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Prediction of overcurrent relay miscoordination time using urtificial neural network

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ABSTRACT

Overcurrent relay plays an important role in the protection of power system. For protection, proper coordination of relays with an appropriate relay settings need to be done. Coordination can be done by selecting an optimal Time Multiplier Setting (TMS) and Plug Setting (PS) considering the fault current at the relay location. ContinuousTime Intervals (CTI) must be maintained between primary relay and secondary relay to ensure correct sequential operation of the relays. However, miscoordination can occurs due to secondary relay trips faster than primary relay. This paper presents an approach for predicting overcurrent relay miscoordination time using Artificial Neural Network (ANN) algorithm in MATLAB software. The efficiency of the proposed approach have been tested successfully on 17 bus test system. The simulation results indicated that the ANN Levenber-Maequardt algorithm is capable to predict the miscoordination time occurs between the primary and secondary relay operating time.

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1. INTRODUCTION

The importance of power system nowadays is simply undeniable where almost everything in this world needs power to operate. When it comes to power system, there are many challenges that need to be faced. The main reason is that it deals with very high power levels. Since it is the main power source in the world, this system need to be designed carefully by considering all the aspects. The main aspect that need to be considered is the protection. In general, high voltages and currents can damage a system if not properly managed. When it comes to the power generating system, it is important to protect its equipment and devices.

Relay is one of the main protection device that is used widely all around the world. It is normally used with a circuit breaker. The main aim of power system protection is to isolate the faulty sections of the power system from the healthy part of the system during the occurrence of the fault current [1]. This is to ensure the healthy part can function normally without any severe damage. system. The speed where the circuit breaker disconnects depends on how fast the tripping signal is obtained from the protective relay. It is always important for the signal transmitted to the circuit breaker is fast enough. Therefore, it depends on the relay settings especially how fast they are set to react during fault occurrence.

The operation time of relay at healthy section cannot be too slow and too fast because tooslow will be result in system damage and too fast can cause miscoordination time of relay operation between the two relays [3]. In order to prevent the miscoordination time of relay operation, a time interval need to be set between the two relay operations time [3-4]. The relay at faulty section is called the primary relay while the one at the healthy section is called the secondary relay.

Artificial neural networks (ANN) can be used in the prediction of miscoordination time of relay operations. ANN are known as biologically inspired computer programs and are designed to simulate in the exact way how human brain processes information. ANN is currently one of the most promising modelling technique. The relay operation can be trained by using the ANN where the ANN will determine the ongoing signals between faults and all other conditions.

2. PROBLEM FORMULATION

The motivation of this study are to determine an appropriate settings of TMS and PS of relay during fault occurrence, to propose new relay operation time and to predict miscoordination time of relay using ANN. All of these requirements shall be fulfilled according to type of relay, linear or non-linear relay characteristics, primary and backup relay constraints as well as coordination constraints [5-6].

2.1 Linear or Non-Linear Relay Characteristic

The non-linear relay characteristics function is based on the standard IEC 60255-4[7]. The characteristics of the relay is Normally Inverse Definite Minimum Time (IDMT) type. The operating time for this type of relay can be expressed as follows:-

$$t_i = \left[\frac{K}{(PS_i)^{\alpha} - 1} + L \right] TMS_i \tag{1}$$

$$I_{sc_i} = \frac{CT_{secondaryratio}\ x\ faultcurrent}{CT_{primaryratio}} \tag{2}$$

$$I_{p_i} = \frac{currentsetting\, x\, CT_{secondaryratio}}{100} \tag{3}$$

$$PS_i = \frac{I_{sc_i}}{I_{p_i}} \tag{4}$$

where I_{sci} is the fault current in CT secondary and $I_{pi}$is the pickup current setting of the *i*-th relay. PS values is the ratio of fault current in CT secondary to pickup current setting. The TMS values is set at 0.5 and the current setting is set at 125%. The constant factor, K = 0.14, L = 0 and α = 0.02.

2.2 Coordination Constraints

In order to predict the miscoordination time for all the relays, the values of the relay operating time of both primary and secondary need to be determined first. The expression below can be used to predict the miscoordination time.

$$T_s - T_p > T_c \tag{5}$$

Where T_s is the operating time of the secondary relay, T_p is the operating time of the primary relay and $T_c$is the coordination time interval which varies from 0.2s – 0.5s depends on different circumstances.

The value of the (CTI) between primary and secondary relay need to be in the range of 0.2s to 0.5s [8-9]. If the CTI falls in this range, the relay pairs can be said having good coordination. If the CTI value falls outside this range and having positive value, the coordination can be said not ideal. If the CTI value falls outside the range and having negative value, it can be said that the relay pairs having miscoordination problem.

3. METHODOLOGY

In this paper, radial network is used to analyze the coordination. The radial network chosen for this research is a power distribution radial network taken from [10].The single line diagram is depicted in Figure 1. The test system comprises of 17 buses, 28 lines and transformers, single generator and 28overcurrent relays. The complete network is analyzed in terms of the power flow and the total load used. It is important to know the important parameters of the network in order to determine the fault current.

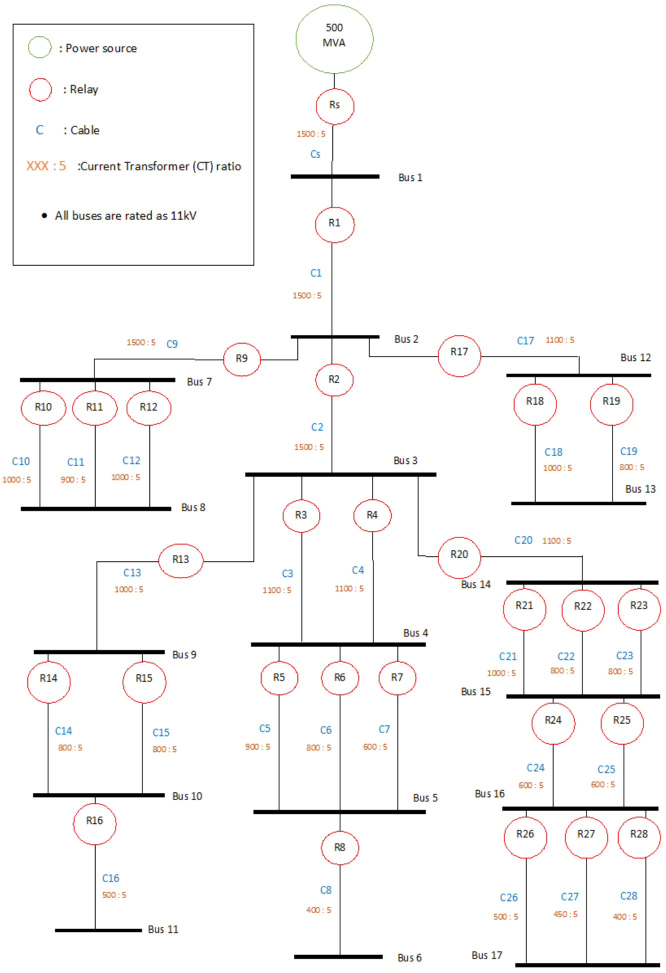

Figure 1. 17-bus test system

ANN will be used to determine the optimal operating time of the relays in the radial network. In other words, the best relay operating time of the relay pair which are the primary relay and the backup relay will be determined by using ANN. The radial network will be designed by using the Easy Power software. Manual calculation will be done in order to determine certain parameters such as the operating time of the relay, primary current value, TMS, PS and so on. The calculation will be verified by using Easy Power simulation results.

The obtained values from calculation, which is verified by simulation is feed in into function fitting training of ANN in MATLAB in order to determine an improved optimal operation time of the relays. Hence, the obtained values from the ANN can be used to produce new time setting for the relay operation and also to predict miscoordination time of the relay operation. Figure 2 simplifies all the execution process.

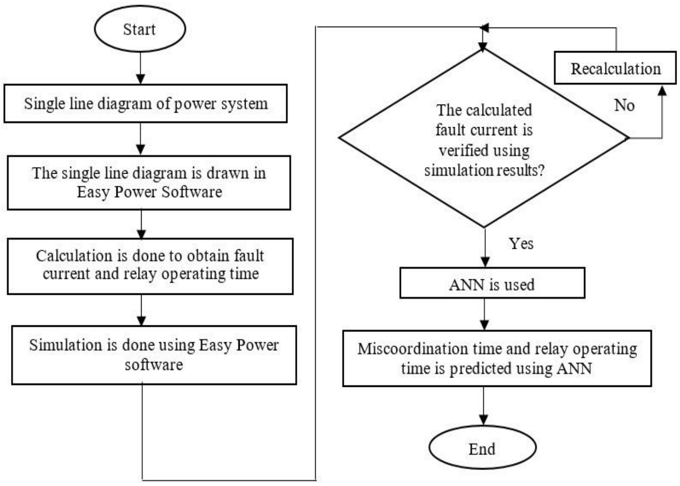

Figure 2. Research Flowchart

4. RESULTS AND ANALYSIS

The proposed ANN was executed on Intel Core i5 2.53 GHz with 4 GB RAM and simulated in MATLAB. The study revealed the feasibility of the proposed ANN to predict miscoordination problem. The system parameters with fault current iscalculated and tabulates in Table 1. It can be observed that the faults occurred in a transmission line is the symmetrical balanced three phase fault.According to this table, the simulation results and the calculation results were almost the same and the difference were small and falls inside the acceptable region which is 1% of the simulated results.

Table 1. Comparison between calculated and simulation results for faulted values

Bus	Calculated Fault Value (kA), a	Simulation Fault Value (kA), b	Difference (b and a) (kA)	Acceptable range (1% of b), (kA)
1	26.243	26.243	0.000	0 – 0.262
2	12.145	12.143	0.002	0 – 0.121
3	8.844	8.846	0.002	0 – 0.088
4	8.261	8.262	0.001	0 – 0.083
5	7.847	7.847	0.000	0 – 0.078
6	7.070	7.070	0.000	0 – 0.071
7	10.240	10.238	0.002	0 – 0.102
8	9.678	9.680	0.002	0 – 0.097
9	7.705	7.705	0.000	0 – 0.077
10	6.703	6.705	0.002	0 – 0.067
11	6.209	6.208	0.001	0 – 0.062
12	8.749	8.751	0.002	0 – 0.088
13	7.804	7.805	0.001	0 – 0.078
14	6.204	6.203	0.001	0 – 0.062
15	5.973	5.973	0.000	0 – 0.060
16	5.443	5.441	0.002	0 – 0.054
17	5.264	5.263	0.001	0 – 0.053

4.1. Fault current each relay and relay operating time

From Table 2. it can be seen that the current setting and the pickup current for all the relays are the same. All the relays at set to operate at 125% current setting. It can be seen that the value of pickup current is solely depends on current transformer secondary ratio. The obtained PS value will be used for the calculation of the relay operating time.Table 2also tabulates the value of relay operating time for all relays. In order to determine the relay operating time, the value of TMS is required. After Artificial Neural Network (ANN) utilized, the new relay operating time will be determined. Thus, the new TMS values will be obtained and will be proposed for the relay setting.

Table 2. Fault current for each relay and relay operating time

Relay	Current Setting (%)	Pickup Current (A)	Fault Current in CT Secondary (A)	PS	TMS	Relay Operating Time (s)
Source	125	6.25	87.477	13.996	0.10	0.258
1	125	6.25	40.477	6.476	0.10	0.368
2	125	6.25	29.487	4.718	0.10	0.444
3	125	6.25	18.777	3.004	0.10	0.629
4	125	6.25	18.777	3.004	0.10	0.629
5	125	6.25	16.522	2.644	0.10	0.713
6	125	6.25	17.113	2.738	0.10	0.688
7	125	6.25	18.200	2.912	0.10	0.648
8	125	6.25	88.375	14.14	0.10	0.257
9	125	6.25	34.127	5.46	0.10	0.405
10	125	6.25	16.495	2.639	0.10	0.714
11	125	6.25	17.156	2.745	0.10	0.686
12	125	6.25	16.495	2.639	0.10	0.714
13	125	6.25	38.525	6.164	0.10	0.378
14	125	6.25	21.963	3.514	0.10	0.550
15	125	6.25	19.988	3.198	0.10	0.595
16	125	6.25	62.080	9.933	0.10	0.298
17	125	6.25	39.777	6.364	0.10	0.371
18	125	6.25	22.050	3.528	0.10	0.548
19	125	6.25	21.613	3.458	0.10	0.557
20	125	6.25	28.195	4.511	0.10	0.458
21	125	6.25	11.350	1.816	0.10	1.166
22	125	6.25	11.125	1.780	0.10	1.207
23	125	6.25	12.231	1.957	0.10	1.036
24	125	6.25	22.667	3.627	0.10	0.536
25	125	6.25	22.667	3.627	0.10	0.536
26	125	6.25	20.350	3.256	0.10	0.586
27	125	6.25	19.578	3.132	0.10	0.606
28	125	6.25	18.488	2.958	0.10	0.638

4.2. Artificial Neural Network (ANN)

In order to undergo training in ANN, the inputs for the network need to be determined. The network required two inputs which are input data and target data. The input data is the relay operating time as in Table 2 while target data is shown in Table 3.

Table 3. ANN target data

Relay	Relay Operating Time (s)	Relay	Relay Operating Time (s)
Source	0.900		
1	0.800	15	0.500
2	0.700	16	0.400
3	0.600	17	0.900
4	0.600	18	0.800
5	0.500	19	0.800
6	0.500	20	0.700
7	0.500	21	0.600
8	0.400	22	0.600
9	0.800	23	0.600
10	0.700	24	0.500
11	0.700	25	0.500
12	0.700	26	0.400
13	0.600	27	0.400
14	0.500	28	0.400

As in Table 3. the relay operating time is the target data for ANN training [11]. The main reason is the relay which is nearer to the power source need to operate slower time compared to the relay which is further to the power source. This is to ensure that there is no miscoordination between relay operations.

Table 4. tabulates the output of ANN which differs with the both input data and target data. The output of ANN is based on best fit or curve fitting technique by using input and target data which was given to the ANN.As indicated in Table 4, the errors values are the difference between the target data and the ANN output. The positive values of errors indicates that the ANN output is faster than the target data. The negative values indicates that the ANN output is slower than the target data. It can be noted that more than 50% of all relays have time improvement based on the ANN output. Hence, the ANN output can be accepted as the new relay operating time. The ANN output also will be used for miscoordination prediction.

Table 4. ANN output time for all relays

Relay	Input time (s)	Target time (s)	ANN Output Time (s)	Error (s)	Relay	Input time (s)	Target time (s)	ANN Output Time (s)	Error (s)
Source	0.258	0.900	0.420	0.480	15	0.595	0.500	0.435	0.065
1	0.368	0.800	0.495	0.306	16	0.298	0.400	0.456	-0.056
2	0.444	0.700	0.628	0.072	17	0.371	0.900	0.500	0.400
3	0.629	0.600	0.415	0.185	18	0.548	0.800	0.564	0.236
4	0.629	0.600	0.415	0.185	19	0.557	0.800	0.543	0.257
5	0.713	0.500	0.590	-0.090	20	0.458	0.700	0.624	0.076
6	0.688	0.500	0.557	-0.057	21	1.166	0.600	0.574	0.027
7	0.688	0.500	0.444	0.056	22	1.207	0.600	0.592	0.008
8	0.257	0.400	0.419	-0.019	23	1.036	0.600	0.665	-0.065
9	0.405	0.800	0.585	0.215	24	0.536	0.500	0.583	-0.083
10	0.714	0.700	0.591	0.109	25	0.536	0.500	0.583	-0.083
11	0.686	0.700	0.552	0.148	26	0.586	0.400	0.456	-0.056
12	0.714	0.700	0.591	0.109	27	0.606	0.400	0.419	-0.019
13	0.378	0.600	0.514	0.086	28	0.638	0.400	0.425	-0.025
14	0.550	0.500	0.560	-0.060					

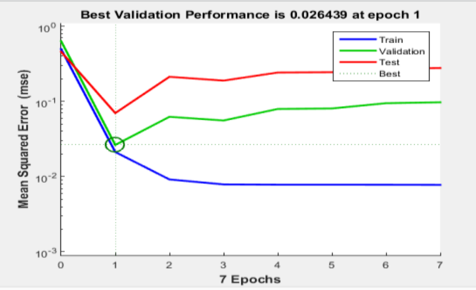

Figure 3. Performance plot of the trained ANN

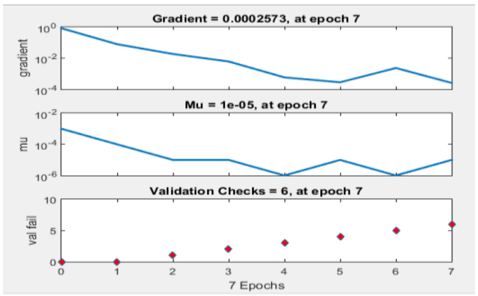

Figure 4. State plot of the trained ANN

Figure 3 and 4 displays the performance plot of the trained ANN which gives the best validation performance of 0.026439 at epoch 1 and the state plot of the trained ANN where the ANN training gave the best network performance function at gradient of 0.0002573 at epoch 7. Figure 5 shows the regeression performance plot where the regression correlation is 0.29098.

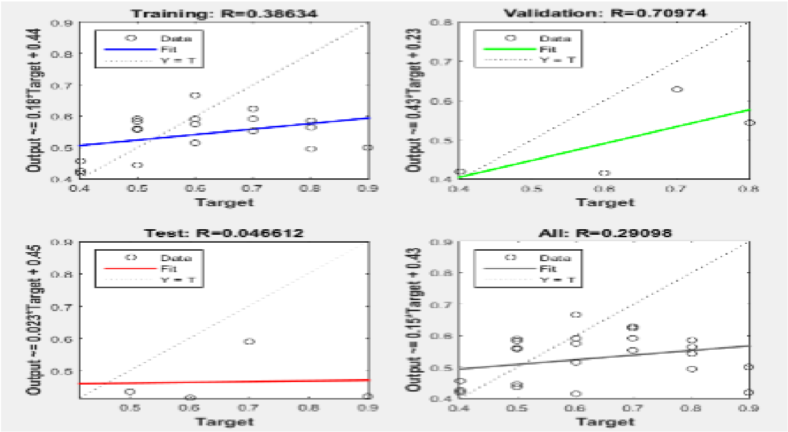

Figure 5. Regression performance plot

4.3. New Relay Operating Time

The new relay operating time is obtained from the ANN output as in Table 4. Thus, the new TMS values will be determined by using eq. 1. The new TMS values are tabulates in Table 5.

Table 5. The new TMS values

Relay	New Relay Operating Time (s)	TMS	Relay	New Relay Operating Time (s)	TMS	Relay	New Relay Operating Time (s)	TMS
Source	0.420	0.16	10	0.591	0.08	20	0.624	0.14
1	0.495	0.13	11	0.552	0.08	21	0.574	0.05
2	0.628	0.14	12	0.591	0.08	22	0.592	0.05
3	0.415	0.07	13	0.514	0.14	23	0.665	0.06
4	0.415	0.07	14	0.560	0.10	24	0.583	0.11
5	0.590	0.08	15	0.435	0.07	25	0.583	0.11
6	0.557	0.08	16	0.456	0.15	26	0.456	0.08
7	0.444	0.07	17	0.500	0.13	27	0.419	0.07
8	0.419	0.16	18	0.564	0.10	28	0.425	0.07
9	0.585	0.14	19	0.543	0.10			

4.4. Prediction of miscoordination time between relays

Prediction of miscoordination time can be done by looking at the difference between the relay operating time of primary relays and secondary relays. The difference is called coordination time interval (CTI). The CTI can be determined by using the eq. 5. The relay operating time calculation are not based on the ANN output but the calculated output. The comparison between the miscoordination time of the calculated output and the ANN output is shown in Table 6. below.

Table 6. Miscoordination time between relay pairs

Relay Pair	Calculated Output Time(s)		ANN Output Time (s)	
	CTI (s)	**Miscoordination**	**CTI (s)**	**Miscoordination**
$R_{source}$and R1	-0.110	Yes	-0.075	Yes
R1 and R2	-0.076	Yes	-0.133	Yes
R2 and R3	-0.185	Yes	0.213	**NO**
R2 and R4	-0.185	Yes	0.213	**NO**
R3 and R5	-0.084	Yes	-0.175	Yes
R3 and R6	-0.059	Yes	-0.142	Yes
R3 and R7	-0.019	Yes	-0.029	Yes
R4 and R5	-0.084	Yes	-0.175	Yes
R4 and R6	-0.059	Yes	-0.142	Yes
R4 and R7	-0.019	Yes	-0.029	Yes
R5 and R8	0.456	**NO**	0.171	**NO**
R6 and R8	0.431	**NO**	0.138	**NO**
R7 and R8	0.391	**NO**	0.025	**NO**
R1 and R9	-0.037	Yes	-0.090	Yes
R9 and R10	-0.309	Yes	-0.006	Yes
R9 and R11	-0.281	Yes	0.033	**NO**
R9 and R12	-0.309	Yes	-0.006	Yes
R2 and R13	0.066	**NO**	0.114	**NO**
R13 and R14	-0.172	Yes	-0.046	Yes
R13 and R15	-0.217	Yes	0.079	**NO**
R14 and R16	0.252	**NO**	0.104	**NO**
R15 and R16	0.297	**NO**	-0.021	Yes
R1 and R17	-0.003	Yes	-0.005	Yes
R17 and R18	-0.177	Yes	-0.064	Yes
R17 and R19	-0.186	Yes	-0.043	Yes
R2 and R20	-0.014	Yes	0.004	**NO**
R20 and R21	-0.708	Yes	0.050	**NO**
R20 and R22	-0.749	Yes	0.032	**NO**
R20 and R23	-0.578	Yes	-0.041	Yes
R21 and R24	0.630	**NO**	-0.009	Yes
R21 and R25	0.630	**NO**	-0.009	Yes
R22 and R24	0.671	**NO**	0.009	**NO**
R22 and R25	0.671	**NO**	0.009	**NO**
R23 and R24	0.500	**NO**	0.082	**NO**
R23 and R25	0.500	**NO**	0.082	**NO**
R24 and R26	-0.050	Yes	0.127	**NO**
R24 and R27	-0.070	Yes	0.164	**NO**

Relay Pair	Calculated Output Time(s)		ANN Output Time (s)	
	CTI (s)	Miscoordination	CTI (s)	Miscoordination
R24 and R28	-0.102	Yes	0.158	**NO**
R25 and R26	-0.050	Yes	0.127	**NO**
R25 and R27	-0.070	Yes	0.164	**NO**
R25 and R28	-0.102	Yes	0.158	**NO**

Table 6. Tabulates the comparison of miscoordination time between the calculated values and the ANN output. From the table, it can be seen that the ANN output produces less miscoordination compared to the calculated output. The calculated output produces 12 pairs of relays which shows good coordination between relay pairs. However, the ANN output produces 22 pairs of relays which shows good coordination, which means more than 50% of total relay pairs. The total relay pairs are 41 pairs. Miscoordination time is the CTI values which have negative values. For example, if a pair of relays have the CTI values of -0.129 s, then the miscoordination time will be 0.129 s. The results in Table 6. also proves that the ANN output is more reliable since it is not only produces less miscoordination time, but also produces faster relay operating time.

5. CONCLUSION

ANN Levenber-Maequardt algorithm has been presented in this paper to predict miscoordination time that occurred between relay pairs. From the results obtained, it can be revealed that the proposed technique demonstrates the significant results betweem ANN output and calculated output. Based on the study, the ANN output are suitable than calculated output since it shows good coordination. Moreover, ANN output produces less miscoordination time and faster relay operating time.

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