Protection coordination analysis applied at biogas power generation plant

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ABSTRACT

Biogas from liquid waste from palm oil processing, palm oil mill effluent (POME), can be utilized in biogas power plants as a source of renewable energy (PLTBg). The PLTBg electrical system is equipped with a coordinated protection system. Then, the protection system must also maintain the continuity of electrical service in parts that are not affected by disturbances. Coordination of the protection system is essential. In this research, the electrical transient analysis program (ETAP) carries out the short circuit current analysis, and the coordination of overcurrent protection is constructed from its inverse-definite minimum time characteristics. The analyzed data contributed to selecting the right protection devices. A combination of overcurrent protection, directional protection, and frequency protection change rate supported a reliable electrical power system for a biogas power generation plant as distributed generation. The result shows that modern microprocessor-based protection relays support several protection features in one device and can be integrated into a supervisory control and data acquisition (SCADA)-controlled protection system to enhance their capabilities.

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1. INTRODUCTION

The availability of electrical energy in Indonesia can be utilized through available renewable energy sources. The Indonesian government has set a target for the availability of electrical energy from renewable sources at 23% of all electrical energy sources by 2025. One of the renewable energies that have the potential to be developed is a biogas power plant (PLTBg) that utilizes liquid waste from palm oil mills or palm oil mill effluent (POME). Biogas sourced from POME contains methane and carbon dioxide. If released into the atmosphere, it will cause global warming effects and damage the environment [1].

The electrical system in PLTBg is equipped with a coordinated protection system that aims to isolate the electrical part in the event of a disturbance. At the same time, the protection system must maintain the continuity of electrical service on parts that are not affected by interference [2]. The development of PLTBg as distributed generation (DG) will increase the level of complexity of the protection system [3]. To keep the electric power system reliable, it is essential to use the best protection system possible.

Several previous studies on electrical protection systems and methods of coordinating protection systems in electric power systems have been carried out by analyzing the overcurrent protection relay scheme. Previous research on short-circuit fault analysis as a basis for electrical system design was carried out using the electrical transient analysis program (ETAP) software application [4]. The electrical system's design is based on the analysis of the maximum fault current to determine the breaking capacity of the power breaker and the minimum fault current to determine the setting of the overcurrent protection relay. Research related to overcurrent protection relay coordination with ETAP application on IEEE 9-Bus [5] overcurrent protection relay settings are based on short-circuit fault analysis results. Then, overcurrent protection relay coordination is carried out with ETAP. The genetic algorithm aims to coordinate the overcurrent protection relay in the inverse definite minimum time (IDMT) [2], [6], [7]. In the IDMT equation, the constant current multiplier setting (CMS) and time dial setting (TDS) of a series of overcurrent protection relays are obtained by implementing a genetic algorithm. Optimizing the disconnection time for the coordination of the overcurrent protection relay is done to minimize the disconnection time, isolate the parts affected by the disturbance at a minimum time, and obtain good electrical system reliability. The existence of distributed generation in an electric power system affects the regulation of the protection system already installed in the electric power system [8]. Compare the results of short-circuit faults with and without DG. It is known that the existence of distributed generation implies an increase in the breaking capacity limit of the power breaker equipment. In the event of significant distributed generation, the application of power disconnect equipment with a higher breaking capacity will be required.

Further, challenges related to the protection system in a distributed generation are discussed in [9], including the difference in the level of short-circuit fault between the distributed generation connected to the distribution network and when it is not connected. Methods and solutions used to overcome problems related to the protection system, such as false tripping, blinding of protection, reconnection with an asynchronous distribution system, or unsynchronized reclosing The protection system equipment detects the magnitude of the fault current with a current transformer (CT), so that the measurement results' accuracy level is influenced by the saturation effect on the CT [10]. This study analyzed the effect of symmetric and asymmetric currents on CT measurement results and their effect on the protective relay operation. The operation of a distributed generation is very sensitive to loss of mains (LOM) interference. Rate of change of frequency (ROCOF) and vector surge (VS) protection relays can be applied for protection against LOM disturbances [11]. It is explained that the ROCOF protection relay is more effective for protection against LOM than VS, but ROCOF is more prone to operational errors. The magnitude of the frequency change rate per unit time on the ROCOF protection relay is very sensitive for protection against LOM interference, with a narrow magnitude range for ROCOF protection settings. O'Donovan *et al*. [12] conducted on a hydroelectric power plant based on a synchronous generator, it was explained that the magnitude of the frequency change rate per unit time of 1 Hz/sec was quite effective for application to a synchronous generator-based power generation unit. The amount of load a power plant serves can be set using the under-frequency load shedding (UFLS) method, as Alhelou*et al*. [13]. When there is a disturbance in the electrical system, the change in the magnitude of the frequency can be used as an indicator of the amount of load the power plant can serve. In order not to cause wider blackouts in the electric power system due to the disturbance, the UFLS method is applied to cut off part of the load served by the power plant.

In this research, the author's development, and amalgamation of several analysis results from previous studies were carried out to obtain a design for coordinating protection systems, monitoring systems, and regulatory systems that can be applied to developing PLTBg. The types of protection devices discussed in this study are overcurrent protection relays (OCR), voltage protection relays, frequency protection relays, and synchronous check relays (SCR). Furthermore, the supervisory control and data acquisition (SCADA) architectural system application is a monitoring method for operational and historical electrical disturbances. The monitoring method is also useful in carrying out maintenance plans, fault analysis, load analysis, reliability analysis, power quality analysis, and other purposes [8]. The monitoring method is carried out by connecting protection equipment, measuring equipment, and operating status monitoring equipment, which is connected to SCADA on an industrial personal computer (IPC) with the IEC 61850 communication protocol standard.

2. THE PROPOSED METHOD

Biogas emitted from palm oil mill effluent comprises 50-75% of methane, 24-45% of carbon dioxide, and some small amounts of other gases. When released into the open air, the emitted biogas will impact global warming caused by its greenhouse gas emission. Instead of causing environmental problems, biogas can be utilized as a renewable energy source for the producing facility's electric power production as distributed generation (DG). The process of electric power generation from biogas, as shown in Figure 1 [14].

Effluent from the palm oil mill is collected in the treatment pond for pre-conditioning before anaerobic digestion, passing into a biodigester. Biogas produced in the digester is directed to the scrubber for hydrogen sulfide removal, the dehumidifier, and the gas generator to rotate the prime mover for the combustion process. The gas generator generates electricity to support the generation plant's parasitic load and export the excess power to the public distribution grid as a DG system.

As DG, the biogas power plant needs to have a sufficient protection mechanism to keep the generation plant in safe condition in the event of an electrical fault, either sourced from the grid or sourced from the internal of the plant. DG is becoming an emerged solution for a more sustainable energy source. The increasing numbers of DG coupled into the public electrical distribution grid bring various challenges, with one of the main challenges being protection systems [14]. Figure 2 depicts the typical electrical setup at the biogas power production facility used in this study.

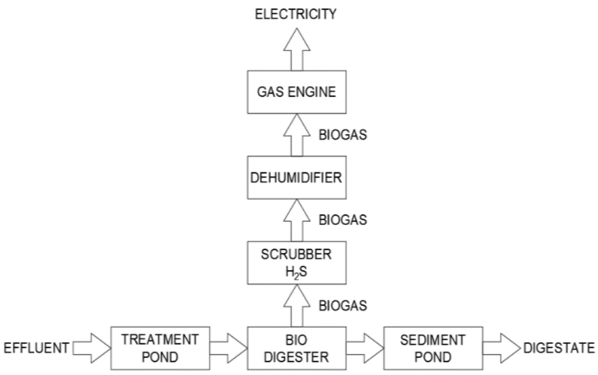

Figure 1. Biogas power generation plant flow chart

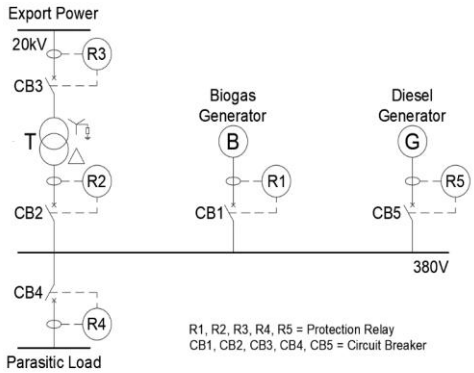

Figure 2. Biogas power generation plant electrical diagram

A diesel generator is operated to serve the power-producing plant's parasitic load at the start-up stage through CB5. Once the biogas supply is sufficient, the generator is operated and synchronized through CB1. Gradually, the biogas generator takes over the parasitic load service, CB5 is cut out, and the diesel generator is in idle condition. After the biogas generation plant runs at normal condition and the electrical system is ready to be coupled with the public distribution grid, CB3 is energized to power up the transformer. The excess power is sent to the public distribution grid by synchronizing CB2 with the electrical system through CB1. Each circuit breaker is associated with a protection relay. In case of an electrical fault, the protection relay must trip the connected circuit breaker to separate the defective area and keep the other section still in service. Protection relays measure the current through the current transformer and measure voltage through the voltage transformer for the medium voltage section or through a direct connection for the low voltage section. Fault in the electrical system contributes to transient system current, which changes the steady-state characteristics of current transformers. Current transformer selection must consider both transient and steady-state situations [15]. Effect of saturation of current transformer at excessive fault current may result in a malfunction of protection relays [10]. The effect of saturation on voltage transformer is not a significant problem because power systems are not operated above normal voltage. Moreover, faults will cause a drop in voltage [16].

3. METHOD

3.1. Coordination of protection system

Microprocessor-based protection relays are assigned with an overcurrent protection function, one of the most common protection functions applied in the power system to deal with excessive current, mainly aimed at operating at fault conditions. Overcurrent protection relay can be used at a definite time, definite current, inverse definite minimum time (IDMT) operation, or the combination of IDMT and definite time. The characteristics of the IEC standard for IDMT overcurrent protection relay as shown in Figure 3 [17].

IEC IDMT characteristics are expressed in mathematic functions as (1) to (4) [18].

$$\text{Standard Inverse (SI)} t = \text{TMS x } \frac{0.14}{I_r^{0.02} - 1} \tag{1}$$

$$\text{Very Inverse (VI)} t = \text{TMS x } \frac{13.5}{I_r - 1} \tag{2}$$

Extremely Inverse (EI): $t = TMS \times \frac{80}{I_r^2 - 1}$ (3)

Long Time Inverse (LTI): $t = TMS \times \frac{120}{I_r - 1}$ (4)

In this equations I_r:I/I_s, I_s: CMS x Ipu, I_{pu}: Pick up current, CMS: Current multiplier setting, TMS: Time multiplier setting.

A power system with a group of overcurrent protection relays installed as a series must be well-coordinated to perform an effective protection system. The furthest relay from the power source should be adjusted to respond to an excessive current fault condition at the shortest delay time. A simple series of overcurrent protection relays can be coordinated with a characteristic graphical solution. Some researchers discussed genetic algorithm methods to manage the coordination of overcurrent protection relays [2], [6], [7]. Quite a useful instrument to manage coordination for larger series of overcurrent protection relays.

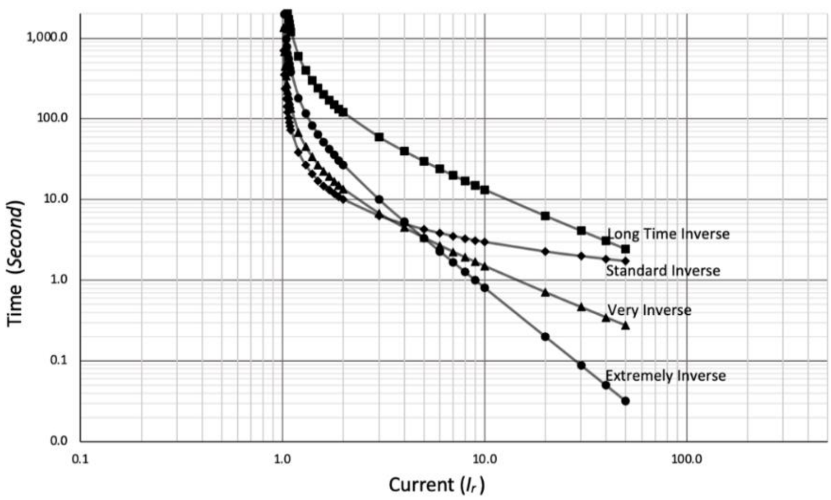

Figure 3. IEC IDMT overcurrent protection relay characteristics

3.2. Protection system issues in distributed generation

Interfacing DG into a power distribution system needs to consider protection coordination, escalated fault current, harmonic, and other protection system issues. Meanwhile, the protection system is used in detecting faults and isolating the parts affected by the disturbance so as not to cause interference or wider damage. The implementation of the protection system in distributed generation needs to be analyzed in several aspects as [9], [14], [18], [19].

3.2.1. Reverse power

Phenomena that arise in DG is power flow which can flow in two directions at every network. Current flows in the reverse direction from normal are mentioned as reverse power flow or back feeding, resulting in malfunction of the protection relay. An example of reverse power flow in normal and fault conditions can be described in Figure 4.

During the normal condition, protection relay R2 senses current flow from the R1 side to the grid, as seen in Figure 4(a). There is no reverse current during normal conditions, where no disturbance occurs. On the other hand, when a fault occurs at the bus, protection relay R2 senses the grid's reverse flow, as shown in Figure 4(b). At this fault occasion, the current at the fault point is escalated from the normal current value. If R2 is not designed to detect this reverse current flow direction and the fault current is not large enough to trip the R2 overcurrent protection, there will be a risk of damage at the fault point.

Reverse power flow could occur during the synchronization process. During the synchronization process, the voltage and frequency of DG are adjusted to get as close as possible to the utility grids. When the circuit breaker is closed while the voltage of DG is slightly below the utility grid voltage, power flows from the grid to DG, which causes reverse power. Reverse power at the generator must not happen for a longer period as it can result in motoring of the generator and damage the prime mover [20].

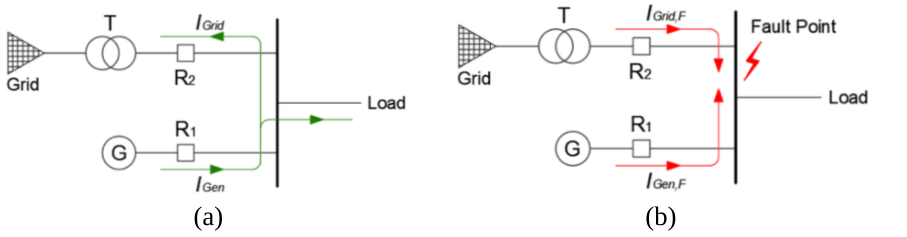

Figure 4. Reverse power flow in (a) normal condition and (b) fault condition

3.2.2. Loss of mains

Loss of mains in DG is when the main power generation at the grid is suddenly out of service, and the DG system is still connected to the load. This condition causes the DG system to turn from grid mode to unintentional-islanded mode instantly. This undesirable unintentional-islanded mode can be dangerous for the following reasons [19]:

- For a system where recloser devices are installed, automatic reclosing of the main power source could happen. This condition can cause unsynchronized reclosing and lead to damage to the equipment.
- The power quality at the islanded network will be affected due to abnormal voltage and frequency. The DG power source is usually much smaller than the main power source. Thus, it will be too small to serve the electrical load at islanded mode.
- Personnel safety is affected due to the unsynchronized reclosing occasion.

3.2.3. Power imbalance

The changing from grid mode to unintentional-islanded mode while the DG is still connected to a load of the main grid could result in a power imbalance just before the protection device isolate the DG from the main grid [9]. Further disturbance at the internal DG from the power plant that produces biogas following the unintentional-islanded mode is the oscillation of voltage and frequency, which might activate the protection relay to trip the internal parasitic load. When this undesired tripping occurs, the biogas generator will lose the prime mover power and cause black-out power at the biogas generation plant.

3.2.4. Synchronizing to power system

Synchronizing a DG to the power system is managed by closely matching and connecting the DG to the power system, as well as the voltage and frequency of the DG to the power system when the angle difference is as close as possible to zero. Fail to follow a safe synchronizing procedure will cause [21]:

- Rapid acceleration or deceleration at the prime mover can damage the generator.
- Excessive current that will damage the generator and other related equipment.
- Power fluctuation and voltage deflection disturbance.
- Activate the protection relay to trip the circuit breaker, which will cause the generator failure to stay connected to the power system.

3.3. Neutral grounding of interconnection transformer

Interfacing a DG to the utility grid is preferable through an interconnection transformer, even though there is the possibility of getting DG at the same rated voltage as that of the utility grid. The common selection for interconnection transformer is grounded wye (utility)/delta (DG) type, with some advantages [22]:

- Isolation of triple harmonics from DG transferred to the utility grid side.
- Voltage sags isolation is caused by a single-phase to ground fault at the utility grid side, permitting the DG to get through voltage sags.
- Does not deliver directly into the utility grid side at a single phase to ground fault, which can present on another ground source on the utility grid.

The disadvantages of the interconnection transformer are:

- Sensitive to Ferro resonance in conductors' installation, particularly at open conductor fault occasions.
- Rely on the neutral grounding of the generator.
- Third harmonics from the DG side may result in a bit much current at neutral on the DG side.
- Ineffective grounded system when islanding mode or open conductor fault occasion.

It is difficult to detect a single phase-to-ground fault that occurs at the utility grid side by voltage protection relay only from the DG side.

3.4. Intentional islanding

Unintentional-islanding mode in the operation of DG must be avoided due to the danger it can cause to the power system as well as the workers. On the other hand, implementing an intentional-islanding mode is preferable to maintain the power system's continuity and reliability [11]. A biogas power generation plant as DG can be operated with islanding mode to serve a certain load of the main grid without connecting to the main grid. In this method, the undesirable unintentional-islanding mode can be avoided.

3.5. Supervisory control and data acquisition

Nowadays, microprocessor-based protection relays are built with communication tools that allow the protection system to be SCADA system-integrated [23], [24]. Design architecture of SCADA empowered protection system as seen in Figure 5. The address register from the connected remote terminal unit (RTU) could be accessed for monitoring dan supervisory control purposes through a local network. Some protection relay with different communication protocols should go through the gateway to be connected to the SCADA monitor. SCADA application in power protection systems improves the supervisory control of the system with real-time data, power and energy management, outage correction, power system reliability, and personnel safety [25].

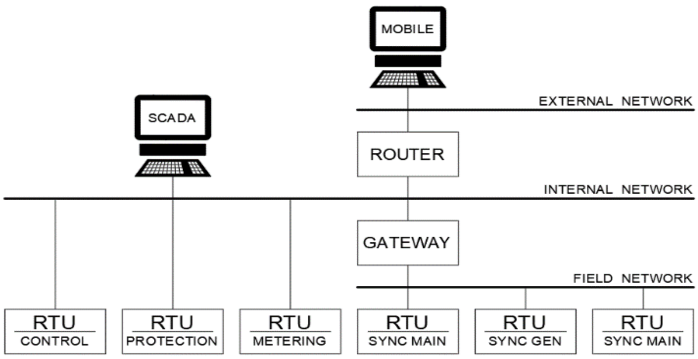

Figure 5. Management and monitoring system application architecture

Another capability of SCADA application in electrical power protection systems is performing different functions of protection settings at different operating conditions. Protection relays can be assigned with several selections of protection groups, for instance, different types of overcurrent characteristics during the energizing period and operation period, providing more protection and safety capability in the power system. Application of SCADA in a power system protection can support adaptive protection capability.

3.6. Protection system issues related to geographical location of distributed generation

Biogas power plant using waste from a palm oil mill is located close to a palm oil mill located in rural areas and usually under-populated areas. The electrical power from grid utility is distributed long distances in rural areas, experiencing a significant voltage drop. Introducing a DG into the grid system has to follow the voltage of the utility grid and can boost the voltage level [26]. Voltage difference impact on power system between daily peak load period and low load period at the rural area is another challenge for DG. The DG needs to get synchronized with the utility grid for load control, which will affect the operational voltage of the internal load at the biogas power generation plant. Usually, power grid operators apply overhead transmission for power distribution in rural areas. Unavoidable electrical faults that happen quite often at this distribution system could impact the power quality and cause unintended islanded mode.

4. RESULT AND DISCUSSION

Protection system in this research is analysed based on the electrical diagram as Figure 6. The electrical power generated by the biogas generator and a diesel generator is used to serve the parasitic load on the generator itself. The biogas generator operates with an electric power source from a diesel generator and electrical power transmitted from the palm oil mill through a CB5 power breaker to operate parasitic loads such as fluid pumps, blowers, mixers, scrubbers, dehumidifiers, and other electrical loads. Meanwhile, there is a short circuit fault alternately between F1, F2, and F3.

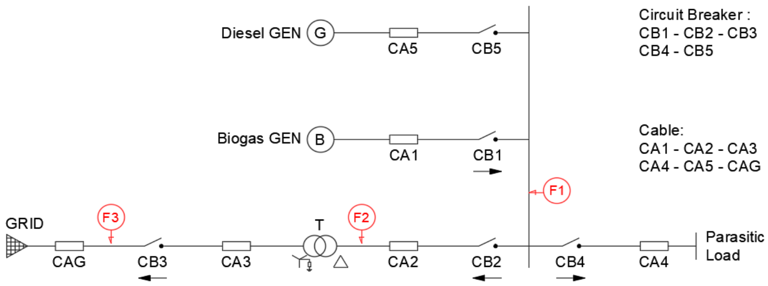

Figure 6. Electrical diagram of biogas power generation

4.1. Short circuit analysis

Power system protection arrangement involves fault current analysis to determine the interrupting and sensing protection devices [8], including circuit breakers, protection relays, and the setting of these protective devices. A method of analysing short circuit current is utilizing ETAP software. Short circuit current is analysed at three fault points F1, F2, and F3, as indicated in Figure 6. The electrical specification from Table 1 is entered into ETAP equipment properties. It is used to calculate maximum and minimum fault current for three-phase bolted fault, single-phase and ground fault, two-phase and ground fault, analysed at each fault point, as in Table 2.

Table 1. Biogas power generation specification

Biogas generator			Transformer		
Base rating	kVA	1625	Rated power	kVA	1250
Base rating	kW	1300	Rated voltage	kV	20/0.38
Voltage	Volt	380	Full load loss	kW	15
Frequency	Hz	50	No load loss	kW	2
Power factor	---	0.8	Rated impedance	%	5.5
Base rating for reactance value	kVA	1715	R1	%	1.04
X’d transient reactance	%	18	X1	%	5.40
X”dsub-transient reactance	%	13	Vector group	---	YNd5
X2 negative reactance	%	19	Neutral grounding resistance	Ω	38
X0 zero reactance	%	2			
Main stator resistance	Ω	0.00093			
Cable conductor			Parasitic load		
X1/R1 (CA1)	Ω / Ω	0.08105 / 0.0601	Lump load	kVA	400
X1/R1 (CA2)	Ω / Ω	0.08105 / 0.0601	Power factor	---	0.85
X1/R1 (CA3)	Ω / Ω	0.1121 / 0.443			
X1/R1 (CAG)	Ω / Ω	0.1121 / 0.443			
X1/R1 (CA4)	Ω / Ω	0.08105 / 0.0601	Rated power	kVA	1250

A generator with solidly grounded neutral has a greater initial ground-fault current than a three-phase bolted fault [27], as can be seen from the ETAP calculation in Table 2. At some fault point, reverse power flow from normal current flow happens, marked with the “-“ sign. The maximum short circuit current determines the minimum breaking capacity of the circuit breaker [4]. The circuit breakers are arranged to isolate the power system from the fault source to prevent wider damage to the system. Based on short circuit analysis from Table 2, the minimum breaking capacity of each circuit breaker be:

- CB1: 54.6 kA with voltage rating 380 V.
- CB2: 44.6 kA with voltage rating 380 V.
- CB3: 14.26 kA with voltage rating 20 kV.

4.2. Overcurrent protection and the coordination

An overcurrent protection relay is widely used to protect against excessive current caused by faults in power system protection. This overcurrent protection relay should not be used solely for overload protection, as excessive current protection is more intended for fault protection. Nevertheless, this relay is chosen to cover both overcurrent and overload protection purposes [18]. A series of overcurrent protection relays are often installed in a power system and require coordination. The coordination of overcurrent protection relays is made under the following consideration, such as Possibly apply the same operating characteristics in the same series of overcurrent protection relays, and the overcurrent protection relay located farthest from the current setting of the electrical power supply is not more than relays behind it [27].

This research analyses CB1-CB2-CB3 circuit breakers as described in Figure 6, with each circuit breaker associated with a protection relay R1-R2-R3 as one series. This series of relays involves a transformer; thus, the starting inrush current of the transformer is to be considered in designing this coordination of the relays. The inrush current of the transformer can be defined through the magnetizing curve and maximum short circuit withstand capacity in terms of temperature [27]. The function of magnetizing transformer curve is given by (5). Meanwhile, based on the transformer specification in Table 1, the given in (5) and the calculation method described well in [28], the characteristic of the transformer inrush current in this research is given by the (6).

$$i_{inrush} = \frac{k_i \,.I_{1nTR}}{\sqrt{2}} \,.\, e^{\frac{-t}{\tau_{inrush}}} \quad (5)$$

$$\mathrm{t} = 0.37\,.\{\ \ln\ (0.242\,/\,\mathrm{i}_{\mathrm{inrush,prm}}\ )\ \} \quad (6)$$

In this equations i_{inrush}: Transformer inrush current (A), k_i :Constant inrush current for transformers, I_{1nTR}: Transformer's primary rate current (A), τ_{inrush}: Constant transformer inrush time (Sec), $\mathrm{i}_{\mathrm{inrush,prm}}$: Primary inrush current of a transformer (kA).

By graphical method for standard inverse IDMT overcurrent protection relay function with pick up current Ipu=35A, the value for TMS=0.07 and CMS=1 can be obtained with the graphic as shown in Figure 7. CB3 curve stands above the transformer inrush current, keeping the transformer safe to pass the energizing period.

Function (7) is used to set R3 overcurrent protection relay protection with device number 51, which is associated with CB3. This overcurrent protection is applied only at the transformer's initial energizing period. The overcurrent protection characteristics are suitable for transformer inrush current protection. Protection relay R3 (associated with CB3) should distinguish between the transformer's initial energizing and operational stages. During the operation stage, the coordination of protection relays R1-R2-R3 (corresponding to CB1-CB2-CB3) is analyzed at a low voltage or 380V section. The coordination is arranged with a minimum grading margin of 0.3 seconds [6], [29]. Each overcurrent protection relay implements a combination of IDMT standard inverse and definite time. The graphical method for this overcurrent protection coordination, as shown in Figure 8.

The protection relay function for each circuit breaker with standard inverse IDMT characteristic, becoming:

$$\text{CB1: } \mathrm{t} = 0.13\ \mathrm{x}\ \frac{0{,}14}{(0.422\ \mathrm{xI})^{0.02}-1} \quad (7)$$

$$\text{CB2: } \mathrm{t} = 0.10\ \mathrm{x}\ \frac{0{,}14}{(0.475\ \mathrm{xI}\ )^{0.02}-1} \quad (8)$$

$$\text{CB3 (LV Slide)} \mathrm{t} = 0.07\ \mathrm{x}\ \frac{0{,}14}{(0.555\ \mathrm{xI}\ )^{0.02}-1} \quad (9)$$

the functions (8), (9), and (10) [26] are used to set R1-R2-R3 overcurrent protection relay protection with device number 51, which is associated with CB1-CB2-CB3. Setting parameters for overcurrent protection relays and their coordination are specified in Table 3.

Table 2. ETAP short circuit analysis

ETAP Short Circuit Analysis Fault Point and Type	CB Min (kA)	1 Max (kA)	CB Min (kA)	2 Max (kA)	CB Min (kA)	3 Max (kA)
Fault Point F1						
Three-phase bolted fault	6.7	13.8	-26.8	-26.8	-0.51	-0.51
Single-phase and ground fault	40.5	45.5	--	--	--	--
Two-phase and ground fault	46.3	54.6	--	--	--	--
Fault Point F2						
Three-phase bolted fault	6.4	12.5	6.4	14.3	-0.62	-0.63
Single-phase and ground fault	41.3	44.5	41.3	44.5	--	--
Two-phase and ground fault	40.0	44.6	40.0	44.6	--	--
Fault Point F3						
Three-phase bolted fault	5.4	8.8	5.4	10.1	-14.14	-14.16
Single-phase and ground fault	--	--	--	--	-14.20	-14.26
Two-phase and ground fault	--	--	--	--	-14.16	-14.23
Fault Point F1	6.7	13.8	-26.8	-26.8	-0.51	-0.51
Three-phase bolted fault	40.5	45.5	--	--	--	--

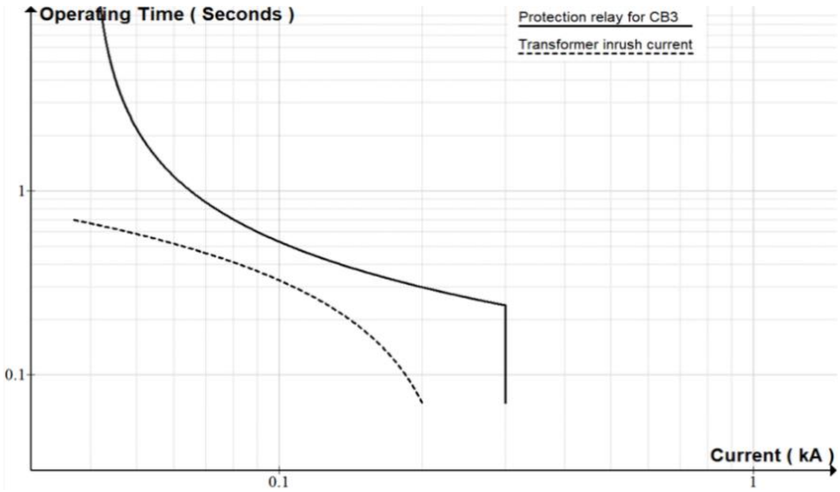

Figure 7. Protection relay characteristics for transformer

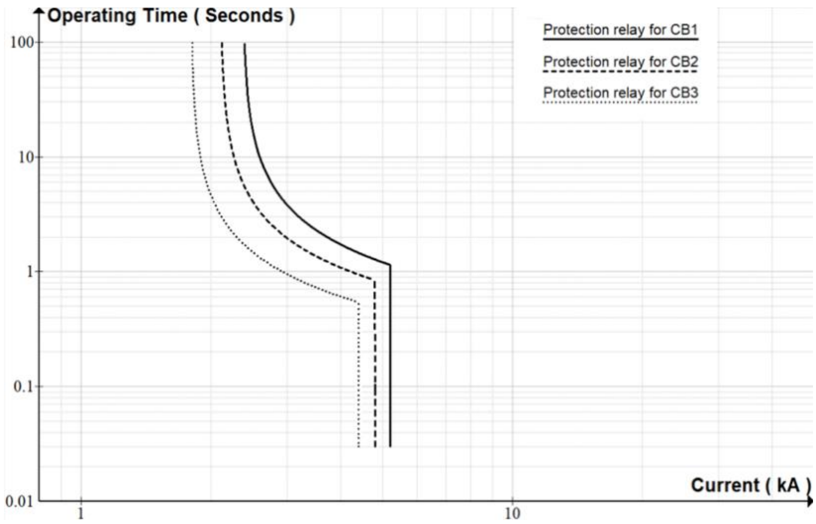

Figure 8. Coordination of overcurrent protection relays

Table 3. Parameters of overcurrent protection relays

PARAMETERS	CB1	CB2	CB3-LV	CB3-HV
Transformer initial energizing				
TMS (time multiplier setting), second	-	-	-	0.07
CMS (current multiplier setting)	-	-	-	1
Ipu (pick up current), A	-	-	-	35
DT (definite time), A	-	-	-	300
DT (definite time), A	-	-	-	Not applied
Normal Operation				
TMS (time multiplier setting), second	0.13	0.10	0.07	0.07
CMS (current multiplier setting)	1.56	1.17	1.00	1.00
Ipu (pick up current), A	1520	1800	1800	34
DT (definite time), A	5200	4800	4400	84
Directiional Power	200A 1s	300A 1s	300A 1s	6A 1S

4.3. Reverse power protection

From Table 2, power flow can happen in the reverse direction at CB3 when there is an electrical fault at the points F1, F2, and F3. R3 directional power relay protection device with number 32 [30], which is associated with CB3, needs to be enabled during the operation stage or after the transformer passes the initial energizing period. Unstable synchronizing operation or synchronizing in the process from DG to utility grid can result in reverse power flow, which will activate directional power protection relay. Setting directional power relay protection must consider this power flow for a proper setting of the device. During the initial energizing process of the transformer, directional power relay protection should be disabled to cover the inrush current of the transformer and should be enabled once the transformer passes the initial energizing period.

4.4. Loss of mains protection

Sudden loss of mains at a power system operating at grid mode will suddenly turn the power system to unintended-islanded mode. The ROCOF protection device number 81R is used by the anti-islanding protection technique is implemented for the anti-islanding protection method [31]. This loss of main protection is enabled at R2 and R3, corresponding to CB2 and CB3. When the protection relay detects loss of mains and trips the circuit breaker, the DG will suddenly lose a large portion of electrical load. This occasion can potentially activate the overvoltage or over-frequency protection relay at the generator side.

4.5. Overvoltage protection and undervoltage protection

The system's voltage will be affected when a short circuit fault in the power system occurs. While performing short circuit analysis with ETAP at fault points F1, F2, and F3, as indicated in Figure 6, the voltage implication calculated by ETAP is seen in Table 4. The voltage value drops in the event of a short circuit fault at a properly neutral grounded system. Undervoltage relay protection device number 27 is enabled to function as backup protection to overcurrent relay protection for short circuit faults. Overvoltage in a power system could be invoked by large load loss, harmonics, voltage regulation, ground faults, or contact with a higher voltage line [32], [33]. An overvoltage relay protection device with the number 59 is enabled for this protection.

Table 4. Parameters of overcurrent protection relays

ETAP Short Circuit Analysis	CB	1	CB	2	CB	3
Fault Point and Type	Min (kV)	Max (kV)	Min (kV)	Max (kV)	Min (kV)	Max (kV)
Fault Point F1						
Three-phase bolted fault	0	0	0	0	19.29	19.29
Single-phase and ground fault	0.18	0.20	0.18	0.20	11.53	11.56
Two-phase and ground fault	0.17	0.20	0.17	0.20	11.30	11.33
Fault Point F2						
Three-phase bolted fault	0.02	0.04	0.02	0.04	19.11	19.12
Single-phase and ground fault	0.19	0.20	0.19	0.20	11.54	11.56
Two-phase and ground fault	0.20	0.22	0.20	0.22	11.28	11.31
Fault Point F3						
Three-phase bolted fault	0.07	0.14	0.07	0.14	0	0
Single-phase and ground fault	0.14	0.15	0.14	0.15	11.53	11.56
Two-phase and ground fault	0.13	0.16	0.13	0.16	11.56	11.60

4.6. Synchronizing controller

Synchronizing DG to the power system is managed by adjusting the field voltage to control the generator output voltage and prime mover speed to control the generator output frequency. An intelligent synchronizing controller can automatically manage the voltage, frequency, and phase angle adjustments. Once the setup value is reached for the voltage, frequency, and phase angle, this instrument instructs to connect the DG to the power system [22]. Once the DG is linked to the electrical supply, the field voltage adjustment will affect the reactive power, and the prime mover speed adjustment will affect the real power. In this way, this intelligent synchronizing controller exports power control and measurement from DG to the power system.

4.7. Design architecture for protection system

An arrangement of design architecture is applicable at a power plant that generates biogas, as described in Figure 9. This design applies microprocessor-based protection relay Energy P3U30, and each R1-R2-R3-R4-R5 is used in conjunction with each circuit breaker CB1-CB2-CB3-CB4-CB5. The critical path that requires protection coordination is protection relays R1-R2-R3. COMAP Intelligent synchronizing control relay S1-S2-S5 are applied to manage automatic power synchronizing, load sharing, load shedding, and exporting power. Information and specification for these protection relays and intelligent synchronizing control relays are described in [34]-[36]. The arrangement for SCADA design architecture is applicable at a biogas power generation plant as DG, as shown in Figure 10. Information and specification for SIEMENS WinCC SCADA are described in [36]. The SCADA accesses each protection relay and intelligent synchronizing control from the registered address with a specific node number for each device. This implementation will enable the operator to monitor a central control room and watch alarm history for traceability and preventive maintenance. Further improvement of SCADA application in this design architecture can implement adaptive protection in the power system, as seen in Figure10.

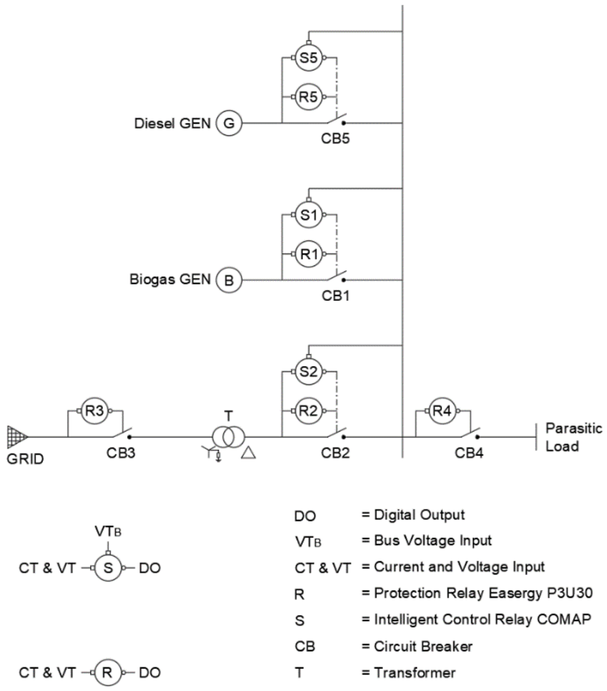

Figure 9. Design architectue for biogas power generation protection system

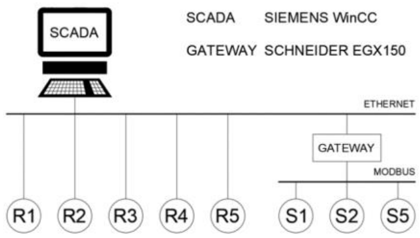

Figure 10. Design architectue for SCADA

5. CONCLUSION

Modern microprocessor-based protection relays provide several protection functions in one device, utilizing a single set of current and voltage transformers. Further, several overcurrent protections relays, arranged in a series, require proper coordination to protect the power system properly. A graphical method can be implemented to coordinate a not-very-complicated arrangement of overcurrent protection relays. Meanwhile, interfacing DG into a power network impacts the overall system reliability. When the DG is installed to support backup power for the system, this implementation will enhance the power system's reliability. On the other side, an improperly interfaced DG to the system will degrade the reliability of the power system. Then, the design architecture of a protection system enhanced by a SCADA system is introduced in this research, applicable to a biogas power generation plant as distributed generation. Application of another type of synchronous type generator for power generation plants can be adopted with a slight modification. The development of this research can be carried out on transient stability in the event of a loss of mains disturbance so that the protection relay activates the power breaker. Also, the generator protection relay could send a tripping signal because it is protecting the electrical system. This would cause the generator to lose its prime mover power.

REFERENCES

[1] A. Sri *et al.*, "Handbook POME to biogas," *Project development in Indonesia*, Washington, Winrock International, 2015.

[2] N. Rezaei, M. N. Uddin, I. K. Amin, M. L. Othman, and M. Marsadek, "Genetic algorithm-based optimization of overcurrent relay coordination for improved protection of DFIG operated wind farms," *IEEE Transactions on Industry Applications*, vol. 55, no. 6, pp. 5727–5736, Nov. 2019, doi: 10.1109/TIA.2019.2939244.

[3] T. Vukasovic, S. Nikolovski, D. Mlakic, and D. Vucini, "Protection coordination of biogas power plant connected to distribution network," *Journal of Electrical Engineering*, vol. 1, 2017, doi: 10.4172/JIEA.1000103.

[4] J. A. X. Prabhu, K. S. Nande, S. Shukla, and C. N. Ade, "Design of electrical system based on Short Circuit study using ETAP for IEC projects," in *2016 IEEE 6th International Conference on Power Systems (ICPS)*, Mar. 2016, pp. 1–6, doi: 10.1109/ICPES.2016.7584102.

[5] S. A. Shaikh, K. Kumar, A. R. Solangi, S. Kumar, and A. A. Soomro, "Short circuit analysis over current relaying coordination of IEEE 9-bus system," in *5th International Multi-Topic ICT Conference: Technologies For Future Generations, IMTIC 2018 - Proceedings*, Apr. 2018, pp. 1–6, doi: 10.1109/IMTIC.2018.8467260.

[6] A. S. Rizal, M. N. Umam, A. M. Syaputra, Hasbullah, A. Gemayel, and Amad, "Study of overcurrent relays coordination optimization based on genetic algorithms," in *Proceeding - 2nd International Conference on Technology and Policy in Electric Power and Energy, ICT-PEP 2020*, Sep. 2020, pp. 100–103, doi: 10.1109/ICT-PEP50916.2020.9249853.

[7] T. A. Abd Almuhsen and A. J. Sultan, "Using of genetic algorithm to obtain proper coordination of directional overcurrent relays.," *IOP Conference Series: Materials Science and Engineering*, vol. 881, no. 1, p. 012131, Jul. 2020, doi: 10.1088/1757-899X/881/1/012131.

[8] S. Katyara, L. Staszewski, H. A. Musavi, and F. Soomro, "Short circuit capacity: A key to design reliable protection scheme for power system with distributed generation," *International Journal of Mechanical Engineering and Robotics Research*, vol. 6, no. 2, pp. 126–133, 2017, doi: 10.18178/ijmerr.6.2.126-133.

[9] U. Shahzad, S. Kahrobaee, and S. Asgarpoor, "Protection of distributed generation: challenges and solutions," *Energy and Power Engineering*, vol. 09, no. 10, pp. 614–653, 2017, doi: 10.4236/epe.2017.910042.

[10] Y. Ma and P. Crossley, "Impact of CT saturation on overcurrent relays," *The Journal of Engineering*, vol. 2018, no. 15, pp. 1274–1280, Oct. 2018, doi: 10.1049/joe.2018.0188.

[11] A. Nassif and C. Madsen, "A real case application of ROCOF and vector surge relays for anti-islanding protection of distributed energy resources," in *2017 IEEE Electrical Power and Energy Conference, EPEC 2017*, Oct. 2018, vol. 2017-October, pp. 1–5, doi: 10.1109/EPEC.2017.8286136.

[12] M. O'Donovan, E. O'Callaghan, N. Barry, and J. Connell, "Implications for the rate of change of frequency on an isolated power system," in *2019 54th International Universities Power Engineering Conference, UPEC 2019 - Proceedings*, Sep. 2019, pp. 1–6, doi: 10.1109/UPEC.2019.8893446.

[13] H. H. Alhelou, M. E. H. Golshan, T. C. Njenda, and N. D. Hatziargyriou, "An overview of UFLS in conventional, modern, and future smart power systems: challenges and opportunities," *Electric Power Systems Research*, vol. 179, p. 106054, Feb. 2020, doi: 10.1016/j.epsr.2019.106054.

[14] U. Shahzad and S. Asgarpoor, "A comprehensive review of protection schemes for distributed generation," *Energy and Power Engineering*, vol. 09, no. 08, pp. 430–463, 2017, doi: 10.4236/epe.2017.98029.

[15] *Power systems engineering committee of the IEEE industry applications society*, "IEEE Std 142-2007 (Revision of IEEE Std 142-1991) IEEE recommended practice for grounding of industrial and commercial power systems," *IEEE*, 2007.

[16] J. L. Blackburn and T. J. Domin, "Protective relaying: Principles and applications, third edition," in *Protective Relaying: Principles and Applications*, Third Edition, 2006, pp. 1–635.

[17] J. M. Gers and E. J. Holmes, *Protection of electricity distribution networks*, 3rd edition, 2nd ed. IET, 2011.

[18] G. J. Scheepers, A. O. Akumu, A. F. Nnachi, J. A. Jordaan, and W. Mubatanhema, "Differential protection of distributed generation interfaced network," in *2020 IEEE PES/IAS PowerAfrica, PowerAfrica 2020*, Aug. 2020, pp. 1–5, doi: 10.1109/PowerAfrica49420.2020.9219956.

[19] C. Reiz and J. B. Leite, "Impact analysis of distributed generation on protection devices coordination in power distribution systems," in 2*021 IEEE PES Innovative Smart Grid Technologies Conference - Latin America (ISGT Latin America)*, Sep. 2021, pp. 1–5, doi: 10.1109/ISGTLatinAmerica52371.2021.9543073.

[20] P. Sudhakar, S. Malaji, and B. Sarvesh, "Reducing the impact of DG on distribution networks protection with reverse power relay," *Materials Today: Proceedings*, vol. 5, no. 1, pp. 51–57, 2018, doi: 10.1016/j.matpr.2017.11.052.

[21] W. Gao, M. Xu, G. Chen, and Y. Liu, "A data synchronization method for relay protection in active distribution network," in *2020 IEEE Sustainable Power and Energy Conference (iSPEC)*, Nov. 2020, pp. 383–388, doi: 10.1109/iSPEC50848.2020.9350996.

[22] B. B. Luo, K. Liu, L. X. Chen, C. X. Wang, and Q. Xiao, "Research on an incorrect operation of grounding transformer protection and its improving measures," in *Proceedings - 2021 International Conference on Power System Technology: Carbon Neutrality and New Type of Power System, POWERCON 2021*, Dec. 2021, pp. 53–56, doi: 10.1109/POWERCON53785.2021.9697496.

[23] M. Rashid, A. Raheem, R. Shakoor, Z. A. Arfeen, and N. Husain, "SCADA based differential protection of power transformers," in *2021 6th International Multi-Topic ICT Conference (IMTIC)*, Nov. 2021, pp. 1–5, doi: 10.1109/IMTIC53841.2021.9719781.

[24] D. Martinez, D. Celeita, D. Clavijo, and G. Ramos, "Hardware and software integration as a realist SCADA environment to test protective relaying control," in *2017 IEEE Industry Applications Society Annual Meeting*, Oct. 2017, vol. 2017-Janua, pp. 1–8, doi: 10.1109/IAS.2017.8101888.

[25] C. Wester, N. Engelman, T. Smith, K. Odetunde, B. Anderson, and J. Reilly, "The role of the SCADA RTU in today's substation," in *2015 68th Annual Conference for Protective Relay Engineers*, Mar. 2015, pp. 622–628, doi: 10.1109/CPRE.2015.7102199.

[26] T. Ackermann and V. Knyazkin, "Interaction between distributed generation and the distribution network: operation aspects," in *IEEE/PES Transmission and Distribution Conference and Exhibition*, 2002, vol. 2, no. ASIA PACIFIC, pp. 1357–1362, doi: 10.1109/TDC.2002.1177677.

[27] ALSTOM (Firm), *Network protection & automation guide: protective relays, measurement & control.* Alstom Grid, 2011.

[28] ALSTOM, *Network Protection and Automation Guide*. Alstom Grid, 2002.

[29] Z. Ye *et al.,* "A calculation method to adjust the short-circuit impedance of a transformer," *IEEE Access*, vol. 8, pp. 223848–223858, 2020, doi: 10.1109/ACCESS.2020.3042983.

[30] J. S. Farkhani, M. Zareein, H. Soroushmehr, and H. M. Sieee, “Coordination of directional overcurrent protection relay for distribution network with embedded DG,” *2019 IEEE 5th Conference on Knowledge Based Engineering and Innovation, KBEI 2019*, pp. 281–286, 2019, doi: 10.1109/KBEI.2019.8735025.
[31] J. P. Holguin, D. C. Rodriguez, and G. Ramos, “Reverse power flow (RPF) detection and impact on protection coordination of distribution systems,” *IEEE Transactions on Industry Applications*, vol. 56, no. 3, pp. 2393–2401, May 2020, doi: 10.1109/TIA.2020.2969640.
[32] D. Tzelepis, A. Dysko, and C. Booth, “Performance of loss-of-mains detection in multi-generator power islands,” in *13th International Conference on Development in Power System Protection 2016 (DPSP)*, 2016, doi: 10.1049/cp.2016.0066.
[33] M. Darwish, C. Marouchos, and P. Dimitriadis, “Overvoltage protection,” in *Proceedings - 2016 51st International Universities Power Engineering Conference, UPEC 2016*, Sep. 2016, vol. 2017-January, pp. 1–4, doi: 10.1109/UPEC.2016.8114105.
[34] R. Burlica, D. Astanei, A. Dragomir, and M. Adam, “Overvoltage differential protection of low voltage circuits,” in *2018 International Conference and Exposition on Electrical and Power Engineering (EPE)*, Oct. 2018, pp. 0599–0602, doi: 10.1109/ICEPE.2018.8559847.
[35] ComAp, “Inteli new technology mains supervision controller IM-NT-BTB, MCB, MGCB operator guide,” Prague, Czech Republic, 2018. [Online]. Available: https://comapcontrol.ru/upload/iblock/983/983469abcbe5ff607f64530f2eafc891.pdf.
[36] D. F. Division and D. P. der Hmi, “SIMATIC HMI WinCC V7.4 SP1 WinCC: communication system manual,” 2017.

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