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Detecting HVDC Fault Locations Using Deep Neural Networks

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Abstract

With a continuous escalation in demand of power, the Indian Electrical system is in constant demand for long transmission lines to fulfill its requirement due to extremely distributed demand and generation location. Advanced HVDC system is one such possibility that finds its utility, especially during long-distance transmission. Such electrical transmission systems are prone to short circuit faults, which subsequently leads to a large current, which will eventually harm or damage the system's equipment. Thus, the system requires a quick restoration in order to reestablish power transmission and assure system safety. Hence, the objective of this work is to develop a model, which can precisely assess the location of the fault. The work intends to cultivate a model, which will not only provide accurate results but is also collectively optimal. A Bi-polar transmission line 814 km long and operates at 700 kV, with the ability to transfer 1500 MW of power, developed on PSCAD/EMTDC software based on CIGRÉ benchmark guidelines. The designed model is further simulated for short circuit fault with fault ON resistance of 0.01 Ω and fault OFF resistance of 1.0 x 10^6 Ω with varying fault location along transmission line at an interval of 1 km. The acquired data collected and processed for feature extraction. Data from both the ends of the transmission line is used for training and testing of deep neural network models. The evaluation of the proposed system has been done based on the mean squared error and accuracy of fault estimation. The error obtained during testing are in the range of 1-2 km, which is outperforms contemporary baseline approaches.

Keywords:

HVDC, Fault Location, Machine Learning, Deep Learning, Mean Squared Error, Accuracy.

1.Introduction

In the present era of deregulation and competition, demand from every energy supplier is to have good continuity, dependability and reliability. Fault location can play a vital role in achieving this aim. As uninterrupted power supply is the prime demand by all consumers. However, faults in power system will leads to the interruption in power supply and it will make system vulnerable towards system outrage/collapsing and will lead to damage various electrical peripheral of switch gear/ electrical equipment. Hence all faults are required to be detected and clear as soon as possible to restart power supply to consumer. Having accuracy knowledge of fault location will come very handy in reducing system outrage time and they're by improving continuity and reliability of system.

Various researches have been done previously towards finding accurate result. In this work, location detection using the mathematical neural network technique is presented. The goal of the work is to prepare a model which can somehow manage to give accurate fault location on HVDC line thus helps in improving the system performance. The proposed work is designed with a motivation to achieve higher accuracy of detection compared to existing work.

2.The HVDC Transmission System

HVDC stands for High Voltage Direct Current. It is generally used for bulk power transmission over long distances.

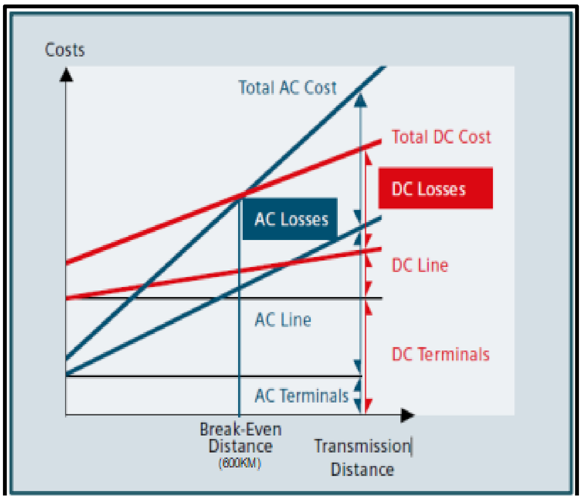

Figure 1 Cost of HVAC vs HVDC

Following are some of the key points which make HVDC an effective counterpart for HVAC:

1) Power Transmission capacity of HVDC is about 30%-40% more than HVAC for same width of conductor.
2) Transmitting DC over long distance is comparatively far much cheaper than 3 phase AC over same distance due to cheap tower and fewer conductors and low losses.
3) DC transmission has no limits over power transmitting distance because HVDC has no reactance and stability problem. Transmission Tower design of HVDC is comparatively simple.
4) Losses in HVDC over long distance is almost 30-40% less than HVAC of same voltage level because of very less corona loss and zero skin effect.

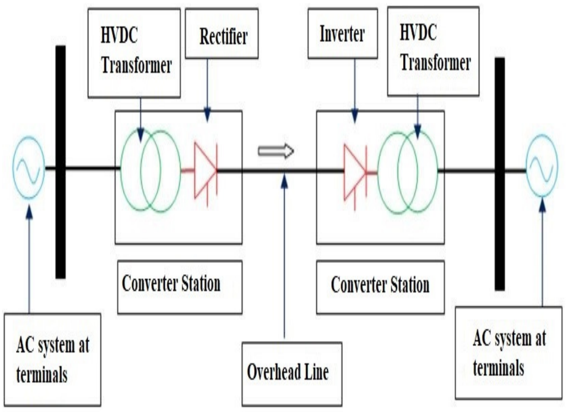

Figure 2 The HVDC System Model

Traditionally, in HVDC transmission (500kV-600kV) the losses accounts for almost about two -three times less than its counterpart HVAC for same amount of power leading to the savings of a large amount of power which can be utilized for the far remote areas of our country where still continue supply electricity is a big challenge due to shortage of electricity.

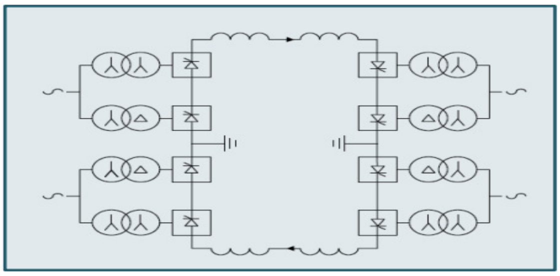

Figure 3 Schematic for Bipolar HVDC System

3. Fault Estimation Using Neural Networks

The goal of this study is to develop a model using machine learning tool to locate fault in bipolar HVDC system. Also, it is desirable from model to perform about duty quickly and effectively and precisely. This study is also carried out carried out to check the effectiveness of neural network in solving our present fault location detection problem for HVDC transmission line. ANN is utilized in excellent property to recognize patterns in non-linearity, it’s robustness and its quick operation. The main objectives of the proposed work are:

- Designing a base model for HDDC on PSCAD.
- Generating faults on the T-Line and collecting voltage and current values for **Generator and Load sides.**
- Designing a mathematical neural network model and training it with the data variables for generator and load side (**Voltage and Current Values)**
- Testing the model and computing mean square error (**MSE)** and Accuracy.
- Obtaining lower error and higher accuracy compared to existing systems.

Artificial Neural Networks (ANN) are one of the most effective techniques for time series or regression problems. The output of the neural networks is given by:

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$$y = f(\sum_{i=1}^{n} x_i w_i + \varphi) \quad (1)$$

Here,
y is the output
x are the inputs
w are the weights
φ is the bias
f stands for the activation function

The commonly logic or activation functions used are the sigmoid, log sigmoid, tangent-sigmoid, rectified linear (ReLu), step or hard-limiting function etc. The mathematical model for a neural networks is depicted in figure 3.

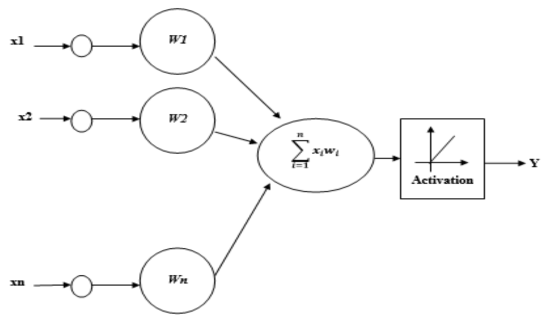

Figure 4 Mathematical Equivalent of Neural Network

The ANN which contains multiple hidden layers and is used for extremely complex pattern recognition problems. The HVDC system would be designed in Power Systems CAD Softtware (PSCAD). PSCAD (Power Systems Computer Aided Design) is a versatile simulation tool for Studying Power system transients. Manitoba HVDC Research Centre has developed this software by the intension of creating a tool which is specifically dedicated toward power system simulation with instantaneous results.It is also known as PSCAD/EMTDC. The GUI of PSCAD significantly increases the power and efficiency of simulation. It allows the user to schematically build a circuit, run a simulation, analyze the results, and manage the data in an entirely unified graphical environment. This tool provides flexibility to simulate model ranging from nanoseconds to seconds. PSCAD finds wide application in planning, operation, design and commissioning.

Previous research papers indicate that the following parameters can be analyzed to estimate faults in HVDC systems:

1. Rectifier side AC Voltage
2. Rectifier side AC Current
3. Rectifier side DC Voltage
4. Inverter side AC current
5. Inverter side AC Voltage
6. Inverter side DC Voltage
7. Distance of fault from Generator (Dependent Variable)

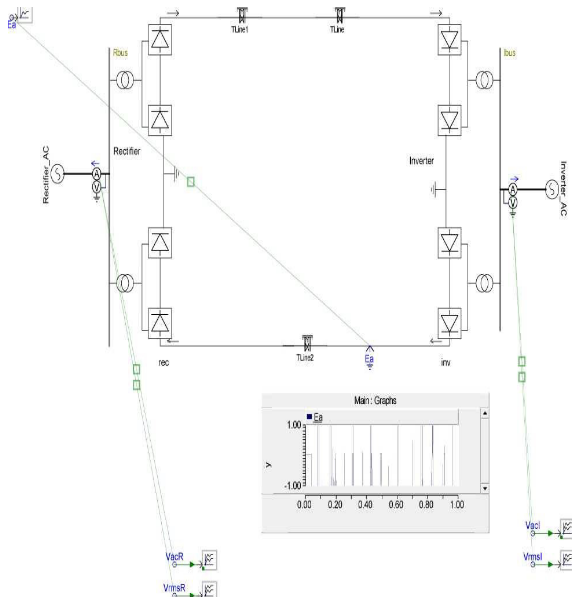

Figure 5 The PSCAD Model for HVDC

It is necessary to train the neural network is such a way that it attains convergence in less number of iterations.

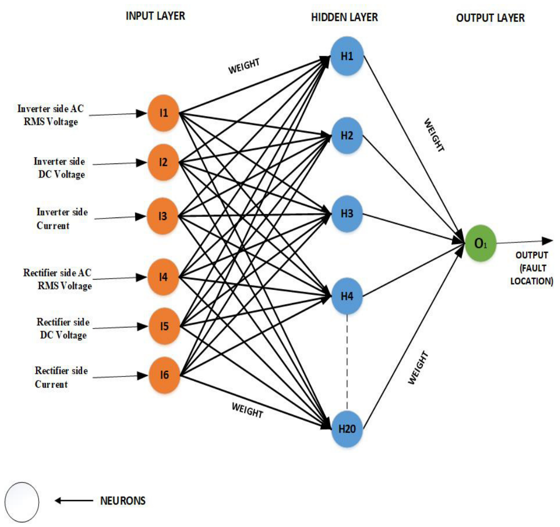

Figure 6 The Neural Network Model

In the previous approaches, there are several techniques and mechanisms to train a neural network out of which one of the most effective techniques is the back propagation based approach. The flowchart of back propagation is depicted in figure 7.

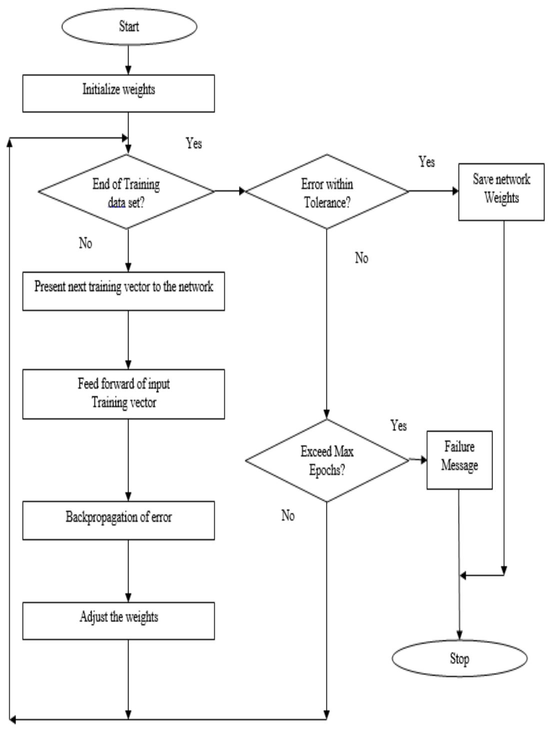

Figure 7 Back Propagation in Deep Nets

The benefit of the back-propagation based approach is the use of the feedback mechanism from the out of the neural network to the input of the neural network thereby affecting the training in each iteration with the error of the previous iteration. This helps the neural network not only in finding patterns in large and complex data sets but also learn from its own errors. Mathematically, it is given by:

$$Y_k = f(X, e_{k-1}) \quad (2)$$

Here,
Y is the output of kth iteration
X is the input to the kth iteration
e_{k-1} is the error of the (k-1)st iteration
f stands for a function of.

The rate at which the error falls is one of the most critical factors in training a back propagation based neural network. The rate of error decrease in generally designated by a negative quantity and is mathematically represented by the gradient (g). Mathematically,

$$g = \frac{\partial e}{\partial w} \quad (3)$$

Here,
g is the gradient
e is the error
w is the weight
Since the weight varies as a function of iterations (n), clearly gradient is also a function of the iteration number (n)

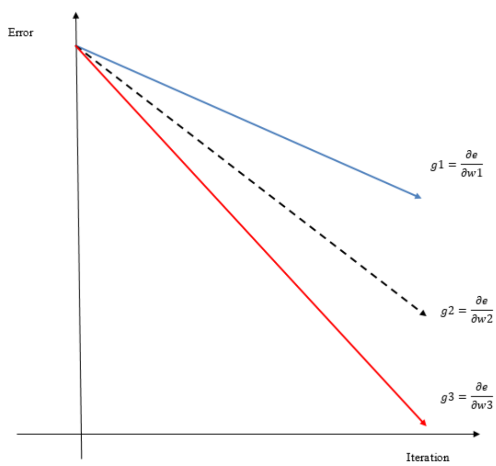

Figure 8 Gradient Descent

4.Simulation Results

The system has been designed for the faulty and non-faulty conditions.

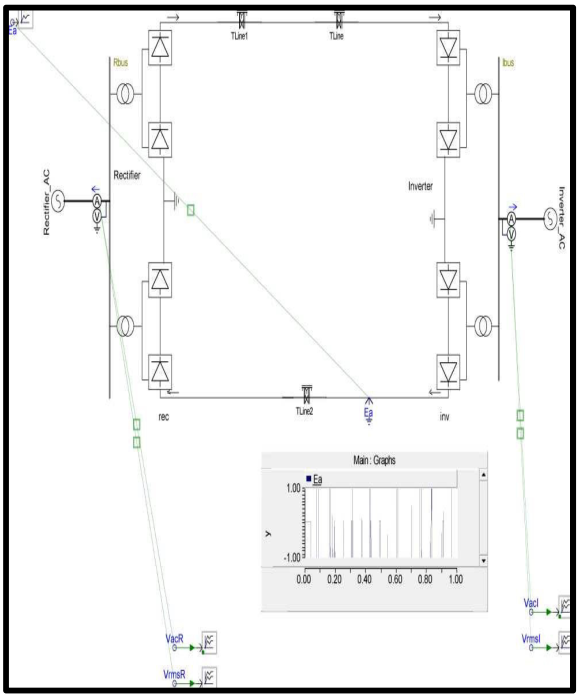

Figure 8 T-Line Section without LG Fault

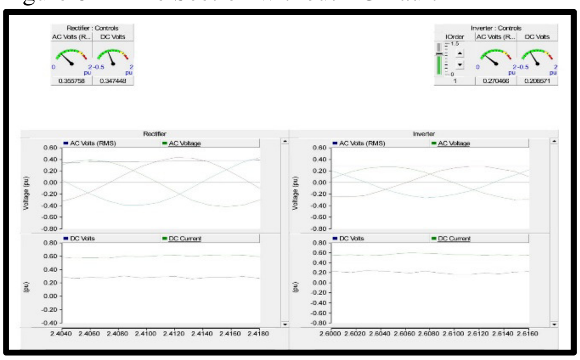

Figure 9 Rectifier and Inverter Voltages and Currents for the NO fault condition

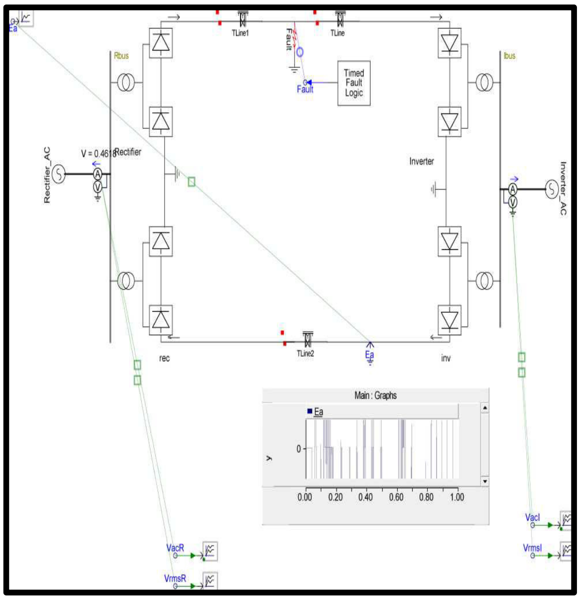

Figure 10 T-Line Section with LG Fault

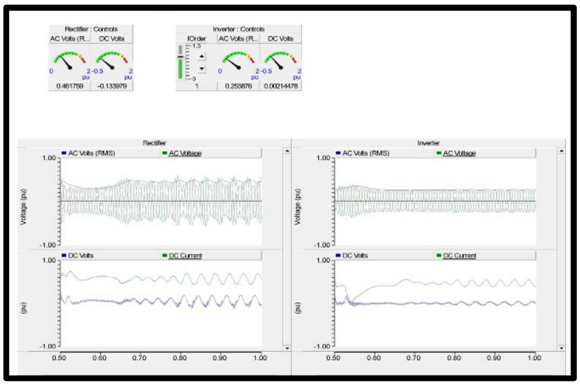

Figure 11 Rectifier and Inverter Voltages and Currents for fault condition

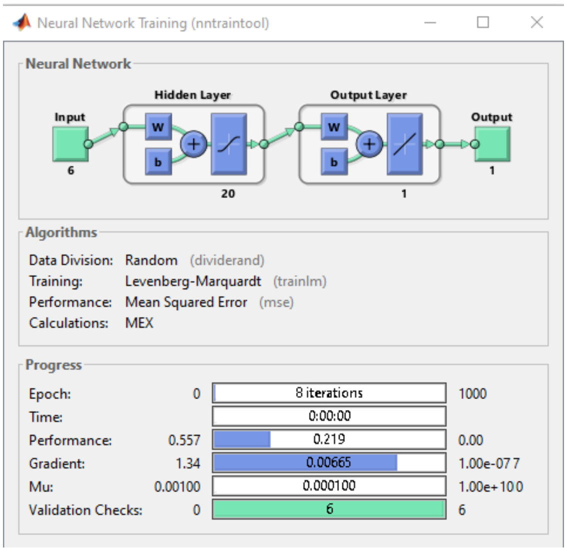

Figure 12 Designed Neural Network Model on MATLAB for fault estimation

Table 1 HVDC Error Analysis

Actual Distance	Estimated Distance	Error
159	160.5	1.56
302	301.3	-0.62
346	344.3	-1.67
458	455.6	-2.31
576	576.8	0.84
684	684.0	0.01
727	727.6	0.67
MAPE	**1.1km**	

Table 1 summarizes the errors in fault estimation for the proposed system. The different between the actual and forecasted fault distances has been used to compute the mean absolute percentage error as:

$$MAPE = \frac{1}{K}\sum_{1}^{K}\left|d_i - \hat{d}_i\right| \qquad (4)$$

Here,
MAPE represents mean absolute percentage error.

d_i represents the actual distance of fault from the generator
$\hat{d}_i$ represents the predicted distance of fault from generator.

5.Conclusion and future work

It can be concluded from the previous discussions that the proposed system is capable of detecting faults in high voltage DC transmission lines based on the neural network model. The rectifier and inverter side voltages and currents for both fault and non-fault conditions have been generated on PSCAD and the correlation among the variables has been analyzed by the gradient descent trained neural network. It can be observed from table 1 that the system attains a mean absolute percentage error of just 1km which is extremely less for a DC transmission line fault location.

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