Fault detection and classification in three phase series compensated transmission line using ANN

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Abstract: Series compensation consists of capacitors in series is used in the transmission lines as a tool to improve the performance after disturbed by a fault. Transmission line needs a protection scheme to protect the lines from faults due to natural disturbances, short circuit and open circuit faults. The fault can happen in any location of transmission line and it is important to know which location has been affected. So that, the fault can be eliminated and can maintain the optimum performance. Therefore, in this paper Artificial Neural Network (ANN) is used to detect and classified the fault happen in single line to ground fault and three phase to ground fault. Two different tests of each types of fault have been tested in order to prove the effectiveness of ANN to detect the fault location by using different length and fault resistance. The simulation has been accomplished in MATLAB with ANN fitting tool which build and train the network before evaluated its performance using regression analysis. The analysis shows that the ANN can accurately detect the different types of faults and classified it into the respective category even the random vectors are put on the system are used.

1. Introduction

Series compensation is basically a powerful tool to improve the performance of EHV lines. It consists of capacitors connected in series with the line at suitable locations [1]. Since 1950s, a series compensation has been in use in electrical networks worldwide. It is an effective way to resolve a many issue in network problem such as for reactive power losses in transmission lines by regulate system voltages to get a better performance. An inductive reactance of a transmission line also partially compensated by the designed series compensated to increase power transfer capability and system stability. Compensation levels typically range from 20% to 80%. Consequently, the reactance due to the series capacitor (XC) will always be less than the inductive reactance of the transmission line (XL)[2]. The performance of transmission line in transfer power capability is may always affected by an open and short circuit faults. The faults in the power system may occur because of natural disturbances like lightning, high-speed winds and earthquake. It may also occur because of some accidents like falling off a tree, vehicle colliding and aeroplane crashing. Besides that, early stage of faults are also cause by the partial discharge (PD) activities in power system component [3-4]. Hence, the integration of fault detection tools seems to be necessary. In order to detect the location of fault in the transmission line, multiple methods are occurring but some of them are exploited offline [5]. The faults on three phase power system transmission lines are compulsory to detect first and then be classified correctly and have to cleared as fast as can so that the performance of the whole system can be maintained and increased [5]. A good fault detection system provides a fast, effective, secure operation of relay and reliable in many ways. ANNs are very powerful in detecting and
classifying the faulty location. It can be applied effectively because it is a programming technique, capable to solve the nonlinear problems easily. The problems in which the information available is and in massive form can be dealt with [6]. In this paper, a series compensated technique is used to increase the power transfer capability of transmission lines after prone to an electrical fault. Then, the system is simulated using MATLAB/Sim Power Systems toolbox and analysed with two different faults which are single line to ground fault and three phase to ground fault. The various faults are modelled, simulated and an ANN is developed for detection and classification of these types of faults. The performance of an ANN is evaluated by simulating the various types of fault and the results obtained are encouraging.

The paper is divided into four sections. The section one is introduction. Second section gives overview of the structure of series compensated in three phase transmission line. Third section is the fault detection and classification method using ANN, which permits the fault detection via a trained neural network such the voltage and current are the inputs and the fault class is the output of the system. Fourth section gives the details of simulation and the last fifth section is conclusion.

2. Modelling a series compensated in three phase transmission line

A three-phase, 60 Hz, 735 kV power system transmitting power from a power plant having six 350 MVA generators to an equivalent system through a 600 km transmission line has been used for simulating the series compensated transmission line. The different faults on the transmission line is study and analyse by split into two 300 km lines connected between buses B1, B2, and B3. The line also split into 100km for other test to show the variance of transmission line used in the real world. An accurate result is achieved when very long transmission line been used with distributed type of parameters. In this project, the parameters used as shown in Table 1 [1]. Each line in series compensated by capacitors representing 40% of the line reactance [1]. The simulation of complete power system modelis simulated by using the SimPowerSystems toolbox available in MATLAB Simulink software as shown in Figure 1. Metal Oxide Varistors (MOV) is used to protect series capacitor when fault current is very high.

| Parameter                        | Value  | Unit          |
|----------------------------------|--------|---------------|
| Voltage                          | 735    | kV            |
| Frequency                        | 60     | Hz            |
| Lines 1 between bus 1 and bus 2  | 100/300| km            |
| Lines 2 between bus 2 and 3      | 100/300| km            |
| Transformer bus 1                | 13.8/735| kV         |
| Transformer bus 2                | 735/230| kV            |
| Shunt reactance                  | 330    | Mvar          |
| Line reactance                   | 105.6  | Ω             |
| Series capacitance               | 62.8   | uF            |
| MOV reference current            | 2      | kA            |

![Figure 1. Three phase series compensated transmission line](image1.png)
3. Fault detection and classification method using ANN

Faulty state
In order to classified the fault, 4 categories faulty states were established. Each category represents 4 tests in this project. Three phase series compensated transmission line is focused on the fault happen at single line to ground and three phase to ground which the value of fault resistance and location of fault are different. The fault classification is summarized in Table 2.

| Category/Test Number | Fault Condition       | Fault resistance (Ω) | Length of transmission line (km) | Symbol | Code   | To detect fault |
|----------------------|-----------------------|----------------------|----------------------------------|--------|--------|-----------------|
| 1                    | Single line to ground | 0.001                | 300                              | F1     | [0;1]  |                 |
| 2                    | Single line to ground | 30                   | 100                              | F2     | [1;0]  |                 |
| 3                    | Three phase to ground | 0.001                | 300                              | F3     | [0;0;1] |                 |
| 4                    | Three phase to ground | 30                   | 100                              | F4     | [0;1;1] |                 |

Fault resistances are varied to identify the fault types at different lines in non-radial power system network. Fault resistances are varied from 0 to 30 ohms [7-8]. The output for single line and three phase is different due to the different phase that used in the system. The duration of fault happens must be declared first so that the code that classified the input can be declared also. Once the ANN is run, the vector code is displayed the output as [x;y] for single line to ground and [x;y;z] for three phase to ground which x,y,z is number 0 or 1. Before the classification process by ANN, the fault location must be determined in order to record the actual fault location. So that, ANN can be analysed whether it can detect and classified the fault correctly or not. It is also, can measure the performance of ANN in classified the fault.

Design of ANN
In this part, one of the important ANN families has been used which is multi-layer perceptron (MLP) neural networks. Figure 2 represent the MATLAB-based model which is the basic block of fault detection system. The database of ANN is taken from the current and voltage of the power system which is resulted in the workspace of the MATLAB as inputs, the codes as shown in Table 2, as targets and the category as outputs. The MLP model is validated by comparing the actual data with the estimated output.

![Figure 2. The block diagram of fault detection](image)

All the parameters for ANN such as fitting network of ten hidden layer sizes, input values and instruction for network trained must be defined using MATLAB M-File format. Figure 3 shows the structure of ANN with two input for voltage and current, ten hidden layer and one output which is detection system either the input is in fault condition or not. This structure is for single line to ground.
fault and for three phase to ground fault, the structure is different which is three for input and output side.

![Figure 3. The block diagram of fault detection.](image)

The ANN is adjusted and trained to get a specific target output. The adjusting process is based on a comparison between output and target, until the output can be same with the target. The root mean square error is used in this training process. It allows the accuracy test of the system either the output can achieve the target and what is the difference result between target and output. It is also explained how accuracy of the data between the data get and the data which have a best fit. The experimental results can be verified by using mean square error which is always choose to analyse in regression analysis[9-11].

The system was trained by using the parameters as shown in Table 1 with a single line to ground and three phase to ground fault are applied on phase A at t = 1 cycle. The two circuit breakers which are initially closed are then open at t = 5 cycles, simulating a fault detection and opening time of 4 cycles. This training is continued once the mean square error detect that the performance of the system is around the line of best fit.

4. Results and Discussion

Figure 4 represents the root mean square error of single phase to ground fault. During the training process, the data is around the line of best fit with the validation performance is 0.0485 at epoch 52. It shows that the regression value is close to 1 and the weights of the network is well adjusted. This system could give a good accuracy on the output data and yet there is a perfect correlation between targets and outputs.

![Figure 4. Mean square error for single phase to ground fault.](image)

The gap between targets and outputs are known as errors. These errors can be determined by using error histogram as shown in Figure 5. The nearest value of error which close to 0, means the greatest
performance of the system achieved. A single line to ground fault at 58 epochs records error as 0.009335 which near to zero. The summary of the validation performance and errors values of others fault type are shown in Table 3.

Table 3. The summary of validation performance and errors values

| Test Number | Validation performance | Error value |
|-------------|------------------------|-------------|
| 1           | 0.0485                 | 0.009335    |
| 2           | 0.0364                 | -0.0092     |
| 3           | 0.00076                | -0.00653    |
| 4           | 0.0157                 | 0.00360     |

The validation performance and error value as shown in Table 3 shows that the system is around the line of best fit which near to zero. The tests are continued to measure the performance of ANN to detect and classified the fault area.

Table 4 shows the classification of fault based on random vector. The random vectors are consisting of faulty area and unfaulty area which represent the real operational system when it disturbs by a fault. ANN will classify the vector as a fault or not by showing it into the results. The first test is taking randomly to test the accuracy of ANN to detect the location of fault of category 1 which the input that used is [12.46;0.6242]. The target shows that the location tested in fault area, that’s mean ANN displayed [0;1] as shown in Figure 6(a). If the input detects unfaulty area, the target was display [0;0] as shown in Figure 6(b). The value of this vector same as test 4, means it is faulty area. From the results, ANN detects the vector perfectly and classified it into the respective code as declared in Table 2. The opposite code declared in Table 2 means the vector is classified as unfaulty/normal area.

Table 4. The classification of fault based on random vector.

| Group | Test Number | Random vector | Code for fault area | Result | Symbol |
|-------|-------------|---------------|---------------------|--------|--------|
| 1     | 1           | [12.46;0.6242]| [0;1]               | [0;1]  | F1     |
|       | 2           | [-12.24;-0.7747] | [1;0]               | [0;0]  | Normal |
|       | 3           | [6.4912;-13.9931;7.5019]| [0;0;1]            | [0;0;0] | Normal |
|       | 4           | [8.9945;0.0369;-0.0444]| [0;1;1]            | [0;1;1] | F4     |
| Group | Test Number | Random vector | Code for fault area | Result | Symbol |
|-------|-------------|---------------|---------------------|--------|--------|
| 2     | 1           | [-9.8822; -0.8303] | [0; 1] | [0; 0] | Normal |
|       | 2           | [-18.6814; -0.4815] | [1; 0] | [1; 0] | F2     |
|       | 3           | [-0.0176; 0.0041; -0.0579] | [0; 0; 1] | [0; 0; 1] | F3     |
|       | 4           | [8.0995; -13.9488; 5.8493] | [0; 1; 1] | [0; 0; 0] | Normal |
| 3     | 1           | [8.880; 0.7784] | [0; 1] | [0; 0] | Normal |
|       | 2           | [8.0453; 0.7262] | [1; 0] | [0; 0] | Normal |
|       | 3           | [-0.0076; 0.0380; -0.0505] | [0; 0; 1] | [0; 0; 1] | F3     |
|       | 4           | [0.0629; -0.0704; 0.0375] | [0; 1; 1] | [0; 1; 1] | F4     |
| 4     | 1           | [-0.0150; -0.7849] | [0; 1] | [0; 1] | F1     |
|       | 2           | [0.0300; 0.0588] | [1; 0] | [1; 0] | F2     |
|       | 3           | [7.9877; -20.5481; 12.521] | [0; 0; 1] | [0; 0; 1] | F3     |
|       | 4           | [6.6603; -13.9881; 7.3379] | [0; 1; 1] | [0; 0; 0] | Normal |

**Figure 6(a). Fault condition for Test 1**  
**Figure 6(b). Normal condition for Test 1**

### 5. Conclusion

A three phase series compensated transmission line with ANN has been developed to recognize the fault location. The values of validation performance and error value of 4 tests shows that ANN able to run the system effectively due to the values are near to zero. It is proven that the values are closer to zero which means, the system is around the line of best fit. Four tests are run using ANN have been proved that the method can accurately detect the different types of faults and classified it into the respective category even the random vectors are put on the system as a fault which can happen in any location on the system. As a conclusion, the ANN model is successfully developed to localized and classified the fault happen in the three phase transmission line system.

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