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Optimization of Relay Settings in Jember Substation Power Transformers Based Particle Swarm Optimization

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Abstract

In their operating system, power transformers can experience two disturbances: internal disturbances and external disturbances. Therefore, a reliable protection system is needed to deal with these disturbances. The differential relay is the principal protection for the transformer to detect an internal fault in the protection zone. However, if there is an external disturbance or outside the protection zone of the differential relay, the relay will not work. The differential relay protection is limited by two current transformers, where it compares the difference in the value of the differential current entering the relay. It is necessary to set the suitable differential relay so that the protection system can work selectively and have reliability. We used conventional calculations and the Particle Swarm Optimization (PSO) algorithm to determine the differential relay setting. There are two types of differential relays used in the Jember Substation for transformer safety 1, 2, 3, and 4. Based on transformer specification data and CT ratio. In the conventional calculation results, the relay setting produces a differential current of 0.01A for transformers 1, 2, 3. Still, for transformer four, it is 0.02A, and the set current for transformers 1 and 3 is 0.86A, but transformers 2 and 4 have a value of 0.96A and 1.15A. Then the PSO relay setting algorithm results with the previously described parameters have better accuracy.

Keywords: Differential Relay, System reliability, Electric Power Distribution Network, Particle Swarm Optimization, Transformers.

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1. INTRODUCTION

One of the main protection systems in transformers is a relay. Relays work very selectively and quickly with no time delay. The differential relay turns on when there is an internal fault in the protected area. Relay current setting must be calculated accurately to prevent protection failure and increase the reliability of an electric power protection system. The function of the relay is to detect the difference in the current value difference between the Current Transformer, the primary, and the secondary [1]. If there is a disturbance outside the secured electrical equipment (external fault), then the current flowing increases, but the circulation will remain the same as usual conditions, so the relay will not work in a superficial failure. However, suppose a disturbance occurs inside (internal fault). In that case, the direction of the current flow will be reversed on one side, causing the balance to be

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disturbed under normal conditions. The current Id will flow from terminal 1 to terminal 2 through the safety relay and activate a relay [2].

Several previous studies included the first setting relay on transformer substation Banaran Kediri based on neural network and conventional calculations [3]. The second is optimizing the overcurrent relay coordination on the 60MVA 150/20KV transformer and the 20 kV Gumul Substation Banaran feeder using the particle swarm optimization (PSO) method [4]. The third reference about the PSO trained ANN-based differential protection scheme for power transformers proves that the PSO optimization results have a simple concept are easy to implement and are efficient calculations [5]. Because of this, this thesis discusses the analysis relay settings on power transformers at the Jember Substation based on Particle Swarm Optimization. The data obtained will be entered and processed through the software MATLAB; a single line diagram will be made on the software to detect electrical power system disturbances

2. LITERATURE REVIEW

2.1 Protection System

In general, an electric power protection system consists of several components specifically designed to identify the condition of the electric power system. It operates based on the value of reading information obtained from the system, such as the value of voltage, current, power, phase angle, frequency, impedance, etc. The main objectives of the protection system are as follows [6]:

1. To prevent or reduce damage caused by system disturbances on faulty equipment.
2. Isolate the disturbed area to a minimum to separate the system experiencing disturbances (abnormal conditions) from normal conditions.
3. Able to provide good electrical service to consumers with high system reliability.

2.2 Differential Relay

Differential relays are relays that work based on increasing the differential current. If on the primary side of the current transformer (CT1) current I_1 flows then on the secondary side of the current transformer (CT2) will flow I_2 current, at the same time, the secondary side of the two current transformers will flow currents of I_1 and I_2 whose magnitude value depends on the ratio installed, if the magnitude of $I_1 = I_2$ so that diff = 0 then the relay will not operate because there is no difference in current difference. However, if the current value is $I_1 \neq I_2$ so that the diff 0 then the relay operates because there is a difference in the current value [7]. The picture below is the working principle of a differential relay on a transformer:

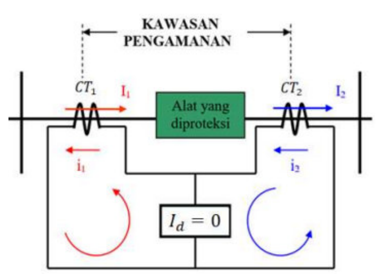

Figure 1. Normal State Differential Relay Circuit

The internal fault is a disturbance that occurs in the protection area of the differential relay. The current will flow to the fault point in an internal fault so that the current is flowing in CT2 changes from its normal direction to the point of disturbance. These disturbances can cause damage to the transformer and make the system unbalanced when working can be assumed as follows [5]:

$$Id = |I_1 + I_2| \tag{1}$$

Because $I_d \neq 0$, the differential relay will operate by giving a trip signal to the CB or power breaker (PMT) if the disturbance is allowed to disrupt the stability of the distribution network system and damage the transformer.

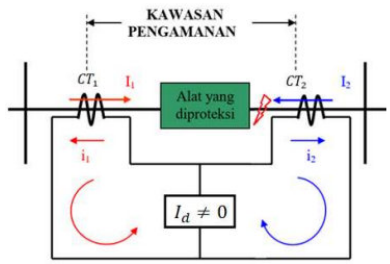

Figure 2. Internal Fault Differential Relay Circuit

In the event of an external disturbance. The differential relay does not work because the magnitude of the current flowing through CT1 and CT2 is the same, but only in opposite directions

$$Id = |I_1 + I_2| = 0 \tag{2}$$

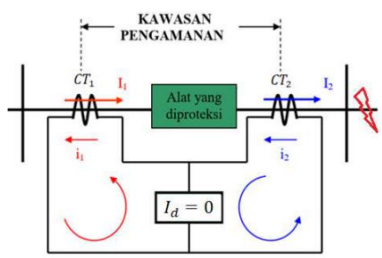

Figure 3. External Fault Differential Relay Circuit

2.3 Differential Relay Setting Conventional Calculation

To obtain the ideal CT ratio is necessary to calculate the rating current and nominal current according to the following equation [8]:

$$I_n = \frac{S}{\sqrt{3} \times V} \tag{3}$$

$$I_{rating} = 110\% \, x \, I_n \tag{4}$$

Where, I_n is nominal current (A), S is distributed power (MVA), V is current on the primary and secondary sides (V).

The error mismatch must also be calculated for the system to run correctly, which is used as an error parameter in reading the difference in current and voltage on the primary and secondary sides of the power transformer. Mismatch error is expected to be as small as possible so that the relay works optimally in securing power transformers.

Mismatch error can be determined by comparing the ideal CT with the CT installed in the transformer. The condition that the mismatch error obtained is not more than 5%. The following is the equation [9]:

$$Error\ Mismatch = \frac{rasio\ CT_{Ideal}}{rasio\ CT_{Terpasang}}\% \tag{5}$$

$$Ratio_{CT} = \frac{CT_2}{CT_1} \times \frac{V_1}{V_2} \tag{6}$$

where, CT (Ideal) is ideal current transformer, V_1 is high-side voltage, and V_2 is low-side voltage.

Then to measure the secondary current value of CT is as follows [2] :

$$I_{CT} = \frac{5}{rasio\ CT} \times I_n \tag{7}$$

$$I_{rele} = \frac{I_{rating}}{rasio\ CT} \times 5 \tag{8}$$

$$A_{CT} = \frac{5}{I_S\ CT} \tag{9}$$

$$I_S = I_{rele} \times A_{CT} \tag{10}$$

Where, I_n is nominal Current (A), I_{CT} is current Entering CT(A), I_{RELE} is recent Entering Relay(A), ACT is Auxiliary CT (A), I_s is secondary current flows on CT1 and CT2 (A).

The differential current measurement is obtained from the difference in the calculation between the high voltage side current and the low voltage side current. As in the following equation [6]:

$$Id = I_2 - I_1 \tag{11}$$

Id is differential current, I1 is secondary current CT1 (A), and I_2 is secondary Current CT2 (A).

Current restraint is the current restraint in the relay. It is used to determine the value of the average current flowing on both sides of the high-voltage or low-voltage transformer based on the CT secondary current value.

$$I_{restrain} = \frac{I_{CT1} + I_{CT2}}{2} \tag{12}$$

Where $I_{restrain}$ is restraint (A), I_{CT1} is secondary Current CT1 (A), and I_{CT2} is secondary Current CT2 (A).

The slope percentage gradient is obtained by dividing the differential current from the restrain. $Slope_1$ is responsible for determining the differential current to function against internal. $Slope_2$ is used to limit the relay disturbance that occurs externally.

$$Slope_1 = \frac{I_d}{I_r} \times 100\% \tag{13}$$

$$Slope_2 = \left[\frac{I_d}{I_r} \times 2\right] \times 100\% \tag{14}$$

If the transformer used is an OLTC type (On Load Tap Changer equation is percentage slope as follows [6]:

High voltage side 165Kv :

$$IH = \frac{s}{\sqrt{3} \times Tap_{tertinggi}} \tag{15}$$

$$I_D H = \frac{IH - I_1}{I_1} \tag{16}$$

Low voltage side 135kV :

$$IL = \frac{S}{\sqrt{3} \times Tap_{terendah}} \tag{17}$$

$$I_D L = \frac{IL - I_1}{I_1} \tag{18}$$

Then the differential current of the tap changer :

$$I_D T = Max\ (I_D H\ ;\ I_D L) \times 100\% \tag{19}$$

where, I_H is the highest tap operating current (A), I_{DH} is the highest tap differential current(A), Tap $_{Highest}$ is the highest tap voltage value on HV side, I_L is the lowest tap operating current(A), I_{DH} is lowest tap differential current(A), and Tap $_{Lowest}$ is the lowest tap voltage value on the HV side.
Then for the Total Slope1 value is the accumulation of the following values [6]:
Tap Error + Excitation Current + Mismatch Error + Safety Factor + Ratio error + $\mathrm{CT}_{150\mathrm{KV}}$ + $\mathrm{CT}_{20\mathrm{KV}}$ = %

The current setting is a limitation (thresholding setting) on the relay. So when the value of the differential current exceeds the setting, the relay will work to decide the CB on the network. The following is a calculation of the setting current.

$$I_{seting} = Slope_1 \times I_r \tag{20}$$

Where, I_r is restrain (A), I $_{seting}$ is setting (A).

2.4 Particle Swarm Optimization

Particle Swarm Optimization (PSO) Algorithm has a provision that each particle searches for the optimal solution by traversing the search space based on position adjustments to the best position of the particle (local best) and adjustment to the best position of the entire flock (global best). The standard PSO algorithm can be written as the following equation [10]:

$$v_i\,(t+1) = w.v_i + C_1.rand\,\big(p_i - x_i(t)\big) + C_2.rand\,\big(p_g - x_i(t)\big) \tag{21}$$

$$x_i\,(t+1) = x_i\,(t) + v_i\,(t) \tag{22}$$

$$w_{it} = w_{max} - \frac{(w_{max} - w_{min}) \times it}{it_{max}} \tag{23}$$

Where Vi_t and X i_t is the velocity and current position of the particle, Vi (t+1) and Xi (t+1) is position Speed of the next iteration, C_1 and C_1 are constants of cognitive and social acceleration, R_{and} is random value between 0 and 1. P_i is the best position of the particle, and P_g is the best position of the swarm, W_{Max} is coefficient inertia weight maximum, W_{Min} is coefficient inertia weight minimum, It is Iterations of 1,2,….. ItMax and It_{Max} are maximum iterations.

3. METHOD

The data used in this study were obtained from PT PLN (Persero) UPT Probolinggo ULTG Jember. The data used in this research include Single line diagrams used at the Jember Substation, transformer specifications, relay, CT data (Current Transformers), line conductor data (impedance, Line length) and load data as shown in tables 1 - 8. Modelling simulation, a single line diagram of the Jember substation was made using the software when a disturbance occurred. Then calculate the value setting current relay that will be used as input and target for analysis using conventional calculations and Particle Swarm Optimization.

A. Transformer Specifications

Table 1. Transformer Specifications 1

Brand	**SHANDONG**
Vector	YNynO(d)
Current	230.9/1732
Working Voltage	150/20 KV
Power	60 MVA
Impedance	12.8%

Table 2. Transformer Specification 2

Brand	**UNINDO**
Vector Group	YNynO(d)
Current	230.9/1574.5
Working Voltage	150/22 KV
Power	60 MVA
Impedance	12.5%

Table 3. Transformer Specification 3

Brand	**XIAN**
Vector Group	YNynO(d)
Current	230.9/1732
Working Voltage	150/20 KV
Power	60 MVA
Impedance	12%

Table 4. Transformer Specification 4

Brand	**UNINDO**
Vector Group	YNynO(d)
Current	230.9/1732
Working Voltage	150/20 KV
Power	60 MVA
Impedance	12.5%

B. Specifications Relay Differential

Table 5. Transformer Relay Specification 1

Differential	**Toshiba GR100**
Current 1	0.3 pu
Differential Current 2	1.0 pu
Setting Slope 1	30 %
Setting Slope 1	80 %
Ratio	CTp = 400/5
	CTs = 2000/5

Table 6. Transformer Relay Specification 2

Brand	Micom P642
Differential Current 1	0.3 pu
Differential Current 2	1.5 pu
Setting Slope 1	30 %
Setting Slope 1	80 %
Ratio	CTp = 400/5
	CTs = 2000/5

Table 7. Transformer Relay Specification 3

Brand	Toshiba GR100
Differential Current 1	0.3 pu
Differential Current 2	1.0 pu
Setting Slope 1	30 %
Setting Slope 1	80 %
Ratio	CTp = 400/5
	CTs = 2000/5

Table 8. Transformer Relay Specification 4

Brand	Micom P642
Differential Current 1	0.3 pu
Differential Current 2	1.5 pu
Setting Slope 1	30 %
Setting Slope 1	80 %
Ratio	CTp = 300/1
	CTs = 2000/5

This study uses software MATLAB 2014b settings relay based on particle swarm optimization with conventional calculation parameter values. This optimization is used to obtain the value of setting current and differential current, which has the percent error based on the original setting of the Jember Substation. Then to model the relay differential software ETAP 19.0.1.

C. Flowchart Research

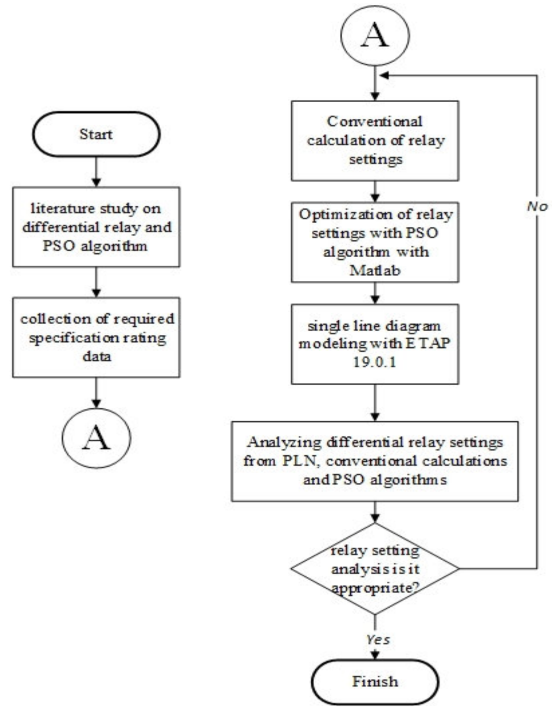

Figure 4. Research flowchart

After getting the setting relay based on conventional calculations, the next step is to program in Matlab 2014b to determine the settings relay differential with Particle Swarm Optimization based on the current value of $I_{Differential}$, $I_{Restraint}$, $I_{Secondary}$ CT, I_{Rating}. Error mismatch where these parameters will be used as input. Meanwhile, for the target or global best, the value of $I_{Setting}$ and $I_{Differential}$.

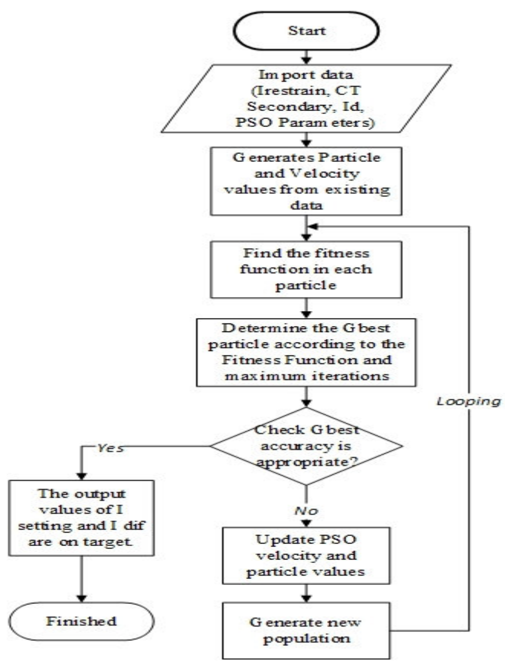

Figure 5. Research flowchart

4. RESULTS AND DISCUSSION

Comparison of output current values setting and differential currents from conventional calculations and the Particle Swarm Optimization contained in transformers 1, 2, 3, and 4.

A. Calculation relay settings conventional differential

Measurement of rated current and nominal current values is used to find the ideal current value on both sides of the transformer, high and low voltage (CT1 and CT2). With the following calculation:

$I_{nominal1} = \frac{S}{\sqrt{3} \times V}$

$= \frac{60.000\ KVA}{\sqrt{3} \times 150\ kV}$

= 230.94 A

$I_{nominal2} = \frac{S}{\sqrt{3} \times V}$

$= \frac{60.000\ KVA}{\sqrt{3} \times 20\ kV}$

= 1732 A

$I_{ratting1}$ = Load × In_1

= 110% × 230.94

= 254 A

$I_{ratting2}$ = Load × In_2

= 110% × 1732

= 1905 A

The mismatch error in detecting current and voltage reading errors according to the SPLN is limited to a maximum of 5%. The protection system cannot work optimally if it exceeds this value.

$CT_1 = \frac{2000}{5} \times \frac{20KV}{150KV} = 53{,}33\ A$

$Error_1 = \frac{53{,}33}{400}\% = 0{,}13\ \%$

$CT_2 = \frac{400}{5} \times \frac{150KV}{20KV} = 600\ A$

$Error_2 = \frac{600}{2000}\% = 0{,}3\ \%$

In calculating the CT secondary current, a correction value (KCT) is needed to minimize the value of the differential current on the high and low voltage sides when a disturbance occurs.

$I_{S\ CT1} = \frac{5}{400} \times 230{,}94\ A = 2{,}886\ A$

$KCT_1 = \frac{5}{2{,}88} = 1{,}73\ A$

$I_{S\ Rele\ 1} = \frac{254}{400} \times 5 = 3{,}17\ A$

$I_{S\ CT2} = \frac{5}{2000} \times 1732{,}05\ A = 4{,}330\ A$

$KCT_2 = \frac{5}{4{,}33} = 1{,}15\ A$

$I_{S\ Rele\ 2} = \frac{1905}{2000} \times 5 = 4{,}76\ A$

After obtaining the CT secondary current value, the differential current can be calculated with the following equation:

$I_1 = I_{sec}$ (Rele) × KCT_1

= 3.17 × 1.73

= 5.48 A

$I_2 = I_{sec}$ (Rele) × KCT_2

= 4.76 × 1.15

= 5.47 A

I_{diff} = I1 – I2 = 5.49 – 5.48 = 0.01 A

In determining the percent slope, attention is paid to the accumulated value in the previous calculation and the applicable provisions wherein,

a. CT_{150KV} = 5%

b. CT_{20KV} = 5%

c. Excitation current factor = 1%

d. Transformer safety factor = 5%

e. Error Tap Changer with the following calculation:

1. Highest Tap Limit 165kV

$$IH = \frac{60MVA}{\sqrt{3} \times 165\text{KV}} = 209{,}95\ A \qquad I_D H = \frac{209{,}95 - 230{,}94}{230{,}94} = -0{,}09\ A$$

1. Lowest Tap Limit 135kV

$$IL = \frac{60MVA}{\sqrt{3} \times 135\text{KV}} = 256{,}6\ A \qquad I_D H = \frac{256{,}6 - 230{,}94}{230{,}94} = 0{,}111\ A$$

2. Differential Current Tap Changer

$$I_D T = Max\ (-0{,}09\ ;\ 0{,}111) \times 100\% = 11{,}1\%$$

Total Slope1 = Tap Error + Excitation Current + Mismatch Error + Safety Factor + CT_{150KV} + CT_{20KV}

Total Slope1 = 11.1% + 1% + 1.125% + 5% + 5% + 5% = 28.23%

Slope2 = 2 × 28.23% = 56.46%

When the differential current exceeds the set current, the relay will send a signal trip on the HVCB (High Voltage Circuit Breaker) to secure the system experiencing interference.

$$Trafo\ 1\ I_{seting} = 28{,}23\% \times 3{,}068\ A = 0{,}866\ A$$

Then after obtaining the set current value, it will be simulated if there is an assumption of disturbance. It is assumed that a disturbance occurs on the high-voltage side of 150kV with a fault current of 600A as follows:

$$I_{f\ relay} = I_f \times Rasio\ CT$$

$$I_{f\ relay} = 600 \times \frac{5}{400} = 7.5A$$

$$i_{2\ fault} = \frac{7.5}{3.84} = 1.95A$$

$$I_d = 4.33 - 1.95 = 2.38A$$

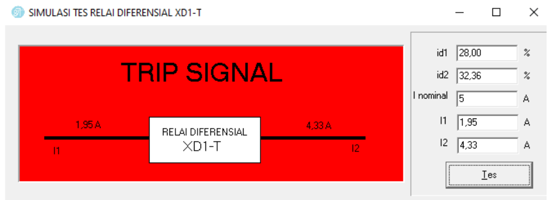

Figure 6. The simulation results of a fault current of 600A on the HV side of 150kV

It is because the differential current of the fault current exceeds the limit of the setting previously calculated. Then when there is an assumption of fault current on the low-voltage side of 20kV with a fault current of 8000A, the calculation is as follows:

$$I_{f\ relay} = I_f \times Rasio\ CT\ , I_{f\ relay} = 8000 \times \frac{5}{2000} = 20A$$

$$i_{2\ fault} = \frac{20}{4.33} = 4.61A, I_d = 4{,}61 - 3{,}84 = 0{,}77\ A$$

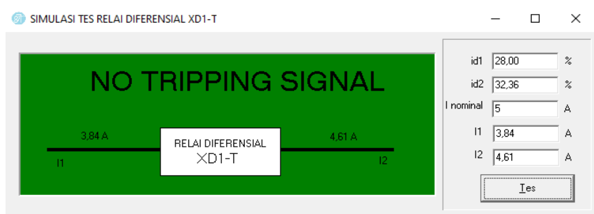

Figure 7. The simulation results of a fault current of 8000A on the LV side of 20kV

It is because the differential current of the fault current does not exceed the limit of the setting previously calculated.

B. Calculation relay setting PSO algorithm Differential

The differential relay setting using PSO is used to find the minimum value of the differential current and based on known parameters to obtain the optimal value. After determining the initialization on the PSO parameters, then updating the position and velocity of the particles, then evaluating the fitness using the objective function on each particle. Pbest is determined by comparing with the Pbest from the previous iteration. Then Pbest is defined as Gbest , then the Gbest best fitness . So get the minimum fitness value by checking whether the solution has reached convergence where the position of all particles goes to the same value by going through 100 iterations. The PSO parameters used are shown in table 9.

Table 9. Parameter PSO

No	Parameter	Description
1.	$I_{teration}$	100
2.	Number of particles	100
3.	W_{min}	0.866
4.	W_{max}	0.01
5.	V_{min}	0.001
6.	V_{max}	1.2
7.	C_1	3.608
8.	C_2	1.73

So for the first iteration calculation ifinitial particle value comes from a random with the limits listed as follows:

$$\mathrm{v_i}\,(\mathrm{t}+1) = 0{,}01 \times 0 + 3{,}608 \times 0{,}9341 \times (0{,}4647 - 0{,}4451) + 1{,}73 \times 0{,}866 \times (0{,}4648 - 0{,}4451) = 0{,}095$$

$$x_i\,(t+1) = 0{,}4451 + 0{,}095 = 0{,}54$$

The iteration process is carried out as long as the criteria have not met the maximum optimization and will stop when the fitness has reached the target. The PSO parameter states that the iteration is carried out 100 times, and the other parameters are written in Table 10. It gets a Gbest of 0.8656, and in other case studies, it can get a Gbest of 0.001. From this iteration, it is very influential on how often the update so that the resulting output value converges with the target. The problem's complexity influences the number of iterations used because of the more extensive the iteration, the longer the computational process.

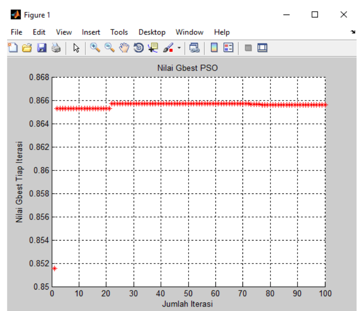

Figure 8. Gbest flow setting results PSO algorithm

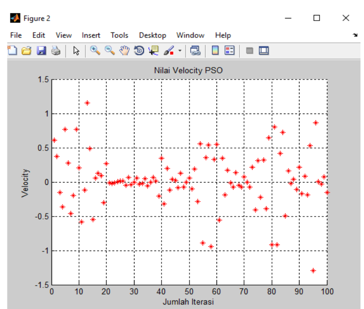

Figure 9. velocity PSO algorithm

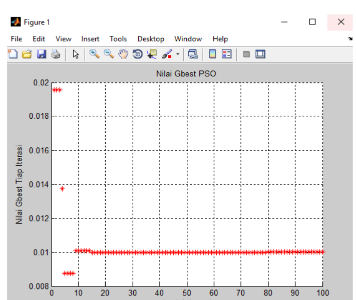

Figure 10. Gbest differential flow PSO algorithm results

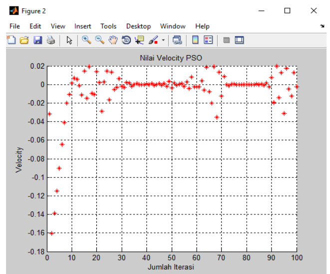

Figure 11. Velocity of PSO algorithm

It can be seen based on Figures 8, 9, 10, and 11 graph plots tend to converge towards points 0.8656 and 0.01, where both are the value of the setting current and the differential current of the relay. So it can be analyzed that using PSO optimization and the parameters mentioned in table IX can obtain Gbest output results that are close to the PLN Setpoint setting value from the Jember Substation worth 0.3 pu or if converted is equal to 0.866 A.

C. Comparison relay settings conventional calculation and PSO algorithms

The results can be displayed in the following output from the research done regarding conventional calculations and optimization of PSO algorithms in settings relay.

Table 10. Comparison of the results of conventional calculation settings and the PSO algorithm

	Conventional Calculation		**PSO Algorithm**		**Setting GI Jember**	
	$I_{setting}$	I_{dif}	$I_{setting}$	I_{dif}	$I_{setting}$	I_{dif}
Trafo 1	0,866	0,01	0,8656	0,01	0,866	0,01
Trafo 2	0,96	0,01	0,8656	0,01	0,866	0,01
Trafo 3	0,866	0,01	0,8656	0,01	0,866	0,01
Trafo 4	1,15	0,02	0,8656	0,01	0,866	0,01

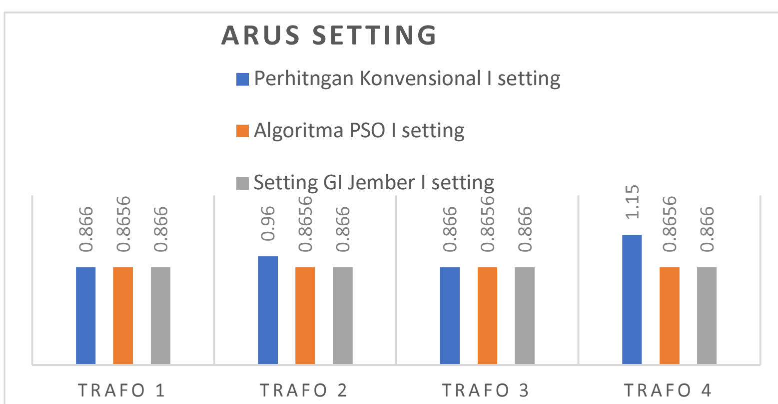

Figure 12. The results of the comparison outputs current setting

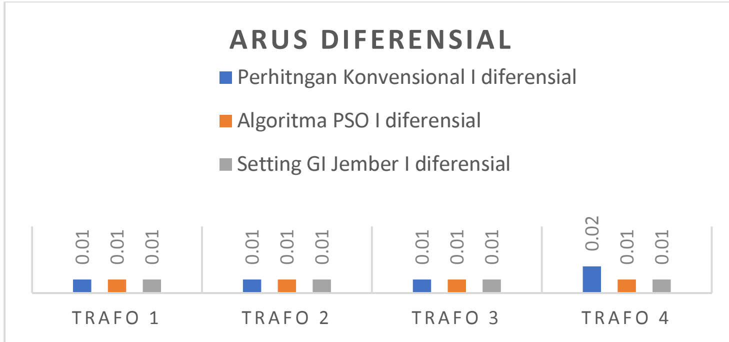

Figure 13. The results of the comparison outputs of differential current

From Table 10, the results of the comparison output current setting in transformers 1, 2, 3, 4, it can be seen that when calculating Conventional transformers 1, 3 have an $I_{Setting}$ Of 0.866A and transformers 2 and 4 have a value of 0.96A and 1.15A. For the value of $I_{Differential}$ on transformer 1, 2, 3 it is worth 0.01A and at transformer 4 it is worth 0.02A. Then in the PSO algorithm method itself, transformers 1, 2, 3, and 4 have an $I_{Setting}$ of 0.8656A. For value $I_{Differential}$ on transformers 1, 2, 3 and 4 are all worth 0.01A. Meanwhile, in setting of the Jember Substation, the $I_{Setting}$ is 0.866A and $I_{Differential}$ is 0.01A. So based on these results, it can be said that the PSO algorithm tends to have an output that is closer to the setpoint of the PLN GI Jember setting compared to conventional calculations, as shown in Figures 12 and 13. It can be seen in the significant difference in the value of the current setting of Transformer 4 in conventional calculations or the PSO algorithm method. Where the conventional calculation produces a setting of 1.15A, but the PSO algorithm obtains a setting of 0.86A. The setpoint or the reference itself is the setting of PLN Jember Substation with a setting of 0.3 pu or equal to 0.866A.

5. CONCLUSION

On the results of conventional calculations setting, the relay produces a differential current value $I_{Differential}$ of 0.01A on transformers 1, 2, 3 but for transformer 4 it is 0.02A, and the setting for transformers 1, 3 is 0.866A, but transformers 2 and 4 have a value of 0, respectively. 96A and 1.15A. Then the results of the PSO relay setting with the previously described parameters. Transformers 1, 2, 3, and 4 produce $I_{Setting}$ current setting of 0.8656A. The differential current value at transformers 1, 2, 3, 4 itself has a value of 0.01A based on the output value compared to the setting of Jember Substation, which is 0.3pu or if it is calculated to equal 0.866A, the particle swarm optimization has better accuracy. For comparison results from conventional calculations and particle swarm optimization between transformer 1, transformer 2, transformer 3, and transformer 4 can be analyzed that the output value of setting current and differential current in the PSO algorithm method has a more accurate value approaching setpoint setting of the Jember GI compared to conventional calculations. With the condition that it must determine the appropriate PSO parameters and fitness function a reasonably optimal.

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