services facilitate condition based maintenance, ensuring maintenance is focused where it is needed, the right maintenance is performed at the right time, and maintenance spend is optimized.

3.7 Simplifying Compliance

Committing to sustainability: Energy analytic platforms enable facility teams to benchmark energy consumption with respect to national or international energy efficiency certifications bodies and to share energy reduction success with the public.

Systems will help track and report on carbon emissions for public disclosure and transparency, to boost green image, meet regulatory compliance, or participate in carbon markets. Many applications also provide simple ways to showcase energy performance to stakeholders via public dashboard displays, which can also encourage energy awareness and energy-efficient behaviors.

CASE STUDY 7:
Shoe factory achieves LEED certification

A large shoe factory sought to achieve LEED certification using a number of steps including installing a system to monitor and modify the energy use of the factory.

Using distributed metering, web dashboards, and reporting tools, the factory was able to reduce energy usage by 18%, which helped achieve LEED certification. The system also allocates costs to 11 different sections of the factory to help measure and balance energy use.

Return on investment has been $US 5k per month in energy savings, with a payback period of 20 months.

Testing backup systems: Organizations like hospitals are required to regularly test and report on their backup power systems (generators, UPS, etc.). This process can be onerous; however, the newest power management systems can help simplify this process by automatically generating compliance, test, and maintenance reports to save time and reduce human error.

Ensuring supplier power quality: It is critical to validate that power quality inside the facility meets required standards for reliability of sensitive equipment. This includes ensuring that a facility's power provider is meeting contract obligations regarding power quality. Power management systems provide a range of capabilities to help simplify this.

Advanced power quality meters provide on-board PQ compliance monitoring and analysis, while analytic software aggregates PQ compliance data from across the facility. Combined reports can be generated that help facility teams track PQ trends and identify the source of risks, including problems coming from outside the facility on the utility grid. These reports can be used as evidence when bringing issues to the power provider.

Gaining cybersecurity peace of mind: Attacks on critical infrastructure in general have been on the rise, with a recent survey conducted by McAfee revealing that in "one year's time one in four have been the victims of cyber extortion or threatened cyber extortion; denial of service attacks had increased from 50% to 80% of respondents; and approximately two-thirds have found malware designed to sabotage their systems." [10]

SIEMENS

Just like the corporate IT network, digitized power distribution systems are one of the critical and vulnerable infrastructures that needs protection. Any choice of digitized solution should adhere to cybersecurity best practices, such as IEC 62443. These should include security training to developers, adhering to security regulations, conducting threat modeling and architectural reviews, ensuring secure code practices, and executing extensive security testing. For more information on mitigating cyberattack risks, see the white paper "Securing Power Monitoring and Control Systems." [11]

3.8 Fast Payback

Clearly, the extensive (yet, not exhaustive) list of applications and benefits presented above make a good case for digitizing facility electrical distribution networks. Such an investment is extremely cost effective, representing tangible ROI. A single solution offers a complete network of smart devices and multiple analytic desktop and mobile applications. The optimal architecture can achieve many different functions with the right mix of meters, monitors, sensors, transducers, and software.

Once in place, the facility can expect monitoring, alarming, and reporting tools that enable enhanced safety and reliability, real energy and operational savings, optimized use of the power infrastructure, and simpler workflows. As such, a digitized power system will optimize both CAPEX and OPEX. Though digitization increases installation cost by 10 to 20%, it results in significantly lower operating costs over the long term. The increase in CAPEX is typically paid for in less than 2 years.

Advances in technology have enabled a nominal incremental investment in digitalization of the electrical distribution infrastructure to reap a very large and fast return on investment.

Also, a powerful single solution with multiple capabilities can pave the way to the future, allowing for new challenges to be addressed, sometimes with unexpected additional benefits. For example, consider how vehicle wheel speed sensors first designed for ABS functionality also spawned traction control capabilities. Similarly, having temperature sensors on conductors and connections can help avoid overheating, fire, and equipment failures. But those same sensors can also be used to track humidity cycles which can help avoid dust build up that can cause arcing, fires, and failures.

4. CONCLUSION

The benefits of digitization of the electrical distribution infrastructure in critical buildings and facilities are almost limitless. The categories of benefit are analogous to the advances that have occurred in the automotive industry, bringing improved safety, reliability, and efficiency, as well as simplification in areas such as regulatory compliance.

However, due to the aging infrastructures of facilities such as hospitals, airports, waste water treatment plants, etc., electrical distribution has not been keeping up with the latest digitization technology trends. As such, most facility teams are still working 'in the dark' by not leveraging available, proven IoT-enabled power management technology to its fullest to achieve optimal performance. Digitization brings insight to costs and risks that are otherwise unmanageable or unforeseen.

Fully digitized electrical distribution systems are becoming the standard with preinstalled transducers and sensors. Digitization occurs in three layers, from connected products, to onsite supervisory applications, to cloud-based analytics and advisory services that offer support for facilities without the required skills and resources. It is important to have digitization in mind when designing, building, or upgrading facilities. It is more cost-effective to have electrical distribution equipment come already digitized from the factory; however, digitizing existing installations will equally result in huge benefits and savings.

The payback from digitization retrofits, or the added cost of a completely digitized infrastructure in new construction, can occur in many different ways. For example, in the case of a critical facility like a data center or hospital, avoiding a major power outage can deliver instantaneous payback. In the case of energy-related costs savings (e.g. optimized energy bill, energy usage reduction) or maintenance cost savings (e.g. predictive practices, extended equipment life), payback is usually within 2 years. Clearly, the benefits outweigh the costs.

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