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Development of an Intelligent Protection Coordination System for Overcurrent and Ground Fault Relays Using Neural Network Methods

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Abstract

PT PAMA PERSADA, a prominent power plant located in Barunang, Kalimantan, operates with two primary feeders. However, persistent issues with protection coordination have been observed in one of the feeders, leading to disruptions in the plant's operational performance. The root cause of these issues was identified as improper coordination of overcurrent relays and ground fault relays. To address this, an evaluation of relay setting coordination was conducted using Electrical Transient Analysis Program (ETAP) 19.0.1 software. Specifically, the disturbances were concentrated in Feeder 2, which supplies power to the KM30 and Parilahung substations, where relay coordination failures resulted in simultaneous tripping events. Through ETAP simulations, the system's power parameters were analyzed, revealing active power of 4.164 kW, reactive power of 780.3 kVAR, apparent power of 4.237 kVA, and a power factor (cos phi) of 0.9. The protection coordination settings adhered to the IEEE 60255 standard, with grading times maintained between 0.2–0.6 seconds. To further enhance the reliability and optimization of the relay settings, simulations were extended using MATLAB software. This approach incorporated the Neural Network (NN) method for fine-tuning relay coordination, achieving a Mean Square Error (MSE) value of 0.33452, demonstrating significant improvements in fault management and protection system efficiency. These findings underscore the importance of integrating advanced computational tools and machine learning techniques for optimizing protection systems in modern power grids, contributing to improved operational reliability and adherence to international standards.

Keywords: Neural Network, overcurrent, ground fault, Main Square Eror, setting relay.

1. Introduction

PT PAMA PERSADA, a steam power control plant located in Barunang, Central Kalimantan, operates with an installed capacity of 2x15 megawatts (MW). Despite its robust operational framework, PT PAMA PERSADA has identified recurring disruptions in the feeders that hinder the reliability and efficiency of its power distribution system. Using the Electrical Transient Analysis Program (ETAP), the plant has analyzed transient disturbances and pinpointed the underlying causes, particularly in Feeder 1 and Feeder 2, which supply power to the KM30 and Parilahung substations.

These disturbances are primarily attributed to simultaneous tripping caused by inadequate coordination between Overcurrent Relays (OCR) and Ground Fault Relays (GFR). Such protection coordination failures can significantly increase the risk of equipment damage, extensive power outages, and, in extreme cases, explosions, especially in areas with a high concentration of flammable materials (Adzani, 2016). To mitigate these risks, the plant requires an advanced relay coordination system capable of dynamically adapting to varying operational conditions.

This research introduces a protection system utilizing adaptive mechanisms, where relay settings are automatically optimized using Neural Network (NN) methods. The NN method offers the capability to adjust relay coordination in real-time, ensuring effective protection under fluctuating power generation and distribution scenarios. Results from the NN method are visualized through detailed graphs, enabling precise analysis of relay behavior under specific conditions (Anisah et al., 2020).

Building upon prior research as a foundation, this study focuses on enhancing the coordination settings of Overcurrent Relays (OCR) and Ground Fault Relays (GFR) at PT PAMA PERSADA. The project aims to develop an intelligent protection coordination system that meets international standards, such as IEEE 60255, while maintaining optimal reliability and safety in power distribution. The title of this research, "Development of an Intelligent Protection Coordination System for Overcurrent and Ground Fault Relays Using Neural Network Methods," encapsulates its core objective.

The anticipated outcome of this study is the implementation of a neural-network-driven adaptive protection coordination system that significantly improves the operational reliability and performance of OCR and GFR at

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PT PAMA PERSADA. By leveraging advanced computational techniques, this research aims to address critical challenges in power system protection, offering practical insights and solutions for the energy sector.

2. Material and methods

2.1. Material

A. System Protection

Electrical power system protection is electrical safety in the electric power system, in the event of an electrical disturbance or overload (Agna et al., 2023b). Where one way to limit equipment damage, by limiting the continuity of the distribution of electricity can run well (Hasben, 2016) . The disturbance that occurs is a short circuit that will cause a large enough current. A large current if not removed immediately will damage the equipment in its path, to release the disturbed area, a protection system is needed (Supriyadi, n.d.).

B. Instrument Protection

- Load Brek Switch

  Load Break Switch is a three-phase circuit breaker which can usually be used at feeder substations or electrically controlled cubicles under normal conditions without any disturbance (Mangapul & Sumander, 2017).
- Busbar

  The busbar installation is usually installed on the split-circuit panel, based on the PUIL 2000 standard, with the following conditions: red for the R phase, yellow for the S phase, black for the T phase and blue for the Neutral wire (Nursalim et al., 2018).

  The busbar size is used the following equation:Circuit Breaker: (Soewono & Noprianti, 2020)

$$In= P/(\sqrt{3}.V.\cos\emptyset\ \eta)$$

- Current Transformer

  Current Transformer is an electrical equipment used to transfer electrical power from a circuit and to reduce the current.

Figure 1. Characteristic Curve 60255

- Circuit Breaker

  Circuit breaker (CB) is a three-phase low-voltage automatic key protector as a breaker with control and relay. The grid protector is mounted on the transformer or the vault wall.

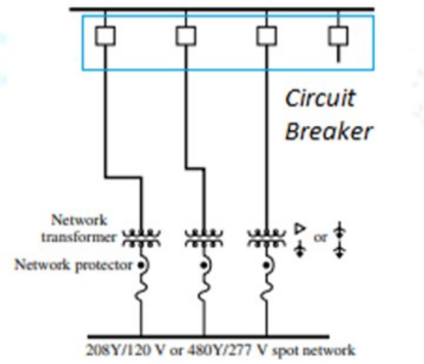

Figure 2. Circuit Breaker

C. **Curve Protection Coordination**

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Protection coordination system is the main system in production control. Where in this system the type of relay that works as follows (Sulasno, 1993).

- Overcurrent

Overcurrent relay is a relay that works against overcurrent (Khabibi et al., 2020). The relay will work if the current flowing exceeds the setting value (I set). It has the working principle of an overcurrent relay that works by analyzing the input in the form of a current which then the results of the current passing will be compared with the setting value, if the current value read by the relay exceeds the setting value, the relay will send a trip command to the CB (Circuit Breaker) as power breaker after the time delay applied to the setting. This overcurrent relay will protect the electrical installation against interference between phases. And the overcurrent relay will work if it meets the following conditions: (Gah & Dami, 2020)

If > Ip (trip)
If < Ip (block)

Where when Ip is the working current used as a parameter for the maximum current value and If is the fault current stated on the transformer secondary winding (Nugraha et al., 2023a). Overcurrent relays function to secure equipment parts of the electric power system, such as generators, utilities, transformers, motors.

- Invers Time

The inverse curve has the following types of operations based on IEC Standard 60255: (Pafela & Hariyanto, 2017)

a. Curve Standar Inverse

$$T(s)=\frac{0,14}{¿¿}$$

b. CurveVery Invers

$$T(s)=\frac{13,5}{¿¿}$$

c. Curve Extremely Inverse

$$T(s)=\frac{80}{\left(\left(\frac{Isc\,Max\,Saluran}{I\,Pickup}^{2}\right)\right)-1}x\,TMS$$

d. Curve Long Inverse

$$T(s)=\frac{120}{\left(\left(\frac{Isc\,Max\,Saluran}{I\,Pickup}^{\square}\right)\right)-1}x\,TMS$$

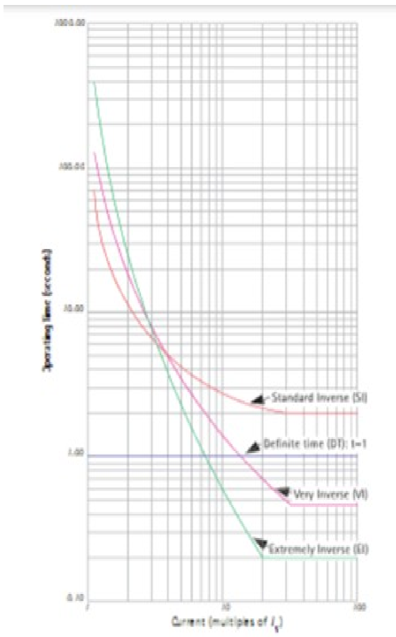

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Figure 3. Characteristic Curve 60255 [13]

- Instantaneous

This current relay will give a command to the PMT when a short circuit occurs and the current value of the disturbance exceeds its setting (Is), then the time period for the relay starts from pick up until the relay works for a certain time and does not depend on the amount of current that works on the relay.

- Definite Time

Relays on overcurrent use certain time characteristics, namely when the response period by the relay to the value of the pick-up current until the relay is complete does not depend on the amount of current that passes through the relay. The relay in this state will work based on a predetermined delay time and does not depend on the difference in the magnitude of the current.

D. Electric Transient and Analysis Program (ETAP)

In designing and analyzing an electric power system, an application software is needed to represent real conditions before a system is realized (Nugraha et al., 2021c). ETAP (Electric Transient and Analysis Program) 19.0.0 is an application software used to simulate electric power systems. ETAP is able to work offline for electric power simulation, and online for real-time data management or used to control the system in real time. The features contained in it also vary, including features used to analyze electric power generation, transmission systems and electric power distribution systems (Pafela & Hariyanto, 2017).

The analysis of the electric power system that can be carried out by ETAP includes: Power flow analysis, short circuit analysis, arc flash analysis, motor starting, protection coordination, transient stability analysis, etc (Nugraha et al., 2021a).

- Load Flow

The power flow study is a calculation of voltage, current, active and reactive power found at network points in normal operational conditions, while the objectives are as follows: knowing the voltages on each bus in the system, both magnitude and phase angle of the voltage, knowing active and reactive power flowing in an existing line in a system, knowing the condition of all equipment, whether it meets the specified limits for delivering the desired electrical power, obtaining the initial conditions for the new system design, and obtaining the initial conditions for the study (Permana et al., 2021). Further studies such as short circuit studies, stability and economic loading.

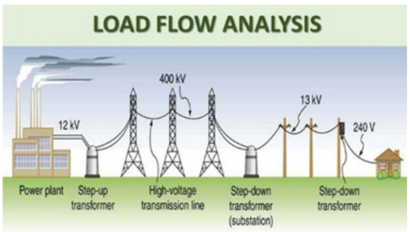

Figure 4. Load Flow Analys [16]

- NN Metod

ANN (Artificial Neural Network) is a nervous system in the human brain. The working process of the human brain is composed of billions of neurons where each neuron will be connected to tens of thousands of other neurons: A neuron consists of 3 main components, namely: Dendrites, an input signal channel whose connection strength to the cell nucleus is influenced by a weight. Cell Body (Cell Body), is where the computational process of weighted input signals to produce output signals that will be sent to neurons. The axon is the part that sends the output signal to other neurons that are connected to the neuron (Kurniawan et al., 2015).

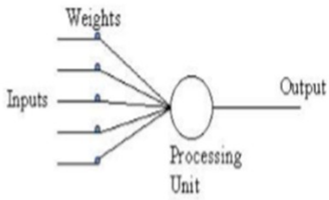

Figure 5. Basic NN Neuron (Kurniawan et al., 2015)

2.2. Methods

A. Electric Transient and Analysis Program (ETAP)

- Load Flow

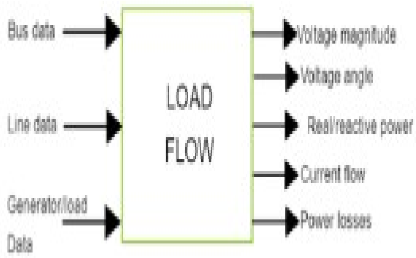

Figure 5. Block Diagram Load Flow

From the information in the figure 5 above, it consists of input, process, and output. Where the input contains transformer data, bus data and equipment data. Meanwhile, the process contains power flow methods, by producing outputs in the form of voltage magnitude simulations, power losses, voltages, and current flows.

- Protection Coordination

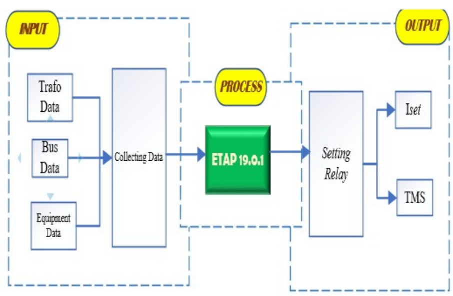

Figure 7. Block diagram Protection

From figure 7 above, it consists of input, process, and output. Where the input contains transformer data, bus data and equipment data, while the process contains a simulation of how the protection coordination works in the ETAP application, by producing outputs in the form of current settings, and time multi settings.

- Analys Calculation

a. Outgoing 1

On the outgoing side, this one will calculate the Iset and Time Multi Setting (TMS) values. The time value (t) used is 0.6 second. The following is a description of the calculation:

Is known:
Load = 36 A
Ihs = 2,048 kA = 2048A
CT = 600/5 A

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Discussion:

I set	=	1,2 x Ibeban
	=	1,2 x 36A
	=	43,2 A
TMS	=	0,6 *x* ¿
	=	0,6 *x* ¿
	=	0,36 second

b. Outgoing 2

a. Gardu KM 30

Load = 25 A
I hs = 840 A
CT = 1000/5 A

I set	=	1,2 x Ibeban
	=	1,2 x 25A
	=	30 A
TMS	=	0,6 *x* ¿
	=	0,6 *x* ¿
	=	0,31 second

b. Parilahung

Load = 0,031 A
I hs = 400 A
CT = 1000/5 A

I set	=	1,2 x Ibeban
	=	1,2 x 0,031A
	=	0,037 A
TMS	=	0,6 *x* ¿
	=	0,6 *x* ¿
	=	0,01 second

B. NN Method

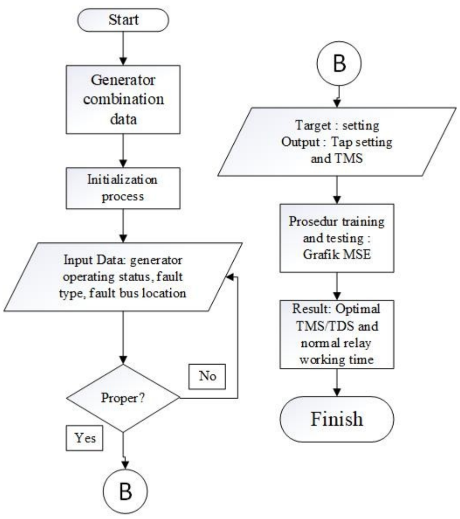

Figure 7. Block diagram Protection

In the Figure obtained the following description,
1. Start by opening the Matlab 2017 software.

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2. Collect generator combination data to be entered in M-Files.
3. The entire data initialization process.
4. The data input process, continued if it is appropriate to the next step namely the target input and output.
5. Perform procedures and testing to generate the MSE graph as evidence of the optimization of the results of setting the relay working time.

3. Results and discussion

Electrical system at PT. PAMA PERSADA uses four voltage ratings, namely 150 kV, 36 kV, and 0.4 kV. The power flow test is carried out to determine the power flow between components that have been integrated, are able to issue current and voltage values and are able to determine the critical and marginal bus sections in the region

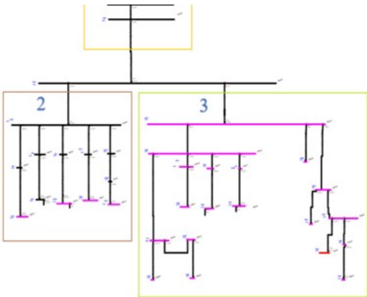

Figure 8. Single Line Diagram

In Figure 8, the power flow simulation will be tested under three conditions, namely at full load, medium load, and low load. There are numberings as regional markers, that number 1 is the generating area, number 2 is the Outgoing I area and number 3 is the outgoing II area. Where the load testing is located in all outgoing areas.

3.1. Protection Coordination

1. Incoming

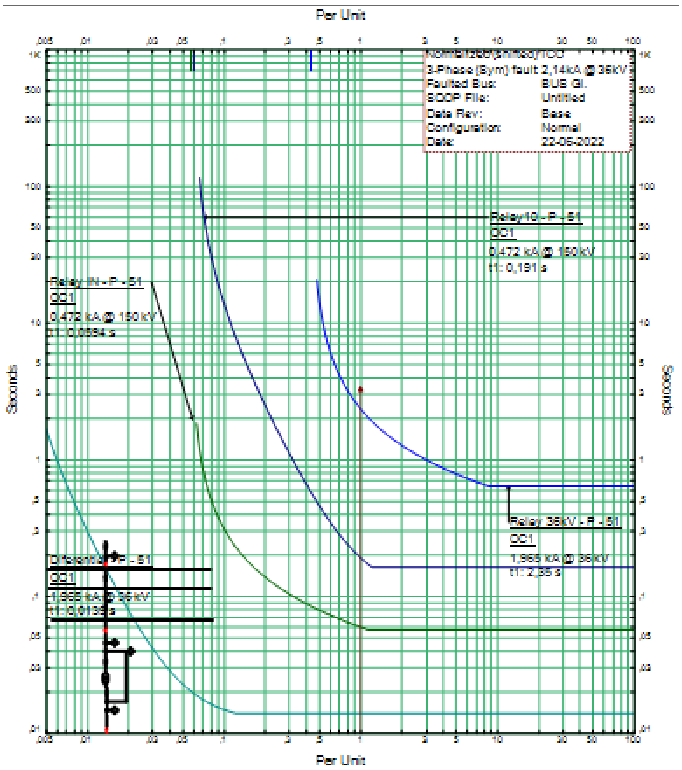

Figure 9. Curve incoming

Table 1. Data Result

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Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
13,9	Diferential	1,965	13,9		Phase - OC1 - 51
23,9	CB 2		10,0		Tripped by Diferential Phase - OC1 - 51
59,4	Relay IN	0,472	59,4		Phase - OC1 - 51
69,4	CB 2		10,0		Tripped by Relay IN Phase - OC1 - 51
191	Relay10	0,472	191		Phase - OC1 - 51
201	CB 1		10,0		Tripped by Relay10 Phase - OC1 - 51
1116	Relay25	0,035	1116		Phase - OC1 - 51
1146	CB 3		30,0		Tripped by Relay25 Phase - OC1 - 51
1989	Relay22	0,074	1989		Phase - OC1 - 51
2019	ARAH TOP		30,0		Tripped by Relay22 Phase - OC1 - 51
2133	Relay15	0,104	2133		Phase - OC1 - 51
2163	OUTGOING1		30,0		Tripped by Relay15 Phase - OC1 - 51
2346	Relay 36kV	1,965	2346		Phase - OC1 - 51
2376	INCOMING		30,0		Tripped by Relay 36kV Phase - OC1 - 51

2. Outgoing 1

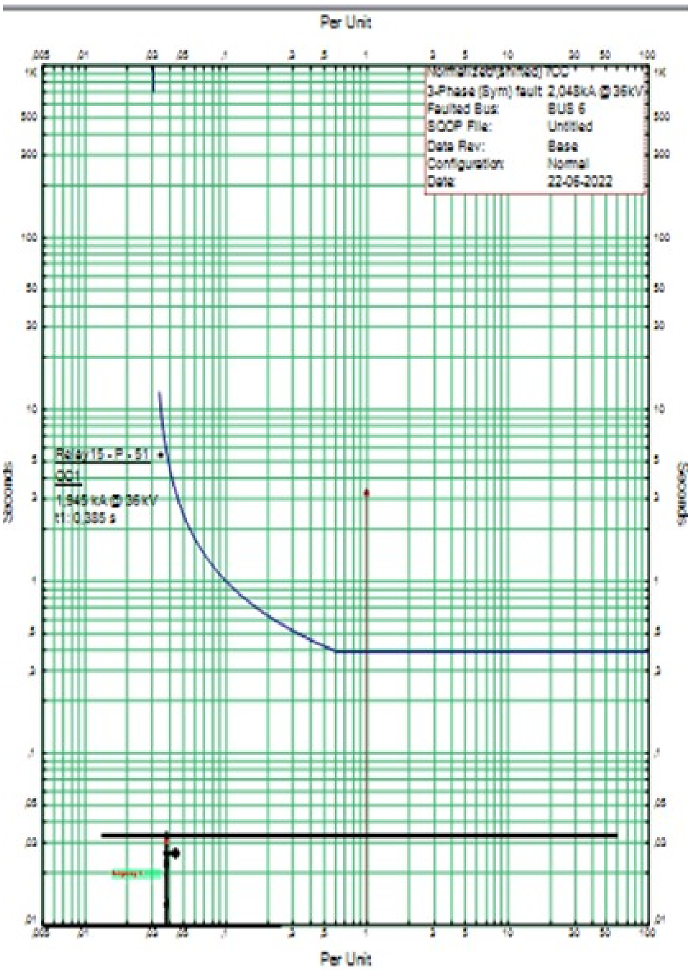

Figure 10. Curve incoming 1

Table 2. Data Result incoming 1

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
415	OUTGOING1		30,0		Tripped by Relay15 Phase - OC1 - 51

3. Outgoing 2

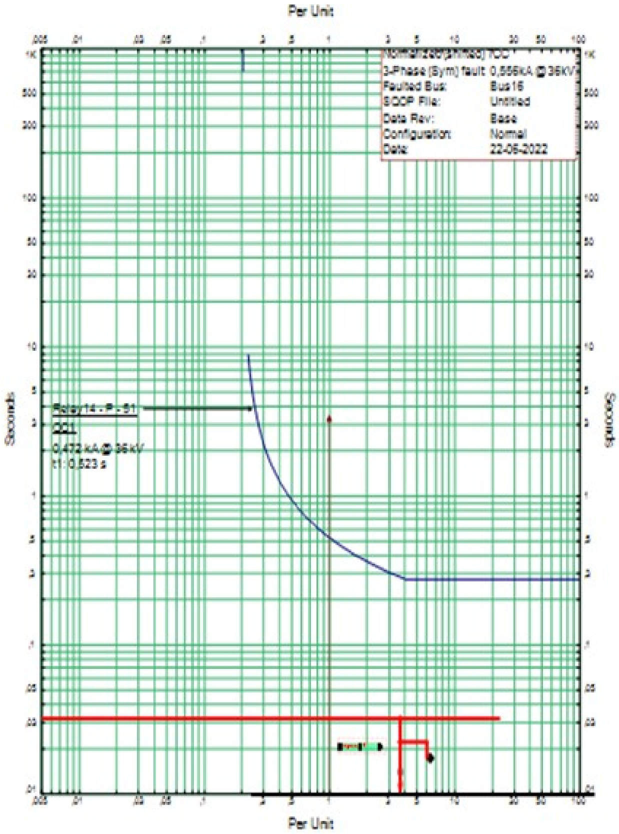

Figure 11. Curve incoming 2

Table 3. Data Result incoming 2

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
23,9	OUTGOING2		30,0		Tripped by Relay14 Phase - OC1 - 51
553	CB 2		10,0		Tripped by Diferential Phase - OC1 - 51

3.2. NN Method

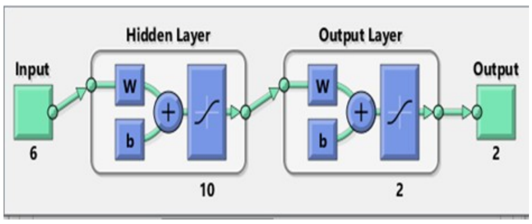

Figure 12. NN Method

The results and discussion sections of your research paper should include the following: findings, comparison with previous research, limitations of your work, causal arguments, speculation, and deductive arguments. The information in Figure 13 explains that each neuron process will be different in the network configuration system used. It is influenced by the value of input and output. The input on the simple NN block diagram contains the value of the generator ON/OFF status of the bus fault, the type of fault, the location of the relay, and the short-circuit current. While the output contains the value of the Tap setting and Ipickup.

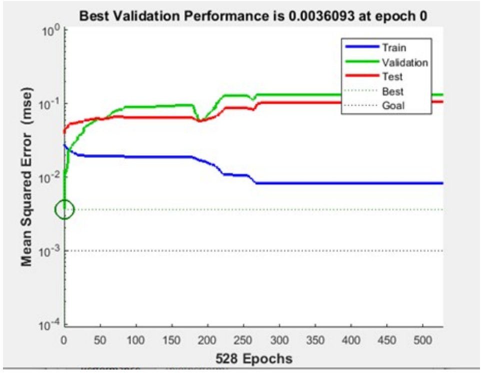

Figure 13. Curve Best Performance MSE

Figure 14 shows the best performance values that reach up to the peak. The performance value is the smallest value that can be achieved during the training run. This is followed by the display of Figure 15 where the smaller the MSE value is similar between the target and the output, it means that it has reached conformity, with the conformity value reaching 0.0036093. From the results of the study, it will be obtained the value of the weight and the value of the bias used as the testing process. In fact, the weight and bias values will be included in Table IV.

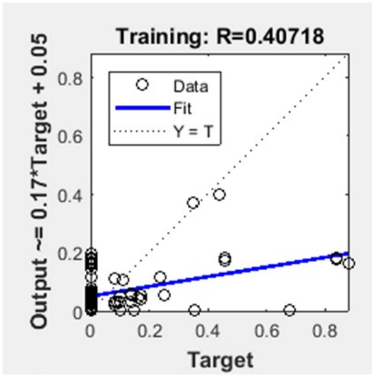

Figure 14. Target Suitibility

Table 4. Data Result NN Method

Start load

Neuron	x1	x2	x3
y1	0.52203	0.15690	-1.08398
y2	-1.02195	0.64329	0.07114

Neuron	Start Bias
y1	-1.4579343
y2	0.95822271

4. Conclusion

Based on the simulation results and analysis of the coordination of Overcurrent Relay and Ground Fault Relay protection on a radial system connected to the generator using the NN method, the following conclusions can be drawn:

1. The protection coordination simulation performed on the Electrical Transient Analysis Program (ETAP) 19.0.1 software can work according to its working principle. The location of the disturbance that dominates is at the KM 30 and Parilahung substations.
2. The time setting used in the existing one does not meet the IEEE 60255 standard with a grading time of 0.2-0.6 second. Therefore, it is improved by selecting the resetting grading time of this final project protection coordination, which is 0.6 second.
3. The results of the fulfillment of the curve used are in accordance with the IEEE 6025 standard in the form of an inverse standard TCC (Time Current Curve) curve. Where the curve does not intersect with other components.

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4. The effect of the NN method system with Matlab 2017 software is used as an optimization of the settings contained in the relay with a target suitability of 0.0036093. As well as being able to display the MSE (Mean Squad Error) graph for relay operation time..

Credit authorship contribution statement

Author Name: Conceptualization, Writing – review & editing. **Author Name**: Supervision, Writing – review & editing. **Author Name**: Conceptualization, Supervision, Writing – review & editing.

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