Integrated Real-Time Geothermal Operational Optimization and Improvement using a Robust Data Management, Visualization, and Diagnostic Analytics Platforms as a Digital Transformation

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ABSTRACT

Indonesia has substantial geothermal potential, and the country's government is committed to exploiting it, both for economic reasons and to meet its obligations as a signatory of the Paris Agreement on the climate change. A digital transformation is one of the main driver for optimizing the geothermal operational production. It has been deployed in Dieng and Patuha geothermal field by integrating steam field to power plant real-time operational data into a data management system platform, which is located on the Head Quarter office server.

A previous method for collecting the operational data in Dieng and Patuha fields was still using paper-based and non real-time data. By end of 2022, there was a digital initiative programme to transform it into a paperless system. By collecting the operational data, tagging from the OPC DA and Modbus Ethernet at both Dieng and Patuha fields, then it can be recorded into data management archive storage. After capturing all the operational data tagging, some formulae can be created in the asset framework environment and used to publishing these tags by utilizing a module in the database builder.

Operational data visualization also has been developed, displaying real-time steam field and power plant operational parameter trends. The advancement in technology like IoT, machine learning, advanced data analytics, and artificial intelligence could be applied to the geothermal operational data based on this platform. These technologies will offer substantial opportunities for technology advancement and cost reduction throughout the geothermal operational improvements. This paper describes some advanced data analytics, and visualization of trends from the steam field to power plant área that could help engineers to make a quick and concise operational improvements.

1. INTRODUCTION

1.1 Background

According to the 2015 Paris Agreement, with incentives granted for renewable and clean energy sources, the use of geothermal energy has to be expanded. Geothermal energy, as a clean and dependable source of heat and electricity, and will play an important part in the clean energy transition alongside other renewable energy sources (Mustofa et al, 2023). Geothermal resources abound in active volcanoes as well as sedimentary basins. The ring of fire is a region on the rim of the Pacific Ocean where frequent volcanic eruptions and earthquakes occur. Most regions of Indonesia are included in the ring of fire path (**Figure 1**), thus creating high availability of geothermal resources in the country. Indonesia has the most geothermal potential in the world and has developed geothermal power plants faster in terms of capacities in the last 5 years. Currently, Indonesia has about 2.28 gigawatts of installed geothermal power capacity, whereas the US has 2.6 gigawatts of installed geothermal power capacity, the most in the world. Moreover, the government seeks to have renewables constitute 23 percent of electricity generation by 2025, almost double that from the current 12 percent. Indonesia has pledged to become carbon neutral by 2060 (General Plan for National Energy, 2023).

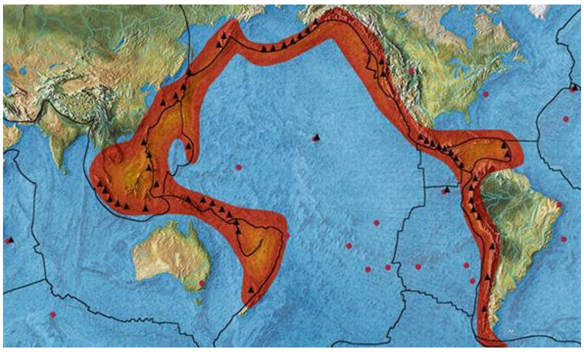

Figure 1: Ring of Fire Map

Geo Dipa Energi, as a Ministry of Finance Special Mission Vehicle (SMV), was assigned the resposibility for operating two geothermal fields: Dieng, with a current capacity of 72.5 MW Gross (60 MW Gross Dieng Unit 1 and 12.5 MW Small Scale Unit), and Patuha, with a capacity of 60 MW Gross. Dieng field is made up of three sub-units or operational units: Steam Field, Power Plant Unit 1, and Small-Scale Power Plant. While Patuha is made up of two sub-units, the Steam Field and Power Plant Unit 1. Geo Dipa encountered numerous obstacles in maintaining excellent production and profitability while operating the entire geothermal stream from subsurface to electricity.

Figure 2: Geo Dipa Energi Operating Goethermal Field

1.2 Operational Digital Transformation Opportunity in Geo Dipa Energi

Prior to the implementation of the digital initiative, the communication protocol between local operators and headquarter engineers was exceedingly complex, with frequent bad quality of the data. The use of a paper-based Operation Log Sheet resulted in potentially superfluous but presently necessary work. The entire traditional file sharing workflow consumed about 14.5 hours for two geothermal plants each day. The local operators need to enter a paper-based log sheet on their local PC, then obtain internal routing approval from their supervisor. Late submission and late compilation of data triggered an increase in non-productive time and obviously weak decision-making. The project team embraced this challenge as an opportunity for improvement. By the end of 2022, the project team initiated the creation of a digital transformation in terms of operational data processing, using a robust data management, visualization, and diagnostic analytics system called “GEOREC” (Geo Dipa Energi Optimization, Reliability, and Efficiency Center). GEOREC is also defined as an asset performance management (APM) tool, aimed at achieving the ultimate goal of operational and maintenance excellence.

1.2.1 Traditional File Sharing Method

Data gathering is the process of collecting, measuring, and analyzing data from various sources to gain insights (digital journal, 2021). However, the data obtained previously could not be used immediately because it was stored on different platforms or was of poor quality. Prior to the implementation of the digital project, several reports were supplied individually and in a scattered way by both Dieng and Patuha.

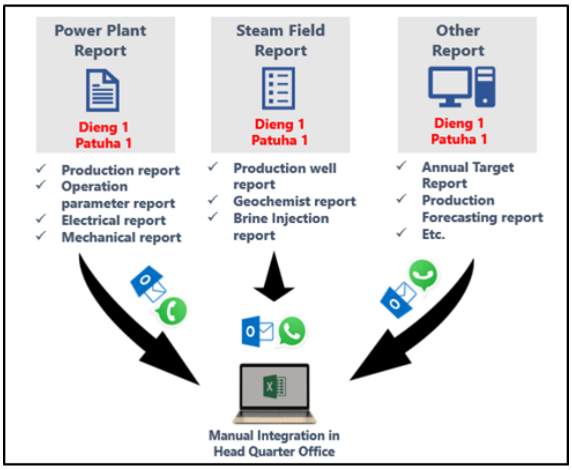

Figure 3: Traditional file sharing methods

As shown in **Figure 3**, there were various manual daily operational data that were divided into three sections: steam field, power plant, and other reports. All reports were manually delivered to the headquarters using communicator applications or corporate mail. Compiling these data certainly resulted in non-productive time for some engineers in the headquarters office.

1.2.2 Accelerating the Digital Initiative Journey

Achieving operational excellence through digital transformation is a process that allows a business to boost operational effectiveness and gain a corporate competitive advantage. Operational excellence is also a step towards passing ISO 55000 certification by utilizing Enterprise Asset Management (EAM). To support the smooth running of EAM in our organization, GEOREC needed to carry out data management and analytics. GEOREC leveraged the use of Distributed Control System (DCS) Open Platform Communication (OPC) and Modbus Protocol to stream data in real-time into a private internet network, thus removing the need to manually collect data from log sheets.

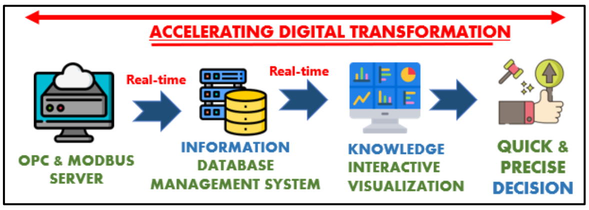

Figure 4: Process Workflow of Seamless Data Transformation

Figure 4 above, shows that the data transformation process using APM tools overcomes the limitations of the previous method. As a result, both engineers and executives are able to make faster and more precise decisions.

2. ASSET PERFORMANCE MANAGEMENT ENVIRONMENT

APM in the electricity generation, transmission and distribution context refers to the decisions that the asset owner has to make to increase asset availability, optimize overall cost of asset maintenance and reduce risks associated with asset operation. Consistent data management, risk management tools and advanced analytics, through smart use of technology are required to make this a reality (Silas Wan, 2017).

International Organization of Standardization (ISO) 55000 defines common language standards for implementing digital asset management strategies that integrate data and give a holistic snapshot of the operational performance of a utility. Thus, it is crucial for an organization to invest in data infrastructure tools that can provide the APM by which ISO 55000 standards can be implemented and maintained.

ISO 55000 certification helps utilities to derive the most benefit from an APM practice by enabling disparate organizational groups to understand assets and to connect real-time, sensor-based data to key people to improve timely decision-making. It also helps utilities adopt a more measured approach to aligning organizational objectives with taking “the long view” of resource planning and risk management (Aveva Journal, 2021).

2.1 Data Management, Asset Framework, and Visualization Architecture

The previous disorganized and chaotic operating data system resulted in much non-productive time for some engineers. Besides that, the traditional file sharing method was extremely demanding in terms of the capacity of the previous platform (corporate mail and personal WhatsApp), and obviously not lean as a business process. To address the drawbacks of the old system, the digital initiative implemented database management system (DBMS), data visualization, and Asset framework (AF).

A database management system, or DBMS, is software designed to assist in maintaining and utilizing large collections of data, and the need for such systems, as well as their use, is growing rapidly (Singh Sweta, 2015). The types of DBMS based on data models are as follows: relational database, object-oriented database, hierarchical database, and network database.

A robust DBMS, visualization, and diagnostic analytics architecture can be represented as in **Figure 5** below. The data are sourced from OPC DA and Modbus ethernet protocols which were installed in the Dieng and Patuha site servers. The previous paper-based data was transformed into digitized real-time data, which was transferred to a DBMS server in the headquarters office. this process cut the previous long cycle time required for transferring data to the head office. After integrating the data, engineers can develop user-friendly visualization and analytics tools that will be very useful for making a quick operational improvement decision based on some trends in the data.

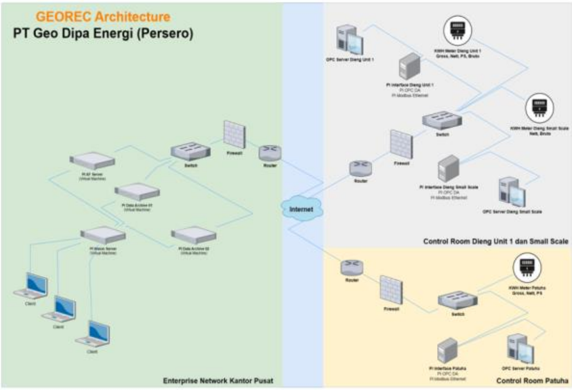

Figure 5: Robust DBMS, Visualization, & Asset Framework (AF) Architecture

2.2 Asset Framework and Data Builder Environment

A database management system which was built in this system is comprised of a real-time historical database and asset framework storage. The data builder is an excel add-on used to create, edit, and delete data collected from historical sources. While the Asset Framework (AF) is a platform to create a hierarchy or structure from the collected data based on site equipment hierarchy. The AF is especially useful for creating a model (analysis and forecasting), event recognition (data that appears to conform to certain logic), and also notification.

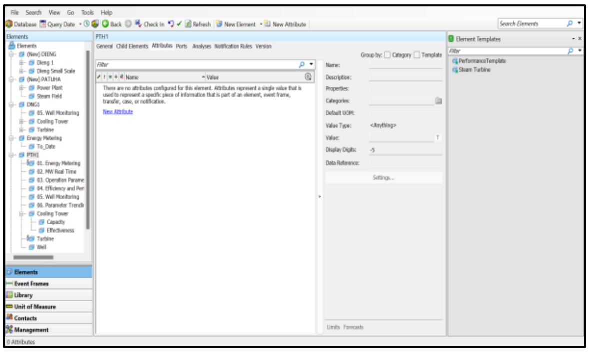

Figure 6: Asset Framework Environment

Moreover, multiple copies of existing Asset Framework objects (elements and attributes, categories, enumeration sets, templates, UOM classes, UOMs, reference types, event frames, transfers, ports, enumeration values, and extended properties) can be easily created by using the builder environment. In this study, there were 2 types of sources of data, namely: OPC DA and Modbus ethernet. These data were transformed into a new operational tag in the environment of the builder by matching the previous instrument tag that was stamped in DCS. Some tags were built based new analysis and were edited by engineers in an asset framework environment.

2.3 Interactive User-Friendly Visualization Platform

The representation of data through use of common graphics, such as charts, plots, infographics, and even animations is categorized as data visualization. Data visualization aims to transform data into a story by showing trends and outliers, thus emphasizing the important point of information. This can be accomplished using variety of applications, including Tableau, Power BI, PI Vision, and others.

Real-time data streams were visualized with PI Vision. Leveraging its connectivity with the historical database and asset framework. Meanwhile, Power BI e easily interconnect data both from historical sources and from other sources such as SharePoint or an SQL server.

Figure 7: PI Vision shows an Overview of Steam Field Parameters

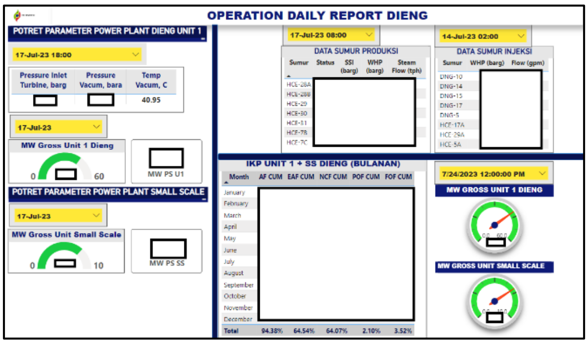

Figure 8: Business Intelligence Platform shows a combination of real-time and manually collected data

3. CASE STUDY & RESULT

The ultimate outcome of integrating the operational data into a robust database management system was not only visualization through a trend chart or other graphs but also the giving of insights with deep knowledge for staff at both the working and management levels. Expectedly, quick and precise decision-making could be generated by implementing the Asset Performance Management (APM) tool. Some production monitoring tools were successfully established in APM Phase 1, however, the focus is still on monitoring the ongoing real-time data from the whole plant scale to the scale of significant individual geothermal equipment.

3.1 Geothermal Plant Real-time Monitoring

The necessity of geothermal power plant monitoring is highlighted in this study, and the impacts of monitoring and operating conditions of geothermal power plants on long-term power output are described. Furthermore, in order to discover the causes of performance failures that prevent the plants from attaining maximum capacity production levels, their operational parameters are continuously monitored, and their continuous performance is computed and monitored.

The electricity generation output from all plants can be represented as in **Figure 9**. By taking some production tags in the archive data such as Gross MWh Output, Net MWh Output, and Availability Hours (AH) of plants, it can be translated into the actual electricity production with the formula below [1]:

$$\boldsymbol{AH} = PH - POH - FOH \qquad [1]$$

$$\boldsymbol{Net\ Prod\ in\ kWh} = AH\ x\ Net\ MWh\ x\ 1000 \qquad [2]$$

Note:
AH: Availability Hours
PH: Period Hours in specified time
POH: Planned Outage Hours in specified time
FOH: Forced Outage Hours in specified time

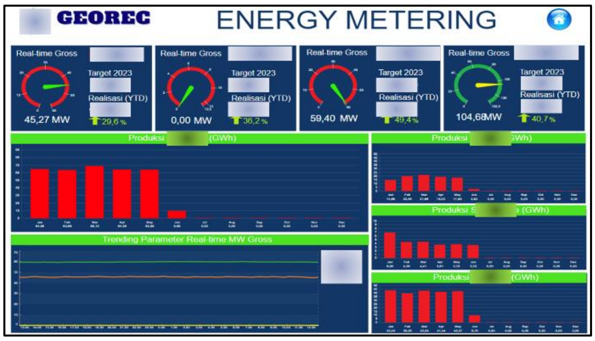

Figure 9: Energy Metering of Plant Production Output

In addition, steam turbine operational parameters were also monitored in APM Phase 1. One of the most importance parameter is steam turbine efficiency (**Figure 10**). The simplified efficiency of a steam turbine is evaluated as follows: net electricity produced/energy input [3]. The energy input in geothermal power plants can be described as the total mass of fluid (kg/s) multiplied by the change in enthalpy (kJ/kg) between outlet turbine and condenser, as illustrated below:

$$\eta_{actual} = \frac{W}{\dot{m}\ x\ (H_{out\ turbine} - H_{condenser})} \qquad [3]$$

where W is the running capacity (kWh), $\dot{m}$ is the total mass flow rate (kg/s), and h is the fluid enthalpy (kJ/kg). The enthalpy parameter came from the steam tables, which have already been attached to the asset framework environment.

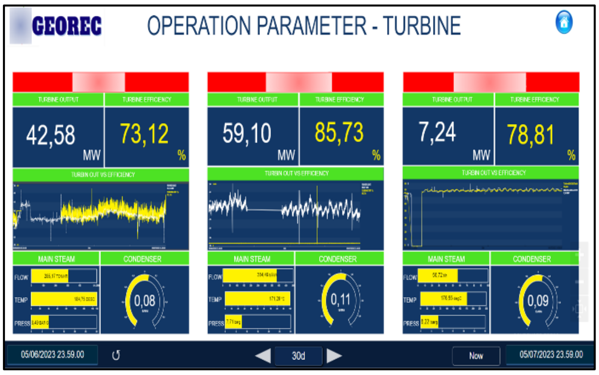

Figure 10: Steam Turbine Operational Parameter

3.2 Steam Field Real-time Monitoring

Development of electrical power from geothermal sources requires continual monitoring and planning, especially in the upstream side. The steam supply from the geothermal production wells determines the capacity factor of the plant. Therefore, the project team also developed a real-time monitoring of the performance of the production wells to capture a production variance opportunity. To make this great opportunity a reality, the first step was collecting production well parameters (wellhead pressure, temperature, steam flow rate, steam quality, separator, and steam line parameters) into one dashboard, as represented in **Figure 11**. By compiling parameters for the production well, they can be easily monitored, one by one, with correlations identified between each other, like interference phenomena.

Moreover, distributions of simplified pressure drop and steam losses can be traced by applying a nodal analysis in this dashboard. The pressure drop from the wellhead to the steam line reflects the fluid condensation phenomena and the flow through the pipe itself, which affects how much steam is provided to the generator. A reduction in steam pressure can also cause an increase in specific volume and, for a given mass flow, an increase in velocity.

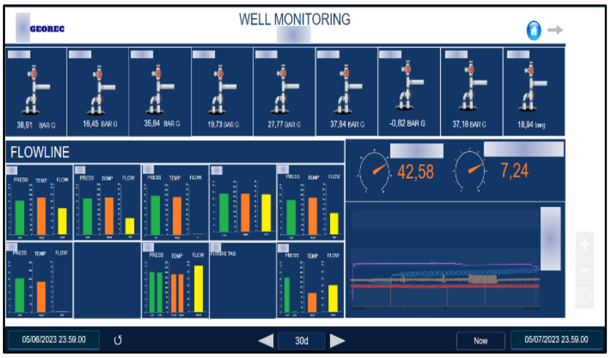

Figure 11: Production Wells Performance Dashboard

A well calibrated simulation can be used to predict how the output of a well will be affected by changing reservoir or wellbore conditions. It can also be matched to the decline of a well and help to understand the possible changes that have caused this decline. A powerful method is the comparison of the output curves of wellhead pressure against flowrate. Reservoir pressure or enthalpy decline change the shape of these curves in different ways, e.g., due to wellbore diameter reduction (due to scaling) or feed zone productivity loss, as shown in Figure 5. The most telling sign of decline due to a wellbore obstruction is a large change in output at higher flowrates/lower discharge pressures, with minimal change in the maximum discharge pressure. At lower flowrates, the effects of a wellbore restriction are smaller due to the lower velocity (Allan, 2019).

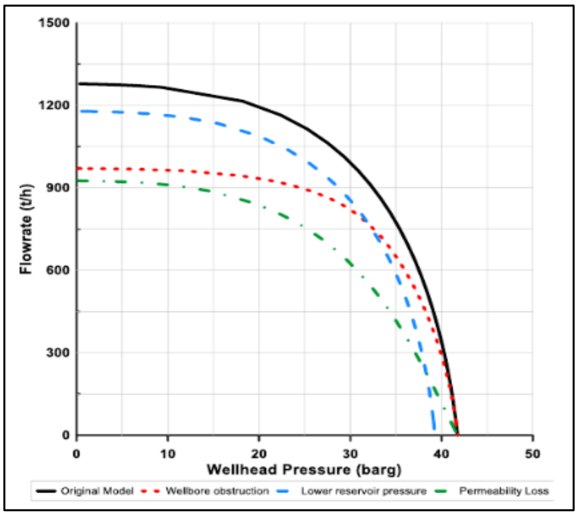

Figure 12: Well Deliverability curve concept

The actual well performance can be monitored by matching actual real-time wellhead pressure and steam flow rate to a deliverability curve for the well which was built using wellbore simulation software. **Figure 10** shows wellhead pressure vs flow rate data that can be exported into an excel sheet to evaluate the performance of the well, to ensure the current level of the production is satisfactory (not too much below or above the expected decline rate).

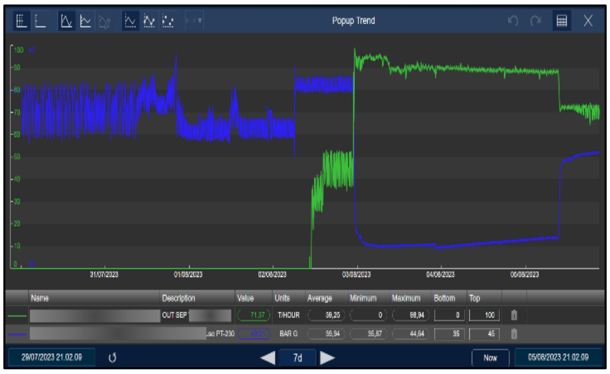

Figure 13:Well head pressure vs steam flow rate

3.3 Operational Equipment Real-time Monitoring

A cooling tower is a heat exchanger component of a geothermal power plant that cools water by connecting it to the surrounding air. The efficiency of the cooling tower is evaluated by examining its effectiveness using the range and approach specified in Equation 4 and 5.

$$\boldsymbol{Range} = T_{inlet} - T_{outlet} \quad [4]$$

$$\boldsymbol{Approach} = T_{outlet} - T_{wet\ bulb} \quad [5]$$

$$\boldsymbol{\varepsilon_{cooling\ tower}} = \frac{Range}{(Range + Approach)} \quad [6]$$

The performance of the cooling tower will be better if the approach value is smaller. By applying this concept, a cooling tower performance dashboard has also already been developed in APM Phase 1. The formula was installed on the visualization platform, and prior to the application of the formula, the inlet and outlet temperature cooling tower tags must be retrieved. However, due to the lack of a wet bulb temperature sensor, the wet bulb temperature is still presumed to have a fixed value in this dashboard.

Figure 14: Cooling Tower Performance Dashboard

3.4 Quick-win mini Root Cause Analysis Forced Outage Plant 1 using Asset Performance Management Tools

Given the constant demand for business development growth in companies, various maintenance techniques have been developed to analyze problems arising in critical equipment and processes, with the main goals of these techniques being to reduce repetitive failures and increase operational reliability. Within these strategies, one of the most extensively utilized methodologies for minimizing the effect of failures and optimizing asset reliability is Root Cause Analysis. When applying Root Cause Analysis in asset maintenance, the usage of digital technologies (Asset Performance Management) is quite beneficial. These tools enable users to recognize a variety of changes in the Failure Mode Analysis process, as well as implement a variety of analysis and process automation possibilities.

In this study, a real example of how to use the APM tool to perform a quick-win analysis in the event of a failure at a geothermal plant will be provided. On January 8, 2023 03:58 AM (GMT+7), one of our production plants encountered a forced outage, with preliminary indications that the central hydraulic oil system had experienced problems. Then, trend analysis of some related parameters in the APM tool was carried out, as represented in **Figure 15** below.

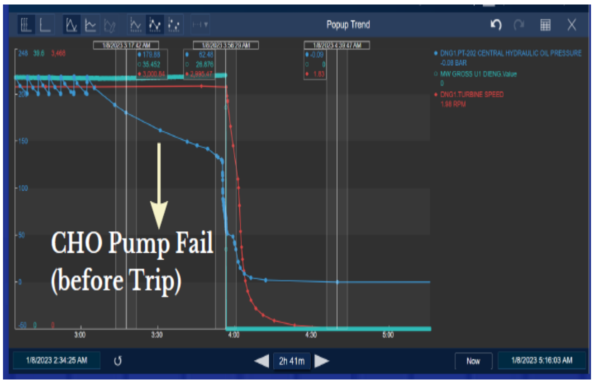

Figure 15: Trend Analysis – Forced Outage Event

The 5 Whys of Force Outage are:

Loss of hydraulic pressure → Turbine Stop Valve closed → Loss of steam supply → Turbine Rundown → Reverse Power Relay Active → Generator Breaker Open

The analysis immediately alerted site stakeholders to the need for troubleshooting and immediate corrective action. The plant was synchronized to the grid on the same day. Advanced real-time monitoring can be deployed, which means the APM can be used as an early detection tool to avoid some failures in the future.

4. CONCLUSION & WAY FORWARD

The digitalization journey at Dieng and Patuha field has resulted in an end-to-end approach of a data system hierarchy which involves collecting data, turning data into information, analysing information into knowledge, and applying knowledge to actions and decisions. This approach has resulted in several success stories that were carried out just around one month after the implementation of the digital initiatives.

The introduction of the end-to-end approach in such a short time came with many challenges at every level of the data hierarchy. It is expected that the product will continuously improve at every level. To improve the data quality, the builder could be used to speed up data sampling from OPC and modbus. The AF analysis is also planned to be evaluated to enrich information gathering. The integration of the enterprise asset management tool with APM would be tremendously helpful to enhance the plant maintenance strategy.

ACKNOWLEDGEMENTS

We acknowledgement pioneering work of the Digital Initiatives team that transformed Dieng and Patuha sites digitally, setting new standards for progress and guiding the performance of the company to a higher level.

Appreciation is due to the Dieng and Patuha stakeholders who embraced collaboration, using new tools provided by the digital team. Their insights and discussions proved vital in addressing challenges.

The diverse support and contributions from many working areas intricately shaped the path of this endeavour.

REFERENCES

Alfian, H., Sigit, P.: Energy and Exergy Analysis of Dieng Geothermal Power Plant. Proc. International Journal of Technology. (2021).

George, A., Justin, P.: Wellbore Simulation to Model Calcite Deposition on the Ngatamariki Geothermal Field, NZ. Proc. Stanford Geothermal Workshop, Stanford, USA. pp. 4 - 5. (2019).

Hyungsul, M., Sadiq, J.: Efficiency of Geothermal Power Plants: A Worldwide Review. *Proc. New Zealand Geothermal Workshop*, Auckland, New Zealand. pp. 1 – 6. (2012).

Hilal, K., Umran, S.: The Importance of Geothermal Power Plant Monitoring for Sustainable Power Production. *Proc. World Geothermal Congress 2020*, Ryekjavik, Iceland. (2021).

Sweta, Singh.: Database Management System. Presentation for the Faculty of Management Studies. India. (2015).

AVEVA Journal.: How ISO 55000 can help transform utility operations through better asset management. *Digitalization Forum*. (2021).

Surya, Darma., Yaumil, L.: Country Update: The Fast Growth of Geothermal Energy Development in Indonesia. *Proc. World Geothermal Congress 2020*, Ryekjavik, Iceland. (2020).