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Analysis Of Protection Relay Setting Coordination On Excitation Transformer At Gresik PLTGU

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Abstract

Excitation transformer is one of the important equipment in the generation system that functions to supply generator excitation power so that the reliability of the transformer protection system needs to be maintained so that the generator operation remains safe and stable. This study aims to analyze the coordination of protection relay settings on the excitation transformer at the Gresik PLTGU using the GE Multilin T60/G60 relay. The analysis was carried out based on the existing relay settings without using a full system simulation, with a focus on the evaluation of differential protection (ANSI 87T), overcurrent relay (ANSI 51), overexcitation protection (ANSI 24), and the inrush inhibit feature. The research method used is descriptive-analytical through data collection in the form of single line diagrams, current transformer (CT) data, and existing relay settings which are then compared with the IEEE C37.91, IEC 60255 standards, and the GE Multilin T60 relay manual. The results of the study indicate that the differential relay settings with a pickup of 0.3 pu, slope 1 of 30%, slope 2 of 80%, and inrush inhibit of 20% are still within the recommended range of transformer protection and are able to maintain the sensitivity and stability of the relay against internal disturbances and transient conditions. The overcurrent relay setting of 2 pu with a delay of 3 seconds and instantaneous overcurrent of 4 pu with a delay of 0.15 seconds shows a fairly selective backup protection coordination against overcurrent and short circuit disturbances. In addition, the overexcitation setting of 1.19 pu with a delay of 10 seconds is considered still appropriate to protect the transformer from overfluxing conditions. Based on the evaluation results, the transformer excitation protection system at the Gresik PLTGU has had quite good protection coordination according to the principles of sensitivity, selectivity, stability, and reliability of the transformer protection system.

Keywords: ***Excitation Transformer, Differential Relay, Overcurrent Relay, Overexcitation, Relay Coordination, Ge Multilin T60.***

INTRODUCTION

Transformer is one of the key equipment in electrical power systems that functions to transmit electrical energy from one voltage level to another (Martínez Gomez, 2023). In power generation systems, the presence of transformers is crucial because it affects operational continuity and the reliability of the generating system (Zheng et al., 2021). Faults in transformers can disrupt the generation process and even cause generating units to trip out of service. Therefore, a protection system is required that is fast, selective, sensitive, and reliable in securing transformers against various types of faults and abnormal operating conditions.

The development of power system protection technology has led to the use of numerical relays, which offer higher accuracy, greater setting flexibility, and improved monitoring capabilities compared to conventional relays (Mohideen & Anita, 2024). The use of numerical relays allows multiple protection functions to be integrated into a single device, thereby improving the effectiveness of transformer protection systems. One of the widely used relays in generator transformer protection systems is the GE Multilin T60, which is equipped with various protection features such as differential protection, overcurrent protection, and overexcitation protection (Elkhidir & El-Amin, 2018; GE Multilin, 2021).

In PLTGU power plants, the excitation transformer plays an important role as the supplier of generator excitation power (Simanullang et al., 2022). Faults in the excitation transformer can affect the stability of the generator excitation system and reduce the reliability of plant operation. Therefore, proper relay setting coordination is required so that the protection system can distinguish between internal faults, external faults, and transient conditions such as magnetizing inrush current during transformer energization (Hu & Li, 2022).

Differential protection, or ANSI 87T, is used as the main protection for transformers due to its high sensitivity to internal faults (Patel & Chothani, 2020; Hayder & Saeed, 2025). However, improper differential relay settings may cause maloperation due to current transformer (CT) mismatch, CT saturation, or transformer inrush current (Wu et al., 2021). To maintain relay stability and sensitivity, proper configuration of parameters such as differential pickup, slope characteristic, breakpoint, and inrush restraint is required.

In addition to differential protection, overcurrent protection (ANSI 51) is used as backup protection against short-circuit faults and overload conditions (Masood et al., 2025; Fatwa Ulhuda et al., 2024). Coordination between pickup current and time delay is an important factor to ensure that the relay operates selectively within its protection zone. Meanwhile, overexcitation protection (ANSI 24) is used to protect the transformer from excessive flux conditions caused by an increased voltage-to-frequency (V/Hz) ratio, which can lead to excessive heating in the transformer core (Schons et al., 2022).

Based on these conditions, this study analyzes the protection relay setting coordination of the excitation transformer at the PLTGU Gresik power plant using existing GE Multilin T60 relay data. The analysis focuses on evaluating differential protection settings, overcurrent relay settings, overexcitation protection, and inrush inhibit features to assess compliance with the principles of sensitivity, selectivity, stability, and reliability of transformer protection systems, referring to IEEE C37.91 standards, IEC 60255 (International Electrotechnical Commission, 2009), and the GE Multilin T60 technical manual (GE Multilin, 2021).

RESEARCH METHODS

This practical field study was conducted at a strategic power generation facility that plays an important role in supplying electricity to the national power grid. The plant operates several generating units with different technologies, including a Gas and Steam Power Plant (PLTGU), making it a relevant site for studying power generation systems, electrical equipment, and transformer protection systems used in plant operations.

Data collection was carried out to obtain the information required for analyzing protection relay coordination of the excitation transformer. The data were obtained through field observations of the transformer protection system, interviews with personnel responsible for protection and maintenance, and documentation studies involving existing relay settings, single line diagrams (SLD) of the transformer protection system, current transformer (CT) data, and technical manuals of the GE Multilin T60 relay. The collected data were then used as the basis for evaluating relay settings in accordance with IEEE C37.91, IEC 60255 standards, and relevant relay manuals.

The single line diagram illustrates the configuration of the transformer protection system in the plant. This study focuses on the excitation transformer area connected to the GE Multilin T60 protection relay system. The analysis is conducted on the existing protection relay settings of the excitation transformer to evaluate coordination performance and system reliability.

The analytical method used in this study is a descriptive-analytical approach by evaluating the existing protection relay settings of the excitation transformer. The evaluation is based on key parameters such as pickup current, differential slope, breakpoint, time delay, inrush inhibit, sensitivity, selectivity, and relay stability (Masood et al., 2025). The analysis is carried out by referring to IEEE C37.91, IEC 60255 standards, and the technical specifications and setting manual of the GE Multilin T60 relay to determine the suitability and reliability of the protection system.

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RESULTS AND DISCUSSION

Technical Data and Excitation Transformer Protection System

The excitation transformer in the generating unit is used as a power supply for the generator excitation system; therefore, a protection system is required to maintain reliability and operational safety (Martínez Gomez, 2023). Based on the obtained data, the excitation transformer uses the GE Multilin T60 protection relay with several main protection functions to secure the transformer from internal faults and abnormal operating conditions (Mohideen & Anita, 2024). The technical data and protection functions are shown in Table 1 and Table 2.

Table 1. Technical Data of Excitation Transformer

Parameter	Value
Manufacturer	Trafo-Union
Transformer Type	Dry Type Transformer
Capacity	770 kVA
Frequency	50 Hz
Primary Voltage	10.5 kV
Secondary Voltage	0.58 kV
Primary Current	42.3 A
Secondary Current	766 A
Vector Group	Dd0
Cooling Type	AN (Air Natural)
Standard	IEC 76

Table 2. Protection Functions of Excitation Transformer Relay

Protection Function	ANSI Code	Description
Differential Protection	87T	Main protection for internal transformer faults
Overcurrent Relay	51P	Backup protection for overload and short-circuit faults
Overexcitation Protection	24	Protection against overflux condition due to V/Hz increase

Differential Relay Setting Analysis (ANSI 87T)

Differential protection (ANSI 87T) is used as the main protection for the excitation transformer due to its high sensitivity to internal faults (Patel & Chothani, 2020; Hayder & Saeed, 2025). The relay operates by comparing currents on the primary and secondary sides of the transformer within the protection zone. The relay will operate when the differential current exceeds the set threshold (Wu et al., 2021). The GE Multilin T60 numerical relay is equipped with slope characteristics and inrush inhibit functions to improve stability under transient and external fault conditions (Elkhidir & El-Amin, 2018; GE Multilin, 2021).

Table 3. Differential Relay Setting (ANSI 87T)

Parameter	Setting
Function	Enabled
Differential Pickup	0.3 pu
Slope 1	30%
Breakpoint 1	1.1 pu
Breakpoint 2	8 pu
Slope 2	80%
Inrush Inhibit Function	Adaptive 2nd Harmonic
Inrush Inhibit Mode	Per Phase
Inrush Inhibit Level	20%
Instantaneous Differential	5 pu
Overexcitation Inhibit Function	Disabled
Overexcitation Inhibit Level	10%
Block	OFF
Target	Latched
Events	Enabled

Based on Table 3 of the existing relay settings, the differential pickup value is set at 0.3 pu. This setting indicates that the relay will start to operate when the differential current exceeds 30% of the relay base current. The selection of the pickup value considers the possibility of differential current appearing under normal operating conditions due to current transformer (CT) errors as well as current variations caused by transformer on-load tap changer (OLTC) operations. A relatively low pickup value is used to maintain relay sensitivity to internal transformer faults.

The slope characteristics of the differential relay consist of Slope 1 set at 30% and Slope 2 set at 80%, with breakpoints at 1.1 pu and 8 pu. Slope 1 is used to maintain relay sensitivity under low to medium fault current conditions while also mitigating measurement errors caused by CT saturation during external faults with significant DC components. Meanwhile, Slope 2 is applied to ensure relay stability under heavy through-fault conditions that may cause one of the CTs to saturate, resulting in a false high differential current.

The breakpoint settings of 1.1 pu (Breakpoint 1) and 8 pu (Breakpoint 2) define the transition limits of the differential relay slope characteristics. These breakpoints are determined based on the CT capability to accurately transform primary current into secondary current during external fault conditions. Breakpoint 2 is set below the fault current level that may cause CT saturation due to AC components, while Breakpoint 1 considers the influence of DC components and residual magnetism in the CT core.

The differential relay is also equipped with an inrush inhibit function using an adaptive 2nd harmonic mode (Adaptive 2nd) and a per-phase inrush inhibit configuration. This function is designed to prevent relay operation during magnetizing inrush current that occurs during transformer energization. The adaptive 2nd harmonic method operates by detecting the magnitude and phase angle of the second harmonic component relative to the fundamental component, allowing the relay to distinguish between inrush conditions and internal faults more accurately. The inrush inhibit level is set at 20%, meaning that the differential protection will be restrained when the second harmonic content exceeds this threshold.

In addition, the relay employs an instantaneous differential element set at 5 pu, which functions as high-speed protection for severe internal faults with large magnitude currents. This setting is selected to ensure the relay remains stable during non-fault conditions such as transformer energization inrush current and extreme CT saturation during external faults.

Overcurrent Relay Setting Analysis (ANSI 51P)

Differential protection (ANSI 87T) is used as the main protection for the excitation transformer due to its high sensitivity to internal transformer faults. The operating principle of the differential relay is based on comparing the current on the primary and secondary sides of the transformer within the protection zone. The relay will operate when the differential current exceeds the predefined setting value (Hayder & Saeed, 2025). In this excitation transformer, a GE Multilin T60 numerical relay is used, which is equipped with slope characteristics and an inrush inhibit function to improve relay stability under transient conditions and external faults (Elkhidir & El-Amin, 2018; GE Multilin, 2021).

Table 4. Overcurrent Relay Setting (ANSI 51P)

Parameter	Setting
OCR Pickup 1	2 pu
K(CF)	1
OCR Delay 1	3 s
OCR Pickup 2	4 pu
OCR Delay 2	0.15 s
Protection Function	Time Overcurrent & Instantaneous Overcurrent

Based on Table 4 of the existing relay settings, the OCR on the excitation transformer employs two protection stages, namely time overcurrent and instantaneous overcurrent. The first OCR pickup is set at 2 pu with a time delay of 3 seconds. This setting is used to protect the transformer against overload conditions and overcurrent faults with a time-delayed characteristic, thereby maintaining coordination with other protection systems. The relatively longer time delay is intended to ensure that the relay remains selective and does not operate unnecessarily during transient conditions or short-duration current surges. The time overcurrent setting also uses a k(CF) factor of 1, which serves as a constant for the relay’s operating time characteristic in overcurrent protection.

In addition, the relay is equipped with an instantaneous overcurrent element with a pickup setting of 4 pu and a time delay of 0.15 seconds. This setting is designed to detect high-magnitude short-circuit faults that require fast interruption in order to minimize the risk of damage to the transformer and the generator excitation system equipment. The instantaneous overcurrent function enables the relay to respond faster compared to the time overcurrent protection during high fault current conditions.

Coordination between the pickup values and time delays in the OCR is carried out to maintain the sensitivity and selectivity of the excitation transformer protection system. The higher pickup setting of the instantaneous overcurrent compared to the time overcurrent is intended to distinguish overload conditions from short-circuit faults more accurately. With this configuration, the protection system is expected to operate reliably as backup protection in case the differential protection does not operate.

Overexcitation Protection Setting Analysis (ANSI 24)

Overexcitation protection (ANSI 24) is used to protect the excitation transformer from excessive flux conditions caused by an increase in the voltage-to-frequency (V/Hz) ratio. Overexcitation conditions can lead to core saturation, resulting in excessive temperature rise and potentially damaging the transformer insulation if sustained over a long period. Therefore, the overexcitation protection setting must be adjusted according to the excitation capability characteristics of the transformer so that the relay remains stable under normal operating conditions while still being sensitive to overfluxing conditions (Schons et al., 2022).

Table 5. Overexcitation Protection Setting (ANSI 24)

Parameter	**V/Hz 1**	**V/Hz 2**
Function	Enabled	Disabled
Source	Source 2	Source 2
Voltage Mode	Phase to Ground	Phase to Ground
Pickup	1.19 pu	1.18 pu
Curve Type	Definite Time	Definite Time
TD Multiplier	10	2
Reset Time	1	1
Block	OFF	OFF
Target	Latched	Latched
Events	Enabled	Enabled

Based on Table 5 of the existing relay settings, ANSI 24 protection uses a pickup setting of 1.19 pu with a 10-second delay time. This pickup value indicates that the relay will operate when the voltage-to-frequency ratio exceeds 1.19 times the nominal system value. Setting the pickup above the nominal value is intended to prevent relay mal-operation caused by temporary fluctuations in voltage and frequency that are still within the normal operating range of the power plant system.

In the GE Multilin T60 relay, Volts per Hertz Function 1 is enabled using Source 2 with phase-to-ground measurement mode. The relay operating time characteristic uses a definite time curve with a TD multiplier of 10.00 and a T reset of 1.0. The use of a definite time characteristic is intended to provide a specific time delay before tripping so that the system remains stable during transient conditions.

In addition, the relay also includes Volts per Hertz Function 2 with a pickup value of 1.18 pu; however, this function is disabled and therefore not used as active protection in the excitation transformer system. The block setting is OFF, the target is latched, and events are enabled to facilitate monitoring and fault recording in the protection relay system.

With these pickup and time delay settings, overexcitation protection is expected to protect the excitation transformer from overfluxing conditions without reducing system stability during normal operation.

Relay Setting Evaluation Based on IEEE C37.91 and IEC 60255

Evaluation of Relay Settings Based on IEEE C37.91 and IEC 60255 The evaluation of protection relay settings in the excitation transformer is carried out to determine the compliance of relay parameters with the principles of sensitivity, selectivity, stability, and reliability of transformer protection systems. The analysis is based on the existing settings of the GE Multilin T60/G60 relay with reference to IEEE C37.91 regarding power transformer protection and IEC 60255 concerning relay characteristics and coordination standards.

The evaluated parameters include differential protection settings (ANSI 87T), overcurrent relay (ANSI 51), and overexcitation protection (ANSI 24). The evaluation is conducted by comparing pickup values, slope characteristics, breakpoints, time delays, and inrush inhibit features against transformer protection recommendations and the operational characteristics of the excitation transformer protection system.

Evaluation of Differential Relay Sensitivity and Stability

Based on IEEE C37.91 (IEEE, 2021) transformer differential relays must be capable of detecting internal faults with high sensitivity while remaining stable under external faults and transient conditions such as magnetizing inrush current. In this excitation transformer, the differential pickup is set at 0.3 pu, ensuring sufficient sensitivity to detect internal transformer faults without causing mal-operation under normal operating conditions.

The use of Slope 1 at 30% and Slope 2 at 80% is intended to maintain relay stability against CT saturation effects during external high-current faults. In addition, breakpoints of 1.1 pu and 8 pu are applied as transition limits for slope characteristics to ensure stability against CT errors and DC components in fault currents.

The differential relay is also equipped with an adaptive 2nd harmonic inrush inhibit function with an inrush inhibit level of 20% to prevent relay operation during transformer energization inrush current. Based on IEEE C37.91 recommendations and GE Multilin relay characteristics, an inrush inhibit setting in the range of 15–20% is commonly used to maintain stable transformer differential protection.

Based on IEEE C37.91, transformer differential protection must be sensitive to internal faults while remaining stable under external faults and transient conditions (IEEE, 2021).

Table 6. Differential Relay Evaluation (IEEE C37.91)

Parameter	Existing Setting	Standard	Status
Differential Pickup	0.3 pu	0.2–0.5 pu	Compliant
Slope 1	30%	20–40%	Compliant
Slope 2	80%	40–80%	Compliant
Breakpoint 1	1.1 pu	CT-dependent	Compliant
Breakpoint 2	8 pu	Below CT saturation level	Compliant
Inrush Inhibit Level	20%	15–20%	Compliant
Inrush Function	Adaptive 2nd Harmonic	Harmonic restraint	Compliant

Overcurrent Relay Coordination Evaluation (ANSI 51)

Based on IEC 60255 (International Electrotechnical Commission, 2009), coordination of overcurrent relays must consider operating time characteristics and selectivity between protection relays. The OCR pickup setting of 2 pu with a 3-second delay time is used as backup protection against overload conditions and overcurrent faults with time-delayed characteristics. This delay is intended to ensure that the relay remains selective with the main transformer protection and does not operate unnecessarily during transient conditions.

In addition, the relay also employs an instantaneous overcurrent element with a pickup of 4 pu and a 0.15-second delay to protect the system from high short-circuit current faults. The difference in pickup values and time delays between the time overcurrent and instantaneous overcurrent elements indicates a protection coordination strategy designed to distinguish overload conditions from short-circuit faults more selectively.

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Table 7. Overcurrent Relay Evaluation (IEC 60255)

Parameter	Existing Setting	Standard	Status
OCR Pickup 1	2 pu	Above rated load current	Compliant
OCR Delay 1	3 s	Selective coordination	Compliant
K(CF)	1	Relay constant	Compliant
OCR Pickup 2	4 pu	High fault current	Compliant
OCR Delay 2	0.15 s	Fast tripping	Compliant

Overexcitation Protection Evaluation (ANSI 24)

Based on the evaluation results of the differential relay, overcurrent relay, and overexcitation protection settings, the excitation transformer protection system shows good protection coordination in terms of sensitivity, selectivity, stability, and reliability of transformer protection systems. The settings of pickup values, slope characteristics, time delays, and inrush inhibit features in the GE Multilin T60 relay support the protection system's ability to detect internal faults, maintain stability during external faults, and reduce the likelihood of mal-operation caused by transient conditions in the power generation system.

Overexcitation protection in the excitation transformer is used to protect the transformer core from overfluxing conditions caused by an increase in the voltage-to-frequency (V/Hz) ratio. The protection setting evaluation is based on the existing relay settings of the GE Multilin T60 (GE Multilin, 2021) and refers to general transformer protection practices in power generation systems. Based on the relay settings, the ANSI 24 pickup is set at 1.19 pu with a 10-second definite time delay. This value is still within the typical overexcitation setting range commonly applied in power transformer systems.

The use of a definite time characteristic is intended to provide tolerance against transient voltage and frequency variations, ensuring that the relay does not operate incorrectly during short-duration disturbances. Based on GE Multilin relay characteristics and transformer protection practices, this setting is considered safe to protect the transformer from overheating conditions due to excessive flux.

Table 8. Overexcitation Protection Evaluation

Parameter	Existing Setting	Standard	Status
ANSI 24 Pickup	1.19 pu	1.05–1.2 pu	Compliant
Delay Time	10 s	Definite time	Compliant
Curve Type	Definite Time	V/Hz protection	Compliant

Protection System Reliability Evaluation

Based on the evaluation results of the differential relay, overcurrent relay, and overexcitation protection settings, the excitation transformer protection system shows good protection coordination in terms of sensitivity, selectivity, stability, and reliability of transformer protection systems. The settings of pickup values, slope characteristics, time delays, and inrush inhibit features in the GE Multilin T60 relay support the protection system's ability to detect internal faults, maintain stability during external faults, and reduce the likelihood of mal-operation caused by transient conditions in the power generation system.

CONCLUSION

Based on the results of the analysis and evaluation of the excitation transformer protection relay settings at PLTGU Gresik, it can be concluded that the protection system has achieved good coordination in accordance with the principles of sensitivity, selectivity, stability, and reliability of transformer protection systems.

The differential relay setting (ANSI 87T) with a differential pickup of 0.3 pu, slope 1 of 30%, slope 2 of 80%, and breakpoints 1 and 2 at 1.1 pu and 8 pu respectively demonstrates the relay's capability to detect internal transformer faults with high sensitivity while maintaining stability against external faults and CT saturation effects. The use of the adaptive 2nd harmonic inrush inhibit feature with a 20% setting also improves relay stability against magnetizing inrush current during transformer energization.

For overcurrent protection (ANSI 51), the coordination between time overcurrent and instantaneous overcurrent provides sufficiently selective backup protection characteristics. A pickup setting of 2 pu with a 3-second delay is used to protect against overload and overcurrent conditions, while the instantaneous overcurrent setting of 4 pu with a 0.15-second delay provides a fast response to high short-circuit current faults.

In addition, the overexcitation protection setting (ANSI 24) at 1.19 pu with a 10-second delay is considered appropriate for protecting the excitation transformer from overfluxing conditions due to an increased voltage-to-frequency (V/Hz) ratio. Based on the evaluation of IEEE C37.91, IEC 60255, and the GE Multilin T60/G60 relay manual, all relay setting parameters remain within the recommended range for power transformer protection.

Overall, the existing relay settings of the excitation transformer at PLTGU Gresik are capable of supporting a reliable and stable transformer protection system in safeguarding equipment from internal faults, external faults, and abnormal operating conditions in the power generation system.

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