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Optimization of overcurrent relay coordination using cuckoo search algorithm in electronic induction systems

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Optimization of overcurrent relay coordination using cuckoo search algorithm in electronic induction systems

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Abstract - Overcurrent relay protection is one of the electrical power supply protection mechanisms that serve to prevent the system from overcurrent. The main issue that occurs when developing the coordination of overcurrent relays is the timing determination of the primary and back-up relay operation. The objective of this study is to develop an optimization method to result a faster operating time of relay coordination. The optimization method was developed and implemented in case of PT Semen Padang (Indarung VI) at 150 kV PLN's source, which was operated with conventional calculation method. The Cuckoo Search Algorithm (CSA) method was proposed as optimization method for calculation. The optimization was used to set the relay time and the secondary current (I_{pickup}) according to the British standard to obtain the optimal Coordination Time Interval (CTI). The CSA method was calculated by MATLAB R2016 software, while the relay testing was done on the ETAP 12.6.0. Results of simulation indicate that the CSA method more capable and faster than the manual calculations in calculating relay setting coordination since almost all of the CTI values were reached in 2.0 to 4.0 seconds.

1. Introduction

The overcurrent relay is a relay which used to protect the system from the overcurrent noise [1]. The overcurrent relay is connected to the circuit breaker, which will trigger the circuit breaker to open if there is interference with certain trip times. Overcurrent relays can be used to protect almost any part of the electrical system such as the transmission lines, transformers, generators, or motors [2]. To coordinate the overcurrent relay, there are many parameter values that must be reached, one of those parameters is used to get the ideal setting value. The ideal setting value must be accompanied by accurate analysis, with the current and time setting values calculation.

One of the obstacles that occur when doing the coordination studies of overcurrent relays is the timing determination of the primary and back-up relay operation. The desired operating time is as fast as possible by the time setting parameters consideration. This is done to minimize the interference effects on the electrical equipment from the arc flash. This exposure explains that failures in overcurrent relay coordination can be caused by the operating time of the back-up relay on the primary relay have not the right timing values [3].

To solve the problem of overcurrent coordination, the various methods and techniques that have been done are classified into 3 types i.e. curve fitting technique, graph theory technique, and optimization technique. Optimization techniques are also divided into 3 types i.e. conventional optimization techniques, interior point optimization techniques, and optimization techniques using artificial intelligence [4].

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The Cuckoo Search Algorithm (CSA) is one of the optimization techniques. CSA is a new heuristic algorithm based on the previous studies results using twelve different stochastic functions which shows better search performance than the other heuristic algorithms such as Particle Swarm Optimization (PSO) algorithms or Genetic Algorithms. The advantage of CSA is using the Levy Flights (the concept of random food searching in animals while flying) as the random step, which allows the search for optimal values in a shorter time [5].

Cuckoo Search Algorithm (CSA) is used to analyze the overcurrent relay coordination. This algorithm shows better performance value because the CSA evaluates the parameter values 2 times, so it will get more optimal value for the overcurrent relay coordination if compared with the manual calculations method.

2. Method

In general, this study was started by designing a single line diagram that explains the data of short circuit current disturbance calculation, load data, and data calculation of maximum load current. The CSA algorithm was developed based on these data to obtain list of relay setting values. These values then test on the relay system by using as software. The development of CSA algorithm and calculation of the relay setting values by the CSA were done by MATLAB R2016 software, while the system testing was done by ETAP 12.6.0 software.

2.1. Indarung VI Electrical System PT. Semen Padang.

The electrical system in Indarung factory is divided into two major parts i.e. the electrical system in VI factory & 2 SS existing and one plant to PLN in connection to VI factory. The electricity load at Indarung VI Plant will be supplied by PLN through 3 units of the 150 / 6.3 kV power transformer with the capacity on each transformer is 30/35 MVA (ONAN / ONAF). The loads in Indarung VI are divided into 3 groups according to the amount of existing substations, for the data loading of the transformer 1 substation can be seen in Table 1. In Indarung VI Plant there are many loads used to support the production process. One of them is a motor i.e. the small and large capacity motor.

Table 1. The burden of Transformer on Substation 1 Indarung Factory.

Substation and Transformer ID	Voltage (kV)	Capacity (MVA)	Input Loading		Output Loading	
			MVA	%	MVA	%
Trafo TRF 1	150/6.3	30	20.955	59.9	20.487	58.5
SS 158 LSC, SILICA-1:						
6 A1Q211T1	6.3/0.4	2	1.277	63.8	1.271	63.6
6C1Q211T1	6.3/0.4	1.6	1.229	61.4	1.214	60.7
SS 348 RAW MILL DRIVE:						
6R1Q212T1	6.3/0.4	1.6	1.266	79.1	1.252	78.2
SS 348 RAW MILL (ID FAN):						
6R1S01T1	6.3/0.7	0.8	0.309	38.7	0.307	38.4

2.2. Single Line Diagram of Indarung VI Factory.

The single line diagrams are designed using ETAP 12.6.0 using the IEC (International Electrotechnical Commission) standard. In this final project, the data of *the* single line diagram is as expressed in Figure 1 which will be used as an analysis material.

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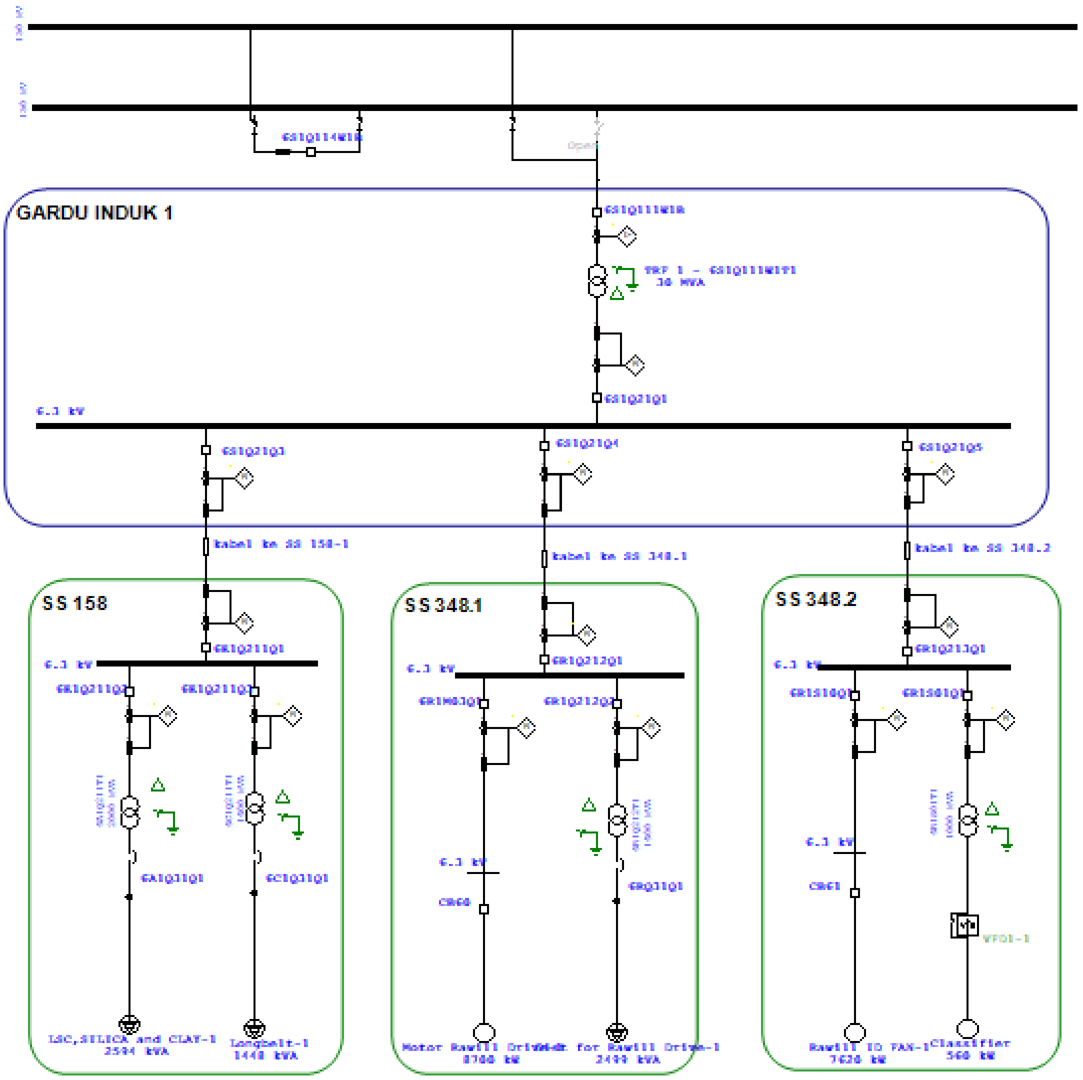

Figure 1. Single Line Diagram Substation Stations 1.

2.3. Method of Calculation of Over Flow Relay Coordinate Settings

There are several values needed to perform the overcurrent relay settings, such as Full Load Ampere (FLA) value and minimum Short Circuit Current (I_{sc} min). These values are used to determine the Current Setting (I_{set}), Time Dial Setting (TDS) and the current pickup (tap currents).

- **Full Load Current (FLA)**

  To use the *Very Inverse* standard relay, it must be calculated first the full load current value. The full load current value is used to calculate the setting current on the primary side (Iset).

$$I\ FLA = \frac{Va}{V \times \sqrt{3}} \quad (1)$$

- **Current setting on the primary side (Iset)**

$$Iset = \frac{kfk}{kd} \times I\ FLA \quad (2)$$

The Iset value above is the current setting on the primary side, while the value to be set in the relay is the secondary side setting value. Therefore, the setting value on the secondary side should be calculated using the CT ratio.

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- **Current setting on the secondary side (Ipickup)**

$$I\ pickup = I\ sett \times \frac{1}{Rasio\ Ct} \tag{3}$$

- **Minimal interrupt current (Min Isc)**

$$Iscmin = \frac{Vll}{Z} \tag{4}$$

The calculated noise current value is used to determine the time dial setting.

- **Time dial (Td)**

$$Td = \frac{\left(\left(\frac{Isc\ minimum}{I\ set}\right)^{\alpha} - 1\right) \times t)}{k} + C \tag{5}$$

Where K and α are coefficients of the curve type, can be seen in Table 2.

Table 2. The coefficient of the curve type.

Curve Type	Coeficient	
	K	**α**
Standard Inverse	0.14	0.02
Very Inverse	13.5	1.00
Extremely Inverse	80	2.00

2.4. Design of Optimization Relay Setting using Cuckoo Search Algorithm (CSA)

In terms of optimization, Indarung VI electrical system relay will be optimized using the CSA method. The optimized value is the time setting (td) and current setting value (I_{set}), and for optimization using CSA requires some parameters to be referenced such as the relay working time (t), primary relay td value (t_p), secondary relay td value (t_b).

The CSA optimization design starts with the initialization of td value with restrictions 0,05 <td <1,2 and the I_{set} limit value i.e. (1,05 × I FLA) <I_{set} <(1,3 × I FLA). So the initial random value of the CSA produces the constraint value, then in the second iterations that exist in the script in the MATLAB software will be evaluated by the objective function of the overcurrent relay coordination on the mathematical equation as follows:

$$min \sum_{f=1}^{fmax} ((\sum_i (t_i + t_{ij})) + \text{PEN} \times \sum_{K=1}^{P} (\Delta t_{Pbk} - |\Delta t_{Pbk}|)^2 \tag{6}$$

PEN value is the *penalty constraint* value of CSA algorithm, and P is the *iteration* value in constraint with the constraint value = Δt_{Pbk}. The value of Δt_{Pbk} can be searched with the following mathematical equations:

$$\Delta t_{Pbk} = t_{pk} - t_{bk} - CTI \tag{7}$$

The optimization calculation with the CSA is done using MATLAB. After obtaining the value of time dial setting, it is necessary to create a table of primary relay and backup relay in order to know the value of Coordination Time Interval (CTI). CTI value is obtained from the t backup value minus by the t primary value and said to be fulfilled if the CTI value greater than 0.2s.

3. Results and Discussion

3.1. Conventional Calculations for More Flow Relay Settings A subsection

Table 3 is result of conventional calculation on CTI that calculate by using above calculation method on overcurrent coordination setting.

Table 3. The CTI value result of the conventional calculation.

Primary Relay	tPrimary	Backup Relay	tBackup	CTI	Condition
Line 158.1	0.3	Incoming 158	0.4	0.1	Not fulfilled
Line 158.2	0.3	Incoming 158	0.4	0.1	Not fulfilled
Line 348.1.1	0.34	Incoming 348.1	0.4	0.06	Not fulfilled
Line 348.1.2	0.3	Incoming 348.1	0.4	0.1	Not fulfilled
Line 348.2.1	0.3	Incoming 348.2	0.4	0.1	Not fulfilled
Line 348.2.1	0.3	Incoming 348.2	0.4	0.1	Not fulfilled
Incoming 158	0.4	Outgoing 158	0.6	0.2	fulfilled
Incoming 348.1	0.4	Outgoing 348.1	0.6	0.2	fulfilled
Incoming 348.2	0.4	Outgoing 348.2	0.6	0.2	fulfilled

From Table 3, it can be seen that there are several CTI conditions for all unresolved primary relay and backup relay. This condition is due to the interval value was less than 0.2 seconds.

3.2. Optimization of Relay Settings with Cuckoo Search Algorithm (CSA)

5 5 The optimization calculation with the CSA was done using MATLAB. After obtaining the value of time dial setting, it is necessary to create a table of primary relay and backup relay such as have been detailed in Table 4, in order to know the value of CTI.

Table 4. The CTI value result of the optimization calculation.

Primary Relay	tPrimary	Backup Relay	tBackup	CTI	Condition
Line 158.1	0.45	Incoming 158	0.87	0.42	fulfilled
Line 158.2	0.48	Incoming 158	0.87	0.39	fulfilled
Line 348.1.1	0.48	Incoming 348.1	0.87	0.39	fulfilled
Line 348.1.2	0.15	Incoming 348.1	0.87	0.72	fulfilled
Line 348.2.1	0.49	Incoming 348.2	0.89	0.4	fulfilled
Line 348.2.2	0.49	Incoming 348.2	0.89	0.4	fulfilled
Incoming 158	0.87	Outgoing 158	1.18	0.31	fulfilled
Incoming 348.1	0.87	Outgoing 348.1	1.11	0.24	fulfilled
Incoming 348.2	0.89	Outgoing 348.2	1.13	0.24	fulfilled

From Table 4, it can be seen that the CTI condition for all primary relay and the backup relay has been reached because the interval value is more than 0.2 seconds.

3.3. Relation Coordination Simulation Testing of Substation (SS) 158 LSC, SILICA

Substation (SS) 158 received the power supply from the substation 1 transformer with a capacity of 30/35 MVA (ONAN / ONAF) and a voltage of 150 / 6.3 kV. SS 158 was divided into 2 groups i.e. 158.1 LSC, Silica Storage & Clay Crusher and 158.2 Longbelt as can be seen in Figure 2 below.

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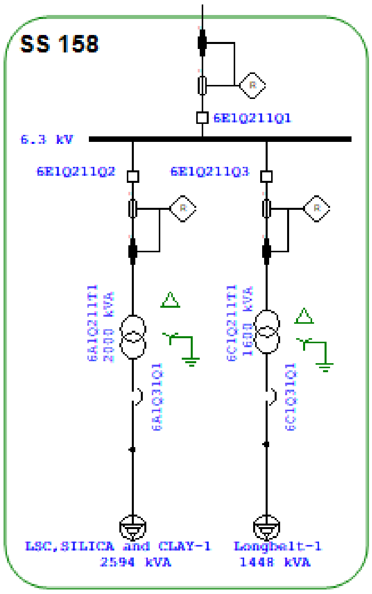

Figure 2. Single Line SS 158.

In SS 158 there were 2 groups i.e. 158.1 LSC, Silica Storage & Clay Crusher and 158.2 Longbelt where each group has the different load types as can be seen in Table 5 of SS 158.1.

Table 5. Load Data of SS 158.1 LSC, Silica Storage & Clay Crusher.

Code	Description	kW	Amp	Volt
6C1L03Q1	Bucket Chain Reclaimer Clay	80.75	250	380
6E1L02Q1	Side Scrapper Reclaimer Silica	80.75	250	380
6A1L02Q1	Bridge Reclaimer Limestone	323	1000	380
6C1Q31SP1	Spare	323	1000	380
6C1Q31Q2	Feeder to MCC 6C1Q311	664.02	1250	380
6C1Q31Q3	Feeder to NDB 6C1Q319	396.98	1250	380
6A1U01M1	Reclaimer Conveyor	90	240	380
6A1U02M1	Belt Conveyor	90	240	380
6A1U02M2	Belt Conveyor	90	240	380
6C1Q31SP2	Spare	110	290	380
6C1M01M1	Clay Crusher	110	290	380
6C1M01M2	Clay Crusher	110	290	380
	Total kW	**2,468.50**		
	Total Kw Static Load	**1,472.57**		
	Total Kw Dynamic Load	**995.93**		
	% of Static Load	**59.65**		
	% of Dynamic Load	**40.35**		

Each group has a Siemens 7SJ62 protective relay contained in the feeder and for incoming on each substation using a MICOM relay of ALSTOM P143 type from Schneider for the detect if there is a phase noise. The name of the relay was according to the substation's name and coupled with the sequence number of relay.

From the load data and single line above, the setting value analyzed result of I_{pickup}, time dial and $I_{setting}$ in MATLAB software using CSA was obtained as expressed in Table 6.

Table 6. SS 158 Rele Settings.

No	Relay's Name	CT Ratio	Relay			
			Curve Type	Setting		
				Ipickup	Time Dial	Isetting
1	INCOMING 158	CT = 600/5 A	Overcurrent	3.51	0.87	421.2
2	158.1	CT = 300/5 A	Overcurrent	3.74	0.45	224.4
3	158.2	CT = 200/5 A	Overcurrent	4.14	0.48	165.6

The setting value as Table 7 will be applied to each relay in substation 158. If those setting values have been applied to the relays, it will be simulated by giving the interference to each end repeater as expressed in Figure 4 below which was simulated at ETAP 12.6.0.

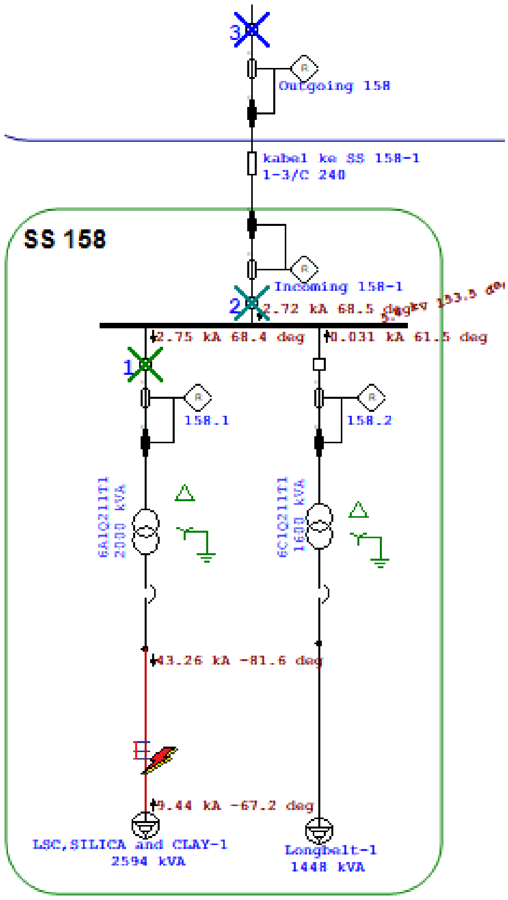

Figure 3. The sequence of Operation SS 158.

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The disturbance was given to the ended repeater and the simulation was done gradually. The first was the disturbance given to group 158.1, then will show the first breaker or power breaker which works faster. From Figure 3, it can be seen that the main safeguard works first (indicated by the cross number 1), followed by backup safety (indicated by number 2 and 3).

The primary relay of group 158.1 works in 0.05 s, with 43.26 kA and SS 158.2 interruption current working at 0.05 s, with 35.69 kA interruption current. The simulation result also expressed with a curve as shown in Figure 4.

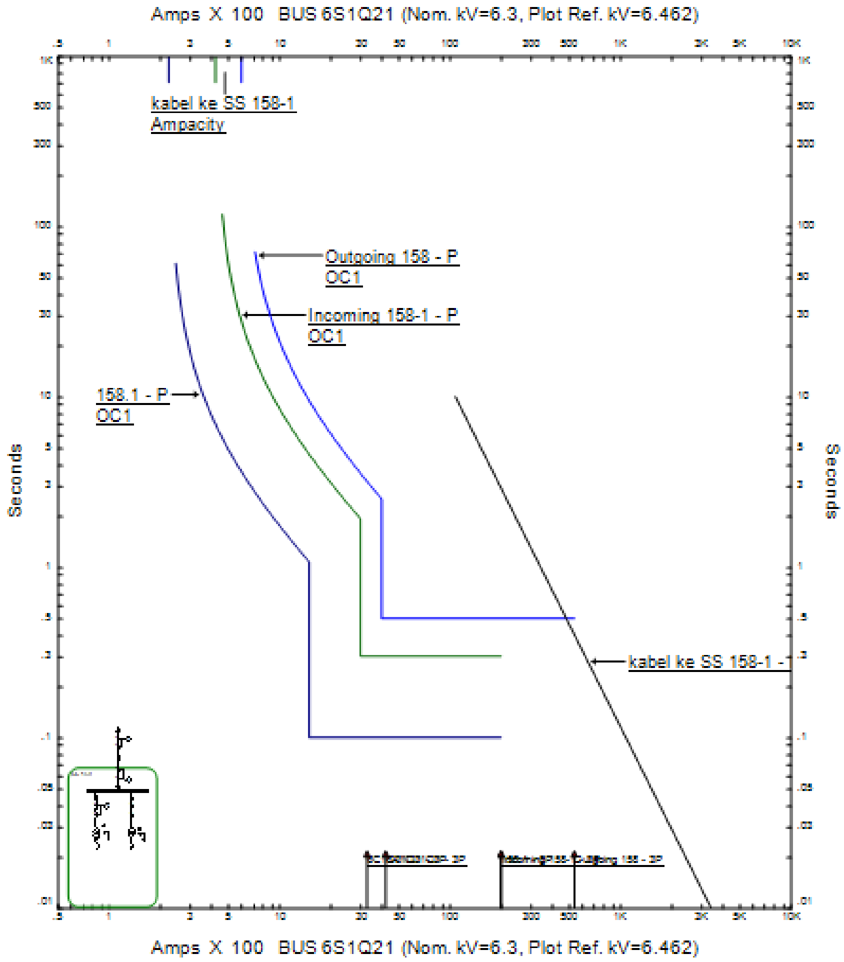

Figure 4. Characteristics of the SS Phase Disorder Curve 158.1.

Figure 4 shows the relay 158.1 as the primary relay, incoming relay 158 and outgoing relay 158 as the backup relays. The 158.1 relays coordinate to incoming 158 and the outgoing 158 relay curve has no overlapping; this condition indicates that the relay settings are correct because the first trip should occur at the primary relay.

4. Conclusion

5 The Cuckoo Search Algorithm (CSA) method was developed successfully to obtain the ideal setting value of the primary relay (t_p) and the backup relay (t_b). The test results of the CSA method show that all Coordination Time Interval (CTI) values are in accordance with the existing standards i.e. 0.2 seconds up to 0.4 seconds. The implementation of the CSA method in the calculation of coordination relay setting as the comparison with the manual calculation results shows that the CSA method has more capable.

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