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Improving the Performance of Distance Relay Protection in Power System Using Ann Intelligent Control Schemes

O.C. Onuba

Lecturer, Department of Electrical Engineering,
Federal University of Technology, Owerri, (FUTO), Nigeria

M. O. Alor

Senior Lecturer, Department of Electrical/Electronic Engineering,
Enugu State University of Science and Technology (ESUTECH), Nigeria

J.C. Iyidobi

Lecturer, Department of Electrical/Electronics Engineering,
Enugu State University of Science and Technology (ESUTECH), Nigeria

Abstract:

This work is centered on improving the performance of distance relay protection in power system using ANN intelligent control schemes. ANN intelligent control scheme is being utilized to make the performance of the distance relay better. The gap in time between when a fault occurs and when the relay sends a trip signal to the breakers for necessary action (tripping) is very critical in the performance of a power system protection network. This is true considering that the length of time a fault persists on the line without necessary action determines the extent of damage and outage a fault can have on the network and consumers. This thesis presents a model for improving the response time/reaction time of distance relays in the power system transmission lines. The Artificial Neural Network (ANN) technique was deployed to improve the response time of the relay under study. To minimize the error of the ANN system, the data collected on the conventional relay of the transmission line under study was augmented by additional data generated from the computer program. The Ikeja West-Ijora 330kv transmission line under consideration and the ANN system were modelled in Simulink MATLAB using the appropriate tools boxes. The result obtained from the relay response time simulation showed that ANN relay recorded 8.78% improvement in relay response time when compared with the performance of the conventional relay. It can be concluded that the developed ANN based relay gave an improved response time when compared with the conventional distance relay.

Keywords: Distance relay, artificial neural network, simulation, transmission line, MATLAB, electrical fault, relay response time, conventional relay

1. Introduction

Power System Protection is a fascinating field of study. A protection scheme in a power system is designed to continuously monitor the power system to ensure maximum continuity of electrical supply with minimum damage to life, equipment, and property. While designing the protective schemes, it is important to understand the fault characteristics of the individual power system elements and also be knowledgeable about the tripping characteristics of various protective relays.

In the past several decades, there has been a rapid growth in the power grid all over the world which eventually led to the installation of a huge number of new transmission and distribution lines. Moreover, the introduction of new marketing concepts such as deregulation has increased the need for reliable and uninterrupted supply of electric power to the end users who are very sensitive to power outages.

Any abnormal flow of current in power systems components is called a fault in the power system [1]. These faults cannot be completely avoided since a portion of these faults also occur due to natural reasons which are way beyond the control of mankind. Hence, it is very important to have a well-coordinated protection system that detects any kind of abnormal flow of current in the power system, identifies the type of fault and then accurately locates the position of the fault in the power system.

The faults are usually taken care of by devices that detect the occurrence of a fault and eventually isolate the faulted section from the rest of the power system. Hence some of the important challenges for the incessant supply of power are detection, classification, majorly location of faults. Faults can be of various types namely transient, persistent, symmetric or asymmetric faults and the fault detection process for each of these faults is distinctly unique in the sense, there is no one universal fault location technique for all these kinds of faults [2]

Distance protection, in its basic form, is a system of protection offering considerable economic and technical advantages. Unlike phase and neutral over current protection, the key advantage of distance protection is that its fault coverage of the protected circuit is virtually independent of source impedance variations [3]

This thesis presents an application of Artificial Neural Network(ANN) for fault estimation along with fault location on 330kV Ikeja west- IJORA transmission line by *Matlab Simulink* utilizing the ANN Toolbox. The ANFIS has been successfully applied for reaction time or relays where the information of the voltage and current data of protection relay and Circuit Breaker are available. The effects of varying fault time have been considered in this work. The obtained results clearly show that the proposed technique can accurately be used to close the reaction time gap of distance relays in transmission lines under various fault conditions thereby improving greatly the conventional distance protection relaying scheme.

Relatively slow response or reaction time of conventional distance relays has really been of concern to the researcher and power stakeholders. This slow response has really caused equipment damage and long outages during fault occurrence. Whenever the relay fails to operate quickly, dangerous current will have ample time to flow to the relevant equipment. These faults which cannot be avoided may be caused by momentary tree contact, animal contact or any other natural reasons like thunderstorm and lightning. This thesis seeks to improve the response time of the distance relay using Artificial Neural Network (ANN).

1.1. Theory of Work

Electrical power system protection is a branch of electrical power engineering that deals with the protection of electrical power systems from faults through the disconnection of faulted parts from the rest of the electrical network. This goal of protection is to make the power system stable by isolating parts that are faulty while leaving as much of the network as possible still in normal operating conditions. For modern power system to have a normal operation of the system without electrical failure and damage to the equipment, two alternatives are available with the designer;

- Design the system so that faults cannot occur,
- Accept the possibility of faults and take steps to guard against the effects of such faults.

Protection scheme required for the protection of power system components against abnormal conditions such as faults etc. essentially consist of protective relaying and circuit breaker, protective relay functions as sensing device, determines its location and sends trip command to the breaker.

Distance relay is being investigated in this research work. Distance relays are actually double actuating quantity relays with one coil energized by voltage and the other coil by current. The current element produces a positive or pick-up torque while the voltage element produces a negative or reset torque. The relay operates only when the V/I ratio falls below a predetermined value. During a fault on a transmission line, the fault current increases and the voltage at the fault point decreases. The V/I ratio is measured at the location of CT's and PT's. the voltage at the PT location depends on the distance between PT and the fault. If the fault is nearer, measured voltage is lesser and if the fault is farther, measured voltage is more. Hence assuming constant fault impedance, each value of V/I measured from relay location corresponds to distance between relaying point and fault along the line. Distance relays are used where over-current relaying is too slow and is not so selective. Traditionally, all relay settings are a compromise. This characteristic makes the distance protection relay susceptible to incorrect operation situation, since the impedance measurement has an error associated. Ideally the reach of the distance relay would have been set to 100% of the line section. However, its not possible to get the exact reach of 100% in practice. There is always certain amount of uncertainty and ambiguity about the actual reach. These situations can be divided into two groups[4]

- Under-reach: here the relay does not operate for a disturbance inside its protection zone. The relay does not operate when it should.
- Over-reach: here the relay operates for disturbances external to its protection zone, the relay operates when it should not.

Under-reach and over-reach events may lead to equipment damage. Power system loss of stability or cascaded black out events.

In this research work the ANN approach is used. ANNs can solve the overreach and the under-reach problems which are very common in the conventional distance relay design. ANN utilizes samples of currents and voltages directly as inputs without computation of *phasors* and related symmetrical components. Various kinds of neural network such as Multi-Layer Perception (MLP), recurrent, Radial Basis Function (RBF), probabilistic neural network etc. are being applied for fault classification and fault location. These are designed by different training algorithms like back propagation, orthogonal least square, extended *kalman* filter etc. The use of ANNs can extend the first zone of distance relays and enhance system security. For selecting the appropriate network configurations, the performance criteria are fault tolerance, minimal response time and generalization capabilities. ANN approach has been used to improve some of the standard functions used in protection of transmission lines. They have been related to fault direction discrimination [5], fault detection and classification [6,7,8], improvements in fault distance computation [9,10,11,12,13,14], adaptive distance protection [15].

The use of separate ANNs, for faults involving earth and not involving earth has proved to be convenient way of classification of transmission faults based on Radial Basis Function neural networks by [16]. For simple and reduced architecture and better learning capability a modular neural network, is proposed by [17], to discriminate the direction of faults for transmission line protection. Such a network considers corresponding phase/ground voltage and current information as input and thereby the redundant inputs in conventional approaches are eliminated.

2. Methodology

The Ikeja West- Ijora 330kv, 62km, 50Hz is the section of the line under consideration in this thesis. The performance of the distance relays in charge of the line were also evaluated and then improved upon using a proposed Artificial Neural network model/approach/technique. This method/model/approach/ technique is geared towards reducing the response time of the relays and making it respond closer to the set time to protect the entire system as it quickly isolates that line for further investigation and consequent repairs. The transmission line was simulated using the robust tool of the sim power MATLAB.

2.1. Evaluation of the Performance of Distance Relay to Be Improved on

Relevant data on the distance relay were collected from the line under study. The data is as shown in table 1.1 below. Close observation from the table shows that in the different zones (representing the line length/distances), the distance relay had a delay in sending trip signal to the breaker. The reaction time and detection time was quite high/sluggish. This evaluation is done to establish the level of accuracy and reaction time of the conventional distance relay in fault detection. This is to serve as a reference for assessing the proposed ANN system being developed for improving the fault detection & reaction time accuracy. Real data on the tripping time of a set of relays were collected as shown in table 1. Also, by calculations we observe the average error in the reaction time as the graph shown in figure 1 buttress this fact.

Mathematically,

$$\% \text{ Error} = \frac{\text{Actual trip time} - \text{expected trip time}}{\text{expected trip time}} \times \frac{100}{1}$$

Region	Expected Trip in (ms)	Actual Trip in (ms)
Zone 1	20	31.9
Zone 2	350	381
Zone 3	940	1020
Zone 4	1130	1227

Table 1: Collected Data Showing Trip Time Check List
Source: Ikeja West-Ijora Transmission Line

Figure 1: Graph Showing Gap in the Response Time of the Conventional Distance Relay

From the graph shown in figure 1 above the red-coloured line shows the time we expect the relay to respond and send signal to the breaker while the blue line shows when the relay actually sent the trip signal. In zone 1, the actual and expected trip time of the relay are quite close. In zone 2, 3, 4 we notice that the expected and actual time of the relay kept on increasing as the time progresses, showing that the gap kept on widening. This widening time gap and slow response time results in a lot of damages to engineering equipment before even the breaker opens thus defeating the aim of the protection using conventional distance relays. This is a shortcoming in the conventional distance relay as this study tries to address.

2.2. Development of a Simulink Model of the Environment of the Study Field (Ikeja-West Ijora 330KV Transmission Line)

A Simulink of a 3-phase model of the Ikeja-West Ijora transmission line was developed in MATLAB with the help of tools in Simulink. It was developed because the performance (slow reaction time) of the developed ANN system will have to be evaluated by connecting the ANN network to it (the transmission line model) so as to assess its performance in reaction/response time. The transmission line parameters were obtained from the transmission substation, Ijora, Lagos. The corresponding Simulink blocks (including transmission lines, 3-phase A.C. source, R-L-C 3 phase load, buses, circuit breaker etc.) were lifted from sim power of sim scape tool box in MATLAB. The blocks were connected and compiled as shown in figure 2 below. This compilation is to ensure there were no errors in the line connection.

Figure 2: Modelled 330KV Ikeja West- Ijora Transmission

2.3. Training the ANN

A feed forward Neural Network with three (3) input layers, one (1) output layer and 10 hidden layers is used in this project. The Neural Network is created by making appropriate selections in the Neural Network graphical user interface (fitting tool). The training data including inputs and targets (shown in table 2) was inputted through the MATLAB workspace, the created network was then severally trained with training data until a good result was achieved. Graphs showing the performance of the created ANN after training and testing is as shown in figures 6 and 7. The ANN control system generated by the above process is as shown in figures 3, 4 and 5.

If the systems performance is satisfactory, then the training/development is complete, else further training is done until the systems performance is satisfactory.

Time(target)	Ia_rms	Ib_rms	Ic_rms(inputs)(*10 ³)
0.02	0.2163	0.2154	0.2198
0.021	0.2210	0.2214	0.2200
0.022	0.2202	0.2208	0.2202
0.023	0.2194	0.2202	0.2203
0.024	0.2197	0.2202	0.2203
0.025	0.2197	0.2203	0.2204
0.026	0.2196	0.2204	0.2205
0.027	0.2196	0.2204	0.2205
0.028	0.2196	0.2203	0.2205
0.029	0.2196	0.2202	0.2205
0.03	0.2195	0.2201	0.2205
0.031	0.2195	0.2200	0.2205
0.032	0.2194	0.2199	0.2205
0.033	0.2193	0.2199	0.2205
0.034	0.2193	0.2199	0.2204
0.035	0.2193	0.2199	0.2203
0.036	0.2194	0.2197	0.2201
0.037	0.2194	0.2195	0.2199
0.038	0.2193	0.2192	0.2197
0.039	0.2193	0.2189	0.2195
0.04	0.2193	0.2187	0.2195
0.041	0.2193	0.2186	0.2195
0.042	0.2193	0.2186	0.2195
0.043	0.2193	0.2187	0.2194
0.044	0.2194	0.2187	0.2193
0.045	0.2194	0.2186	0.2192
0.046	0.2194	0.2185	0.2191
0.047	0.2194	0.2185	0.2191
0.048	0.2194	0.2185	0.2191
0.049	0.2194	0.2186	0.2192
0.05	0.2195	0.2188	0.2192

Time(target)	la_rms	lb_rms	lc_rms(inputs)(*10^3)
0.051	0.2196	0.2190	0.2192
0.052	0.2196	0.2191	0.2191
0.053	0.2197	0.2192	0.2190
0.054	0.2197	0.2192	0.2189
0.055	0.2197	0.2191	0.2188
0.056	0.2197	0.2191	0.2188
0.057	0.2197	0.2191	0.2187
0.058	0.2197	0.2191	0.2187
0.059	0.2197	0.2191	0.2188
0.06	0.2197	0.2191	0.2188
0.061	0.2196	0.2190	0.2188
0.062	0.2195	0.2190	0.2188
0.063	0.2194	0.2189	0.2188
0.064	0.2193	0.2189	0.2189
0.065	0.2192	0.2189	0.2189
0.066	0.2192	0.2190	0.2190
0.067	0.2192	0.2191	0.2190
0.068	0.2192	0.2191	0.2190
0.069	0.2191	0.2191	0.2190
0.07	0.2190	0.2190	0.2191
0.071	0.2187	0.2190	0.2191
0.072	0.2183	0.2190	0.2190
0.073	0.2199	0.2189	0.2186
0.074	0.2260	0.2190	0.2168
0.075	0.2367	0.2203	0.2129
0.076	0.2497	0.2236	0.2074
0.077	0.2620	0.2286	0.2019
0.078	0.2712	0.2336	0.1979
0.079	0.2757	0.2369	0.1962
0.08	0.2752	0.2374	0.1959

Table 2: Input Data for Training

2.4. Design and Implementation of the Artificial Neural Network System for Improving Distance Relay Performance

This design is made for the purpose of enhancing the response time of the relay under study.

Necessary training sessions were done on the ANN that will be used to improve the performance of the distance relay. The efficiency of most Artificial Intelligence systems in controlling other systems depends on the level of training and volume of data used to implement the training. As a result of this, the first step is developing the data needed for the training of the ANN system. The training data and structure is as shown in table 2 and figures 4 and 5. The training processes is also as shown in figure 3 as shown below.

Figure 3: Neural Network Training in MATLAB

Figure 4: Model of Created ANN

Figure 5: Subsystem Blocks of the Trained ANN

3. Results and Analysis

Figure 6: Neural Network Training Performance

From the graph shown above, it can be seen that the train, validation and test pattern progressively approached the best performance pattern. The best validation performance (circled) came at 3.7032×10^{-5} at epoch 14.

Figure7: Training, Validation and Test Graphs

From the above training, validation and test graphs we notice that the data, fit and output(y) almost are in line showing an improved system

The time is used is the target and the Ia, Ib&Ic are the inputs. We notice from the graph of figure 7 above that the training, test, and validation were almost in one direction showing a good ANN training. The graph in figure 6 shown above also buttresses the above fact.

The model when simulated in the MATLAB environment shows that the actual trip time is reduced and error reduced. We also notice that when trained ANN is removed, the trip time increases but when ANN is connected the trip time reduces. The diagrams above show this. The graph below also buttresses this fact. **Table 3** shows a reduced relay reaction time.

Region	Expected Trip in ms	Actual Trip in ms
Zone 1	20	29.59
Zone 2	350	353.4
Zone 3	940	946.1
Zone 4	1130	1138.00

Table 3: Reduced Relay Reaction Time

Figure 8: Graph Showing Reduced Trip Time When ANN Is Incorporated

From the graph of figure 8 shown above we can see that after the training, implementation and incorporation of the ANN into the test line, there is now a closure in the time gap. Zone 1 showed an instant response, zone 2 showed a very close time lapse, zone 3 also showed a close time lapse, zone 4 also improved. Generally, we can see from the graph that there is now an improvement when ANN is incorporated.

Checking the percentage error from table 4.2, we have;

$$\frac{\text{Actual trip time} - \text{expected trip time}}{\text{expected trip time}} \times \frac{100}{1}$$

$$\text{From zone 1; \% error} = \frac{29.59 - 20}{20} \times \frac{100}{1} = 47.95\%$$

$$\text{From zone 2; \% error} = \frac{353.4 - 350}{350} \times \frac{100}{1} = 0.97\%$$

$$\text{From zone 3; \% error} = \frac{946.1 - 940}{940} \times \frac{100}{1} = 0.649\%$$

$$\text{From zone 4; \% error} = \frac{1138 - 1130}{1130} \times \frac{100}{1} = 0.707\%$$

$$\text{Average \% error} = \frac{47.95 + 0.97 + 0.649 + 0.707}{4} = 12.57\%$$

We observe that there is a reduced error when the ANN relay is incorporated into the transmission line. This reduction in error is calculated as follows;

Average error without ANN incorporated - Average error with ANN incorporated

$$21.35\% - 12.57\% = 8.78\%$$

The above difference in errors shows an improved performance of the distance relay when Artificial Neural Network (ANN) is incorporated.

4. Conclusion and Recommendation

Using a feed-forward Neural Network with a robust training and reasonable volume of data, it is possible to design a network that can enhance the distance relay performance on a transmission time. In this thesis, relevant data was gotten from the *Ikeja West-Ijora* 330kv transmission line during the relay commissioning test. The transmission line model was designed according to the line specifications. The ANN was then trained using several data generated by the system. Test and validations were carried out and training processes were satisfactorily done. The trained network was now incorporated with the distance relay and the line, the overall model was developed and subsequently simulated. The result of the simulation showed a reduction in reaction time of the distance relays. The developed system was able to respond in less time. From the calculations of the reaction time error, we notice the error reduced from 21.35% to 12.57% which is a huge improvement of the conventional distance relays.

I recommend that future work on this should focus on online taking of the fault information on relay protection and actual fault location in the central control company to obtain a better and faster fault location time. The SCADA system should be improved with the ANN incorporated to it.

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