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# A Neural Network Based Fault Locator Algorithm for Series Compensated Transmission Lines

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**ABSTRACT:** The electrical faults on transmission lines are detected and isolated by the system protective devices. Transmission lines with series compensators require more attention and special protection settings. Once the fault has been cleared, outage times can be reduced. This paper demonstrates the usage of artificial neural network (ANN) for extra high voltage (EHV) series compensated transmission line fault location. The results show that the proposed ANN is promising and very accurate for fault location estimation. Furthermore, the ANN for the compensated line by one three-phase bank has been presented. In addition, a new fault detection and location method have been extensively tested using MATLAB software for a 400-kV, 300-km transmission line. The results demonstrated a high accuracy and robustness of the ANN-based algorithm. Fault detection, types, locations, path resistances and the fault inception angles are studied. The different power system data currents, voltages, capacitances, angles and time constants of the sources are covered. Experimental results were provided to confirm the theoretical results which coincided perfectly together. The results of the present work were complied and clarified with other works.

**Keywords:** *artificial neural networks, fault detection, fault location, series compensation, and transmission lines.*

## 1. INTRODUCTION

Electrical power transmissions from the generating plants via transmission lines while keeping some important parameters are very necessary. These parameters are voltage, current, resistance, conductance and impedance. The electrical fault on transmission lines is one of the important studies, and thereby the transmission line fault location has been the subject of interest to more researchers [1]. For this reason, if a fault occurs on an electrical transmission line, it is very important to estimate it and to detect its location in order to make necessary repairs and to restore the outage part as soon as possible. Determining the accurate fault location helps expedite service restoration, reduce outage time, operating costs, and customer complaints. During the last decade a number of fault location algorithms have been developed. The researchers classify it according to the nature of the transmission line,
nature of technical method and the power transmission circuits to eight types. Accordingly, there are series compensated line, phasor measurement units (PMUs), wavelet transform, number of terminal (three-terminals/two-terminals|), artificial neural networks (ANN) travelling wave, status of measurement data (synchronized
unsynchronized) and voltage level (H.V/M.V). Series compensated lines are widely used for long transmission lines in order to increase the capacity of power transfers and improve the transient stability.

Accurate fault locating algorithms for series compensated lines were presented [2, 3]. They performed two ways of synchronization of measurements. An algorithm using the generalized fault loop model leading to compact formulae has been developed [4]. A combined fault location scheme for three-terminal transmission lines using wavelet transforms (WTs) is presented [5, 7]. The global performance of the proposed fault location technique based on travelling waves using both synchronized (three terminals) or local end data (one terminal) was highly satisfactory concerning accuracy and speed of response. The three-terminal power lines fault locators are applied [8]. Estimation of the distance to the fault and indication of a faulted section are performed using three-phase current from all three terminals. Additionally, three-phase terminal voltages at the fault locations are installed.

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Neural fault detector and locator were trained using various sets of data available from a selected power network model. Three fault locators are proposed and a comparative study of the proposed fault locators is carried to determine the best ANN fault locator structure [9]. The artificial neural networks could be used for on-line fault detection and location in transmission systems. In case of travelling wave, presented by an algorithm of fault location for the existence of series capacitors, fault resistance, fault type and any existing mutual coupling between

the lines. Simulation results show a good correlation between the actual and estimated fault locations for all cases study [10]. The based on voltage level (H.V/M.V) is tested and a digital fault location and monitoring technique for overhead power distribution lines with laterals are presented [11]. This technique is based on the utilizing of the fault voltage and current samples obtained at a single location of a typical distribution system with laterals. These are filtered after the analogue to digital conversion process by using digital filtering techniques to obtain power frequency components of voltage and current samples. In case of statistical algorithm fault location algorithms utilize statistical information about the undefined parameters such as equivalent impedances of the system at the unmonitored end of the transmission line or those containing random errors [12]. Knowledge about the distribution of these results are more accurate fault location for lines with grounded neutral, especially in case of distant short circuits through a large transient resistance. The algorithms calculate not only the expected value of the distance to the fault, but also another important additional characteristic for the fault location, namely, the length of the line segment, where the short circuit is occurred.

Many successful applications of (ANN) for power systems have been demonstrated, including security assessment, load forecasting, control, etc. This work deals with the fault detection and fault location of transmission line equipped with series compensated unit.

## 2. SERIES COMPENSATED TRANSMISSION LINE

The series compensation has been proven to be a quite advantageous approach in long-distance power transmission. In Fig (1), by reducing the transmission line inductive reactance, the power transfer capacity is enhanced, losses are reduced, and the steady state as well as transient stability of the system is improved. Due to the adding of a string of compensation, the traditional protection system faces the problems of changes in the parameters of the system. These changes are abrupt variations in line impedance at the point of compensation, voltage or current inversion, generation of sub harmonic frequencies, and change in compensator impedance due to the capacitor over voltage protection arrangements [13-16]. Therefore, the protection system needs to be redesigned to cater these changes.

Now, it is well known that, for successful operation of any digital distance protection scheme, accurate knowledge of phases involved in the fault (fault type) is absolutely necessary [16 - 18].

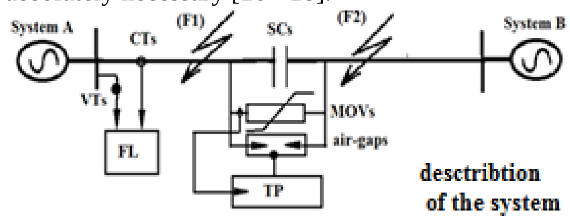



Fig (1) A schematic presentation of a series compensated line [1].

## 3. ANN BASED FAULT LOCATION ALGORITHM

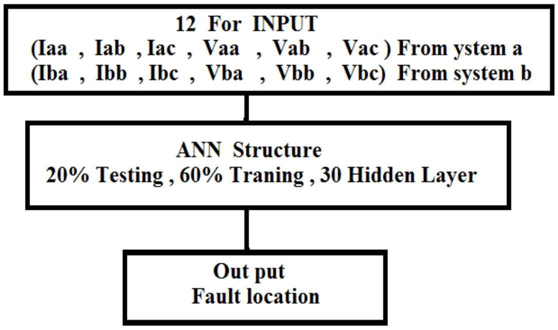
The fault location problem in transmission lines using ANN consists of a neural network that allows obtaining the position of the fault using a number of electrical parameters measured in a line terminal. These parameters are the values of voltages and currents during fault and pre-fault in steady state. Due to the fault type, the voltage and current values are going to be very different. This divides the fault location problem into two steps: step 1 the fault classification and step 2 the fault location. ANN has three interconnected layers. The first layer consists of input neurons. Those neurons send data to the other layer, which in turn sends the output neurons to the third layer named training layer. An artificial neural network, involves choosing from allowed models for which there are several associated algorithms. Fig (2) explains the three layers of neurons net which help find the accurate fault location in the present work.

The design process of the ANN fault detector and locator goes through the following points:

1. Preparation of a suitable training data set that represents cases that the ANN needs to learn.
2. Selection of a suitable ANN structure for a given application.
3. Training the ANN.
4. Evaluation of the trained ANN using test patterns until its performance is satisfactory.

Many successful applications of ANN for power systems have been demonstrated earlier, including security assessment, load forecasting [9].

Regarding Fig (1), the fault detection task can be formulated as a pattern classification problem. The fully connected three-layer feed neural network (FNN) is used to classify faulty data sets and the error backpropagation algorithm is used for training. The numbers of neurons in the input and hidden layers are selected empirically through extensive simulations. Various network configurations are trained and tested in order to establish an appropriate network with satisfactory performances, such as the fault tolerance, time response and generalization capabilities. In order to construct a good neural network system, it is vitally important to train and test it correctly.



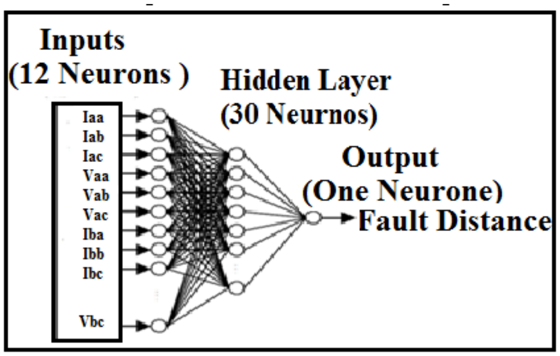




Fig (2) Simple neural network is containing three layers.

With supervised learning, the ANN is trained with various input patterns corresponding to different types of fault (a–g, b–g, c–g, a–b–g, a–c–g, b–c–g, a–b, a–c, b–c, a–b–c and a–b–c–g, where a, b, and c are related to the phases and g refers to the ground) at various locations for different fault conditions (fault inception angles, fault resistances) and different power system data (source capacities, source, voltages, source angles, time constants of the sources) as resumed in Table 1.

Major functional blocks of the proposed fault detector and locator are shown in Fig ( 3). Voltage and current signals at the transmission line (relay location) will be acquired by the relay through series compensated (SC). After pre-processing, both signals will be fed to the fault detector to detect a fault, and if the fault is detected, the fault locator estimates the distance to the fault in the transmission line. The proposed fault detector is designed to indicate the presence of fault. The occurrence of the fault is determined by identifying the power system state directly from instantaneous current and voltage. The fault locator is designed to estimate the distance of the fault in the transmission line using the fundamental phasor magnitude of the voltage and current signals. The fault detection and the fault location use only one terminal line data extracted at the relay location.

**Table 1: Parameter settings for generating training patterns.**

| Type of system | 300 | 1000 |
|---|---|---|
| Fault location FL(km) | 300 km of 10, 40, 80 , 100,140,230,250 ,290 km | 1000 km of 50, 150, 250, 350, 450, 550, 650, 750, 850, 950 km |
| Fault inception angle _f (deg) | 0 and 90 | 0 |
| Location of SC | 150 km | 500 km |
| Fault resistance Rf (Ohm) | 0.01, 1, 10 and 100 | 0.01 |
| Source capacities [ c1 c0 ] | [13 E-9 , 8.5 E-9] | [13 E-9 , 8.5 E-9] |
| Source voltages (Vrms Phase to phase) | 400 kV | 400 kV |
| Time constants of the sources | 1.4 s | 1.4 s |

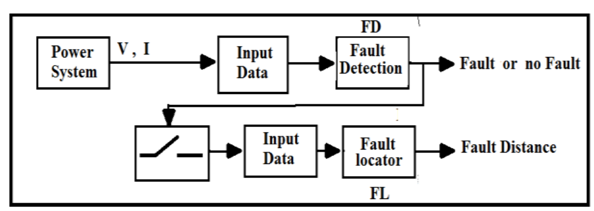



Fig (3) Major blocks constituting the fault detector and locator

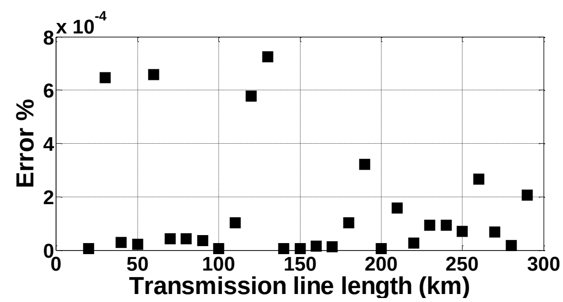
A good ANN fault detector is obtained when the response time is minimal, the ANN output values are stable in the normal conditions, and capable of providing fast and accurate fault detection in a variety of fault situations. The only means of verifying the performance of a trained neural network is to perform extensive testing. After training, the neural fault detector is then extensively tested using independent data sets consisting of fault scenarios never used previously in training. As mentioned before, the fault detector performances are evaluated in terms of the response time of the fault. The best performances are obtained when the response time is minimal value.

## 4. NUMERICAL VERIFICATION OF THE PROPOSED ALGORITHM

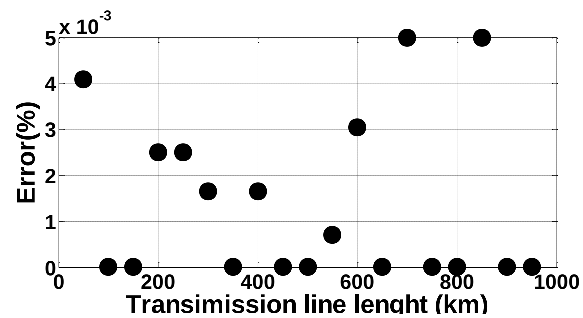
In this section, the performance of the proposed ANN-based fault location and fault detection are addressed. The system under studying is composed of a double end fed transmission line. In order to perform these operations some analysis must be done to compare the algorithm operation. The fault location algorithm that can provide both fault classification and location is an ideal reference for the correct fault location operation. The algorithm can be incorporated into an automated fault analysis by providing high speed indication of the fault type and fault location [11]. The transmission line under consideration is 300 km, 400kV equipped with a series compensated unit that represents the equivalent source impedance. The system is simulated using MATLAB software package, and in which the transmission lines were simulated using the distributed parameters model, while local and remote end sources are simulated also. Modelling of the series compensator protection (MOV) and capacitive voltage transformers have been considered.

To verify the performance of the proposed algorithm for fault location, the algorithm has been tested under different sets of transmission line lengths. e.g. 600, 800 and 1000 km. The transmission line has been extended between two sources as shown in Fig (1). The proposed fault detector is designed to indicate the presence of the fault. The occurrence of the fault place is determined by identifying the power system state directly from instantaneous current and voltage data. The fault location is designed to estimate the distance of the fault in the transmission line using the fundamental phasor magnitude of the voltage and current signals.

The ANN-based fault location uses the magnitudes of the three phase voltages (|Va|, |Vb|, |Vc|) and phase currents (|Ia|, |Ib|, |Ic|) corresponding to the post-fault fundamental frequency (50 Hz). The output of the ANN fault locator is the estimation of the fault location (in km) in the transmission line. It should be mentioned that the input variables have to be normalized in order to fit into the ANN input range. The output of the ANN fault location is the fault location on the transmission line. The structure of each fault locator corresponds to the number of neurons in the input, hidden and output layers. The number of neurons in the input layer corresponds to the number of the input variables to the ANN. All faults are located correctly and precisely after several cycle delays. The reason for the good estimation of fault distance is the extensive body of training patterns. The ANN based fault locator results for the faults with different system conditions and parameters are presented and the errors of fault distance are calculated. The ANN fault location is to locate faults in our transmission line. The fault location is activated when a fault is detected by the fault detection. The ANN forms the fault location using the magnitudes of the voltage and current phasor corresponding to the post-fault fundamental frequency as inputs to the ANN. Fig (4) (a) and (b) show the results of the diagram for the fault location for 300 km and 1000 km respectively.




(a)




(b)

Fig (4) The fault detection values for:
(a) 300 km and (b) 1000 km.

## 5. EXPREMENTAL VERIFICATION OF THE PROPOSED ALGORITHM

The proposed neural network-based on fault detector and fault locator for transmission line of 400 kV. The transmission line length is 300km has been studied. Increasing the length of the transmission line from 600 km to 1000 km in a step of 200 km is done to verify the results of the main line. The transmission line is extended between two sources as shown in Fig (5). The fault locator is put before and after the SC unit but in case of the fault location, it will be put after the series compensation. The construction of the SC unit will change the evaluation performance of the proposal that is represented by distributed parameters and the frequency dependence on the line parameters were taken into account. The proposed fault detector is designed to indicate the presence of the fault. The occurrence of the fault is determined by identifying the power system state directly from the instantaneous current and voltage. The fault locator is designed to estimate the location of the fault in the transmission line using the fundamental phasor magnitude of the voltage and current signals.

of fault distance is the extensive body of training patterns.

The ANN based fault locator results for the faults with different system conditions and parameters are presented and the errors of fault distance are calculated.

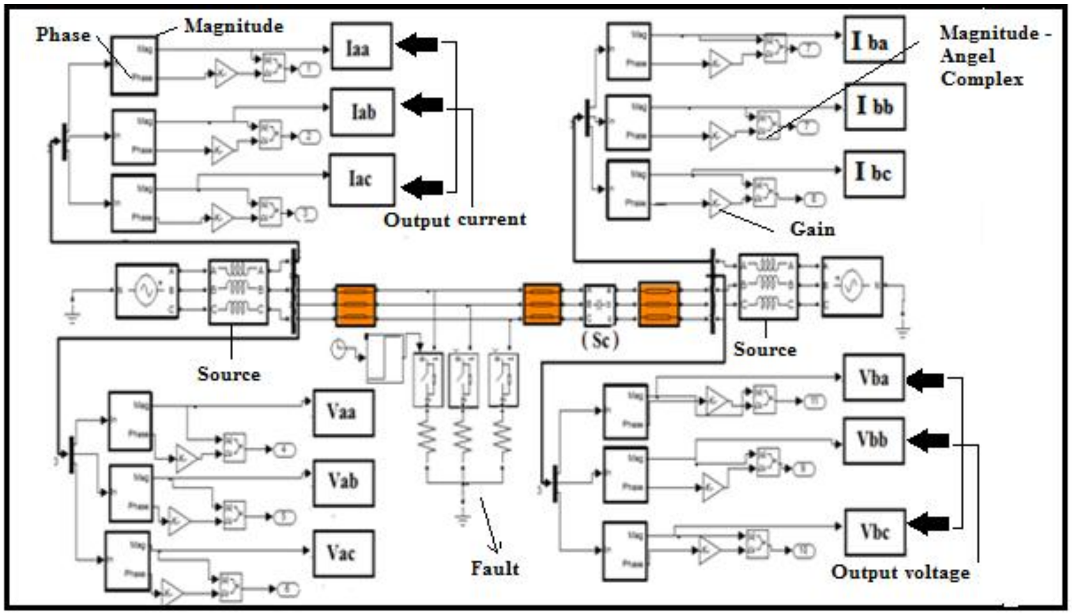



Fig (5) Construction of generation power system with series compensated unit.

## 6. POWER SYSTEM NETWORK SIMULATION

A 400 KV power system is simulated using Matlab® Simulink and Matlab® Power System toolbox. Sim Power System toolbox for various types of faults is used with different system conditions and parameters. The triple-line diagram of the system under study is simulated using the suggested construction as shown in Fig (5).

## 7. RESULTS

After training, the neural network based fault locator is extensively tested using independent data sets consisting of fault scenarios. For different faults of the validation/test data set, fault type, fault location and fault inception time and power angles are changed to investigate the effects of these factors on the performance of the proposed fault location. Extreme cases like faults near the protection zone boundary including fault resistance are also included in the validation data set. The network is tested by presenting in different locations of faults along the transmission line with different fault types, different fault locations, fault inception and different transmission line lengths. All faults are located correctly and precisely after several cycle delays. The reason for the good estimation

### 7.1 TRAINING TESTS ON THE NEURAL FAULT

The training tests of the neural fault are as shown in Table 2.

**Table 2: Training tests of the neural fault**

| Type of system | 300 | 1000 |
|---|---|---|
| F | 50 Hz | 50 Hz |
| Source voltages (Vrms Phase to phase) | 400 kV | 400 kV |
| Fault inception angle _f (deg) | 0 and 90 | 0 |
| Location of SC | 150 km | 500 km |
| Fault resistance Rf (Ohm) | 0.01, 1, 10 and 100 | 0.01, 1, 10 and 100 |
| Source capacities[ c1 c0 ] | 94.5 , 308 | [13 E-9 , 8.5 E-9] |
| Time constants of the sources | 1.4 s | 1.4 S |

### 7.2 INPUTS AND OUTPUTS

The ANN based fault locator uses the magnitudes of the three phase voltages (|Va|, |Vb|, |Vc|) and phase currents (|Ia|, |Ib|, |Ic|) corresponding to the post-fault fundamental frequency (50 Hz). The output of the ANN fault locator represents the estimation of the fault location in km.

## 8. DATA DEDUCTION

The ANN fault locator is used to locate faults in our transmission line. The fault location is activated when a fault is detected by the fault detector. The ANN forms the fault location using the magnitudes of the voltage and current phasors corresponding to the post-fault fundamental frequency (50 Hz) as inputs to the ANN. Figures (6, 7) show the results of the diagram for the fault location.

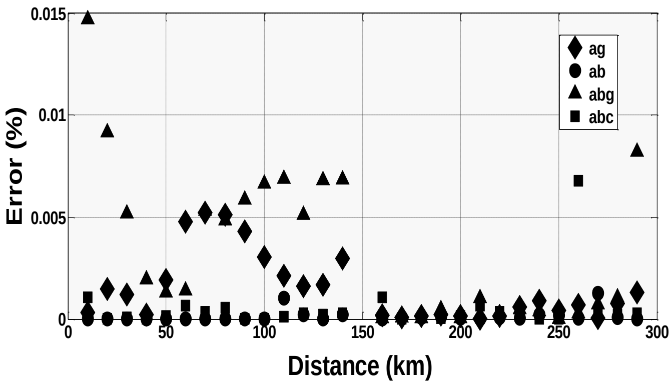
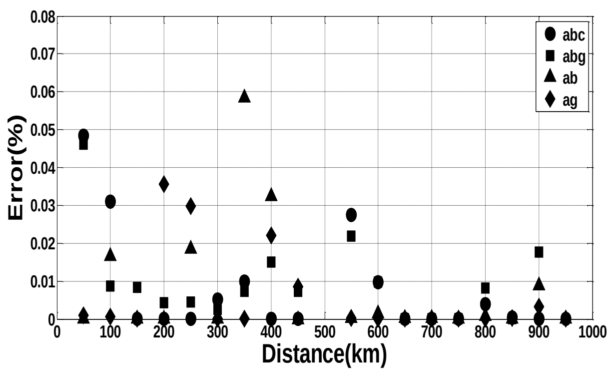



Fig (6) Fault location error for a 300 km transmission line




Fig(7) Fault location error for 1000 km transmission line

The output value of the neuron in the output layer with the linear activation function are calculated and plotted as shown in Fig( 4) for the transmission line of 300 and 1000 km. Fig( 6) shows the fault location on the 300 km transmission line used and Fig( 7) shows the fault location on the 1000 km transmission line used. Fig(5) are explain the phase faults a , b , c for the three lines before and after the series compensator unit for the two transmission lines used.

## 9. EXPERIMENTED TEST SYSTEM

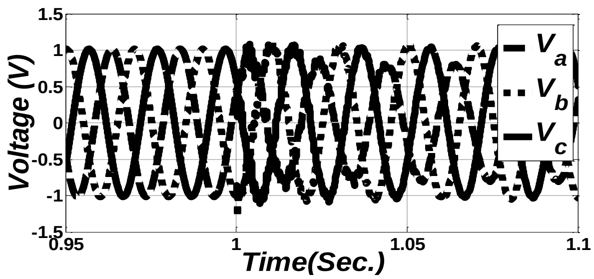
For data acquisition, National Instrument-Data Acquisition Card (NI-DAQ) has been installed at both transmission line module ends. NI-DAQ collects the three-phase voltages and currents from both line ends and send the obtained data as a string to a central PC for essential analysis. The transmission line module has been divided different sections, e.g. 36-km, 100-km, and 360-km. The transmission line compensated with capacitor bank unit at the middle of line as shown in Fig (1).The capacitive compensation levels equals 82% according to changing the firing angle. The over voltage protection of thyristor controlled series capacitor (TCSC) is provided by connection of the metal oxide varistor (MOV) across it. The MOV reference voltage ($V_{REF}$) is calculated as (2-3) times of the nominal capacitor voltage, taken at the minimum capacitive compensation level and the maximum line current. The parameters of the used system, TCSC and MOV, are given in Table (1). The test systems have been modelled for computer simulations in MATLAB/ Simulink environment. The examples of recorded waveforms from simulation of test system in different operation modes of TCSC during fault conditions are shown in Figs (8, 9). The results obtained are scheduled with the same simulated line length in Table 3 which explains the results obtained during the experiments tests. The results obtained showed that the good agreement between the test results and theoretical results for the same length of the line. The tested and simulated lines are having the same cases of the voltage, line current, impedance and condenser capacity.

**Table 3: Comparison between the tested and simulated lines.**

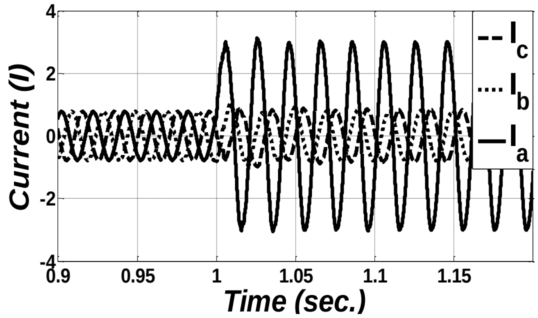
| Line,km | Theoretical | | Practical | |
|---|---|---|---|---|
| | Before SC | After SC | Before SC | After SC |
| 136 | 1.58E-01 | 6.55E-05 | 1.44E-01 | 1.55E-13 |
| 360 | 6.55E-05 | 2.27E-13 | 5.67E-05 | 2.95E-13 |
| 396 | 1.54E+00 | 1.58E-01 | 5.67E-05 | 1.01711 |
| 460 | 1.539375 | 5.67E-05 | 0.13695 | 5.36832 |

The results have been obtained during the experiments of tested lines of 136 km. Fig( 8) shows the line current waveforms, the phase voltages across TCSC, and the MOV current of the faulted phase. The waveforms of a-g at pre and during fault at the middle of line before the MOV when fault resistance Rr equal zero and 82% compensation degree of TCSC. In this condition, the fault current is low and MOV under operation. Fig (9) shows the recorded waveforms for a fault at 25% of line length, with no fault resistance and compensation degree of TCSC. In this case, the fault current is high enough and MOV operates for decreasing the voltage across the TCSC. In this condition, if the absorbed energy in the MOV exceeds its allowable limit and fault is not cleared within a certain time, TCSC will transit to circuit breaker bypass mode.

**a-g Voltage**




**a-g Current**




**MOV Current**

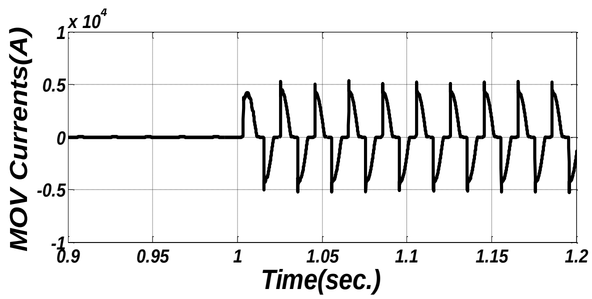
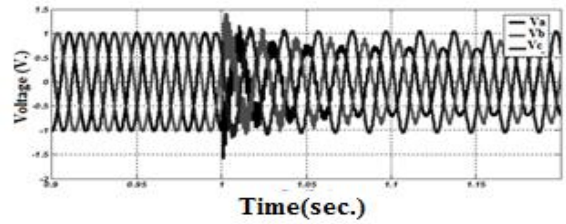



Fig (8) a - g the current, voltage and MOV current wave forms of fault at MOV 136 km transmission line.

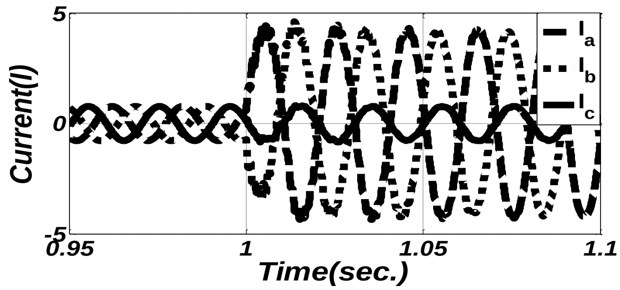
In case of the a-b-g at the middle of the line before the MOV with fault resistance equal to zero and 82% compensation degree of TCSC, the fault current is suddenly increasing and then becoming constant after one minute from the testing time. The same case happened for the voltage. In this condition, if the absorbed energy in the MOV exceeds its allowable limit and fault is not cleared within a certain time, TCSC will transit to circuit breaker bypass mode.

In the case of the simulation for tested line the fault errors are in same limits of the simulated results as shown in Fig (10) which shows the values of errors having nearly the same values.

**a-b-g Voltage**




**a-b-g Current**




**MOV Current**

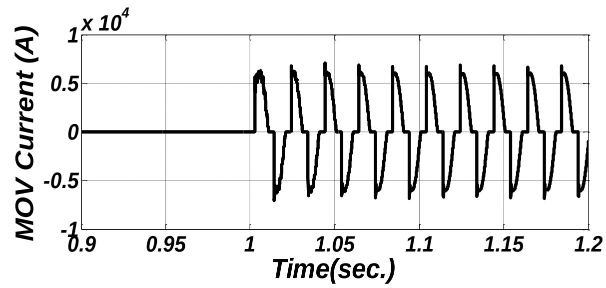



Fig (9) a-b-g The current, voltage and MOV current wave forms of fault at 136 km transmission line.

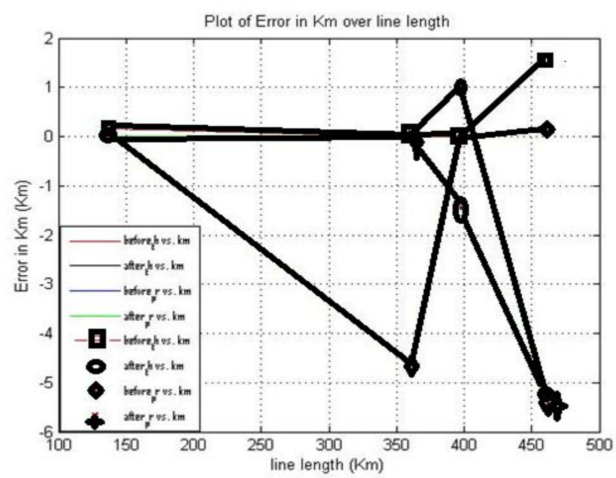



Fig (10) The fault error of the line tested and simulated line at the same line length

## 10. RESULTS

Study of previous work in the field of the present research revealed that Sami Ekici et-al [19] has the same results that have been obtained in the present research. These results provided research to find 400 volts and 200 kV. Table 4 shows the results for all of the tested three lines

The results of previous work of S. Ekici et-al [19] are plotted in Fig (11). To insure the present work results, it is necessary to confirm these results by measuring the standard deviation of these results. Table 4 shows the standard deviation of the obtained reading. Fig( 12) shows the plotted readings.

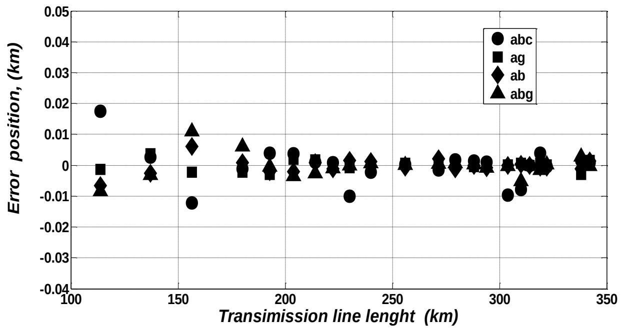



Fig (11) S. Ekici et-al Results [19]

Table 4 Standard deviation readings according to the phase fault type.

| Distance \ Phase | Ab | Abc | Abg | Ag |
|---|---|---|---|---|
| 300 | 17.897957 | 37.1075 | 46.9565 | 16.847 |
| 600 | 109.32411 | 67.3436 | 491.973 | 136.29 |
| 1000 | 138.44173 | 226.038 | 715.612 | 337.78 |

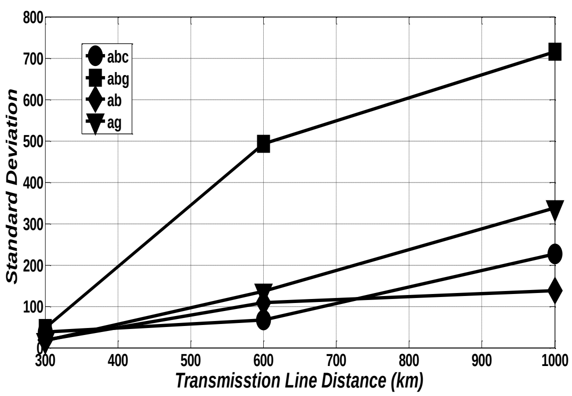



Fig (12) The plotting points of standard deviation according to Table 4.

## 11. CONCLUSIONS

In this paper, a proposed fault location and detection algorithm for series compensated transmission line was presented and discussed. The fault location and detection scheme is mainly based on one of the most artificial intelligent techniques robustness and availability, neural network. The algorithm used is theoretically examined under different cases to ensure accurate results, using MATLAB software package. All results that show the robustness response of the algorithm have been presented. In most cases, the error is found to be from 0 to 0.016 %. In addition, the algorithm has been examined experimentally, at different fault locations (rear and in front of the compensation capacitor) using laboratory equipment, and the essential results have been presented as well. It is mentioned that worthy, the laboratory transmission line model is built based on real data, and the data acquisition card (NI-DAQ PCI-6229) is manufactured and calibrated by National Instrument Company (NI). Finally, the proposed fault locator algorithm is superior and considers a reliable solution for power system utilities which may have SC lines.

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