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# Overcurrent Relay Coordination using an Adaptive Neuro Fuzzy Inference Systems (ANFIS)

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**Abstract**

OCR is the most widely used for the protection of distribution systems and protection backups in transmission systems. Maloperations can occur if the primary relay and backup relay are not adequately coordinated. It is essential that during abnormalities or disorders, OCR must be able to isolate only the wrong parts of the power system from a healthy system. Relay operation time can be reduced by proper coordination between primary and backup relays by selecting the optimum TMS and PS values. And because of that, relay coordination is an important part of power system protection. OCR time coordination is significant to reduce power outages by avoiding the mal-operative reserve relay. PS and TMS values with the help of MATLAB programming. In this study on the PLN system, Suralaya 150kV IEEE 23 Bus. 4 CM, NLP, GA, and ANFIS methods compared to 31 OCR, 38 main relay pairs, and backups produced 152Δt, 304 main and backup relay operation times. By looking at negative polarity optimization, NLP is superior to 64.340%, while ANFIS is superior to 94.875%.

**Keywords**: over current relay; plug setting; time multiple setting; ANFIS

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## 1. Introduction

Protection coordination is defined as the process of selecting settings or delays time characteristics of protection devices so that the operation of the device will occur in a certain order to minimize customer service disruption and power system isolation due to power system interference [1].

The most important parameter for OCR coordination is TMS, which has a direct influence on the operation time of OCR. Increased TMS results in an increase in OCR relay operation time and vice versa. PS is set to stable for the maximum load current the equipment can carry continuously but must also be sensitive enough to detect minimum interference at the intended end of the range [2].

Over the years, electric power system engineers relied on conventional methods to provide OCR coordination. This method is based on a trial process and repeated errors that can be tiring and time-consuming depend on the complexity of the network of coordinated power systems. As a result, in the 1960s, it was proposed to automate relay coordination procedures using computer programs [3], [4].

However, this automatic method is reported to be computationally intensive and does not provide an optimal solution, but the best solution to the solution is tried [5].

A comprehensive review of various coordination optimization methods to address this issue is given in [6], [7]. From this review and an independent literature review conducted for this study, the following evolutionary algorithms have been applied for optimal relay coordination:

- Genetic Algorithm (GA) [8] [13],
- Evolutionary Programming (EP) [14], [15],
- Differential Evolution (DE) [16], [19],
- Metaheuristic Techniques (MT) [20],
- Non-Linear Programming (NLP) [21],
- Modified Jaya Algorithm (MJA) [22].

Relay coordination uses conventional optimization methods that were originally proposed. The drawback is that there are constraints in terms of the number of constraints that conventional coordination algorithms can handle [6].

In addition, this algorithm cannot take all system conditions into consideration, and therefore the results obtained are always trapped in local optimum relay settings [14].

Evolutionary algorithm optimization techniques (GA, EP, DE, MT, NLP, and MJA) are proposed to deal with setbacks in conventional optimization methods. The first researchers to apply the evolutionary algorithm technique to the problem of relay coordination were So et al. in 1997 [8].

Since then, many evolutionary algorithms have been applied by other researchers as shown above.

Researchers reported an increase when evolutionary algorithms are compared with conventional optimization techniques. Because of the previous discussion, not all available evolutionary algorithms have been investigated.

The purpose of this study is to expand previous work and include new *Evolutionary Algorithms*, specifically, *Genetic Algorithm* (GA), *Nonlinear Programming* (NP), and *Adaptive Neuro Fuzzy Inference Systems* (ANFIS).

Therefore, a comparative study of the new evolutionary algorithm with ANFIS for OCR coordination problems is useful given the success and ease of use of this algorithm in other engineering problems such as power systems.

R. K. Ahuja and A. Mahesh has carried out past research on the application of ANFIS's new evolutionary algorithm to the problem of power system stability and satisfactory results have been reported [23], [24].

The research object in the existing system in the PLN electricity system is Suralaya 150 kV IEEE 23 Bus, which the researcher will examine the optimum total operating time from the Conventional Method calculation then compare it with the NLP, GA and ANFIS algorithms. The value of coordination optimization will be shown in the comparison of the parameters produced.

This study uses the Adaptive Neuro Fuzzy Inference System (ANFIS) method [23], [24] as the main method that has the ability to analyse objective functions and also has the advantage of optimizing coordination in different systems.

With this benefit, the authors hope to improve OCR coordination so that they can protect the power system based on the ANFIS method better than their previous works.

## 2. Materials and Methods

This section provides an overview of different relay coordination and OCR techniques, as discussed [2], [25], [26]. Relay coordination is needed to ensure that while protection relays operate as quickly as possible, relays can also isolate only faulty system parts from the network. It even ensuring that power system disruptions do not cause power supply disruptions to larger parts of the power system network.

### 2.1. Time Coordination

In coordination with the time method, adjacent protection devices form the main protection pair, and the backup is set to operate in multilevel time. Protection devices that are closest to interference are arranged to trip in a short period, and each adjacent breaker returns to the source operating in a more extended period after a predetermined time delay.

For a simple radial power system, OCR at A will be set to operate faster for interference close to A than relays at B and C for interference close to A. OCR on B is set to operate faster than OCR in C for interference at B, and so on (see Figure 1.).

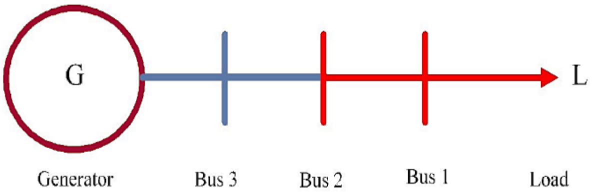

**Figure 1**. A simple network of radial power systems

The predetermined delay time between the operating time and the adjacent relay is referred to as the grading margin. Grading margins for protection systems are used to accommodate the following factors [2], [25], [26]:

- Time relay error;
- CT ratio error;
- Circuit Breaker Time [27];
- Time to overshoot the relay;
- Margin security limits.

For previous electromechanical relay technology, a typical 0.4-second margin was used because of overshoot and longer safety margins, while 0.3-second grading margin was used for newer numeric relay technologies. In this study, a grading of 0.3 seconds was used.

### 2.2. Coordination of Flow Current

Because of the difference in impedance between the source and the fault location for different fault locations, the fault currents generated by the disturbances at different locations of the power system will differ greatly. Therefore, the current magnitude can be used to set the relay closer to the fault to operate before the upstream relay. The relay on C (see Figure 1, *supra*) can be set to the BC trip path for interference at B, and relay at B can be set to the BA trip line for interference at A, and so on.

Relays that use this coordination method are known as instantaneous OCR.

### 2.3. Coordination of Flow Current and Time

In this coordination method, the protection devices applied in locations A, B, and C in Figure 1 (*supra*) are designed to use inverse or inverse operating characteristics. The higher the fault current, the faster the operation time of the protection device, and the lower the fault current, the slower the operating time of the device.

For example, for interference that is close to Circuit Breaker A, a protection device at A is usually set to operate in 0.2 s, but will operate in 0.8 s for interference near Circuit Breaker B. For interference near Circuit Breaker B, protection devices in B will operate faster than protection devices at A. In this way, coordination and operating speed have been increased.

Protection relays that use inverse or inverse operating characteristics are known as Inverse Definite Minimum Time Lag (IDMTL) relays.

The mathematical formula IEC 255 standard for modelling the relay operating characteristics of IDMTL is shown in Equation (1).

$$t = TMS \times \left( \frac{K}{\left( \left( \frac{I_f}{PS} \right)^{\propto} - 1 \right)} \right) \quad (1)$$

where:

$t$: relay operation time;
$PS$: Plug Setting;
$I_f$: interference current;
$TMS$: Time Multiple Setting;
$K$ and $a$: constants for different relay.

are the characteristics, as shown in Table 1.

**Table 1**. Constanta For Various IEC 255 Relay IDMTL

| Characteristics | *a* | *K* |
|---|---|---|
| Normal Inverse | 0.02 | 0.14 |
| Very Inverse | 1.0 | 13.5 |
| Extremely Inverse | 2.0 | 80 |
| Long-time Inverse | 1.0 | 120 |

In interconnection networks, where currents can flow in one direction from OCR, OCR is configured to operate in one direction only. This type of relay is known as Directional Over Current Relay (DOCR).

The DOCR is set to operate when the current flows to line [26]. IDMT DOCR coordination involves selecting a pick-up setting or Plug Setting (PS) and Time Multiple Setting (TMS).

The principle of OCR is a relay that works with the analogue current input, where the relay will work if it detects a fault above a specific setting for phase-out interference. OCR is set to be greater than the nominal capability of the smallest equipment (110 %-120 %) and must work on a minimum 2 phase short circuit current interference.

In a well-coordinated protection system, the IDMT relay curve cannot cross the minimum and maximum fault currents, as shown in Figure 2 [28].

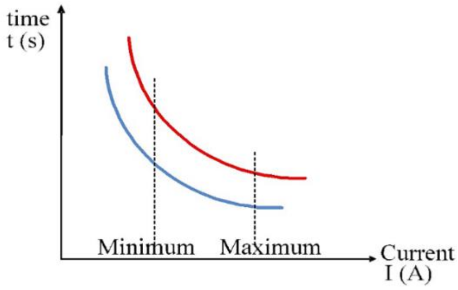

**Figure 2**. Example of a relay curve with proper coordination [28]

### *2.4. Characteristics of Over Current Relay with ANFIS*

Different time-flow mathematical formulas can represent OCR.

In applying better evolutionary OCR coordination algorithms, some mathematical models used to describe OCR can be categorized as follows:

- Standard IEC 255- 4;
- Various operating characteristics;
- Mathematical polynomial approach.

OCR is the most widely applied in the industry using the operating characteristics of the IEC 255-4 standard inverse relay, represented by Equation (1).

Therefore, the operating characteristics of IEC 255-4 for OCR are used in this study.

The following objective functions, which minimize (optimize) the main operating time of the relay, are investigated in this study. It consists of two inputs $Z_{1,r}$ and $Z_{2,r}$ .

Output is expressed in $Z_r$

If $Z_{1,r}$ is $A_1$ and $Z_{2,r}$ is $B_1$
then

$$f_1 = p_1.Z_{1,r} + q_1.Z_{2,r} + r_1 \quad (2)$$

If $Z_{1,r}$ is $A_2$ and $Z_{2,r}$ is $B_{12}$
then

$$f_1 = p_2.Z_{1,r} + q_2.Z_{2,r} + r_2 \quad (3)$$

$$f_1 = \Sigma t_m \quad (4)$$

The adaptive Neuro Fuzzy Inference System Input Parameters are:

coordination value ($D_t$) max: 50;
tolerance (percent): 90;
b (formula for layer): 2;
given ANFIS input: $Z_{t-2}$ and $Z_{t-2}$.

Clustering Fuzzy C-Means:

w : 2;
minimum error: 0,001;
initial objective function ($P_0$): 0;
maximum iteration: 1000;
many clusters: 2;
random value generation: μ1 and μ2
calculate of the centroid:

$$V_{kj} = \frac{\sum_{i=1}^{n}((\mu_{ik})^{w}).X_{ij}}{\sum_{i=1}^{n}((\mu_{ik})^{w})}$$

cluster objective function: $P_t$
total P cluster: $P_1.(U_1)^w$
repair U partition matrix: $\Sigma[(Z-V_1)^2]^{-1/(w-1)}$
matrix degree membership: $\frac{\left[\sum_{j=1}^{m}(X_{ij}-V_{kj})^2\right]^{-1/(w-1)}}{\sum_{i=1}^{n}\left[\sum_{j=1}^{m}(X_{ij}-V_{kj})^2\right]^{-1/(w-1)}}$
output layer degree: $\mu_A(x) = \frac{1}{1+\left|\frac{x-c}{a}\right|^{2b}}$
percentage: $\frac{|z_{target}-z_{output}|}{z_{target}} \times 100\%$
tolerance: 100% - $P_{tolerance}$

As shown before, the grading margin between the main relay and the backup is very important because it allows the main relay to have enough time to trip to the main fault before the backup relay can trip. The condition is done to maintain relay selectivity and coordination. As a result, formulated optimization problems minimize the limits on the following constraints:

$$0.15 \leq TMS \leq 0.5 \quad (5)$$

$$0.5 \leq PS \leq 6.25 \quad (6)$$

$$\Delta t \geq 0 \quad (7)$$

### *2.5. Proposed System*

Adaptive Neuro-Fuzzy Inference System (ANFIS) is a combination of fuzzy inference system mechanisms that are described in neural network architecture. The fuzzy inference system used is the first-order Tagaki-Sugeno-Kang (TSK) fuzzy inference system with consideration of simplicity and ease of computing.

To ensure that the ANFIS algorithm is able to solve a given problem, the objective function or fitness must be chosen so that the OCR parameter minimizes the operating time for the main relay while ensuring adequate relay coordination between the primary and backup relays. Furthermore, it must be ensured that objective functions are minimized within parameter limits.

In general, researchers have used the main relay operating time for main zone interference as an objective function for optimization problems.

Other writers included additional terms besides limitations in objective functions. The different researchers handle obstacles is discussed in the next section.

In research [8], TMS, PS choices, and coordination time intervals were added as part of the objective function.

In research [10], the coordination time interval is also part of the objective function.

On [16], relay operation time for interference in the backup zone is also added as part of the objective function.

In research [8], a strategy for overcoming solutions to one of the constraints discussed was not used. Then shows that this method can produce more current parameters that minimize relay operation time but are not selective.

Razavi [10] suggests improvements, which include a term that compares grading margins to grading positive margins. If there is an objective non-conformity, it is increased by certain factors, to anticipate an improper solution.

In research [15], boundary constraints are handled by entering terms that look at the number of constraints and increase the objective function value by a factor. In this study, to deal with constraints, stationary penalty functions were used [29].

## 3. Results and Discussion

In Figure 3, the ANFIS flow chart method is presented.

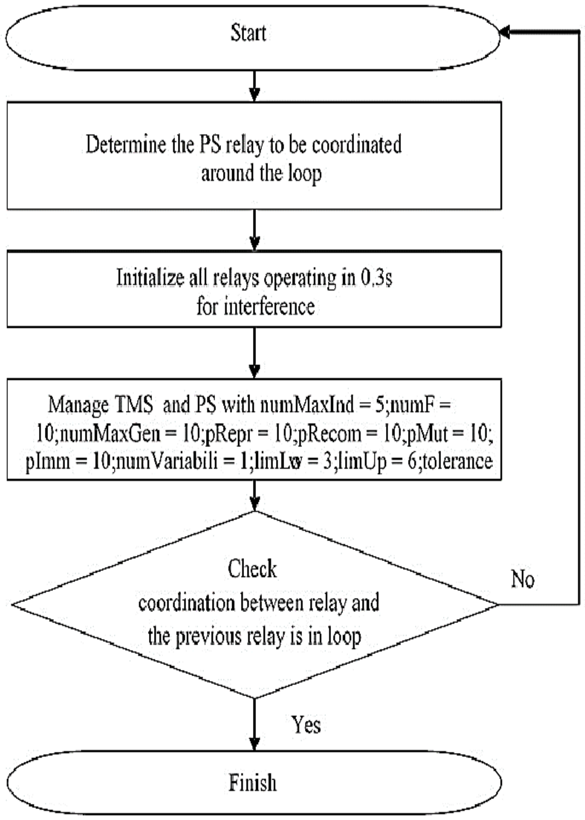

**Figure 3**. ANFIS flow chart method

The Flow Chart the ANFIS Method can be seen in several stages in optimizing the coordination of OCR functions including:

1. Determine the PS relay that will be coordinated around the loop, which aims to optimize coordination of the tests to be performed.
2. Initialize all relays operating in 0.3s for interference.
3. Setting TMS and PS with% Rule Base% [input1 input2 output 1 2 = or 1 = and] rule1 = [1 1 1 1 2]; rule2 = [2 0 2 1 0]; towards system optimization.
4. Perform coordination checks between the relay and the previous relay in the loop.
5. Make a report on the results of optimization analysis coordinating.

From the method above, the measurement techniques and testing the validity of PS and TMS parameters are secondary injection. This tool is used to carry out the testing of the secondary side of the substation system by injecting current, voltage, a frequency so that the time according to the setting is obtained.

Considering the safety of personnel and equipment, testing is carried out at maintenance shutdowns and clutching equipment systems on buses that are not extinguished so that other equipment is not disturbed by testing activities. The tests carried out on PLN System Suralaya 150 kV IEEE 23 Bus as shown in Figure°4.

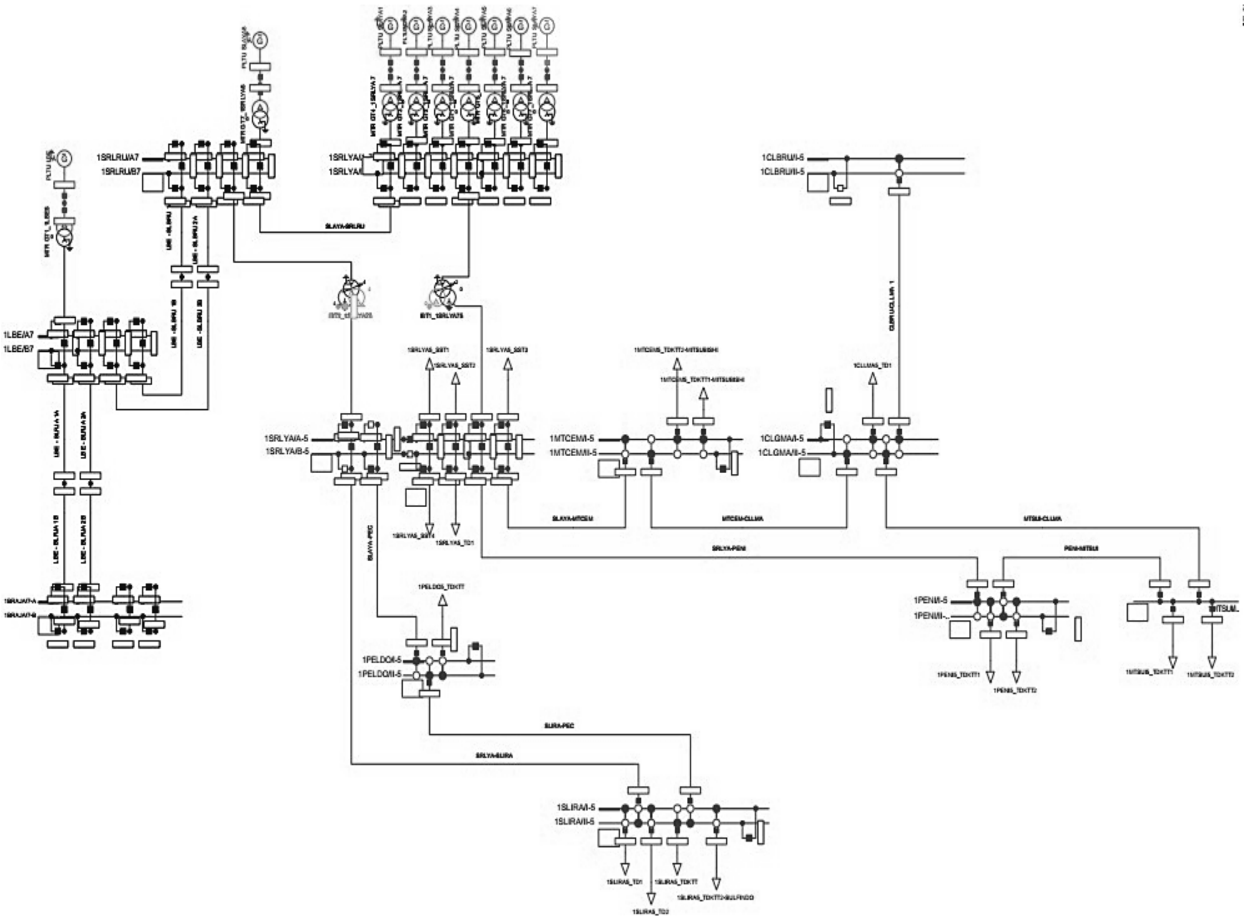

Figure 4. PLN System Suralaya 150kV IEEE 23 Bus

The following OCR parameters are obtained from each optimization algorithm as shown in Figure 5 and listed in Table 2.

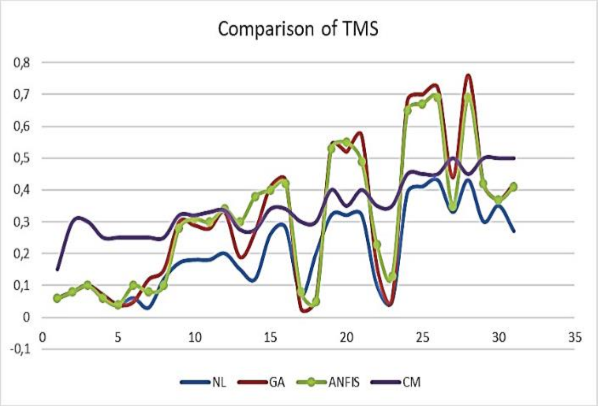

**Figure 5**. TMS parameter comparison chart relay coordination method

**Table 2.** TMS Parameters Relay Coordination Methods

| No. TMS | NL | GA | ANFIS | CM |
|---|---|---|---|---|
| TMS 1 | 0,06 | 0,06 | 0,06 | 0,15 |
| TMS 2 | 0,08 | 0,08 | 0,08 | 0,3 |
| TMS 3 | 0,1 | 0,1 | 0,1 | 0,3 |
| TMS 4 | 0,07 | 0,07 | 0,06 | 0,25 |
| TMS 5 | 0,04 | 0,04 | 0,04 | 0,25 |
| TMS 6 | 0,06 | 0,05 | 0,1 | 0,25 |
| TMS 7 | 0,03 | 0,12 | 0,08 | 0,25 |
| TMS 8 | 0,12 | 0,15 | 0,1 | 0,25 |
| TMS 9 | 0,17 | 0,3 | 0,28 | 0,32 |
| TMS 10 | 0,18 | 0,29 | 0,31 | 0,32 |
| TMS 11 | 0,18 | 0,28 | 0,3 | 0,33 |
| TMS 12 | 0,2 | 0,33 | 0,34 | 0,335 |
| TMS 13 | 0,15 | 0,19 | 0,3 | 0,275 |
| TMS 14 | 0,12 | 0,27 | 0,38 | 0,275 |
| TMS 15 | 0,26 | 0,41 | 0,4 | 0,34 |
| TMS 16 | 0,28 | 0,43 | 0,42 | 0,34 |
| TMS 17 | 0,07 | 0,03 | 0,08 | 0,3 |
| TMS 18 | 0,2 | 0,06 | 0,05 | 0,3 |
| TMS 19 | 0,32 | 0,54 | 0,53 | 0,4 |
| TMS 20 | 0,32 | 0,52 | 0,55 | 0,35 |
| TMS 21 | 0,32 | 0,57 | 0,49 | 0,4 |
| TMS 22 | 0,1 | 0,16 | 0,23 | 0,35 |
| TMS 23 | 0,05 | 0,06 | 0,13 | 0,35 |
| TMS 24 | 0,39 | 0,68 | 0,65 | 0,45 |
| TMS 25 | 0,41 | 0,7 | 0,67 | 0,45 |
| TMS 26 | 0,43 | 0,72 | 0,69 | 0,45 |
| TMS 27 | 0,33 | 0,44 | 0,35 | 0,5 |
| TMS 28 | 0,43 | 0,76 | 0,69 | 0,45 |
| TMS 29 | 0,3 | 0,42 | 0,42 | 0,5 |
| TMS 30 | 0,35 | 0,37 | 0,37 | 0,5 |
| TMS 31 | 0,27 | 0,42 | 0,41 | 0,5 |

The parameters specified from the conventional coordination method are also included in the table.

From Table 3 and Figure 6, it also can be seen that NL and ANFIS provide TMS parameters from OCR, which are slightly smaller than the parameters provided by GA.

**Table 3**. PS Parameters Relay Coordination Methods

| No. PS | NL | GA | ANFIS | CM |
|---|---|---|---|---|
| PS 1 | 0,15 | 0,187 | 0,468 | 0,5 |
| PS 2 | 0,93 | 0,741 | 0,921 | 0,93 |
| PS 3 | 0,93 | 0,289 | 0,874 | 0,93 |
| PS 4 | 1,65 | 2,103 | 2,592 | 5,5 |
| PS 5 | 4,07 | 5,357 | 5,439 | 6 |
| PS 6 | 2,51 | 4,725 | 2,187 | 5,5 |
| PS 7 | 5,08 | 2,273 | 3,356 | 5,5 |
| PS 8 | 1,05 | 1,817 | 3,126 | 5,5 |
| PS 9 | 1,02 | 0,77 | 1,031 | 1,2 |
| PS 10 | 1,06 | 1,102 | 0,413 | 1,2 |
| PS 11 | 0,77 | 0,882 | 0,671 | 0,96 |
| PS 12 | 0,87 | 0,834 | 0,665 | 0,96 |
| PS 13 | 3,02 | 4,532 | 1,725 | 5 |
| PS 14 | 4,82 | 2,709 | 0,593 | 5 |
| PS 15 | 0,34 | 0,281 | 0,472 | 1,15 |
| PS 16 | 0,34 | 0,644 | 1,141 | 1,15 |
| PS 17 | 2,74 | 4,624 | 3,329 | 4,65 |
| PS 18 | 0,79 | 3,99 | 4,219 | 4,65 |
| PS 19 | 0,4 | 0,355 | 0,177 | 0,75 |
| PS 20 | 2,98 | 3,214 | 1,489 | 3,25 |
| PS 21 | 0,56 | 0,425 | 0,663 | 0,75 |
| PS 22 | 2,43 | 2,525 | 1,751 | 4,75 |
| PS 23 | 3,77 | 4,307 | 3,035 | 4,75 |
| PS 24 | 0,45 | 0,33 | 0,124 | 1,25 |
| PS 25 | 3 | 2,499 | 1,192 | 3 |
| PS 26 | 3 | 0,603 | 0,198 | 3 |
| PS 27 | 0,95 | 1,481 | 1,978 | 2,5 |
| PS 28 | 5,29 | 3,702 | 5,128 | 6,25 |
| PS 29 | 2,58 | 3,488 | 3,244 | 4,75 |
| PS 30 | 2 | 4,365 | 4,172 | 4,75 |
| PS 31 | 3,44 | 3,815 | 3,81 | 5 |

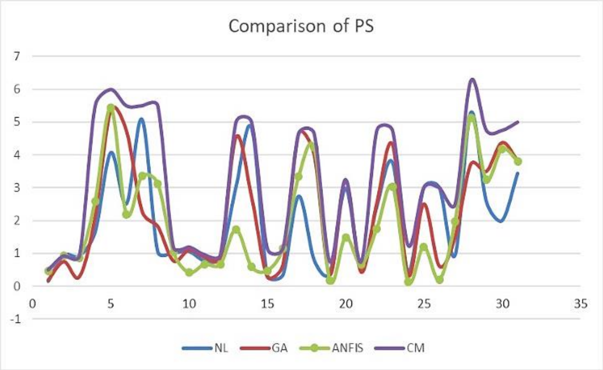

**Figure 6**. PS parameter comparison chart relay coordination method

The above parameters produce the following overall operating time for all relays on the network.

Because of the premature convergence shown, GA provides a much higher TMS parameter than the NL and ANFIS parameters.

The result in Table 4 shows that NL and ANFIS provide slightly shorter operating times for main relays and backup relays compared to GA. GA provides the highest overall operating time.

**Table 4**. Full Time of Operation for Coordination Methods

| Operating Time | NL | GA | ANFIS | CM |
|---|---|---|---|---|
| Main operating time (∑tm) | 3,175 | 4,656 | 4,805 | 7,686 |
| Backup operating time (∑tb) | 6,591 | 10,244 | 9,719 | 10,148 |
| ∑Δt | 3,416 | 5,587 | 4,914 | 2,462 |

## 4. Conclusion

The optimization method used in the system to provide optimum value is ANFIS, while GA is fast at the beginning of the search and does not produce better results than the conventional relay coordination method of the possibility of premature convergence at the beginning of the algorithm.

Value of optimization of OCR protection system TMS and PS generated on the PLN system Suralaya 150 kV IEEE 23 Bus.

For four methods, 23 buses, 31 OCR, 38 main relay pairs and backup produce 152 Δt, and 304 main relay and backup operation time.

Non-linear Algorithm (NL) give away main operating time (∑tm) 3,175 s and backup operating time (∑tb) 6,591 s with ∑Δt 3,416 s.

Genetic Algorithm (GA) give away main operating time (∑tm) 4,656 s and backup operating time (∑tb) 10,244 s with ∑Δt 5,587 s.

Adaptive Neuro Fuzzy Inference System (ANFIS) give away main operating time (∑tm) 4,805 s and backup operating time (∑tb) 9,719 s with ∑Δt 4,914 s.

And Conventional Method (CM) give away main operating time (∑tm) 7,686 s and backup operating time (∑tb) 10,148 s with ∑Δt 2,462 s.

In this study on the PLN system Suralaya 150kV IEEE 23 Bus. 4 CM, NLP, GA, and ANFIS methods compared to 31 OCR, 38 main relay pairs and backups produced 152 Δt, 304 main and backup relay operation times.

By looking at negative polarity optimization, NLP is superior to 64.340 % while ANFIS is superior to 94.875 %.

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