Electric Drive Health Assessment

Pantaleon Su Lai Tiing, Suriatee Saikhol Rosli, Muhammad Fiqri Abdul Rahman and Mohd Faiz Abdul Hamid
Electrical Engineering Department
Group Technical Solutions of PETRONAS, Kuala Lumpur, Malaysia
panta@petronas.com.my, suriateerosli@petronas.com.my, fiqri_rahman@petronas.com.my, faiz.hamid@petronas.com.my

Abstract

Electric drives are widely used to regulate the flow of power supply between source to motor either due to Process or Operation requirement and as means to lower motor's inrush current. The use of AC electric drives is expected to increase due to pressing need to reduce operational cost, increase productivity and energy saving in line with company's efforts towards electrification. There have been records of failure of electric drives in the past which have caused major production loss within Petroleum Nasional Berhad (PETRONAS) operations. Common drives' failure mechanisms are converter malfunction or electronic component failures, voltage dip susceptibility, insulation degradation and so on which could be avoided through effective preventive maintenance and condition-based monitoring via data analytics. This paper describes a methodology on Electric Drive Health Assessment (EDHA) and as a web-based data analytical tool to assess and monitor electric drives' key components and parameters that contribute to a drive health index. Based on the drive health index and corresponding risk, operators are able to closely monitor the condition of electric drives in their facility which will prompt them to carry out necessary intervention. EDHA was developed based on PETRONAS installation, operation and maintenance practices, maintenance data and lessons learnt gathered from assets which have been operating for more than 30 years.

Keywords
Electric drives, Motor, Health Index, Digital tool, Web-based application.

1. Introduction
Electric drives performance has direct impact to load and subsequently affecting production reliability. As multi-national oil & gas corporation, PETRONAS occupies tens of AC high-voltage drives and hundreds of low-voltage drives consist of Variable Speed Drive (VSD), Soft Starters, Voltage Source Inverter (VSI) and Current Source Inverter (CSI) or Load-Commutated Inverter (LCI). With the organization's aspiration towards Net Zero Carbon Emissions by 2050, electrification efforts by means of Turbine-to-Motor conversion and demand for energy efficiency, the use of electric drives is expected to grow significantly.

Electrical drives play a vital role in ensuring smooth load start-up with various load profile, meeting process requirement and stabilizing electrical network during transient condition. High Voltage (HV) drives are normally associated with high criticality loads, which failure of these consumers will lead to major plant production interruption. Over time, the performance of drives decreases due to ageing, parts obsolescence, wear-and-tear, and stresses (Hamid 2021). Preventive maintenance activities for electric drives typically involves detailed visual inspection and supported with Original Equipment Manufacturers' (OEM) offline condition-based monitoring. In our assets, this maintenance practices are normally performed during a plant turnaround which occurs every 4 to 6 years. Electric drive electronic components degradation and other failure mechanisms could go undetected until the next inspection and maintenance task is performed which pose a risk of drive unexpected failure. Thus, Electric Drive Health Assessment (also known as *EDHA*) was developed to establish drives centralized data depository and to achieve maximum reliability and availability of drives by monitoring drive key components' parameters. The application built-in algorithms will assist operators in prioritizing maintenance activities based on drives' component parameters. Likelihood of failure (LoF) methodology of individual drive was derived from key parameters found in maintenance and operation records which is presented in an intuitive graphical user-interface dashboard. The future state of EDHA will leverage on cloud computing services and machine learnings, integrating Internet-of-Things (IoTs) based sensors in providing wholesome overview of drives health status with better accuracy of failure prediction capability (David et al.2021).

2. Problem Statement

2.1 Pain Points

Most electric drives installed within PETRONAS assets have been designed to suit the operational duty and load characteristics of induction motor with expected lifetime of at least 20 years. As for drive components for electronic controls, the lifetime is expected to be less than 10 years. However, over the past few years and recent year, there have been records of drives failure which have cause extended plant downtime and production loss. Understanding the root cause of drive failure and records of failure modes will assist the plant operators in establishing a better maintenance plan and conduct a complete diagnostic and preventive maintenance (Al Badawi et al. 2015), (ABB 2011).

Table 1 below highlights the common failure or degradation mechanisms for electric drives and the cause of failure. (Klima et al. 2019), (Sasidharan and Isha 2016).

Table 1. Drives failure mechanisms and its cause.

Failure Mechanisms	Cause
Converter malfunction	Power electronic component failure, electronic control board failure.
Overheating	Hot spots, dry connection, cooling system failure
Flashover	Dielectric breakdown, internal faults in drive
Cooling system failure	Fan failure, leakage, high demineralized water conductivity
Auxiliary & control circuit malfunction	Loose wiring, insulation failure, component failure
Voltage dip drop-out	Wrong logic configuration, wrong/drifted settings
Harmonics	Harmonic filter failure

Despite good design and detailed preventive maintenance approach, it is difficult for operators to predict drives' time to failure due to ineffective data analysis and absence of real-time or online condition-based maintenance. Although our assets have adopted extensive planned preventive maintenance strategy for electric drives, the inspection are offline tasks that do not reflect the overall condition of the drive. Hence, leading to inaccuracy in detecting anomalies. Effective monitoring is somewhat overlooked since offline maintenance tasks are mostly dependent to OEM support and the inspection results only reflect the in-situ condition of drives with no analysis or trending done to identify early inception of fault or degradation of components. The absence of analytical tool has become an insistent gap to operators in gauging the life span of drives' components causing risk of unexpected failure.

Another major pain point is that there is no central depository for electrical drives. Offline-based maintenance tasks such as records on electronic components replacement, drive settings change or records on measurements are typically stored as hardcopies where findings or results were not trended and analyzed. Furthermore, critical drives' parameters reside in three different platforms i.e., Distributed Control System (DCS), Electrical Network Monitoring & Control System (ENMCS) and Integrated Motor Control System (IMCS) without statistical analysis to alert operators for proactive intervention. Due to unknown drive statistical data, troubleshooting and repair by OEM is called upon on a case-to-case basis.

2.2 Objective of EDHA

The main objective of EDHA is to improve the reliability and availability of electric drives by monitoring electric drive key components' condition to prevent failure during operation.

Its main function is to quantify the drives' health based on parameters which are obtained from preventive and predictive maintenance records in operating plants. The drive health index score combined with the consequence of failure will serve as an input in determining the risk rating for each drive tag number. This information serves as a snapshot of the drive condition which is displayed on a digital dashboard to alert the maintenance crews for immediate remedial action.

EDHA is designed as a web-based application and analytical tool (software) that can perform condition monitoring, diagnostics, and prescriptive analytics for electric drive. EDHA helps in trending and easy retrieval of electric drive maintenance database and incidents of drive failure record along with impact of drive failure to plant operations.

EDHA is also a centralized database where the data related to drives across the PETRONAS group is kept and managed. In moving towards risk-based maintenance, the build and deployment of EDHA is divided into two phases. For the first phase of EDHA, efforts have been made to gather internal practices and maintenance data from across twelve assets which includes refinery, LNG, onshore terminals, offshore and petrochemical facilities to incorporate drive key parameters into EDHA's methodology to assist our maintenance engineers with better decision making and faster response on maintenance of the drives.

3. Methodology

The evaluation/assessment methodology used for EDHA is established based on three main elements to assess drive health condition, prediction of failure and impact of drive failure to PETRONAS Plant production or Business units. The main elements are:

- Drive Health Index (DHI)
- Likelihood of failure
- Risk of failure

3.1 Drive Health Index (DHI)

The drive health index is calculated based on specific parameters for each sub-system of electric drive. The selection of parameters is from records of failure modes and degradation mechanisms based on Failure Mode Effect Analysis (FMEA) approach for low-voltage and high-voltage drives (Hamid 2021), (BS EN IEC 60812:2018).
Inspection checklists from OEM and historical maintenance data obtained from operating plants are used to determine the relevant parameters and scoring criteria. In this approach, DHI is calculated based on the outcome of three (3) elements below (Singh and Siddh 2016), (Yang et al. 2016):

- P1 – Drive Condition
- P2 – Maintenance history
- P3 – Operating Environment

3.1.1 Drive Condition (P1)

Under this element, the drive health index is broken down into six (6) key sub-system to assess the overall health of drives (Sasidharan and Isha 2016), (IEC 61800 2021), (Strangasy and Aviyente 2015):

- Converter i.e., Inverter and the DC link
- Protection and control system
- Cooling system
- Resistor, Inductor and Capacitive (RLC) components
- Enclosure/Cabinet
- Auxiliaries

The specific parameter input is obtained and referred from records of existing maintenance practice, testing and operational history of the drive system that has been performed by asset owner. The following online or offline tests are some of the common tests performed for drive by OEM: (IOGP JIP33 2021), (IOGP JIP33 2022)

- Visual inspection
- Insulation resistance (IR) test
- Contact resistance test.
- Power electronic component tests
- Logic and settings verification
- Functional test
- Voltage dip ride-through
- Alarm history log monitoring
- Thermography
- Vibration monitoring
- Harmonics measurement

For each sub-system of drive, specific reliability parameters will have an index score which is a number between 1 to 1000 represented by the following categories:

1) Good
2) Acceptable
3) Questionable
4) Poor

The parameters that are being scored for drive's key sub-system are given in Table 2. Similarly, Table 3, 4. 5, 6 and Table 7 listed the parameters for remaining sub-systems.

Table 2. Parameters for drive sub-system – Converter

Index Score	**Good**	**Acceptable**	**Questionable**	**Poor**
	1	**10**	**100**	**1000**
Power electronic component - Deviation from nominal, %	≤5%	>5% ≤10%	>10% ≤20%	>20%
Obsolescence – spare parts availability	Spare parts available for more than 5 years	Spare parts available for the next 5 years	Spare parts available for the next 2 years	Spare parts not available/Obsolete
Charging resistance – Deviation from nominal, %	≤5%	>5% ≤10%	>10% ≤20%	>20%
Temperature/Hot spot	Normal	Minor	Moderate	Severe

Table 3. Parameters for drive sub-system - Protection and Control System

Index Score	**Good**	**Acceptable**	**Questionable**	**Poor**
	1	**10**	**100**	**1000**
Electronic card/board controller condition	Good	Good but obsolete in 5 years	Good but obsolete in 2 years	Faulty/Obsolete
Active alarm severity status	No	Low	Medium	High/Critical
Protective devices (MCB, fuse, etc.) functionality	Healthy	N/A	N/A	1 or more defect
Interlocks functionality	Healthy	N/A	N/A	1 or more defect
Limit switches functionality	Healthy	N/A	N/A	1 or more defect
Control cable IR, MΩ	≥5	≥2, <5	≥1, <2	<1
Control battery *(if any)* i) Voltage deviation, % ii) Age, Year/s	 ≤5% <5yrs	 >5%, ≤10% ≤5yrs	 >10%, ≤20% >5yrs, ≤10yrs	 >20% >10yrs
Auxiliary relays functionality	Good	Minor defect	N/A	Major defect
Volt dip drop-out compliance *[Note]*	Proven to comply	Partially comply – can withstand dip up to 60% for 200ms	Partially comply – can withstand dip up to 20%.	Drop out at voltage dip of less than 20%
Software/Firmware version	Updated	N/A	N/A	Outdated

Note: The results are evaluated based on IEC60034-4-34 (Class 3) Curve

Table 4. Parameters for drive sub-system – Cooling System

Index Score	Good	Acceptable	Questionable	Poor
	1	10	100	1000
Air filter condition	Clean	Minor	Moderate	Severe
Ventilation fan condition	Good	Minor defect	Fan running noisy	At least 1 fan not working
Ventilation fan motor IR, MΩ	≥15	≥10, <15	≥3, <10	<3

Table 5. Parameters for drive sub-system – RLC Components

Index Score	Good	Acceptable	Questionable	Poor
	1	10	100	1000
Capacitor – condition	Good	Minor	Moderate	Severe
Capacitance measurement – Deviation from nominal, %	≤5%	>5%, ≤10%	>10%, ≤20%	>20%
IR, MΩ	≥50	≥30, <50	≥10, <30	<10
Age, Year/s	<5yrs	N/A	5-7yrs	>7yrs
Inductor - condition	Good	Minor	Moderate	Severe
Inductance measurement – Deviation from nominal, %	≤5%	>5%, ≤10%	>10%, ≤20%	>20%
IR, MΩ	≥50	≥30, <50	≥10, <30	<10
Resistor - condition	Clean	Minor	Moderate	Severe
Resistance measurement – Deviation from nominal, %	≤5%	>5%, ≤10%	>10%, ≤20%	>20%
IR, MΩ	≥50	≥30, <50	≥10, <30	<10

Table 6. Parameters for drive sub-system – Enclosure/Cabinet

Index Score	Good	Acceptable	Questionable	Poor
	1	10	100	1000
Power cable/internal wiring tightness, thermography	Good, no signs of overheat	Minor signs of overheat	Major signs of overheat	Severe signs of overheat
Power cable IR, MΩ	≥50	≥30, <50	≥10, <30	<10
Optic/data cable condition *(if any)*	Good	Minor	Moderate	Severe
Cubicle physical condition	Good	Minor	Moderate	Severe
Earthing condition	Good	N/A	N/A	Severe
Air filter condition	Good	Minor	Moderate	Severe
Ventilation fan – condition/vibration/current measurement	Good	Minor defect	Fan running noisy	At least 1 fan not working
Ventilation fan motor IR, MΩ	≥15	≥10, <15	≥3, <10	<3

Table 7. Parameters for drive sub-system - Auxiliaries

Index Score	Good	Acceptable	Questionable	Poor
	1	10	100	1000
Heat Sink *(If any)*- condition	Good	Minor degrade	Moderate degrade	Severe
Contactor condition	Good	Minor wear	Moderate wear	Defective
Transducer condition	Good	Minor	Moderate	Severe
CT – IR, WR, condition	Good	Minor degrade	Moderate degrade	Defective

VT - IR, WR, condition	Good	Minor degrade	Moderate degrade	Defective
HMI panel – display, annunciator functionality	Good	N/A	N/A	Defective
Built-in harmonic filter *(If any)*- condition	Good	Minor defect	N/A	Defective
Bypass *(If any)* - condition	Good	Minor defect	N/A	Defective

The worst parameter score will be taken from each sub-system where scores ranging from 6 to 6000. The calculated health index score for drive condition (P1) will be assigned with a four-stage indicator as shown in Table 8 below:

Table 8. Drive Health Index Score and Indicator

Index Score	**Probability of Failure (P1) Indicator**
>600	Very High
>60 - 600	High
>6 - 60	Moderate
<6	Low

3.2 Maintenance History (P2)

In this category, each drive at operating plants has specific maintenance strategy in terms of major maintenance interval depending on the drive criticality. The time interval for major maintenance could be performed every four to six-yearly or during shutdown opportunity or as per OEM recommendation, whichever is earlier. Based on this, below is the formula used to derive to a weightage:

T = (TLI - TMI) / TMI

T = Weightage for P2
TLI = Time/Date from last Major Inspection performed
TMI = Major Inspection Interval

Table 9 depicts the evaluation on final 'T' value whereby asset owner needs to query if the drive has experience repetitive failure from the date of last inspection until the next major inspection.

Table 9. Evaluation on maintenance history 'T' value.

T	**Repetitive Failure?**	**Probability of Failure (P2) Indicator**
T < (-0.5)	Yes	Moderate
	No	Low
(-0.5) ≤ T < 0	Yes	High
	No	Moderate
T > 0	Yes	Very High
	No	High

3.3 Operating Environment (P3)

Under Operating Environment, the installation environment of the drive is assessed in terms of its location and whether it is in a ventilated or air-conditioned room. The probability of failure risk indicator is as shown in Table 10 below:

Table 10. Probability of failure risk indicator for P3

Operating Environment	**Near the sea/Offshore?**	
	Yes	**No**
Ventilated/HVAC not in operation	Very High	High

Air-conditioned room/HVAC is in operation	Moderate	Low

3.4 Likelihood of Failure

The likelihood of failure (LoF) takes input from Drive Health Index (DHI) risk indicator and convert into a score as shown in Table 11 below:

Table 11. Conversion of P1-P3 risk indicator into score

Risk Indicator	Score
Very High	100
High	30
Moderate	10
Low	1

Total probability of failure (TPF) is function of LoF score for drive condition (P1), maintenance history (P2) and operating environment (P3) whereby each element is weighted as per formula below to provide an overall condition of the drive:

$$\begin{aligned} TPF &= f(P1, P2, P3) \\ &= 0.6P1 + 0.25P2 + 0.15P3 \end{aligned}$$

3.5 Consequence of Failure

The consequence of failure (CoF) is very much depending on drive application and is determined by asset owner via classification of equipment criticality. The impact of drive failure is determined based on plant operation risk appetite on the severity of asset loss/damage and severity of monetary loss in terms of production loss and repair or replacement cost. The guiding principle for each impact rating is as below:

- Insignificant
- Minor
- Moderate
- Major
- Catastrophic

3.6 Risk Matrix

Finally, a risk rating for the drive is determined based on the TPF and CoF which is pre-defined in a Risk Matrix table to prompt asset owner on the next cause of action to be pursued.

Depending on the risk tolerance level of each PETRONAS plant or business unit, the impact to business is related to consequence description as described in earlier section. Consequence of Failure (CoF) evaluates the drive's criticality using user-selected input in conjunction with the generated Total Probability of Failure (TPF) to provide an overall risk failure rating for the drive.

The Risk Matrix table and the recommended action is as shown in Figure 1 and Table 12 below:

TPF \ Impact	Insignificant	Minor	Moderate	Major	Catastrophic
Very High	D1	D2	D3	D4	D5
High	C1	C2	C3	C4	C5
Medium	B1	B2	B3	B4	B5
Low	A1	A2	A3	A4	A5

Figure 1. Risk Matrix Table.

Table 12. Risk Rating and Recommended Action

Risk Level	Recommended Action
Very High	Reduce/Manage- Urgent action
High	Reduce/Manage- Plan for action
Medium	Continue to monitor
Low	Risk is acceptable/No action

4. Solution

Based on methodology above, a centralized web-based application is designed to store and analyze multiple electric drives data to address the pain points mentioned in Section 2.1 in this paper. Prior application development, the methodology was validated using 95 numbers of variable speed drives (VSD) from a refinery plant which have been in operation between Year 2008 to 2020.

The development of EDHA application started in March 2023 which includes the following key features:

i. Drives Online Database/Inventory Management to manage drives' inventory for registered PETRONAS Operating units.
ii. Module Drives Assessment Registry to input assessment data, calculate drive health index, quantify consequence of failure, and establish risk rating based on risk matrix.
iii. Dashboarding to provide overview of drives health status including risk of failure and to allow Users to view the key sub-components of each drive's parameters, download data, print reports, charting and trending.

With a cloud-based server, EDHA solution is easily scalable and accessible from remote as shown in Figure 2 on the application architecture.

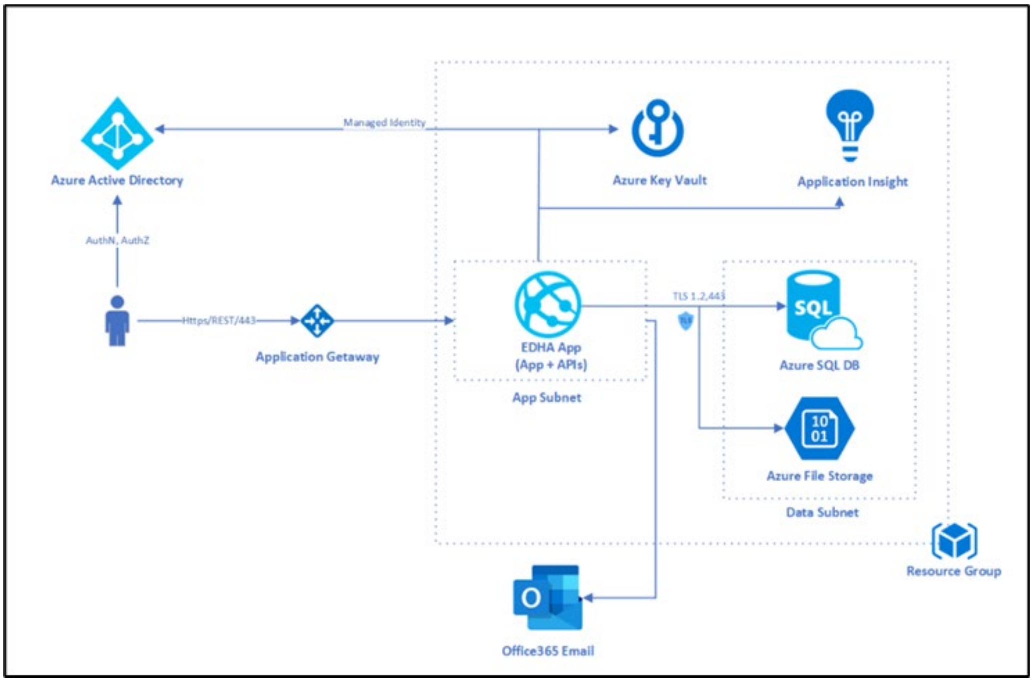

Figure 2. Architecture of centralized web-based EDHA application.

4.1 Drives Dashboard

In moving towards risk-based maintenance, offline drives data has been gathered including record of test reports from OEM which is embedded in web-based application for faster and efficient processes and minimize loss of historical maintenance reports.

For each operating plant, their drives' general data such as drive type, rating, cooling system, drive location, Manufacturer and so on are gathered from offline database into a cloud-based database. Figure 3 shows the information of a HV VSD via 'Insight Dashboard' of a refinery plant.

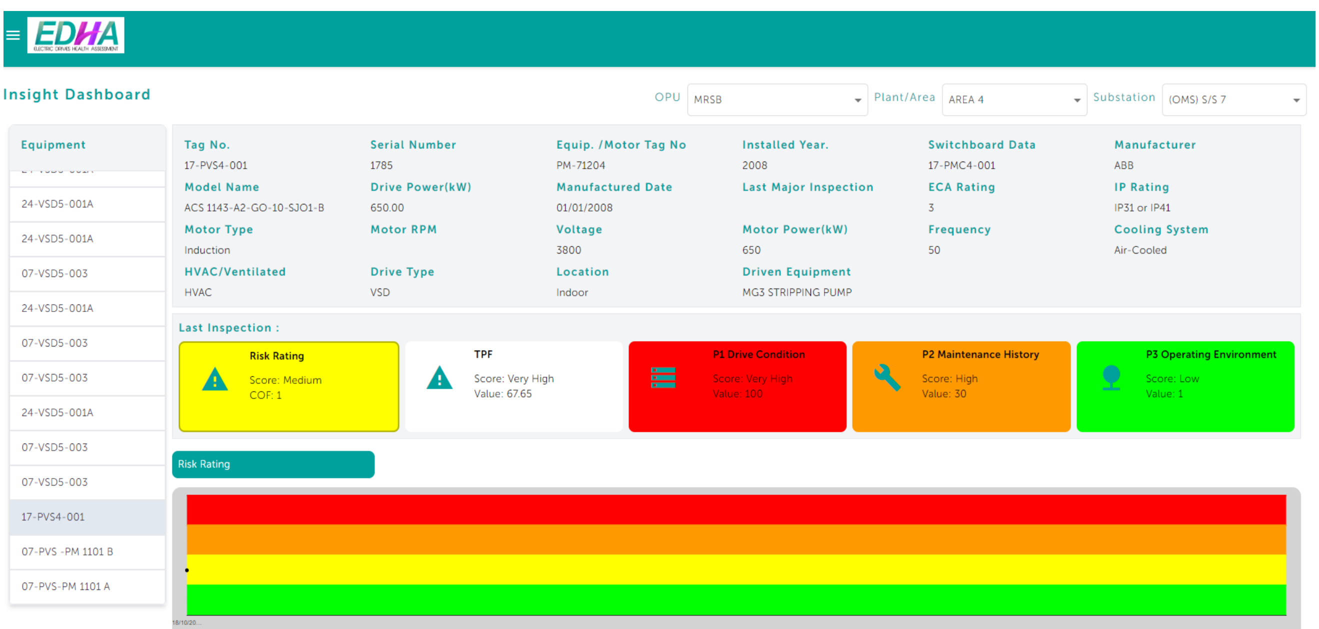

Figure 3. Snapshot of EDHA Dashboard

Parameters with quantitative data will be trended to assist operators to recognize early signs of drive failure. Risk rating will also be recorded and trended at every inspection performed by operator.

The integration of EDHA with another application or platform will require stable and reliable backbone supporting network with compliance to High-Performance Computing platform (IEEE 1588), (Strangasy and Aviyente 2015). As the platform evolves towards maturity, data exchange across multiple platforms potentially can be vulnerable and cause severe data breaches to the users. To ensure data security and minimizing data leakages, up-to-date cyber security measurement must be in place as part of user data security management framework (Panagiotis and Elias 2023).

5. Conclusion and Recommended Improvement

Based on the development of EDHA as a digital tool, it will be an essential digital solution in supporting PETRONAS' growth and sustainability agenda. The platform not only aims to improve drives' reliability and prevent ad-hoc failures but also ensuring PETRONAS operating units align to each other in driving down the operational expenditures through integrated dashboards and optimizing maintenance intervals. Nevertheless, there are further improvements to the application. Generally, most of the drives installed do not subscribe to online condition-based monitoring as they are not equipped with measurement sensor. Integration with Internet of Things (IoTs) based sensors on drives and motors, artificial intelligence and machine learning algorithms with EDHA platform will provide online parameters of the drives for better accuracy in predicting failure. This enhancement is crucial towards making the platform fit for future and scalable throughout PETRONAS operating units.

As the journey towards digitalized asset management is being implemented across the globe, readiness of infrastructure backbone and effective cyber security policy are crucial to support the company's digitalization agenda. The algorithm for electric drive analysis can be combined with diagnostics for induction motors, transformers, and switchgear; to provide an overview of the integrated machine and drive string with the aim of realizing an intelligent substation (David et al. 2021). Greater collaboration among technical society members and industry players on this cyber-security issue will foster the adoption of digital twin technology and cut the cost of ownership significantly.

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Biographies

Pantaleon Su Lai Tiing is currently holding a position as Electrical Custodian in Group Technical Solutions (GTS) of PETRONAS with more than 30 years of experience in technical consultancy, Specialized Engineering Services (SES), electrical equipment and system Operation & Maintenance within PETRONAS Operating Units and to external Clients. Due to his vast experience and technical know-how which he acquired mostly from Malaysia LNG (MLNG), he is the appointed Group Technical Authority (GTA) for high-profile projects, technical assessments, and due-diligence reviews for PETRONAS Downstream and Upstream businesses. He holds a B. Eng in Electrical & Electronics Engineering from Universiti Malaya, Kuala Lumpur and he is a Professional Engineer, Competent Electrical Engineer, Steam Engineer and actively involved in developing standards and guidelines for Electrical and Petroleum Industries such as IOGP JIP33.

Suriatee Saikhol Rosli is currently a Staff Electrical Engineer in Group Technical Solutions (GTS) of PETRONAS with 18 years of experience to date in technical consultancy, Specialized Engineering Services (SES), technical support in Operation & Maintenance including Construction, Commissioning, plant Turnaround and startups within PETRONAS Operating Units and to external Clients. She earned her B. Engineering (Honors) in Electrical & Electronics Engineering from Universiti Teknologi PETRONAS (UTP), Malaysia and a graduate member of the Board of Engineers Malaysia (BEM). Her career with PETRONAS started with secondment to Sarawak SHELL for offshore F6 Rejuvenation Project, following that she has led in many PETRONAS high-profile projects i.e., PETRONAS Floating LNG 2 (P-FLNG2), Malaysia Refining Company (MRC) Diesel EURO 5 and leading in ongoing renewables and carbon capture projects. She is heavily involved in the review of PETRONAS Technical Standards, Skill-group learning modules and technical governance reviews.

Muhammad Fiqri Abdul Rahman is currently a Staff Electrical Engineer in Group Technical Solutions (GTS) of PETRONAS with 15 years of experience to date in technical consultancy, technical support and Specialized Engineering Services (SES) for PETRONAS Operating Units and for external Clients**.** He graduated with a Bachelor of Engineering in Electrical & Electronics Engineering from The University of Western Australia and started his career as a Maintenance Engineer with PETRONAS Gas Berhad (PGB) where he was working closely on cogeneration & gas processing facilities. He has been part of PETRONAS's largest project investment ever undertaken i.e. the Refinery & Petrochemical Integrated Development (RAPID Project) for Integrated Refinery and Petrochemicals facilities in Pengerang where he led in field engineering, pre-commissioning, commissioning, and start-up for complex utilities facilities. He is a certified Professional Engineer and a member of Institute of Engineers Malaysia (IEM), Board of Engineers Malaysia (BEM) and IEEE.

Mohd Faiz Abdul Hamid is currently holding a position as Senior Electrical Engineer in Group Technical Solutions (GTS) of PETRONAS with more than 17 years of experience in technical consultancy, technical support, and Specialized Engineering Services (SES) for PETRONAS Operating Units and for external Clients. Prior with PETRONAS, he was a Project Manager for Duta Berkat Corporation and was also a Lead Electrical Engineer in Toyo Engineering Corporation for various international Oil & Gas projects. He holds a B. Engineering in Electrical Engineering from Universiti Teknologi Malaysia (UTM), and he is a certified Professional Engineer by the Institute of Engineers Malaysia (IEM) and a member of Board of Engineers Malaysia (BEM). He is heavily involved in the review of PETRONAS Technical Standards, Petroleum Industries standards such as IOGP JIP 33, Skill-group learning modules and technical governance reviews.