Smart Microgrid : Power Monitoring And Management System With Self-Healing Ability

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***Abstract*— This research proposed a smart microgrid power monitoring and management system with self-healing ability. Solar power plant have been integrated into the microgrid, which previously relied on DG and PLN power supply. However, system monitoring and control are limited. This study develops an effective, efficient and reliable smart microgrid by integrating an online monitoring and control system, a power management system and self-healing system. Online monitoring and control system is effective for monitoring and controlling a microgrid and can detect and analyze potential faults at ease. Power management system is necessary to enhance the efficiency and reliability of power supply. Then, with self-healing ability, enable to detect, to prevent, to isolate and to recover faults automatically, making smart microgrid more efficient and reliable. Through the Siemens TIA Portal, the study compared the simulation results of existing microgrid system with smart microgrid system incorporating online monitoring and control system, power management system and self-healing system. Using some fault scenarios, The MTTD, MTTR and availability rate values are obtained. As result, the proposed smart microgrid system reduces the time required to detect and to recover faults efficiently. Thus, the reliability of power supply also increased significantly.**

Keywords—online monitoring and control, power management, self-healing, smart microgrid

I. Introduction

Microgrid integrate small-scale electricity systems with multiple distributed energy resources and local loads, often sourced from renewable energy like wind and solar [1]. Real-world microgrid, which showcase various hardware and control systems, have also been implemented. Technical and operational challenges in the design and operation of microgrid include the control, protection, and infrastructure considerations [2]. Real-world microgrid have been demonstrated, highlighting the wide range of hardware and control options available [3].

The electricity system of a company grows in parallel with its production activities. Initially, the power supply was relied on DG (Diesel Generator) alone. With an increase in productivity, the primary power supply shifted from DG to PLN (State Electricity Company). Following the government's carbon reduction policy, they installed on-grid solar power plant (PLTS) as part of a microgrid power supply. This system is integrated with the 20 kV MV (Medium Voltage) distribution network to form a microgrid system.

1,350 kVA PLN as the primary power supply, 1,000 kW PLTS on-grid generate power supply during the day and 1,500 kVA DGs as the secondary power supply, supply the load in the microgrid. However, system monitoring and control are limited. An online assessment is required to enhance microgrid performance [4]. An innovative solution to enhance the efficiency and reliability of power supply is smart microgrid system. Paper [5] highlighted the significance of smart microgrid in enhancing power quality and facilitating the sharing of grid-integrated power supplies. Smart microgrid, as discussed in Paper [6], offer the potential for a more intricate and effective electricity system through their operation, control, and protection.

Online monitoring and control system is essential for effective and real-time microgrid management. This will facilitate the detection and analysis of potential faults. Acting quickly to control the microgrid can reduce the duration of power outages. The data can also be stored and analyzed to enhance the microgrid performance. Power management system is used to enhance the microgrid, to prevent shutdown and faults, thereby making the microgrid more efficient and reliable. Self-healing system can automatically detect, prevent, isolate, and normalize faults [7]. The self-healing capability, which minimizes the outage duration and unsupplied loads [8], refers to the ability of the system to improve reliability.

This research proposed a smart microgrid power monitoring and management system with self-healing ability. The results of this research will contribute to the development of more efficient and reliable power supplies on microgrids. This research also has a positive impact on the understanding of the relationship between online monitoring and control system, power management system and self-healing system in the context of smart microgrid, contributing to the scientific literature and the development of electricity system technology.

II. Methods

A. *Related work*

This paper [9] investigates the detailed operation, control, and protection mechanisms of smart microgrid with an emphasis on integrating wind and solar energy as distributed resources. This paper discusses renewable resources in microgrid and their control mechanisms in grid-connected and isolated states. This study focuses on challenges and microgrid control architectures, encompassing primary and secondary control levels and microgrid protection techniques. In [10]

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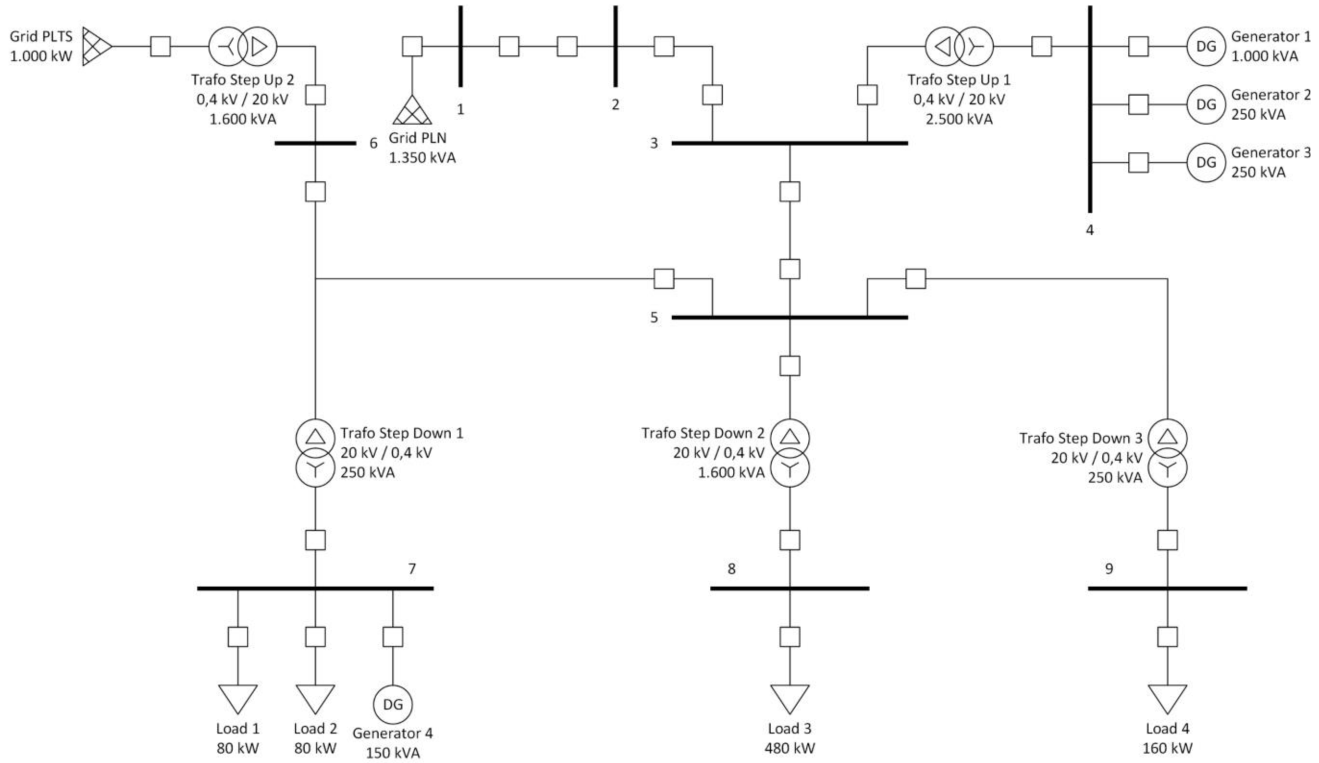

Fig. 1 SLD of existing microgrid system

presents a MILP (Mixed-Integer Linear Programing) optimization problem for devising a smart self-healing strategy for smart grids. The smart grid system was used to evaluate the proposed strategy, which prioritizes power supply restoration to customers based on their importance while minimizing operational expenses. The study's findings detail the ideal setup after a fault, with disconnected loads and controllable distributed generation operations. The loss minimization reconfiguration problem is solved efficiently and accurately.

B. Existing microgrid

PLN with 1,350 kVA power supply connected to a PLN's MV cubicle on bus 1 and linked to customer's MV cubicle 1 on bus 2. Customer's MV cubicle 2 on bus 3 is connected to bus 2 as the primary power supply. DGs with a total of 1,000 kVA synchronized power supply with a 0.4/0.23 kV output voltage using three 1 ,000 kVA, 250 kVA , and 250 kVA DGs on bus 4 raise the voltage to 20 kV with a 2,500 kVA step-up transformer linked to bus 3, as the secondary power supply. Customer's LVMDP (Low Voltage Main Distribution Panel) on bus 7 has a 150 kVA backup DG for loads on bus 7. 1,000 kW on-grid PLTS with an output voltage rating of 0.8 kV is raised to 20 kV with a 1,600 kVA step-up transformer, linked to an MV cubicle and connected to bus 5.

C. Proposed smart microgrid

The study will use Siemens TIA Portal software to simulate the electricity system without any hardware. Fig. 2 presents the design of the smart microgrid system. The smart microgrid system is described in the following explanation.

Siemens TIA Portal software is used to simulate a microgrid, online monitoring and control system, power management system and self-healing system. Arrow 1

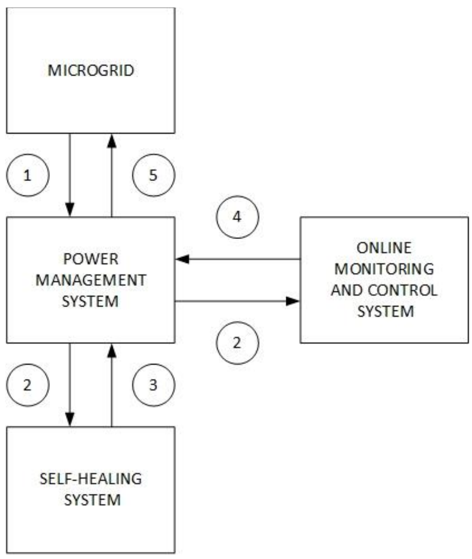

Fig. 2 Smart microgrid system

represents data transmission from the microgrid to the power management system, which is processed by the PLC. Online monitoring and control system and self-healing system receive data from the microgrid, represented by Arrow 2. The self-healing system analyzes the real-time data and sends the results back to the power management system, represented by arrow 3. The operator manages the microgrid in real-time through the SCADA interface. The flow of control commands from the online monitoring and control system to power management is represented by Arrow 4. Arrow 5 represents power management system that optimally controls the microgrid based on data from the self-healing system, monitoring and control commands, and pre-determined results. The cycle repeats.

D. Siemens TIA Portal

The Siemens TIA Portal is software designed to facilitate the programing and configuration of industrial automation systems, specifically those using PLCs from Siemens [11]. This software allows users to develop, configure and maintain automation systems more efficiently by integrating various components such as PLCs, HMI (Human Machine Interface), SCADA and network devices in a single platform. The Siemens TIA Portal offers a GUI (Graphical User Interface) that makes it easy for users to use, making the user interface intuitive. With this software, it enables integration between PLC, HMI, SCADA and network devices, enabling users to control and monitor the system in real-time, which is a very important feature in industrial applications that require remote supervision and control. The software supports system simulation, allowing users to test and validate programs before deployment to the field. This reduces the risk of errors and improves operational efficiency [12].

E. Mechanism of smart microgrid system

The proposed smart microgrid integrate online monitoring and control system, power management system and sel-healing system. The online monitoring and control system, the electrical parameters of each component can be displayed, such as on each bus, line, transformer, load and DG. There are 4 colors used in the components: gray, inactive; green, active / safe; yellow, warning / unsafe; and red, fault / dangerous. Then, each CB, DG and PLTS can be controlled.

The power management system, the load is ensured to receive a good power supply. ATS (Automatic Transfer Switch) system with voltage protection and load sharing on the DGs can generate power supply in the power house. If there is an outage fault of the main power supply source or if it is unsafe or dangerous, the ATS system will switch the power supply source from the main power supply source to the secondary power supply source. Load sharing system ensures that the generated power supply of the DGs is sufficient to supply the load, preventing the DGs from over-generating power supply during small loads and overloading during large loads.

The Self-healing systems rely on real-time monitoring and control and power management, analyze electrical parameter data, prevent faults, isolate faults, and recover the fault quickly, as long as the fault is not permanent. This self-healing system incorporates CB control to disconnect the power and isolate faults. A tripped CB shortens its lifespan. Thus, self-healing deactivates CB before tripping if the line is overloaded. In case of DG overload, self-healing temporarily disconnects the second priority load to prevent it from happening until the generated power supply is sufficient to supply the load, then, it is reconnected. If a CB trip is due to a short circuit fault, the CB will reset and reactivate.

F. MTTD, MTTR and availability rate

MTTD (Mean Time To Detect) denotes the time required to recognize a fault following machine failure [13]. The MTTD is essential for reducing downtime and maximizing system accessibility.

$$MTTD = \frac{Total\ Detect\ Time}{Number\ of\ Failure} \quad (1)$$

MTTR (Mean Time To Repair) represents the typical duration of repair for a component or system [14].

$$MTTR = \frac{Total\ Repair\ Time}{Number\ of\ Failure} \quad (2)$$

The Availability Rate [15] measures the proportion of the total planned machine/system operation time that is spent in a ready state for use. The actual operating time was calculated as a percentage of the planned operating time.

$$\text{availability rate} = \frac{loading\ time - downtime}{loading\ time}\ X\ 100\% \quad (3)$$

G. Fault scenarios

The MTTD and MTTR values for the microgrid were obtained by dividing the respective total detection and repair times by the number of failures that occurred each time. The availability rate is the quotient of the planned operating time and the difference between the planned operating time and downtime. The test results will help determine the electricity system's reliability and efficiency at the site, allowing for the identification of improvements and better operational choices. The fault scenarios are power outage faults from the PLN, power supply from PLN is over voltage, power supply from PLN is low voltage, DG is overloaded (power supply is increased), DG is overloaded (power supply is diverted), overload on the load and short circuit on the load.

III. Results and Discussion

In this section, the proposed smart microgrid system is tested. The MTTD, MTTR and availability rate values are determined based on the test results. For existing microgrid systems, the values of detect time, repair time and downtime are based on direct observation and information from stakeholder. In several fault scenario case studies, simulations are conducted.

1) Power outage faults from the PLN
2) Power supply from the PLN is over voltage
3) Power supply from the PLN is low voltage
4) DG is overloaded (power supply is increased)
5) DG is overloaded (power supply is diverted)
6) Overload on the load
7) Short circuit on the load

A. Case 1 - Power outage faults from the PLN

In case 1, the power supply to the load is provided by both the PLN and PLTS, as shown in Fig. 3. Suddenly, the PLN's power supply goes off, causing the microgrid to shutdown. In existing microgrid systems, customers can only determine power outage faults from the PLN as the cause upon investigation. The customer supply the load using the DG. They turn on the DG, then deactivate and activate the related CB at the powerhouse to supply the load. The PLN's power supply status remains unknown to them. Upon knowing the PLN's power supply is back, they visit the power house to turn off the DG and activate the related CB to supply the load using the PLN's power supply. The detect time value in this case is from the power outage fault on the PLN's power supply that occurred until they received the report, which lasted 10 min. The repair time value is from the cause known until the load was supplied, which took 20 min. Thus, the downtime is 30 min.

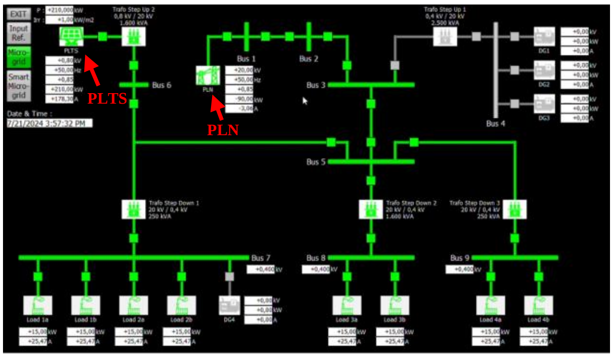

Fig. 3 The power supply to the load is provided by both the PLN and PLTS

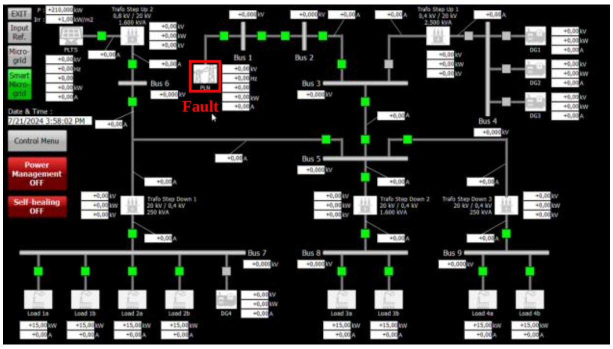

Fig. 4 Monitoring an outage fault of the PLN's power supply

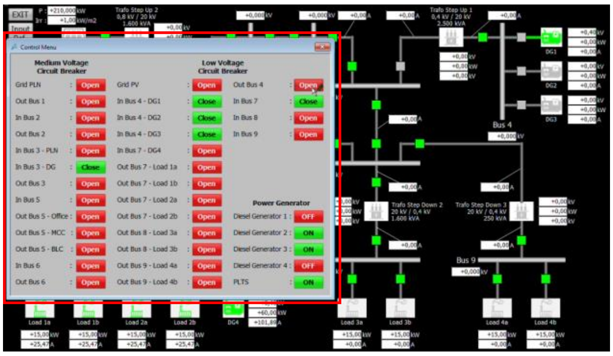

Fig. 5 Control Menu window to deactivate and to activate CBs and DGs

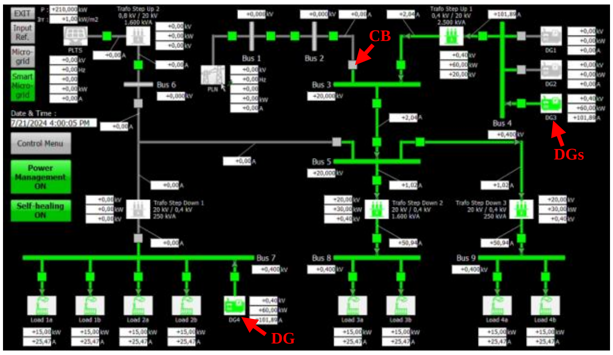

Fig. 6 Switching power supply using DG with power management

The smart microgrid's online monitoring and control system can monitor the cause of the shutdown fault, see Fig. 4. The customer can turn on the DG from the Control Menu window in the control room, then deactivate and activate the related CB to supply the load, as shown in Fig. 5. They can know when the PLN's power supply is on. Then, they can deactivate and activate the related CB so that the load receives power supply from the PLN and turn off the DG remotely. However, with the smart microgrid's power management system, these actions are efficiently automated, as shown in Fig. 6. The self-healing system plays no role in this case. The detect time, repair time, and downtime value using smart microgrid system are given in Table 1.

TABLE 1. TABLE OF DETECT TIME, REPAIR TIME AND DOWNTIME VALUES OF CASE 1

System	*Detect Time (minute)*	*Repair Time (minute)*	*Downtime (minute)*
Microgrid	10	20	30
Smart Microgrid	0.1	0.2	0.3

B. Case 2 - Power supply from PLN is over voltage

In case 2, as in case 1, the power supply to the load is provided by both the PLN and PLTS. Suddenly, the PLN's power supply is over voltage, causing the possibility of damage to the equipment in the load. In existing microgrid system, the customer do not know when this fault occurs until they receive a report. The customer then supply the load using the DG to ensure a safe voltage for the load. They do not know when the PLN's power supply is turned back to normal. The detect time value in this case is from the over voltage on the PLN's power supply occurred until they received the report, which lasted 15 min. The repair time value is from the cause known until the load is powered, which took 20 min. Thus, the downtime is 35 min.

The smart microgrid's online monitoring and control system can monitor when an over voltage on PLN's power supply occurs and turns back to normal. Aside from the customer can manually take action using the Control Menu window in the control room, the smart microgrid's power management system efficiently and automatically deactivates related CB to isolate the load from a harmful power supply, then supplies the load using the DG, as shown in Fig. 7. The self-healing system plays no role in this case. The detect time, repair time, and downtime value using smart microgrid system are given in Table 2.

TABLE 2. TABLE OF DETECT TIME, REPAIR TIME AND DOWNTIME VALUES OF CASE 2

System	*Detect Time (minute)*	*Repair Time (minute)*	*Downtime (minute)*
Microgrid	15	20	35
Smart Microgrid	0.1	0.2	0.3

C. Case 3 - Power supply from PLN is low voltage

In case 3, as in cases 1 and 2, the power supply to the load is provided by both the PLN and PLTS. Suddenly, the PLN's power supply is low voltage, causing the possibility of a decrease in the equipment power in the load. In existing microgrid system, the customer do not know when this fault occurs until they receive a report. Then, they contact the PLN to ask them to return the voltage back to normal. The load is still using the PLN's power supply with poor voltage. The detect time value in this case is from the low voltage on the PLN's power supply occurred until they received the report, which lasted 30 min. The repair time value is from the cause known until the PLN's power supply is turned back to normal, which took 20 min. Thus, the downtime is 50 min.

The smart microgrid's online monitoring and control system can monitor when a low voltage on the PLN's power supply occurs and returns to normal. Aside from the customer

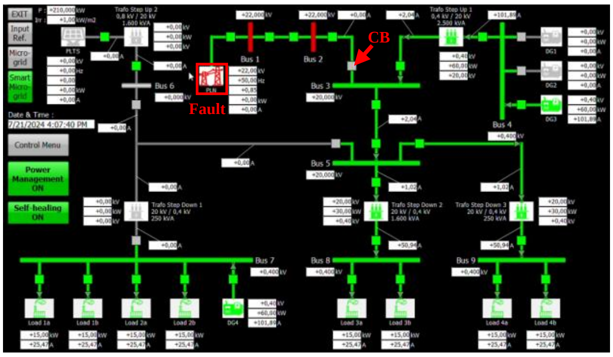

Fig. 7 The power supply to the load provided by the DG due to an over voltage fault in the PLN's power supply

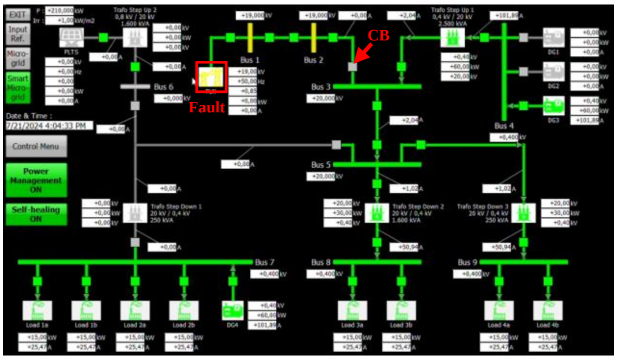

Fig. 8 The power supply to the load provided by the DG due to low voltage fault in the PLN's power supply

can manually take action using the Control Menu window in the control room, the smart microgrid's power management system efficiently and automatically turns on the DG, deactivates and activates related CB to supplies the load using the DG, as shown in Fig. 8, until the PLN's power supply is turned back to normal. The self-healing system plays no role in this case. The detect time, repair time, and downtime value using smart microgrid system are given in Table 3.

TABLE 3. TABLE OF DETECT TIME, REPAIR TIME AND DOWNTIME VALUES OF CASE 3

System	*Detect Time (minute)*	*Repair Time (minute)*	*Downtime (minute)*
Microgrid	30	20	50
Smart Microgrid	0.1	0.2	0.3

D. Case 4 - DG is overloaded (power supply is increased)

In case 4, the power supply to the load is provided by the DG, as illustrated in Fig. 9. The load's power usage changes over time. First, the load can be supplied using only 1 DG. Then there is a gradual increase in the load's power usage which causes the DG to overload, as shown in Fig. 10, causing the microgrid to shutdown. In existing microgrid system, the customer is not aware of this fault. The customer must go to the power house to turn on the DG to increase the generated power supply. The detect time value in this case is from an increase power usage in the load until the DG is overloaded, which lasted 20 min. The repair time value is from the shutdown of the microgrid until the power supply was restored, which took 15 min. Thus, the downtime is 35 min.

The smart microgrid's online monitoring and control system can monitor the load's power usage changes. The customer can turn on another DG to increase the generated power supply so that the DG does not overload. However, they should no longer monitor and manually control it as the smart microgrid's power management system does so automatically, which is known as load sharing. But, the smart microgrid's power management system could not control the load. In case of a significant increase in the load's power usage, the smart microgrid's self-healing system will deactivates CB for unprioritized loads and turns on another DG, before the DG's power supply is sufficient to supply the load, which is known as load shedding, and reactivates the CB of the load, as shown in Fig. 11. The detect time, repair time, and downtime value using smart microgrid system are given in Table 4.

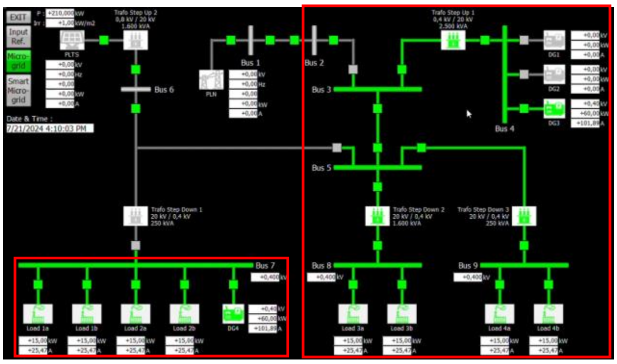
Fig. 9 The power supply to the load is provided by the DG

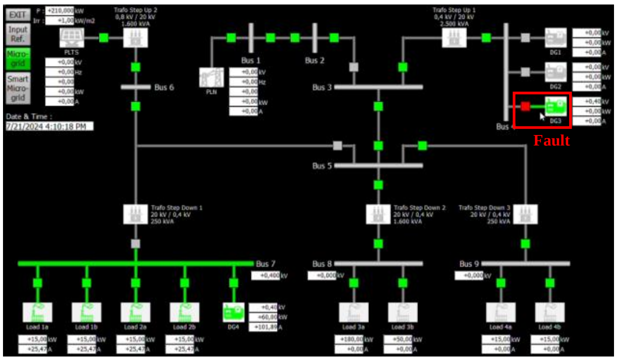

Fig. 10 The DG is overloaded due to an increase in the load's power usage

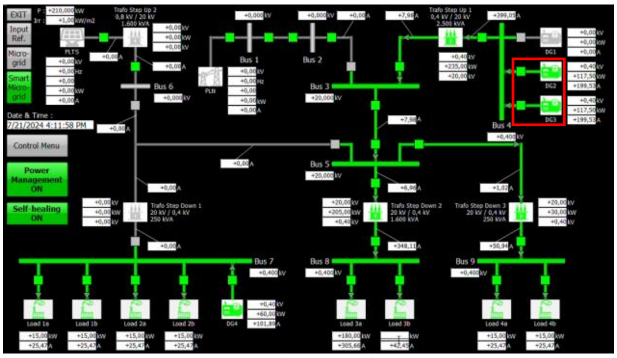
Fig. 11 Smart microgrid increases the DG's generated power supply automatically

TABLE 4. TABLE OF DETECT TIME, REPAIR TIME AND DOWNTIME VALUES OF CASE 4

System	*Detect Time (minute)*	*Repair Time (minute)*	*Downtime (minute)*
Microgrid	20	15	35
Smart Microgrid	0.05	0.167	0.217

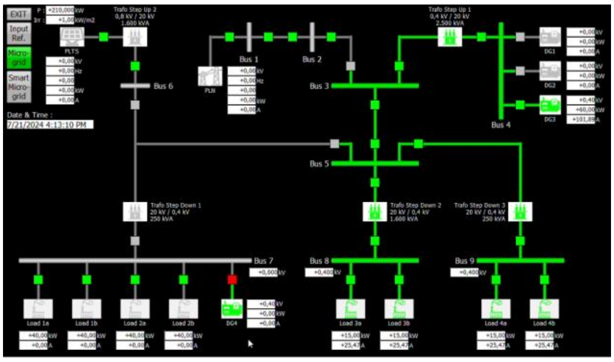

Fig. 12 The DG is overloaded due to an increase in the load's power usage, causing other loads to not be supplied

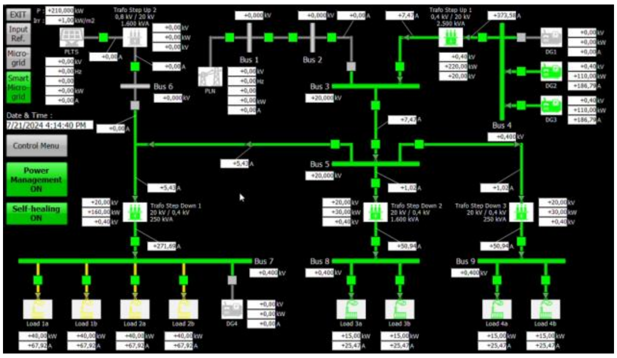

Fig. 13 Smart microgrid diverts the power supply to the load using DG in the power house

E. *Case 5 - DG is overloaded (power supply is diverted)*

In case 5, as in case 4, the power supply to the load is provided by the DG. The load's power usage changes over time. At bus 7, initially, the load can be supplied to the office and utility areas using the DG. Then there is a gradual increase in the load's power usage which causes the DG to overload, as shown in Fig. 12, causing other loads to not be supplied. In existing microgrid system, the customer is not aware of this fault. The customer must reduce the power usage of the load, then go to the panel room to turn on the CB that trip due to overload. The detect time value in this case is from an increase power usage in load until the DG is overloaded, which lasted 10 min. The repair time value is from the shutdown of the microgrid until the power supply was restored, which took 10 min. Thus, the downtime is 20 min.

As in case 4, the smart microgrid's online monitoring and control system can monitor the load's power usage changes. From the control room, using the Control Menu window, the customer can immediately deactivate the CB for unprioritized loads to avoid overloading the DG. If the load is required to be on, then the power supply can be diverted using the DG at the power house. With the smart microgrid's power management and self-healing system automatically performs this task, as shown in Fig. 13. The detect time, repair time, and downtime value using smart microgrid system are given in Table 5.

TABLE 5. TABLE OF DETECT TIME, REPAIR TIME AND DOWNTIME VALUES OF CASE 5

System	*Detect Time (minute)*	*Repair Time (minute)*	*Downtime (minute)*
Microgrid	10	10	20
Smart Microgrid	0.05	0.167	0.217

F. *Case 6 - Overload on the load*

In case 6, the power supply to the load is provided by the PLN. Slowly, an area is overloaded due to power usage on the load exceeds the capacity. As a result, the CB that protects the load trips. In existing microgrid system, the customer does not know what caused the shutdown. After investigation, it is known that the CB in the load area was tripped. The customer will activate the CB again so that the load receive power supply. Normally, when a load is overloaded, the power usage of the load is reduced because some equipment must be reactivated after shutdown. However, if an overload still occurs, the CB will trip again. A CB with frequent trips will reduce its lifetime. The detect time value in this case is from the CB trips until the customer knew the cause, which lasted 5 min. The repair time value is from the cause known until the load was supplied, which took 10 min. Thus, the downtime is 15 min.

The smart microgrid's online monitoring and control system can monitor the cause of the shutdown fault, as shown in Fig. 14. From the control room, using the Control Menu window, the customer can immediately deactivate the related CB so that it does not trip. However, if the customer realizes this fault too late, the CB will still trip. The customer can reset the CB and reactivate it from the control room. However, with the smart microgrid's self-healing system, this can be resolved automatically. If the load is overloaded, self-healing deactivates the CB before it trips, as shown in Fig. 15. A few moments later, the CB was reactivated and the load continued to receive power supply. This will increases the CB lifetime.

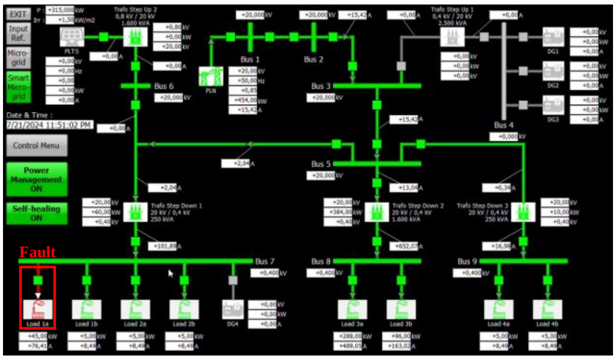

Fig. 14 Smart microgrid can detect when an overload fault occurs

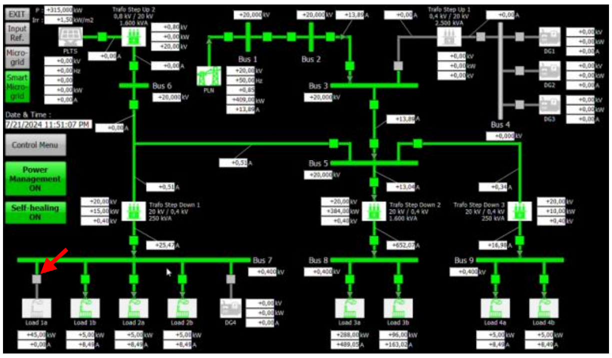

Fig. 15 Smart microgrid deactivates CB before it trips due to overload fault

The detect time, repair time, and downtime value using smart microgrid system are given in Table 6.

TABLE 6. TABLE OF DETECT TIME, REPAIR TIME AND DOWNTIME VALUES OF CASE 6

System	*Detect Time (minute)*	*Repair Time (minute)*	*Downtime (minute)*
Microgrid	5	10	15
Smart Microgrid	0.05	0.083	0.133

G. Case 7 - Short circuit on the load

For case 7, as in case 6, the power supply to the load is provided by the PLN. A short circuit fault suddenly occurs in one of the load areas. As a result, the CBs that protect the load and the area trip, so other loads become unsupplied, as shown in Fig. 16. In existing microgrid systems, the customer do not know what caused the shutdown. After investigation, it is known that the CBs in the load area is tripped. They will try to activate the CBs again so that the load receive power supply. However, because they do not know the cause of the CBs trip due to a short circuit, the CBs will immediately trip again after being activated. An investigation to find out the short circuit fault point is carried out until it is finally found and resolved. The detect time value in this case is from the CBs trip until the customer knew the cause, which lasted 20 min. The repair time value is from the cause known until the load was powered, which took 10 min. Thus, the downtime is 30 min.

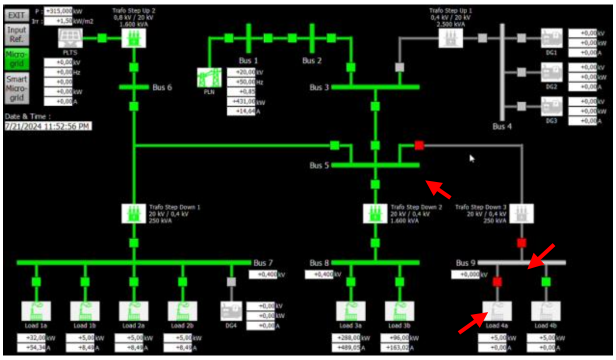

Fig. 16 A short circuit fault occurs, causing the CBs trip

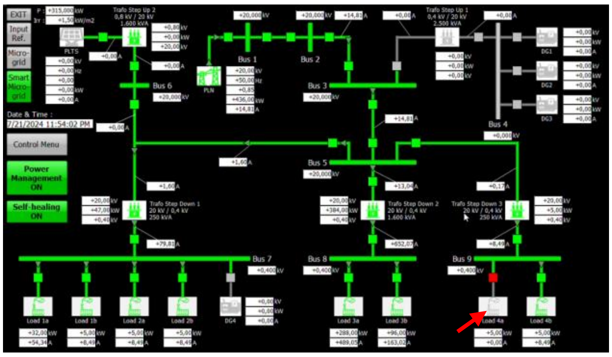

Fig. 17 Smart microgrid resets and reactivates the affected CBs except for the CB of load with a short circuit

The smart microgrid's online monitoring and control system can monitor the cause of the shutdown fault. From the control room, using the Control Menu window, the customer can immediately reset the CBs and reactivate the affected CBs except for the CB of load with a short circuit. With the smart microgrid's self-healing system, this can be resolved automatically, as shown in Fig. 17. The detect time value, repair time value and downtime value in this case using a smart microgrid system can be seen in table 7.

TABLE 7. TABLE OF DETECT TIME, REPAIR TIME AND DOWNTIME VALUES OF CASE 7

System	*Detect Time (minute)*	*Repair Time (minute)*	*Downtime (minute)*
Microgrid	20	10	30
Smart Microgrid	0.05	10	10.05

H. MTTD, MTTR and Availability Rate

MTTD, MTTR and availability rate values were taken from Detect time, Repair time and Downtime data for each case with a loading time of 30 days or 43,200 minutes, using equations (1), (2) and (3), as presented in Table 8. In existing microgrid system, the MTTD value, MTTR value and availability rate value are 15.714 min, 15 min and 99.502%.

TABLE 8. TABLE OF MTTD, MTTR AND AVAILABILITY RATE

System	*MTTD (minute)*	*MTTR (minute)*	*Availability Rate (%)*
Microgrid	15.714	15	99.502
Smart Microgrid	0.071	1.573	99.973

With the smart microgrid system, integration of online monitoring and control system, power management system and self-healing system, has an MTTD value of 0.071 min, an MTTR value of 1.573 min, with an availability rate of 99.996%. There is an increase in MTTD, MTTR and availability rate of 99.54%, 89.51% and 0.064%, respectively, compared with the existing microgrid system.

From these data, it can be seen that the implementation of smart microgrid systems (Online Monitoring and Control, Power Management, and Self-healing) significantly improves the efficiency in detecting problems (MTTD), making repairs (MTTR) and maintaining system availability (Availability Rate) compared to existing microgrids. Although if the fault is permanent there must still be action from the user, the advantages in early detection and high availability rate make smart microgrid systems a better choice for maintaining power supply reliability.

IV. CONCLUSION

The proposed smart microgrid system, which consists of an online monitoring and control system, a power management system, and a self-healing system, is very effective and more efficient and reliable than the existing microgrid system[1]. This smart microgrid system increases MTTD by 99.54%, MTTR by 89.51%, and availability rate by 0.064% compared to the existing microgrid system.[2]

The integration of these three systems will create a smart microgrid that is more adaptive and responsive to faults. The online monitoring and control system provides real-time information about the microgrid conditions, while power management system manages the power supplies efficiently. Self-healing can detect, prevent and isolate faults, and repair nonpermanent faults very efficiently. [3]

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