

## Fault detection, classification and section identification on distribution network with D-STATCOM using ANN

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### Abstract

*This paper presents easy and efficient method of fault detection, fault classification and section identification in distribution networks with distribution static synchronous compensator (D-STATCOM) using artificial neural networks (ANN). The neural network uses Levenberg-Marquardt backpropagation algorithm for training. The D-STATCOM (average) model available in MATLAB has been modified to perform fault analysis. D-STATCOM is used for reactive power compensation, and regulates the system voltage by absorbing and generating reactive power. Fault is simulated for different function of D-STATCOM in which it absorbs reactive power like an inductor and generates reactive power like a capacitor. The present work reports the results of fault detection, fault classification and section identification whether it is forward fault and reverse fault in distribution network with D-STATCOM.*

### Keywords

*Distributed network, D-STATCOM, ANN, Fault detection, Section identification, Fault classification, Levenberg-Marquardt backpropagation algorithm.*

### 1. Introduction

Nowadays, the flexible alternating current transmission system (FACTS) device is widely used in transmission and distribution system to enhance power transfer capability and stability of the power. There are so many devices which are used in transmission line but D-STATCOM is a shunt device which is used only in distribution networks. D-STATCOM is similar to STATCOM, but only difference is STATCOM is used in transmission level. The performance of D-STATCOM system is to reduce power quality problems and improve distribution system performance under all types of system related disturbances and system unbalance faults, such as line-to-line (LL) and double line to ground (DLG) faults etc. [1]. It improves the power quality like voltage fluctuations, voltage sag, voltage swell etc. The D-STATCOM operates when there is a sudden change in source voltage (increase/decrease), it absorbs or generates reactive power. In D-STATCOM two voltage source converter (VSC) and capacitor is used to provide the dc voltage to the VSC. The two modelling approaches (detailed and average model) are explained by the researcher in a +3/-3 Mvar D-STATCOM on a 25kV network by comparing their static and dynamic performance.

The detailed and average model is compared when system is changes from inductive to capacitive operation. Chopping of dc voltage is observed on detailed whereas average value is observed in average model [2]. Several methods exist for detecting, classifying and section identification on transmission line [3-16]. ANN is widely used for fault detection, fault classification and section identification. The researcher worked on fault detection, fault classification and direction estimation for uncompensated transmission lines [3-12]. Directional relay based on negative or zero sequence components or compensated post fault voltages are almost common [3, 4] but the relay is slowly operating for all types of faults, travelling waves is proposed for reducing the operating time of directional relay [5, 6]. The protection over doubly fed transmission line [3, 7] greater portion of the line length can be protected comparing to earlier techniques. The input training data of the recording devices was sampled using digital signal processing [8] for fault classification. The protective relay scheme based on discrete wavelet transform and ANN provide primary and backup protection of 99% to the line within quarter cycle time [9]. The adaptive neuro-fuzzy inference system approach is used for directional estimation in sectional transmission lines [10]. Fuzzy inference system is used to improve the performance of directional relaying, fault

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classification in transmission line. The fuzzy logic based relay is less complex and better than other AI based methods such as ANN, support vector machine, SVM and decision tree because training patterns is not required [11].

The researcher worked on fault detection, fault classification and direction estimation for compensated transmission lines [13-16]. Superimposed sequence components-based integrated impedance (SSCII) technique is used for fault detection and fault classification in shunt (Staticvar compensator) compensated line. The magnitude of SSCII is small for internal fault and very large for external faults [13]. ANN and wavelet transform is used for the protection of transmission line with FACTS (Thyristor-Controlled Series Capacitor) device [13]. Fault detection and direction estimation based on ANN [15]. The fault detection and fault classification is based on Wavelet Entropy used in FACTS Compensated Transmission lines, the FACTS device are static synchronous series compensators (SSSC) and Unified Power Flow Controller (UPFC) which is placed in the midpoint of the transmission line [16].

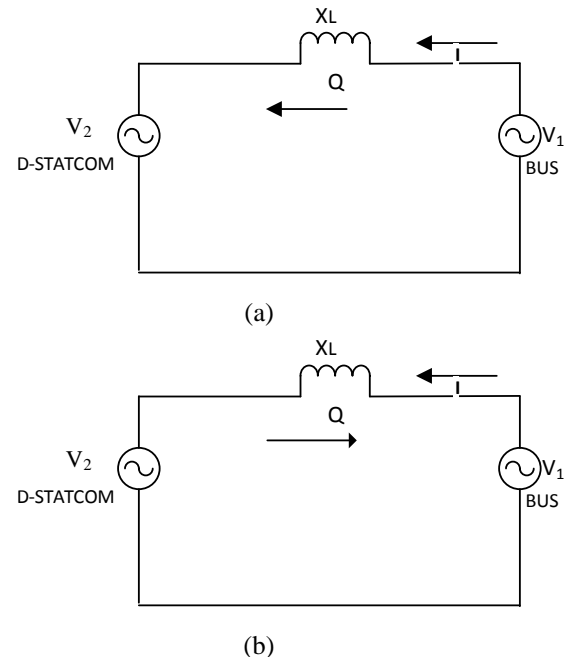
This paper presents Artificial Neural Network algorithm is applied for the fault detection, fault classification and section identification for forward and reverse fault in distribution network with D-STATCOM. Various combinations of fault resistance, fault inception angle, fault distance and type of fault are considered. The data used in this technique is obtained from the simulate model of D-STATCOM on a 25kV network, which is done on MATLAB. The result based on this algorithm is simple, fast and accurate.

## 2.Operation of D-STATCOM

D-STATCOM is a shunt device which is used to regulate the system voltage by generating and absorbing reactive power. The network is connected to the D-STATCOM through the transformer and D-STATCOM consists of PWM inverter and PWM inverter consist of two IGBT bridges. At the DC side of inverter, a capacitor provides dc link voltage and that capacitor takes power from the network for charging. The controller of D-STATCOM provides control to dc link voltage and bus voltage. The main role of D-STATCOM is to synchronize the bus voltage by generating and absorbing reactive power just like a thyristor static compensator (TSC). The transfer of reactive power between the network and D-STATCOM is possible through the leakage

reactance of the coupling transformer by using a secondary voltage in phase with the primary voltage (network side). Secondary side is D-STATCOM and primary side is network. There are two conditions for operation which are (also shown in *Figure 1*):

- If the bus voltage is higher than the secondary voltage then the D-STATCOM absorbs reactive power like an inductor.
- If the bus voltage is lower than secondary voltage then the D-STATCOM generates reactive power like a capacitor.



**Figure 1** D-STATCOM operation (a) inductive operation (b) capacitive operation

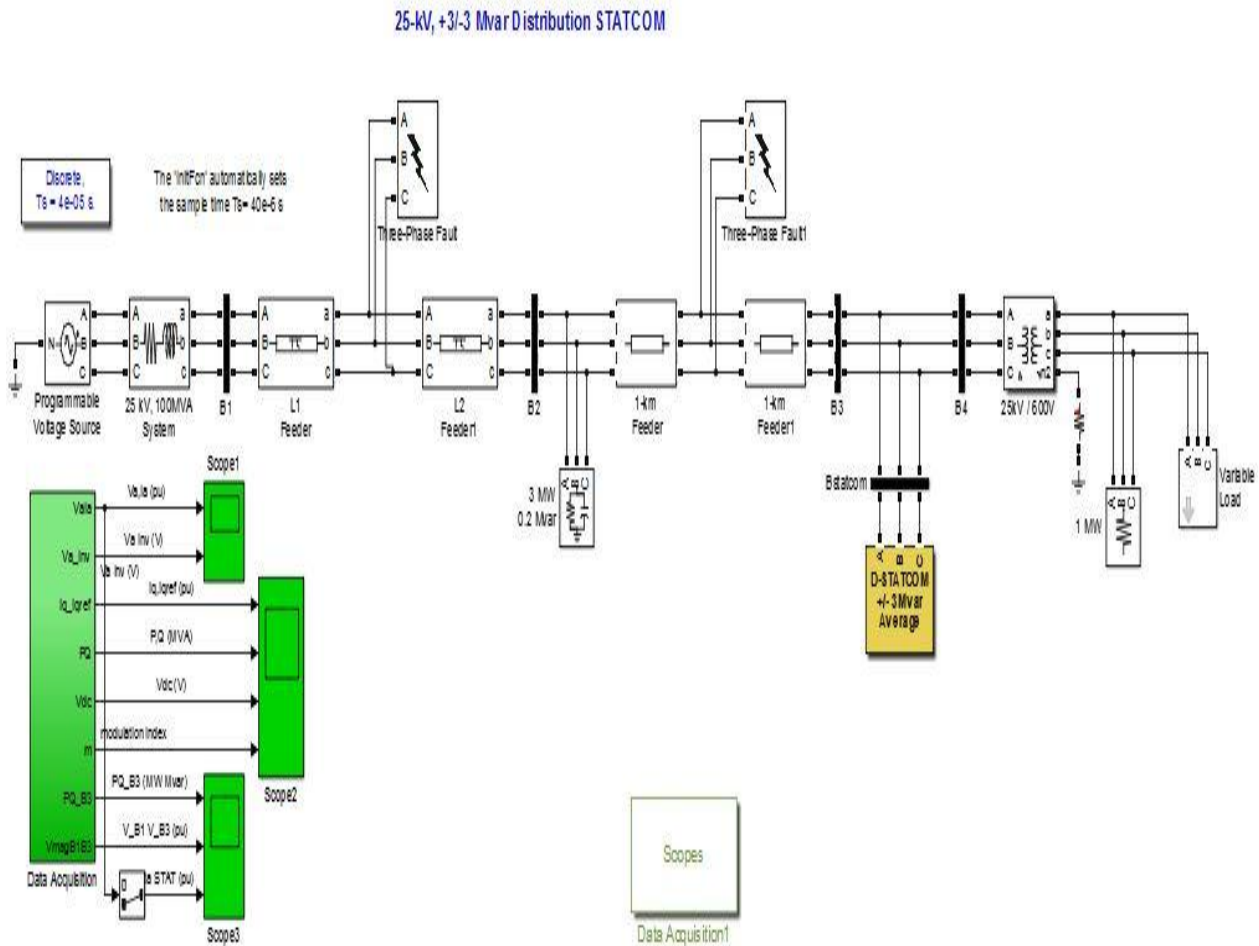
In steady state condition D-STATCOM produces small active power to compensate the inverter losses and the bus voltage leads the inverter voltage by a small angle.

## 3.Modelling of D-STATCOM

The D-STATCOM is used to regulate the parameters of 25kV distributed network. We consider here, a +3/-3Mvar D-STATCOM connected to distribution network [2]. Two feeders of 21 km and 2 km are there which transmit power to the load. Feeder of 21 km is modelled by pi-equivalent circuit and connected between the bus 1 and bus 2, whereas 2 km feeder is connected between bus 2 and bus 3. For power factor correction, a shunt capacitor is added at bus 2. Two different loads are connected to the bus 4 through distributed transformer of 25kV/600V and which are resistive load of 1MW and variable load.

In D-STATCOM two voltage source converters are used which consist of IGBT, 10,000 microfarad capacitor is used to provide dc to the voltage source converter and we get ac from the output side. An LC filter is used in output side of the inverter to provide quality factor and a resistance is connected in series with the capacitor. Voltage and current acquisition is

done using anti-aliasing filter. Controller of D-STATCOM consists of Phase Locked Loop, and two measurements system (voltage and current) and DC voltage regulator. Simulink model of distribution network with D-STATCOM shown in *Figure 2*.



**Figure 2** Simulink model of distribution network with D-STATCOM

### 3.1 Measurement of voltage and current and pre-processing of data

At sampling frequency of 1,200 Hertz, 20 samples per each cycle, voltage and current waveforms have been generated from the model. The starting of one cycle obtained high value of voltage and current waveform because of the transient. Transient occurs due to switching operation of devices. The fault occur after the voltage source is increased by 6% at the time of 20 ms. The voltage is decreases and current is increases during the fault. The Power system model

is simulated in the MATLAB Simulink software and obtained fundamental components of three phase voltage and current by using Discrete Fourier transform (DFT) from bus 1, 2 and 3. The fundamental components of three phase voltage and current of bus 2 is used as an input to the ANN module. The *Figure 3* shows voltage and current waveforms of phase A-G (ground) fault in forward section at 1-km from Bus-2, 10-ohm fault resistance and 0-degree fault inception angle. The training

process is fast and improved by using pre-processing of three phase voltage and current signals.

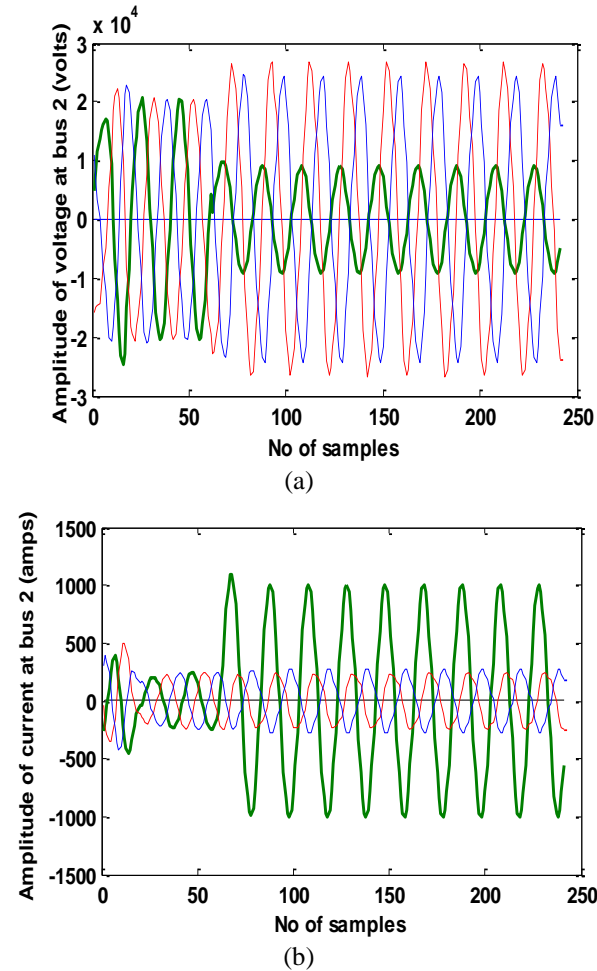


Figure 3 (a) Voltage and (b) current waveforms of bus 2 during phase A-G (ground fault)

#### 4. Artificial neural network (ANN)

ANN is an information processing model inspired by the biological nervous system. An ANN is composed of a large number of highly interconnection processing elements (neurons) working in unison to solve specific problems. An ANN is configured for a specific application such as pattern recognition or data classification through learning process [17]. Artificial neural network is fast, simple, efficient and accurate technique. The training patterns are required. It is used for linear as well as non-linear model. ANN is a programming technique, and can easily solve the linear and non-linear problems for fault detection, fault classification and section identification. For best results, the factors that need to be appropriately selected are

- Selection of numbers of layers
- Number of neurons in each layer
- Selection of activation functions
- Learning algorithm parameters

Figure 4 shows one way connection of Feed forward network from input to output layer. In feed forward neural network, back propagation algorithm is applied to obtain the good results.

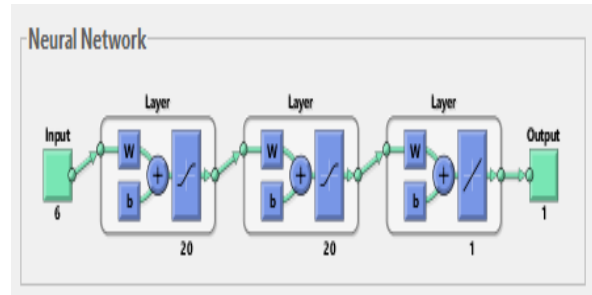


Figure 4 Architecture of ANN

#### 5. Training and testing

The model of distribution network with D-STATCOM is built in MATLAB/ Simulink and ANN algorithm is used. The Levenberg-Marquardt backpropagation based algorithm is used for training the neural network. The training data set consists of total (3 fault resistances \* 39 fault lengths \* 3 fault inception angles \* 11 types of faults = 3861) fault cases and one no-fault case is added. Since, it is a supervised learning method so Target is needed for learning process. Training is done by taking activation function which are (tansig, tansig) and two hidden layers (20, 20) and checking the regression plot is accurate.

Table 1 shows, different fault cases, variation in fault parameters is consider in training data, 11 fault types have been simulated with different fault inception angle (0, 45, 90) degree and different fault resistance (0, 50, 100)ohm at different fault distance, and no fault samples also considered.

Table 1 Training pattern

Training pattern	Reverse section Is 21 Km, Fault increase in each 1 step
fault length (Km)	forward section is 2 km, fault increase in each 0.1 step
Fault inception angle in degree	0, 45, 90
Fault resistance (ohm)	0, 50, 100
Type of fault	A-G, B-G, C-G, AB, BC, CA, AB-G, BC-G, CA-G, ABC, ABC-G

### 5.1 Fault detection

For fault detection, six inputs are provided to the neural network, which are three phase voltages (VA, VB and VC) and three phase currents (IA, IB and IC). For developing of data set for training, all different eleven types of faults and no-fault conditions are also considered. The training data set consists of total (3 fault resistances \* 39 fault lengths \* 3 fault inception angles \* 11 types of faults = 3861) fault cases and one no-fault case is added. The output of neural network is in form of '0' and '1' ('no' or 'yes'), which shows '0' for nofault data and '1' for faulted data. *Figure 5(a)* shows the testing result during B-C fault at 5.45 km reverse section from bus 2 and 30 degree fault inception angle and the top figure 5(a) represent the instantaneous value of three phase voltage and middle represent the instantaneous value of three phase current and bottom represent the output result for the detection. Similarly *Figure 5(b)* shows the testing result during BC-G fault at 0.55 km forward section from bus 2, and 30 degree fault inception angle, the top two figure represents the instantaneous value of three phase voltage and current in which clearly visible that the voltage of phase B and C decreases and the current of same phase is increases and the output shows the fault occur at 51.3891ms of time; relay operates with in 1.0909 ms.

Thus the proposed relay take maximum 2.9 ms time to detect the forward fault.

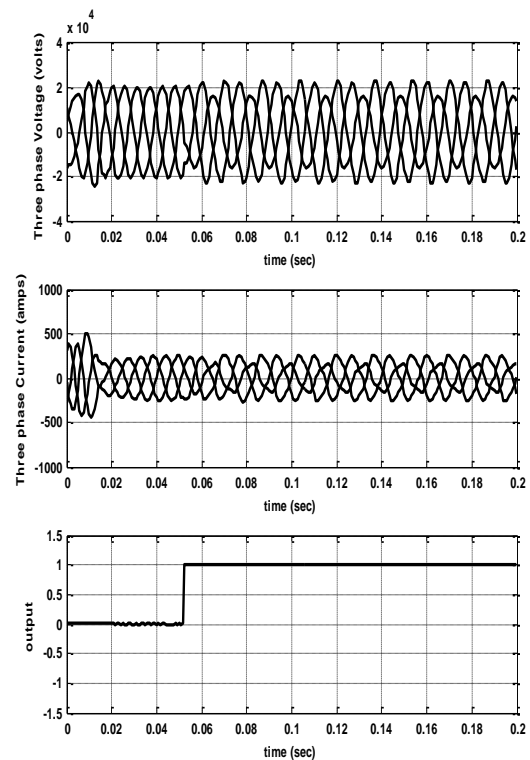
### 5.2 Section identification

The six inputs provide to the neural network and getting 2 outputs. The section identification is done at middle bus (bus2) and it checks whether the fault has occurred in forward direction or reverse direction. Training is done with two activation function's (tangig, tansig), two hidden layer (20, 20) and checking the regression plot is accurate as same process employed in detection. After testing the two outputs get from neural network in the form of '0' or '1'. First output is reverse section and second is forward section. *Figure 6(a)* shows the fault occur at 5.45km reverse section from bus 2, 30 ohm fault resistance, 30m degree fault inception angle and phase BC fault. The top plot, represents the output of reverse section and the bottom plot represent the output of forward section, the output of ANN based detector and direction estimator is '0' up to 52.48ms of time; indicating there is no fault in the system. After 52.48ms of time it starts increasing, which shows that there is a fault in reverse line section and reaches to 1 in 53.31ms time thus the proposed relay

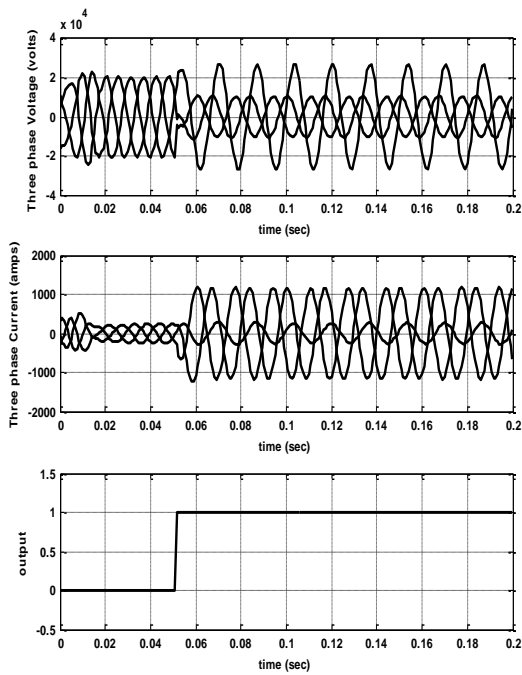
take 1.9ms time to detect the reverse fault. Similarly *Figure 6(b)* shows the testing result at 0.55 km forward section from bus 2, 10 ohm fault resistance, 30 degree fault inception angle and phase BC-G (ground) fault and takes 2ms time to detect the fault.

### 5.3 Fault classification

The same process which was employed in detection is used in classification. Six inputs ( three phase voltage and three phase current) are taken but the neural network takes four outputs A, B, C and G, which should be '0' for no fault and '1' if there is any fault. According to various fault condition, various possibilities can be represented. The neural network which is proposed can distinguish accurately between eleven faults. Two modules have been designed for fault classification according to the type of fault (LG, LLG, LLLG) and (LL, LLL) because training matrix is very large, the complexity increases and it takes more time to train the data. One data set contains single line to ground fault, double line to ground fault and triple line to ground fault. Second data set contains double line fault and triple line fault. Training is done using two hidden layers (20, 20) and activation functions (tansig, tansig)



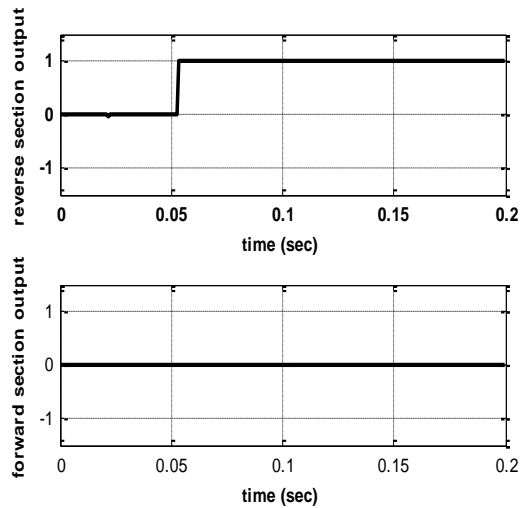
(a)



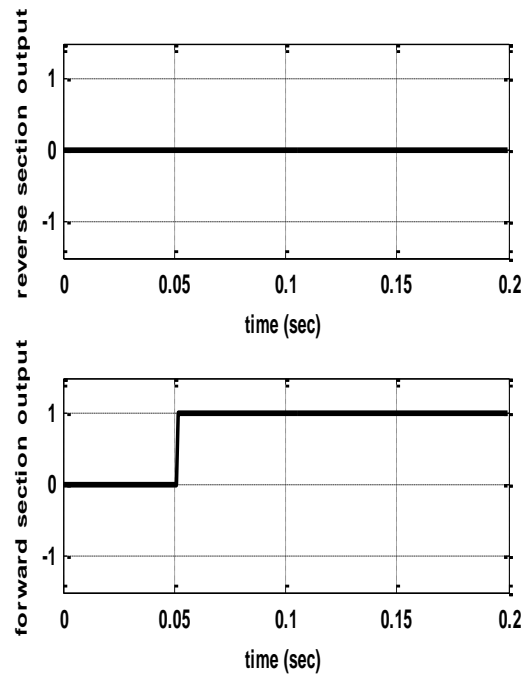
(b)

**Figure 5** (a) Three phase Voltage, Current and detector output during phase B-C fault at 5.45 km from Bus 2 with fault resistance of 30 ohm at time 51.3891ms

(b). Three phase Voltage, Current and detector output during phase B-C fault at 0.55 km from Bus 2 with fault resistance of 10 ohm at time 51.3891ms



(a)

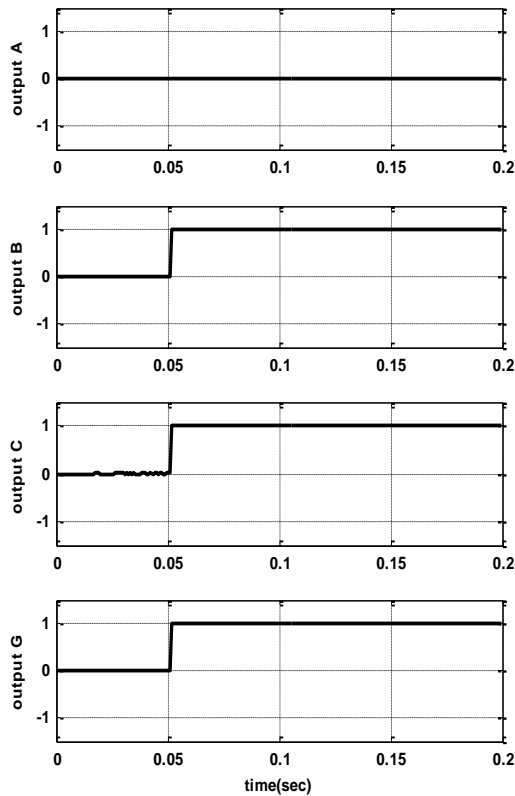


(b)

**Figure 6** (a) Reverse section output and Forward section output during phase B-C fault at 5.45 km from Bus 2 with fault resistance of 30 ohm at time 51.3891ms

(b) Reverse section output and Forward section output during phase B-C fault at 0.55 km from Bus 2 with fault resistance of 10 ohm at time 51.3891ms

The regression plot and performance curve prove that the training is accurate. After training, testing is done by taking single fault resistance, single fault inception angle and single fault length with one type of fault. The test result for fault classification is shown in figure in which taken same parameters as used in fault detection. In fault classification the relay operates for forward direction, the results shows for forward section only. *Figure 7* shows the testing result at 0.55 km forward section from bus 2, 10 ohm fault resistance, 30 degree fault inception angle and phase BC-G (ground) fault, the outputs of figure show that Phase-B goes high(1) at 52.48ms time, Phase-C goes high(1) at 52.48ms time and G (ground) goes high (1) at 52.48ms time with other output phase-A goes low (0) and conforming that it is double line to ground fault (BC-G).



**Figure 7** Test result for BC-G fault at 0.55 km from Bus 2 at fault inception time is 51.3891ms and fault resistance of 10 ohm

## 6. Conclusion and future scope

The proposed method is simple and accurate technique for fault detection, fault classification and section identification (forward or reverse) which gives successful result under various fault conditions. The fundamental components of three phase voltage and current are used as an input to the neural network. For training Levenberg-Marquardt, backpropagation algorithm is used in neural network. Advantage of the proposed method is suitable for different fault conditions such as fault resistance, fault inception angle, fault type, fault distance, etc. The result gives high accuracy and exact operation of proposed fault detection, classification, section identification approach. With advent of smart grid technologies, the use of ANN based relays will help in fast fault analysis replacing the conventional relays and the use of D-STATCOM will help to maintain the voltage profile thereby increasing the reliability over distribution network.

## Appendix

System Parameters of Figure 2 (Base MVA=100)

A 3-phase ac source:

Rated voltage: 25kV

Line parameter of 21km Feeder:

Positive sequence resistance: 0.1153  $\Omega$ /km

Zero sequence resistance: 0.3963 $\Omega$ /km

Positive sequence inductance: 1.048e-3 H/km

Zero sequence inductance: 2.730e-3 H/km

Positive sequence capacitance: 11.33e-9 F/km

Zero sequence capacitance: 5.338e-9 F/km

Line length: 21km

Line parameter of 2km Feeder:

Positive sequence resistance: 0.1153  $\Omega$ /km

Zero sequence resistance: 0.3963 $\Omega$ /km

Positive sequence inductance: 1.048e-3 H/km

Zero sequence inductance: 2.730e-3 H/km

Positive sequence capacitance: 0 F/km

Zero sequence capacitance: 0 F/km

Line length: 2km

25kV +/-3 Mvar DSTATCOM:

DC voltage (controller): 2400

Cut off frequency: 2000

Capacitor: 10000e-6 F

Transformer:

Rated voltage: 25kV/600V

Load:

Load1: 1MW

Load2: variable load

Nominal voltage: 600V

Current: 3000 amp

Sample time: 4e-5 s

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## Conflicts of interest

The authors have no conflicts of interest to declare.

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