Realizing Electrical Digital Twin (EDT) via Intelligent Substation (IS)

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Abstract

This paper delves into the transformative effort to realize electrical digital twin via Intelligent Substations (IS), as applied within the oil and gas industry. IS, is one of the PETRONAS cyber-physical solutions, harmoniously merges intelligent electrical equipment and systems into the electrical supply chain, targeting the revenue loss from sudden death or trip of electrical equipment, reduction of operating expenses (OPEX) by enhancing equipment reliability and efficiency. This paper presents a structured methodology for transitioning from traditional to digital substations. The symbiotic relationship between digital substations, intelligent devices, sensors, and Equipment Analytics applications is explored, emphasizing their crucial role in enhancing industrial maintenance strategies. Focusing on the Alternator Health Indicator (AHI), a pivotal IS equipment analytics application, AHI's real-time monitoring capabilities are demonstrated, showcasing its data collection methodology, analysis, and effectiveness in predicting equipment health to minimizing downtime before failure occurs. The study concludes with proposed enhancements including the incorporation of advanced machine learning algorithms, integration with Industrial Internet of Things (IIoT) sensors, and user-friendly interfaces, envisioning a more resilient and proactive approach to equipment maintenance strategies towards reaching higher level of Remote Autonomous Operation (RAO).

Keywords
Digital, Electrical, Analytic.

1. Introduction
Intelligent Substation (IS) is a cyber-physical solution that integrates intelligent-based electrical equipment and systems (those controlled by microprocessors) with the electrical supply chain. This enterprise solution aims to reduce operating expenses (OPEX) through increasing asset reliability and improving energy efficiency. In the past, many oil and gas assets would face high OPEX when electrical equipment failure and network disturbances caused unplanned plant shutdowns. Based on the series of situational assessments, studies, understanding of technical functionalities, and capabilities of the respective electrical equipment technology and systems, IS was developed to address the electrical equipment challenges and pain points. IS was established to address the pain points on “How Might We Integrate Artificial Intelligence (AI) on electrical equipment and system to visualize the real time conditions of electrical equipment towards eliminating unplanned downtime?”.

IS is also referred to as Electrical Digital Twin, will make diagnostic of existing electrical equipment and asset, feasible. IS allows the digital twin to exchange information autonomously, enabling remote operation and control of equipment such as initiating actions of starting, stopping and synchronizing generators, opening and closing breakers and much more. The IS applications were developed using in-house algorithm, which utilize both real-time and offline data for prognosis, trending, artificial intelligence and big data analytics for real time electrical system and equipment monitoring, prediction and prescriptive action before failure happen. The data also allows it to generate KPI dashboards for seamless decision making and optimized operation.

Several IS applications was developed to provide holistic view of the current Equipment / Asset state as well as predict Equipment / Asset future state to further maximize revenue and reduce cost from sudden failure to existing operations. Three (3) key IS applications have been designed and deployed thus far.

i. Alternator Health Indicator (AHI), an advanced analytics tool that includes prescriptive and predictive elements for generator alternator performance behavior.
ii. Electrical System Digital Simulator (ESDS), enables visibility of real-time electrical operating conditions, predicts equipment life and electrical system behaviors, as well as enhances operation capability envelopes (limits).
iii. Programmed Analysis of Transformer Health (PATH), a centralized online analytical tool and database that uses an algorithm to display, analyze, and assess transformer health and condition.

This paper will put a specific focus on the first IS applications developed, AHI. AHI currently serve as the cornerstone of Intelligent Substation (Electrical Digital Twin) solutions and has seamlessly integrated into the very heart of electrical digital applications. This exceptional product has garnered widespread acceptance and boasts installation in generator installations in Malaysia. It stands as a formidable bulwark against unplanned downtime resulting from sudden generator alternator failures or trips, preventing equipment malfunctions.

1.1 Objectives

The objectives of this paper are as below:

1. To present the concept of Intelligent Substation (an Electrical Digital Twin), that was developed and established based on guided pathways and trajectory, leveraging on the structured Remote Autonomous Operation (RAO) methodology.
2. To depict and showcase one of the IS key equipment analytics application (AHI - Alternator Health Indicator) that was patented and implemented in oil and gas facilities.

2. Literature Review

Intelligent Substation employs a digitalized substation concept that marks a revolutionary advancement in the realm of electrical engineering and industrial automation. At its core, a digital substation represents a sophisticated, digitally enabled infrastructure designed to enhance the management, control, and monitoring of electrical power systems. Andrey et al. (2021) and Oganyan et al. (2018) have outlined some of the model and architecture proposed for a digital substation. Unlike conventional substations, digital substations are equipped with cutting-edge technologies such as sensors, communication networks, and advanced computational systems. These elements work in harmony to collect vast amounts of real-time data from various components within the substation, including transformers, circuit breakers, and switches (Andrey et al. 2021). Through intelligent algorithms and data analytics, this wealth of information is processed and analyzed, providing actionable insights into the substation's performance, health, and efficiency. For instance, many substation management automation modules able to be deployed with digitalized infrastructure in support of many smart grid applications (Rui and Xinying 2020). A digital substation is envisaged to have the capability to predict potential faults, optimize energy distribution, and facilitate rapid responses to fluctuations in demand or supply. By leveraging guided pathways and trajectories, these substations operate as proactive entities, ensuring the seamless flow of electricity, enhancing grid resilience, and ultimately shaping a more sustainable and reliable energy infrastructure for the future.

In the realm of modern digital substation, the symbiotic relationship between intelligent devices, sensors and Equipment Analytics applications, is critical in fully exploiting the potential and versatility of a digital substation. Equipment Analytics applications, exemplified by cutting-edge technologies will enable a transformative leap in the industrial maintenance strategies. The knowledge on the machineries characteristics and behavior, will be able to be used to enhance the existing condition monitoring regime with utilization of Information Technology (IT) systems (Diana et al. 2015). Such equipment analytics applications will harness the power of data analytics, machine learning algorithms, and sensor technologies to monitor, interpret, and predict the health and performance of critical equipment, such as generator, within industrial setups (Saleh et al. 2021). For instance, Mohamad and Badi (2023) has made attempt to develop algorithms based on statistical control charts and parametric data in applying the condition-based maintenance for equipment analytics application to detect subtle deviations and anomalies in real-time. This proactive approach to maintenance is critical as it is not only minimizing downtime, but also substantially reduces operational risks and associated costs due to equipment failures and maintenance.

The literature reviewed herein underscores the symbiotic relationship between digital substations and equipment analytics applications. Although little have made clear distinction on pathway trajectory to guide and facilitate change from a traditional to digital substation. This paper will attempt to address some of the gaps posed by the research in a digital substation implementation. A methodology which includes clear pathway and trajectory to move from Traditional substation into a digital substation will be introduced to ensure a structured and seamless implementation with sustainable approach. The paper will also demonstrate an example of equipment analytics application used by a digital and intelligent system. This application (AHI) transfers the generator characteristic into digital remote monitoring and equipment applications, utilizing IT technology architecture and system.

3. Methods

Development of Intelligent Substation (IS) begins with the identification of its key features and functionalities. There are three (3) key features of IS (Figure 1):

- Data Integration - Visualization of operational condition, health status and fault prediction of electrical equipment.
- Infrastructure - Adopt Smart Sensor and latest communication system requirement based on IEC 61850 to enable information exchange.
- Analytics - Intelligence-based application for interpretation of information / data for effective decision making.

IS functionalities including its designed to receive real-time data from multiple electrical applications through:

- Electrical Network Monitoring & Control System (ENMCS)
- ESMART – Electrical System Monitoring, Analytic and Real Time Tracking
- Real-time Power System Analysis applications
- Other equipment control system interface and cloud-based applications.

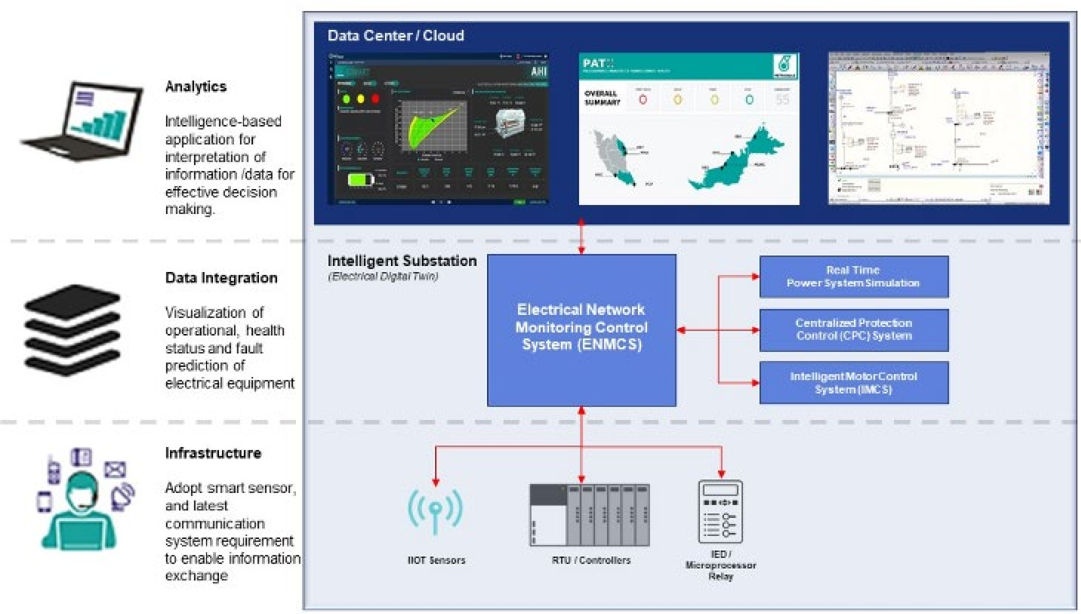

Figure 1. IS Key Features and Data Flow Architecture.

IS applications was established based on systematic approach and matrix, driving towards digitalization based on RAO (Remote Autonomous Operation) methodologies. Each application will be navigated through respective RAO level. It begins by setting and strengthening the technical database and develop foundation for network communication to bring electrical OT (Operating Technology) up to Level 2 (descriptive level). Once the foundation established, next is to embark on remote operations programming and supported with remote assistance technology at site. At this RAO level, the OTs are equipped with Predictive and Prescriptive analytics capability (RAO level 3 and 4 respectively). Once the OT at this stage, it is then ever ready to be accelerated with Artificial Intelligence and Machine Learning (Figure 2).

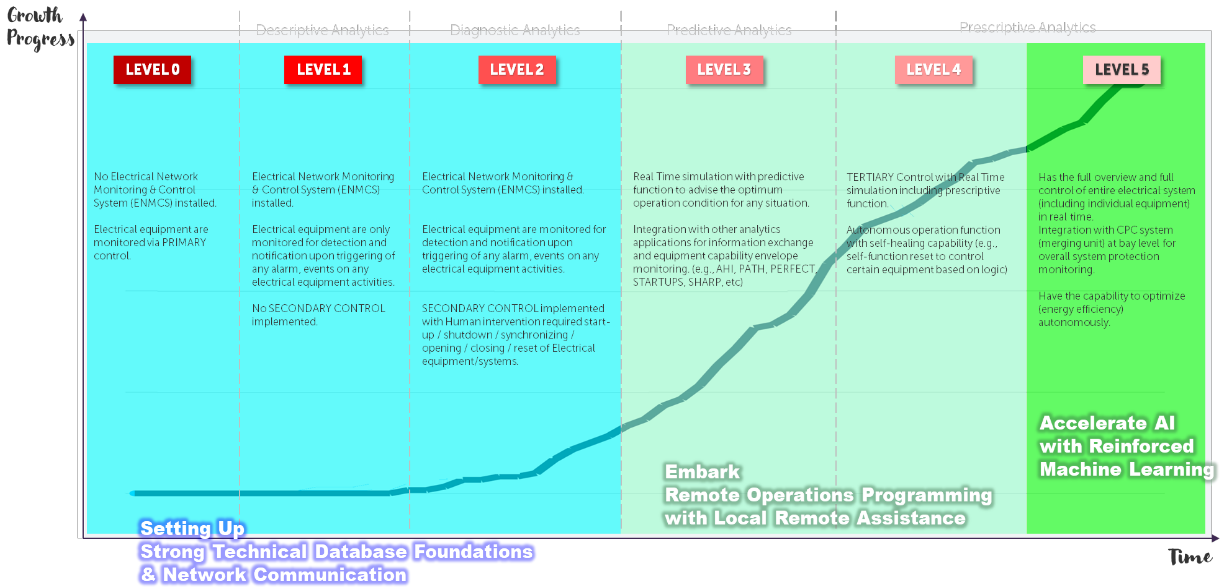

Figure 2. IS establishment based on RAO methodology.

The Intelligent Substation integration with equipment analytics application is best depicted in Figure 3. The assimilation of equipment analytics lies in the core foundation of IS building blocks, comprise of Equipment Analytics for each core electrical equipment, the system diagnostics integration with existing electrical network monitoring or ancillary system in place and finally the Electrical Information Management Systems (EIMS). All these applications will be integrated by a common system integrator which acts as a brain for the Intelligent Substation. Next section will detail out the methodology and data collection used for one of the keys IS equipment analytics applications, Alternator Health Indicator (AHI).

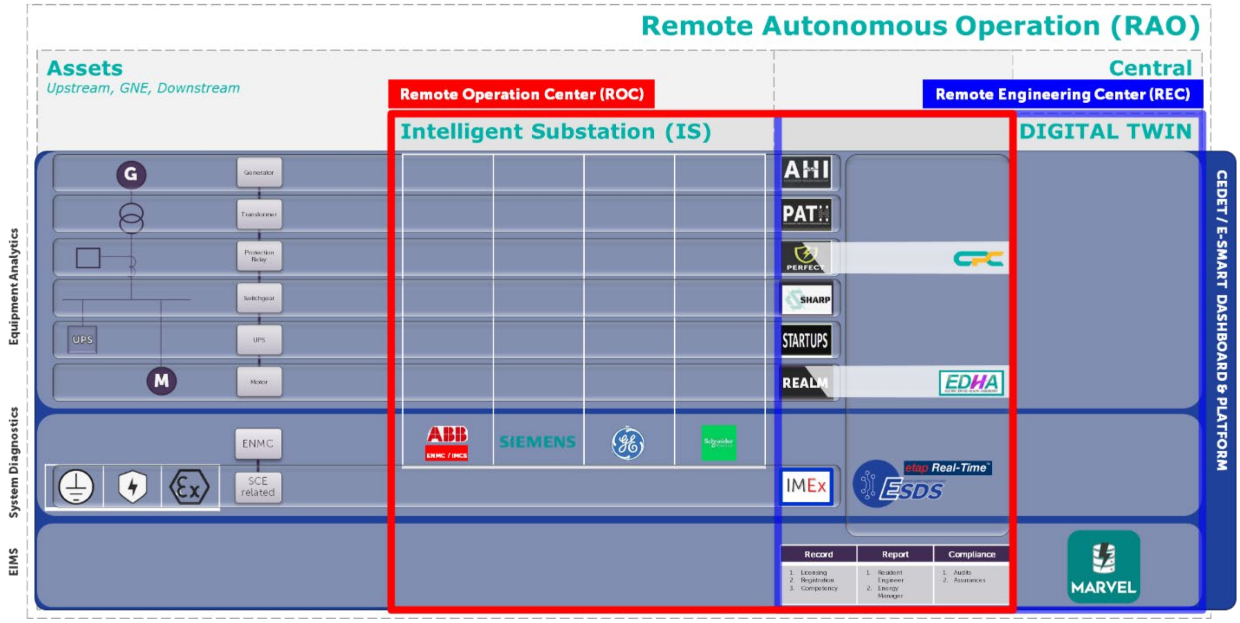

Figure 3. Foundational Building Blocks of Intelligent Substation, integrated with Equipment Analytics applications.

4. Data Collection

Alternator Health Indicator (AHI) is an advance equipment analytics tools designed to provide visibility on real time monitoring of generator alternator's health which includes prescriptive and predictive elements on generator alternator's performance behavior. It uses an algorithm model for early detection of anomaly and any potential faulty behaviors based on real time operating parameters of Real Power, Reactive Power, Voltage, Excitation Current, and other operating parameters, such as vibration, temperatures. The methodology used to harness the generator alternator data can be depicted by the IT/OT system infrastructure in Figure 4. Data from the generator alternator are retrieved and transmitted via hardwired single to either DCS or ENMC Controller which later transmitted to the core IT network backbones. The data transmitted beyond Level 3.5 up to level 4 Process Control Network with most of the generator alternator data will reside in the PI (Process Information) server for depiction in PI vision or Power BI. The key algorithm for AHI lies in PETTA server and other Application and Database server which made up to the core function of Alternator Monitoring System. The heart of the AHI equipment analytics application lies in this Alternator Monitoring System which processes the alternator output data.

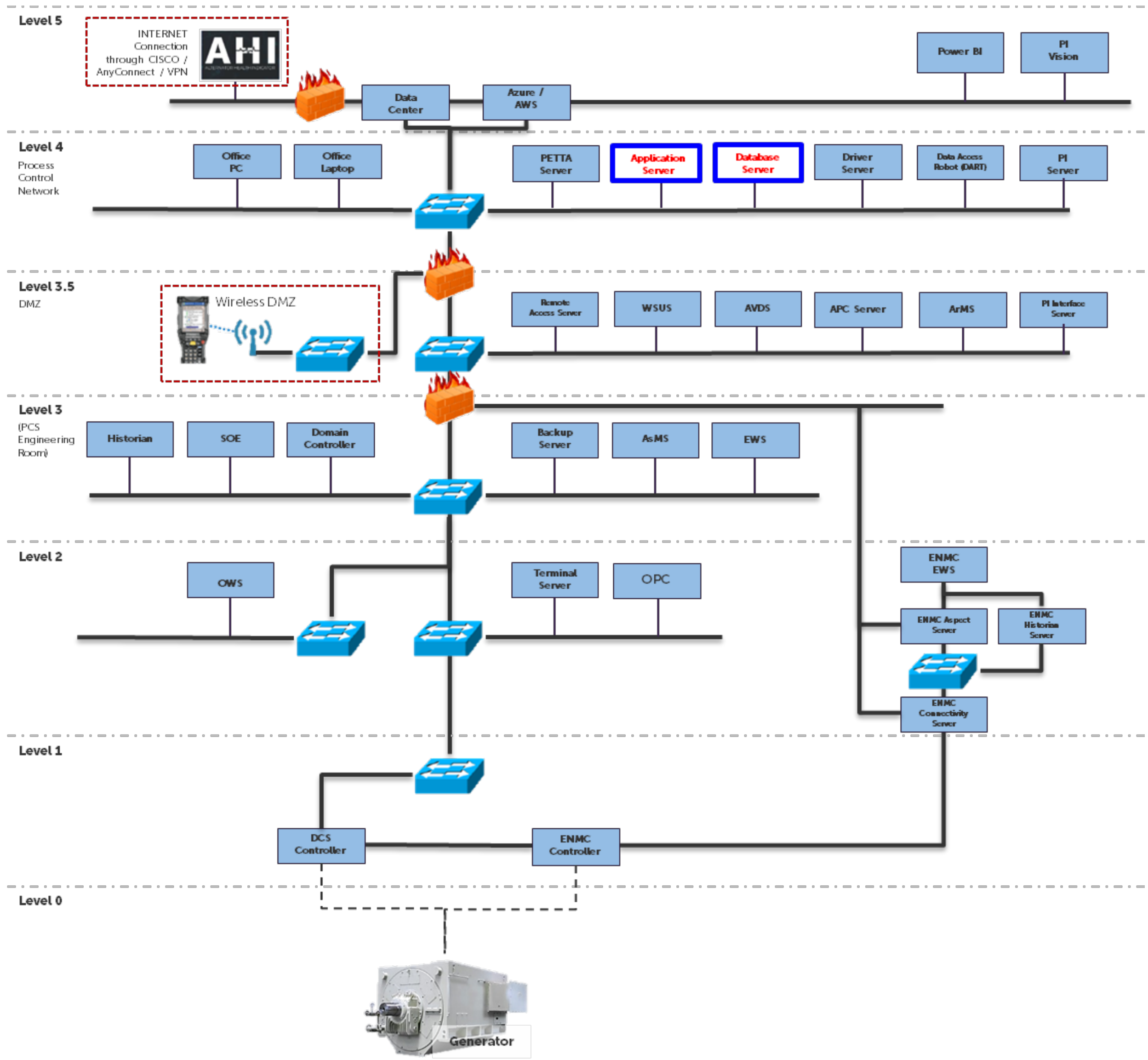

Figure 4. IS Data Architecture based on Purdue Enterprise Reference Architecture (PERA).

The alternator output data comprises of the instantaneous output of the alternator such as, real power, output current and / or power factor of the alternator. The output data also comprises of indications of the actual output voltage and a measured excitation current of the alternator with a time stamp indicating the time and date at which the output data was captured.

Upon receive of the alternator output data, the processor of the alternator monitoring system will look up for the characteristics reference curves for the alternator in the alternator characteristics curve storage. The characteristics curves stored in the alternator characteristic curve storage comprise of V-curves and open circuit characteristics (OCC) voltage curves. These curves may be specific to the alternators and may indicate the characteristics of the alternators when manufactured or initially tested.

Once configured, the DC excitation current of the alternator is estimated and compared with the measured excitation current received from alternator output data. The deviation between the calculated and measured DC excitation current are then compared against the generator alternator threshold, and further actions will be recommended based on the percentage deviation. Finally, the graph showing the deviation is generated using the graph generation module of the processor and the output is displayed to user, using the output interface of the alternator monitoring system.

5. Results and Discussion

IS implementation has significantly improved the electrical equipment reliability, and Overall Equipment Effectiveness (OEE) of the machines. The visibility of data provided by the IS applications enabled fast data retrieval and informed decisions for timely mitigation of electrical equipment risk reduction and control. With predictive analytics in place, IS allows early identification of issues and risks with proactive intervention to mitigate any potential risk of electrical equipment failure, reduces associated electrical inspection and maintenance cost, and ultimately, minimizes the risk of production cost and impact. Figure 5 show sample of the IS equipment analytics application (AHI) dashboard used in real application in one of the oil and gas plant.

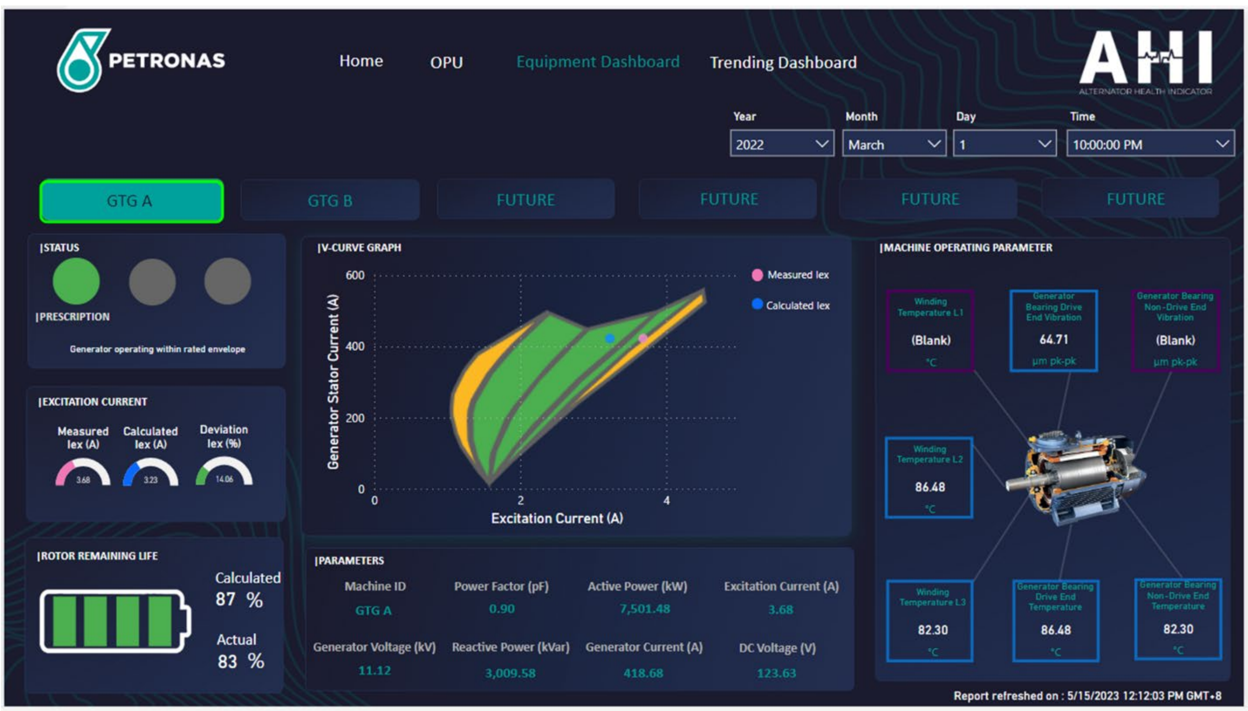

Figure 5. Sample of an Alternator Health Indicator (AHI) dashboard.

IS AHI application was implemented at most PETRONAS assets where users have realized benefits from optimized generators maintenance cost and prevention of unplanned power imports from utilities. The cost of AHI implementation is relatively small if compared to the savings that it may bring. The total number of value creation have been increasing, realized from avoidance of planned frequency shutdown maintenance to condition based shutdown maintenance, on need basis. The generator reliability have also been improving consistently by up to 2% on average (Figure 6).

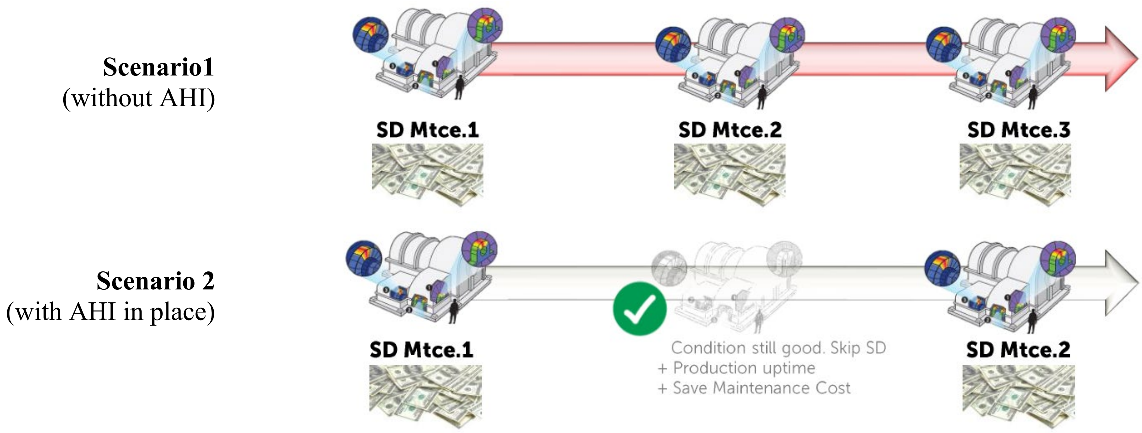

Figure 6. AHI form of cost savings / value creation.

5.3 Proposed Improvements

IS equipment analytics (particularly AHI) effectiveness and precision will continue to be enhanced with several key improvements. Firstly, expanding the range of monitored parameters beyond the basic ones currently observed would provide a more comprehensive understanding of the alternator's health. This could include variables such as voltage fluctuations, temperature differentials, and load variations, offering a holistic view of the alternator's performance. Additionally, integrating advanced machine learning algorithms into the AHI system would enable it to recognize subtle patterns and trends within the data, enhancing its predictive capabilities. Moreover, enhancing the AHI's real-time monitoring features and integrating it with Industrial Internet of Things (IIoT) sensors, technologies and robotic applications would allow for instant alerts and remote monitoring, ensuring rapid response to any irregularities. Furthermore, investing in research and development to incorporate new predictive maintenance models based on historical data would enable organizations to anticipate potential issues and plan maintenance schedules more efficiently. Lastly, to address the critical aspect of decarbonization, the AHI application will be incorporated into an enhanced green variant version, known as EverWatt. EverWatt stands as an end-to-end power generation optimizer, emphasizing the reduction of greenhouse gas (GHG) emissions without compromising reliability. This innovative approach integrates machine health, energy system optimization, and GHG accounting within an AI power platform. Thus, with these comprehensive improvements, coupled with the integration of decarbonization via EverWatt version enhancement, it will collectively elevate the Generator Alternator Health Indicator, making it a robust and indispensable tool for proactive, sustainable and environmentally conscious equipment maintenance strategies.

6. Conclusion

This paper has presented the concept of Intelligent Substation (in realization of Electrical Digital Twin), that was developed and established based on guided pathways and trajectory of Remote Autonomous Operation (RAO) methodology. The paper has also demonstrated an example of equipment analytics application (AHI) that was patented and implemented in oil and gas facilities.

In summary, the Intelligent Substation (IS) and its key Equipment Analytics application (e.g. AHI), have heralded a new era in industrial maintenance strategies, particularly within the oil and gas sector. IS, integrates intelligent electrical equipment with the supply chain, aiming to reduce operating expenses through increased asset reliability and enhanced energy efficiency. The success of IS and AHI has been evident across many oil and gas assets, showcasing substantial improvements in generator reliability and operational efficiency. IS applications value creation for the industry is expected to grow even more in the coming years. IS applications is currently being developed to cater for other electrical equipment, such as Uninterruptable Power Supply (UPS), Switchgear, Protection Relay, Motor and Ex equipment. It will soon to be rolled out to more oil and gas and utility assets in the industry. The establishment of IS is a key achievement in pursuit of PETRONAS techno-digital excellence. IS is future proof for PETRONAS as it provides the key foundation towards achieving the aspiration of attaining higher level of Remote Autonomous Operation (RAO) for electrical equipment and systems in PETRONAS.

Acknowledgements

This project was developed and funded by PETRONAS based on the collective learning, tacit knowledge and experience from all PETRONAS Operating Plant and Assets. Author would like to thank all the PETRONAS Electrical Group Technical Authority (GTA) Advisors, namely Ir. Salmey A Halim, Ir. M Faudzi B M Yasir, Ir. M Faizal B Hamdan, Ir. Pantaleon Su Ting and all other IS Team Lead, Electrical Asset Team Lead and PETRONAS Group Digital for important contribution in successful development and deployment of IS at all PETRONAS assets groupwide to date.

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Biographies

Ir. Ts. Noor Mohd Fadzli B Othman is currently a Principal Electrical Engineer, based in Kuala Lumpur for PETRONAS Group Technical Solutions (GTS). He received an M.Sc. in Energy Management from Universiti Teknologi Malaysia (UTM), Johor, Malaysia and a B.Sc. in Electrical & Electronics Engineering from the University of Adelaide, Australia. He possessed almost 20 years of technical experience in electrical maintenance, project execution and delivery, engineering design and consultancy role, spanning over Petrochemical, Downstream and

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Ir. Ts. M Nazim B Hamid is currently a Staff Engineer, based in Kuala Lumpur for PETRONAS Group Technical Solutions (GTS). He possessed more than 17 years of technical experience in Industrial and Oil & Gas business. He is a Staff Electrical Engineer competent in Design, Installation, Fabrication and Commissioning of Electrical works, involved in Domestic and International projects execution in PETRONAS at various project stages with a balance exposure in Engineering and Project Management involving various project requirements i.e., onshore, offshore, Green field and Brown field projects. He is currently the team lead in one of the Intelligent Substation solutions for Generation namely Alternator Health Indicator (A.H.I) and team lead for Flare to Power (FTP) under PETRONAS Decarbonization Initiatives as well as an Electrical Project Technical Authority (PTA) for several projects under engineering and EPCC execution. He is also a member of Generation and Co-leader for Electrical Skill Group of Uninterruptible Power Supply (UPS). He is a registered Professional Engineer with Practicing Certificate (PEPC), ASEAN Chartered Professional Engineer (ACPE) and a member of Malaysia Board of Technologist (MBOT). He is one of the recipients for Malaysia Technology Excellence Awards (MTEA) 2022 under category Engineering Analytics for the award-winning solution, INTELLIGENT SUBSTATION – AHI.

Ir. Salmey B A Halim Salmey has more than 30 years working experience of which 22 years were related to power industries with direct involvement in PETRONAS Capital projects under various roles and responsibilities. He directly involved in the development and execution of 1200MW COGEN Plant in RAPID, Pengerang, Johor Darul Takzim and 350MW COGEN plant in PETRONAS Integrated Petrochemical Complex in Kertih, Terengganu Darul Iman and Gebeng, Pahang Darul Makmur. In addition, he provided technical leadership role for various M&A Due Diligence activities and Design Feasibility Studies for PETRONAS ventures in the United Kingdom, Mauritania, Myanmar, Canada and Singapore. Work as Custodian for Electrical (Protection and Control), he also assumed the role of Group Technical Authority (GTA) while at the same time act as an Advisor for Electrical Skill Group fraternities. His professional industry affiliations include registered as Competent Engineer with Energy Commission of Malaysia, Chairman of National Technical and Management Committee for Explosion Proof Equipment of Malaysia, mirroring IECEx Technical and Management Committee respectively. Affiliation with University include appointment to sit in Industry Advisory Panel for University Technology PETRONAS.

Noor Ekhsan B M Isnain is currently a Principal (Distribution), based in Kuala Lumpur for PETRONAS Group Technical Solutions (GTS). He received a B.Eng. in Electrical Engineering from Universiti Teknologi Malaysia, Johor, Malaysia. He currently performed role as Technical Professional delivering electrical consultation and solution to all PETRONAS Operating Plant Unit. He possessed 25 years of technical experience in electrical operation, maintenance, project execution and delivery spanning over Refinery, Oil and Gas industry. He is currently involved in the enhancement as well as employment of Alternator Health Indicator (AHI) in supporting Intelligent Substation (IS) for PETRONAS OPU worldwide. He is also currently the team lead for facilitating and guiding Electrical Skill Group Technology Inventory & Ruler (TI&R) revision for PETRONAS group. He is a Focal Person for JIP33 S560 Low Voltage Switchgear, Alternate Member for Jabatan Standard Malaysia WG/E/7/6- Power System Planning, Operation and Studies, Co-lead the SKG13 Ex Equipment Level 1 Module Team, Member of SKG13 Electrical Ex Equipment Community of Practice (CoP) and appointed TPCP Assessor for Staff level TPCP Assessment SG13 Electrical by PD&T Skill Group Champion. He is a registered member of Board of Engineer Malaysia and the Institution of Engineers Malaysia.