A Novel Study on Bipolar High Voltage Direct Current Transmission Lines Protection Schemes

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ABSTRACT

In long dc transmission lines identification of fault is important for transferring a large amount of power. In bipolar Line commutated converter transmission lines are subjected to harsh weather condition so accurate and rapid clearance of fault is essential. A comparative study of the bipolar system with both converters healthy and one converter tripped is studied. Most of the research paper has focussed on transmission line faults in bipolar mode but none of them had focussed when HVDC system works in monopolar mode after the fault. In the proposed scheme the voltage signals are extracted from both poles of the rectifier ends and are processed to identify the faults in transmission lines.The Artificial neural network is utilised in detecting the fault in both bipolar and monopolar system. Since it can identify the relationship between input and output data to detect the fault pattern it can be utilised under all conditions. Moreover, benefits of the proposed method are its accuracy, no requirement of the communication system as it acquires data from one end and has a reach setting of 99%.

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1. INTRODUCTION

HVDC transmission line finds widespread application in transmission of bulk power over long distance. The effect of ground impedance in the ac line has a disadvantage that under steady state it can affect the efficient power transfer but DC link has an advantage that ground impedance and its effect is negligible [1]. In [2], HVDC technology and reliability assessments on HVDC systems from a number of papers are reviewed. The paper is reviewed for increasing demand of power and penetration of HVDC system for quantitative assessment of dc link. The dc link can be used as an interconnection between two different frequencies. In [3], effect of discharging current on detection of fault is also considered. Some of the protection scheme is proposed in [4]-[8] but none of them had detected under half voltage operations. These schemes suffers from some of the disadvantages in sensitivity under high fault resistance, close up faults and requires data from both ends. VSC based multi terminals connection in wind farm subjected to dc faults are studied in [9]. In [10], wavelet based fault detection for fast detection of faults in VSC based HVDC is adopted. In [11]-[13] artificial neural network for fault identification is proposed but has not tested under half voltage opearation. Protection scheme is studied in detailed in distributed systems in [14]. In [15], soft computing using fuzzy, genetic algorithm, Back-propagation neural network (BPNN) based algorithm is proposed for pattern identification and maximum power point. In [16] distance protection is suggested for ac systems using Rogowski coil but it has been vaildated for low voltage and lacks in high voltage. In [17] NN based contoller is used for AC/DC systems and its performance are compared with conventional controller. Spectogram is used to identify and classify the harmonic signals in power system in distribution side but has not not discussed in transmission side [18]. In [19] wavelet based MRA is used for detecing the faults but has not been proved for time domain. The traveling wave has inherent problem in detecting the faults at high resistances in [20]. In [21] memory requirement will increase because computation is more and lacks the mathemetical model. High sampling frequency is a drawback and requirement of data from both ends are essential in [22]. This causes delay in time and synchronisation of data. The main contribution of the proposed work is that fault detection in Bipolar HVDC system with dc transmission line faults when one group of converter is tripped has been studied which none of the above paper has described. The paper is organised as follows - Section 2 describes the basic concept of ANN module using BPNN, Section 3 contains HVDC system topologies and the proposed method for fault detection, Section 4 contains the results, Section 5 contains the conclusion of the work.

2. ARTIFICIAL NEURAL NETWORK ANALYSIS

An artificial neural network (ANN) has artificial neurons and has a mathematical model or computational model. A neural network consists of an interconnected group of artificial neurons, and the information is processed as it comes from the neighboring neurons and leads an outcome of the process then neurons decide the output. The ANN system was developed using the MATLAB package for automatic selection. It has input structure for obtaining and processing the data for network training. For verification of trained network, its operations are checked with the results.

If $X_1, X_2, X_3, \dots\dots\dots X_n$ are the input neurons, $w_1, w_2, \dots\dots\dots w_n$ are weighted interconnection links, $(x_1, x_2, x_3, \dots\dots\dots x_n)$ are the activation functions, y_{in} the output are represented using Equations (1)-(3)

$$y_{in} = x_1 w_1 + x_2 w_2 + x_3 w_3 \dots\dots\dots\dots\dots\dots\dots . x_n w_n \quad (1)$$

$$y_{in} = \sum_{i=1}^{n} x_i w_i \quad (2)$$

$$y = (y_{in}) \quad (3)$$

2.1. Pre-processing and feature extraction

Pre-processing of voltage signal involves rms values of the instantaneous voltage signals. HVDC model is simulated using Matlab software and instantaneous voltage samples are obtained at relaying point.

2.2. Training data set

Preparation of training is done on the different location of fault for line to ground faults in bipolar HVDC. Fault Location
Training: 20,60,100,140...................................,940km
Testing: 10,30,50,70..,930km
The total number of voltage samples used for training the neural network is half cycle data from the instant of fault.

3. HVDC TOPOLOGIES

3.1. Asymmetrical monopole

HVDC converter system has mainly two types of topologies Monopolar and Bipolar. The Monopolar HVDC is widely used with earth as ground return.

3.2. Bipolar system

In bipolar system both the poles carry current and is used to transfer large power. It has advantge that fault in one transmission line also causes current to flow through other transmission lines at reduced power. The two converters are connected from the AC source and has advantage that even if one converter is not operating or tripped the other converter carries half the power as shown in Figure 1.

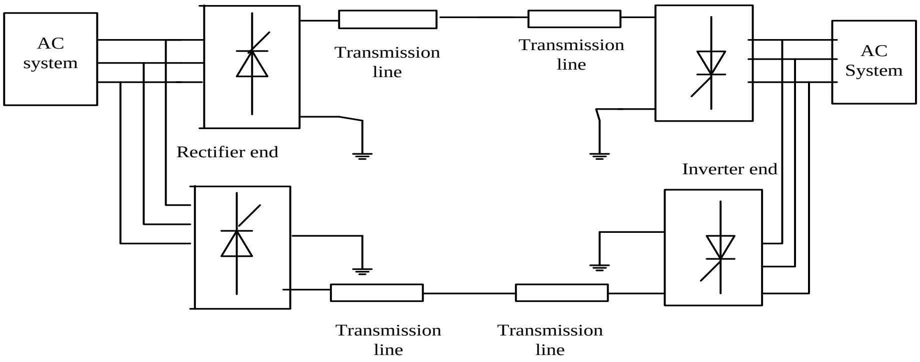

Figure 1. Bipolar system

3.3. Twelve pulse converter

In HVDC transmission 12 pulse converter is preferred and is made by connecting series combination of two bridges. One transformer Y/Y for one bridge and other transformer Y/Δ for another bridge is used for 30^0 phase displacement. The dc link voltage is obtained from the two bridges and is the sum of individual dc voltages [1]. The equations represents various parameters in which e_{aS}, e_{bS}, e_{cS} are the secondary phase voltages from star -star transformer given to bridge1, E_{LL} is line to line voltage, e_{bcS}, e_{acD} is line to line voltage in star connected winding and line to line voltage in delta connected winding, v_d voltage for one interval, V_{dc} is average dc voltage.

$$e_{aS} = \sqrt{\frac{2}{3}} E_{LL} \sin(wt + 150^0) \quad (4)$$

$$e_{bS} = \sqrt{\frac{2}{3}} E_{LL} \sin(wt + 30^0) \quad (5)$$

$$e_{cS} = \sqrt{\frac{2}{3}} E_{LL} \sin(wt - 90^0) \quad (6)$$

$$e_{bcS} = \sqrt{2}\, E_{LL} \sin(wt + 60^0) \quad (7)$$

$$e_{acD} = -\sqrt{2}\, E_{LL} \sin(wt - 270^0) \quad (8)$$

$$v_{d=}\ e_{bcS} + e_{acD} = \sqrt{2}\, E_{LL} \sin(wt + 60^0) - \sqrt{2}\, E_{LL} \sin(wt - 270^0) \quad (9)$$

$$V_{dc} = 2V_{do}\ cos\,\alpha = \frac{6}{\pi}\sqrt{2}\ E_{LL}\, cos\,\alpha \quad (10)$$

3.4. Proposed fault detection method

The proposed method is tested with a power system network designed in MATLAB/SIMULINK for 980km transmission line. Bipolar system is built from monopolar in simulink from 12 pulse thyristorised based converter with power capacity of 1000 MW (500 kV, 2 kA). DC interconnection is used to transmit power from a 500kV, 5000MVA, 60Hz system to a 345kV, 10000 MVA, 50Hz. The following steps are done for the detection of a fault and are shown in the Figure 2.

a. The rectifier end signals with both converters working or pole to pole voltage are taken as an input.
b. The trained data is tested using algorithm backwards propagation neural network after normalising the data.
c. The training network has 30 neurons in hidden layer, tan-sig transfer function with lavenberg marquerdt algorithm as training algorithm.
d. The output layer detects the output.
e. This is tested for transmission line with fault in one converters of bipolar systems and if detects fault then output is HIGH.

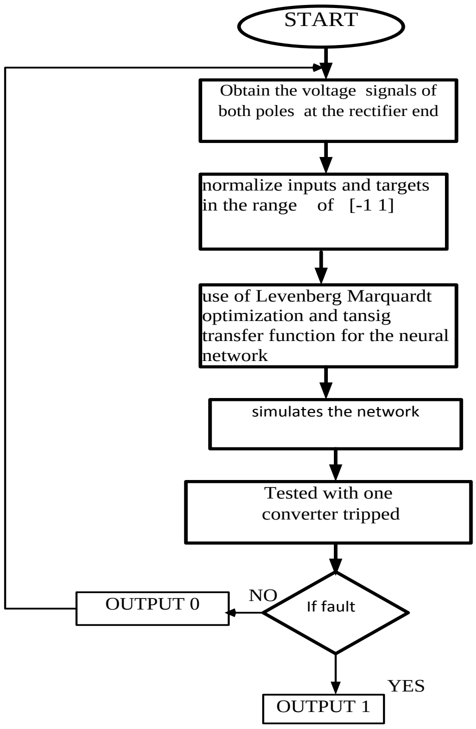

Figure 2. Flow chart for the proposed scheme

4. RESULTS AND DISCUSSIONS

The system under varying parameters are tested and tables are formed. In Table 1 varying fault location and detections results are shown. Bipolar system with both converters and one converter tripped for line to ground fault is verified. In Table 2 and Table 3 near end and far end fault location are tested for verification of results. Table 4 is formed for varying fault resistance because traveling wave protection finds difficult to detect faults for resistance more than 20 ohm. The detection time is calculated and is found to be less than a cycle.

4.1. Performance of the method varying fault location during P1G fault in bipolar sytem and with one converter tripped

For varying fault location 10, 250, 490, 730, 970km with both converter working (bipolar system) and with one converter tripped (monopolar system) transmission line faults are analysed. The output signal becomes high and is shown by Table 1.

Table 1. Performance of the Method Varying Fault Location during P1G Dault

Fault Location(km)	BPNN-D Bipolar with full voltage operation Output	BPNN-D Bipolar with one 12 pulse converter tripped Output
10	1	1
250	1	1
490	1	1
730	1	1
970	1	1

The results are analysed for P1G fault at 250km as shown in the Figure 3. Here fault occurs at 40 ms and is detected in 3ms as shown in Figure 3(c) with both converters working. One of the converter is tripped and fault detection occurs at 4ms as shown in the Figure 3(f). The controller identifies the pattern of fault and is detected within a cycle. In Figure 3(a) pole to pole voltage is shown and when fault occurs the pole voltage decreases. The pattern of fault is same in Figure 3(d) where pole voltage becomes half since monopolar operation occurs. In Figure 3(b) current in each pole is shown and when fault occurs it increases. The pattern of fault is same in Figure 3(e) where pole current increases.

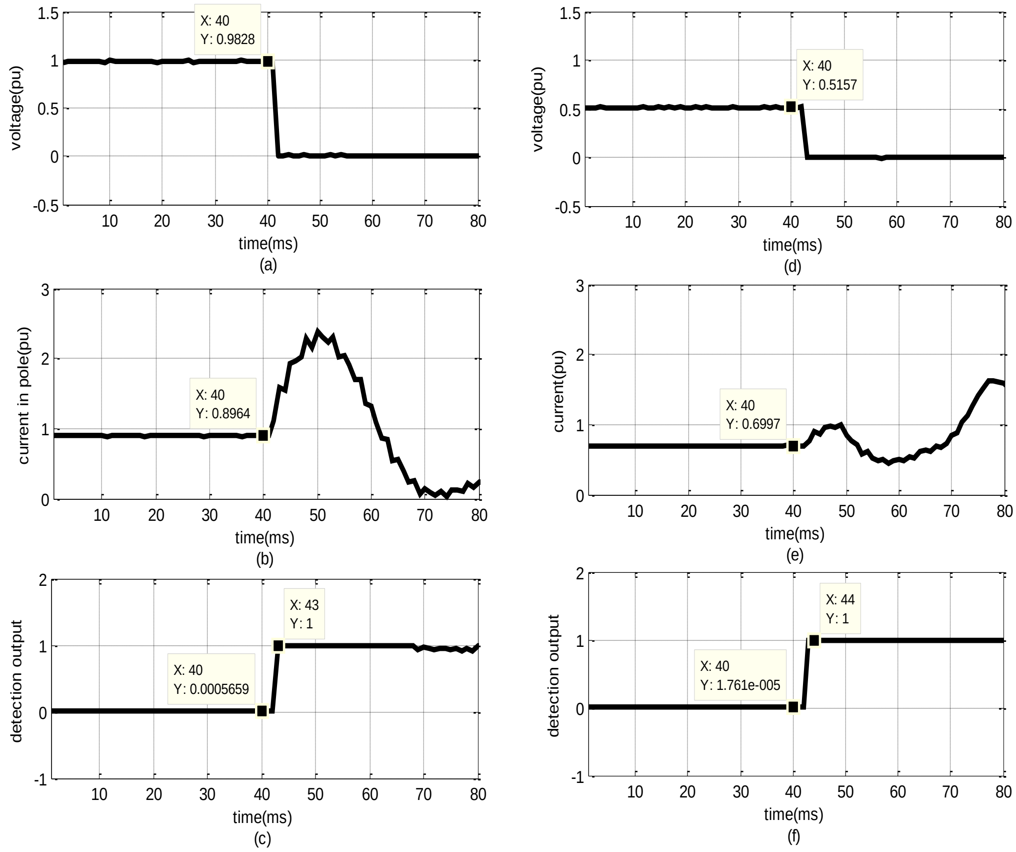

Figure 3. Signals during fault at distance of 250km at 40ms in bipolar system (a) Voltage between pole to pole (b) Current of each pole (c) Fault detection output (d) Voltage between pole to pole with one group of converter tripped (e) Current of each pole (f) Fault detection output.

4.2. Performance of the method for near end p1g fault in bipolar sytem and with one converter tripped

The results are analysed and shown in the Table 2 for P1G fault for near end locations. In the Table 2 detection output with time is shown for near end locations 1, 3.5, 6, 8.5km. In Figure 4 for location of 1km fault occurs at 40 ms and is detected in 4ms as shown in Figure 4(c) with both converters working. One of the converter is tripped and fault detection occurs at 3ms as shown in the Figure 4(f).

Table 2. Performance of the Method in near end Faults

Fault Location (km)	BPNN-D Bipolar with full voltage operation		BPNN-D Bipolar with one 12 pulse converter tripped	
	Time(ms)	output	Time(ms)	Output
1	4	1	3	1
3.5	5	1	4	1
6	7	1	5	1
8.5	8	1	5	1

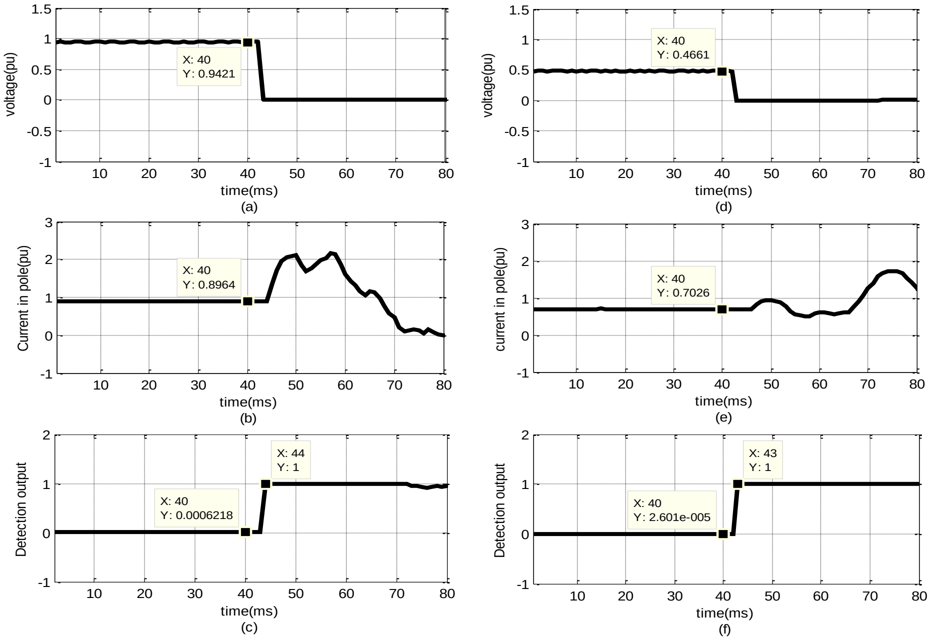

Figure 4. Signals during fault at distance of 971km at 40ms in bipolar system (a) Voltage between pole to pole (b) Current of each pole (c) Fault detection output (d) Voltage between pole to pole with one group of converter tripped (e) Current of each pole (f) Fault detection output

4.3. Performance of the method for far end during p1g fault in bipolar sytem and with one converter tripped

The far end results are analysed and shown in the Table 3 for varying locations at an interval of 2km for P1G fault. The fault is varied from location of 971 and is tested upto 979km. The detection time increases with distance but is less than a cycle.

Table 3. Performance of the Method in Case of far end Faults

Fault Location (km)	BPNN-D Bipolar with full voltage operation		BPNN-D Bipolar with one group of 12 pulse converter tripped	
	Output	Time(ms)	Output	Time(ms)
971	1	4	1	3
973	1	6	1	5
975	1	8	1	7
977	1	8	1	8
979	1	11	1	9

4.4. Performance of the method for varying resistance during P1G fault in bipolar sytem and with one converter tripped

The method is tested for varying resistances and are shown in the Table 4 for P1G fault. The resistances are varied from 0 to 100 ohm and detection time is measured and the detection time is less than half of a cycle.

Table 4. Performance of the Method Varying Fault Resistance

Fault Resistance (Ω)	BPNN-D Bipolar with full voltage operation		BPNN-D Bipolar with one group of 12 pulse converter tripped	
	Time(ms)	output	Time(ms)	Output
0	3	1	3	1
20	4	1	4	1
40	6	1	5	1
60	7	1	6	1
80	8	1	7	1
100	8	1	7	1

5. CONCLUSION

The proposed scheme ANN based fault detection method is implemented in bipolar transmission lines but is also suited for monopolar transmission lines with ground return. LCC based converters are trained from the ANN controller can identify the pattern of faults. There can be change in configuration of HVDC but controllers made from ANN remains the same. The advantages of the proposed fault scheme can be outlined as follows:

a. The proposed method is robust against variation of fault resistance and distance
b. It detects the faults within a cycle.
c. The accuracy, reliability, robustness is very high as high fault resistances faults can be determined.
d. Unlike travelling wave based methods it can detect near end and high fault resistance faults without any problem.

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