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A New Fault Identification Method for HVDC Transmission Line

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Abstract: ***This paper presents a transient based fault identification for High Voltage Direct Current (HVDC) system. Characteristics of the HVDC system during internal and external fault are studied. Variation of transient energy and the relation between various parameters of the line are analyzed during each fault. Based on that the transient method is developed. Transient energy can be obtained by measuring the voltage and current at the two terminals of the line. Identification of internal fault and external fault can be done correctly and quickly from the calculated value of transient energy. The transient current can be analyzed to find out the type of internal and external fault. The test system is modeled in MATLAB - SIMULINK package based on CIGRE HVDC benchmark system.***

Keywords: HVDC transmission, Protection, Fault Identification, Transmission line

1. Introduction

High Voltage Direct Current Technology is a most attractive transmission technology when power has to be transmitted over long distances. In last half century, its application has widely increased. A total of around 70000MW of transmission capacity is transmitted around the world through 95 HVDC projects. Due to the burgeoning demand for electrical power in one area and concentration of electrical generation in another area, a number of high capacity long distance HVDC systems are planned where bulk power from one region to another region is being transmitted.

The fault taking place on HVDC transmission lines may cause the instability of the power system and lead to a large economic loss. Quickly identifying the faults can prevent the destruction of power system stability [1]. Traveling wave based methods are widely used for the detection of faults in HVDC system. But it has disadvantage such as it is easily affected by noise, difficulty in accurate detection of wavehead, requirement of complex and expensive equipments, cannot be implemented automatically etc. [2].

A protection scheme based on the characteristics of low frequency differential transient energy is proposed for Ultra High Voltage Direct Current (UHVDC) systems [3],[4]. The effect of distributed parameters cannot be ignored since modern HVDC system is meant for long distance [11]-[14]. A new fault identification and location scheme is proposed in this paper. The test system is modeled in MATLAB based on CIGRE HVDC benchmark system.

2. Protection Method

In Figure.1 the main structure diagram of the typical HVDC transmission system is shown. Protection devices are installed at points A at the rectifier DC side and B at the inverter DC side. I_A and I_B are DC currents, V_A and V_B are DC voltages at A and B respectively. The positive directions of currents and voltages are defined in the diagram.

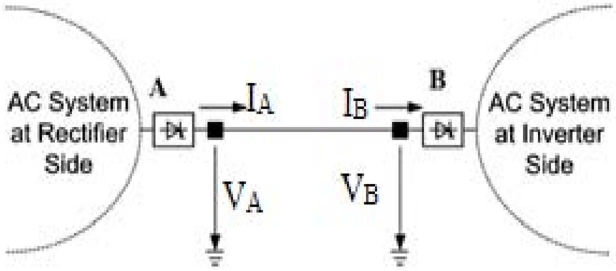

Figure 1: Structural diagram of HVDC system.

The energy at the two points is given by,

$$\left.\begin{aligned} E_A &= \int_{t_1}^{t_2} P_A(t) \\ E_B &= \int_{t_1}^{t_2} P_B(t)\,dt \end{aligned}\right\} \quad (1)$$

The increment of the transient energy during any disturbance is given by,

$$\left.\begin{aligned} \Delta E_A &= \int_{t_1}^{t_2} \Delta P_A(t)\,dt \\ \Delta E_B &= \int_{t_1}^{t_2} \Delta P_B(t)\,dt \end{aligned}\right\} \quad (2)$$

Where $P_A(t)$ and $P_B(t)$ are instantaneous power and $\Delta P_A(t)$ and $\Delta P_B(t)$ are their increments

Thus, the increment of transient energy in the dc line is

$$\Delta E = \Delta E_A - \Delta E_B \quad (3)$$

At steady state conditions ,

$\Delta E_A = \Delta E_B = 0$

Then,

$\Delta E = 0$

When a fault occurs difference in transient energy will no longer be zero. The value of ΔE will depend on the type of the fault.

2.1 External Fault

The lumped parameter model of dc transmission line is shown in Figure 2. Here leakage conductance is neglected

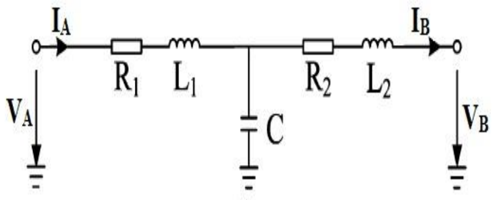

Figure 2: Lumped Parameter Model

The increment of voltage and current caused by the distributed parameters of the transmission line can be described as follows

$$v_L = R_1 i_A + R_2 i_B + L_1 \frac{di_A}{dt} + L_2 \frac{di_B}{dt} \quad (4)$$

$$i_C = C\frac{dv_C}{dt} \quad (5)$$

Where,

$v_L = v_A - v_B$

v_L- voltage drop in dc overhead line, i_C- charging current by the equivalent shunt capacitance in the dc overhead line, R_1,R_2- resistance of the dc overhead line, L_1,L_2- self-inductance of the dc overhead line, C- line-to-ground capacitance of the dc overhead line, v_C-capacitor voltage by equivalent shunt capacitance.

The series inductance of dc transmission line has an effect on the protective relay during the external fault at the inverter side. It is shown in Figure 3.

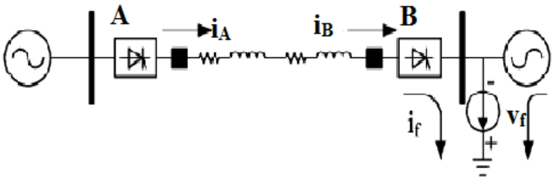

Figure 3: Effect of series inductance

The equivalent system impedance varies with fault F_1 and becomes lesser than the value at normal operation. Therefore, a rapid drop in voltage occurs at two ends of the dc transmission line.

A superimposed fault current i_f can be seen in Figure 3. Now the transient currents under fault F_1 at two ends of the dc transmission line can be obtained as follows

$$\left.\begin{aligned} i'_A &= i_A + i_f \\ i'_B &= i_B + i_f \end{aligned}\right\} \quad (6)$$

Substitute (6) in (4), then

$$v_L = R_1 i_A + R_2 i_B + (R_1 + R_2) i_f + L_1 \frac{di'_A}{dx} + L_2 \frac{di'_B}{dx} \quad (7)$$

And

$v'_A - v'_B = v_L$

Before F_1, there is

$v_A - v_B = R_1 i_A + R_2 i_B$

It means

$$\Delta v_A - \Delta v_B = (R_1 + R_2) i_f + L_1 \frac{di'_A}{dt} + L_2 \frac{di'_B}{dx}$$

So there are,

$$\left.\begin{aligned} &\Delta v_A < 0 \text{ and } \Delta v_B < 0 \\ &|\Delta v_A| < |\Delta v_B| \end{aligned}\right\} \quad (8)$$

Shunt capacitance of the dc transmission line also has an effect on its protection. There is always shunt capacitance between the overhead dc line and ground during normal operating conditions. Effect of shunt capacitance during an external fault is shown in Figure 4.

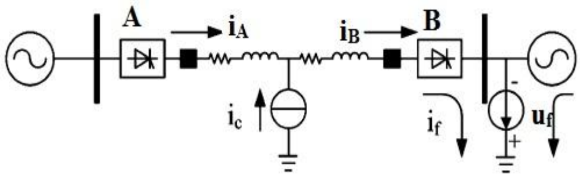

Figure 4: Effect of shunt capacitance

With the fault F_1 capacitance current is discharged from the shunt capacitance to the dc line. Discharging current of the equivalent capacitor under transient state condition is substituted by an equivalent current source and is shown in Figure 4.

The equivalent discharge current of the dc line is given in (5). Under the fault F_1, the transient currents in the dc lines are,

$$\left.\begin{aligned} i'_A &= i_A + i_f - \frac{1}{2} i_C \\ i'_B &= i_B + i_f - \frac{1}{2} i_C \end{aligned}\right\} \quad (9)$$

Increments in two transient currents are,

$$\left.\begin{aligned} \Delta i_A &= i_f - \frac{1}{2} i_C \\ \Delta i_B &= i_f + \frac{1}{2} i_C \end{aligned}\right\} \quad (10)$$

It is clear that $i_f > i_C$, so from (9) and (10) there is

$$\left.\begin{aligned} &\Delta i_A > 0 \text{ and } \Delta i_B > 0 \\ &|\Delta i_A| < |\Delta i_B| \end{aligned}\right\} \quad (11)$$

Now the increment in power is given by,

$$\left.\begin{aligned} \Delta P_A &= \Delta v_A \Delta i_A \\ \Delta P_B &= \Delta v_B \Delta i_B \end{aligned}\right\} \quad (12)$$

Substituting (8) and (11) in (12) gives

$$\Delta P_A < 0 \text{ and } \Delta P_B < 0$$

$$|\Delta P_A < |\Delta P_B|$$

Therefore $|\Delta E_A| < |\Delta E_B|$

Then there is,

$$\Delta E > 0$$

A similar conclusion can be obtained by analyzing the ac fault at the rectifier side based on the aforementioned procedures. External fault includes ac fault at the rectifier as well as inverter side. From the above analysis we can conclude that the difference of transient energy between two ends of the dc line is positive under external faults.

2.2. Internal fault

With the internal fault, the voltages at two ends of the dc line drop sharply. Figure 5 shows the superimposed circuit of the HVDC transmission system. v_f and i_f are the additional fault voltage source and the additional fault current respectively. Therefore it is clear that in this condition, the current i_A always ascends while i_B descends.

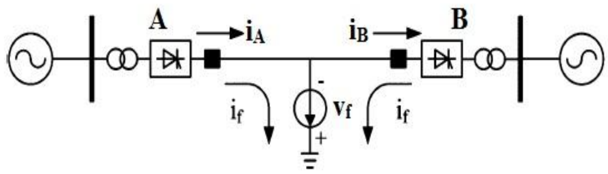

Figure 5: Internal fault

The increment of transient voltage and current will be as follows

$$\Delta v_A < 0$$
$$\Delta v_B < 0$$
$$\Delta i_A > 0$$
$$\Delta i_B < 0$$

Substituting these in (12), we get

$$\Delta E_A < 0$$

$$\Delta E_B < 0$$

On substituting these relations in (3) it is obvious that

$$\Delta E < 0$$

It can be concluded as the difference of transient energy between two ends of the dc line is negative under internal faults.

3. Identification of Type of External Fault

External fault in HVDC system is either at the rectifier stations or at the inverter station. The value of current at the point A and B can be effectively used to identify external fault. The nominal value of I_A and I_B is 1 pu. Whenever fault occurs, this value changes. If the value of I_A and I_B are greater than the nominal value, fault will be at inverter side. If the value of I_A and I_B are less than the nominal value, fault will be at rectifier side.

4. Identification of Type of Internal Fault

The fault that occurs in an HVDC line are mainly of two types. These faults can be identified easily by analyzing the current data. Current at the two end of the dc transmission line I_A and I_B are different in each type of fault. Two types of faults are described below.

1. Open Circuit

Figure 6: Open circuit fault

Figure 6 shows the open circuit fault. Here the line breaks and an open circuit fault occurs. Both current I_A and I_B will be equal to zero.

2. Pole to ground fault

Figure 7: Pole to ground fault

This is the commonly occurring fault in dc transmission line. The pole to ground fault. In this fault the value of currents I_A and I_B are not equal to zero. The value of I_A will be greater than I_B.

5. MATLAB model of CIGRE HVDC benchmark system

Modeling of HVDC system is done in MATLAB based on first CIGRE HVDC benchmark system. The system is a mono-polar 500-kV, 1000-MW HVDC link with 12-pulse converters on rectifier and inverter sides. It is connected to weak ac systems. Damped filters and capacitive reactive compensation are also provided on both sides. Total length of the transmission line is 2000km [6]. System frequency is 50 Hz. AC filters are added to absorb the harmonics generated by the converter as well as to supply reactive power to the converter. MATLAB/SIMULINK model of HVDC system is shown in Figure 8.

6. Results

6.1 Identification of internal and external fault

According to the proposed method, transient energy is used to identify internal and external faults. After modeling the CIGRE system in MATLAB, simulation is done for both external and internal faults. External fault applied is three phase fault and internal fault is pole to ground fault. At a time one of the fault is activated. Fault starts at 0.7s.

The transient energy during an external fault (rectifier or inverter) is shown in Figure 9. From the figure it is clear that the transient energy is positive when the fault starts at 0.7s.

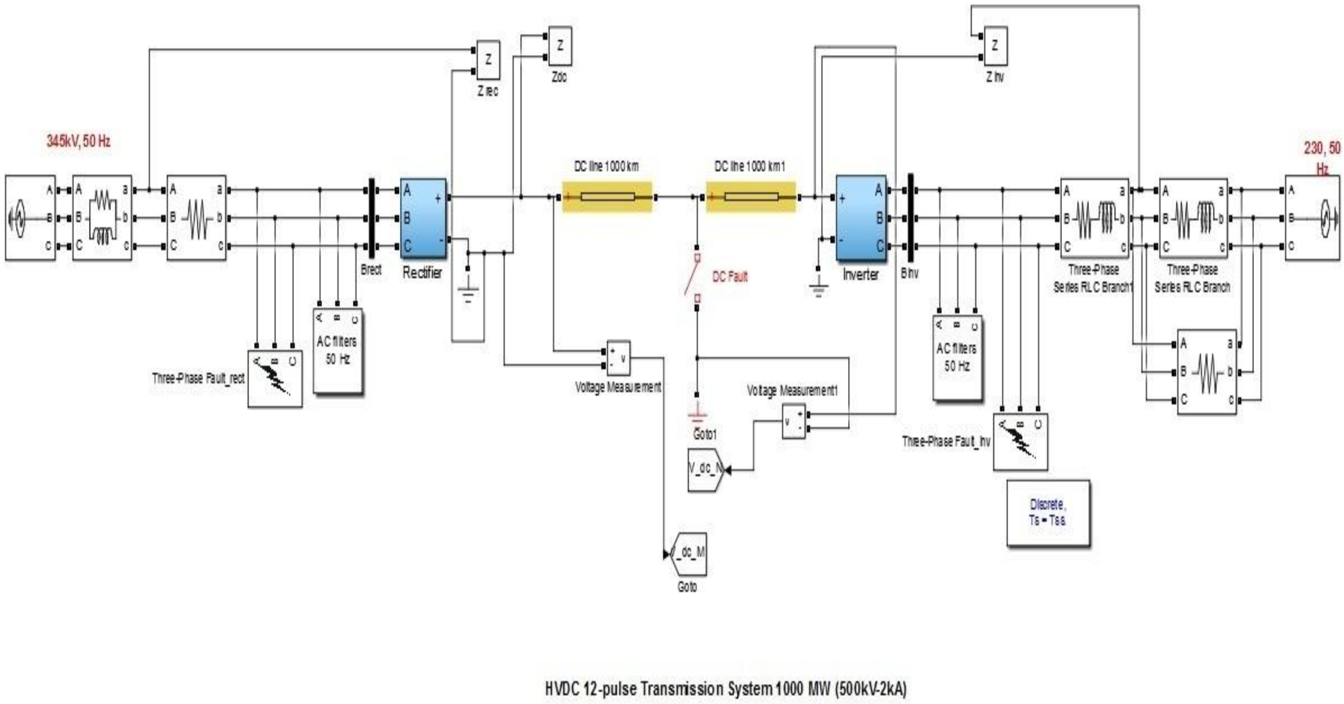

Figure 8: MATLAB model of CIGRE system

Therefore transient energy can be effectively used to identify external faults.

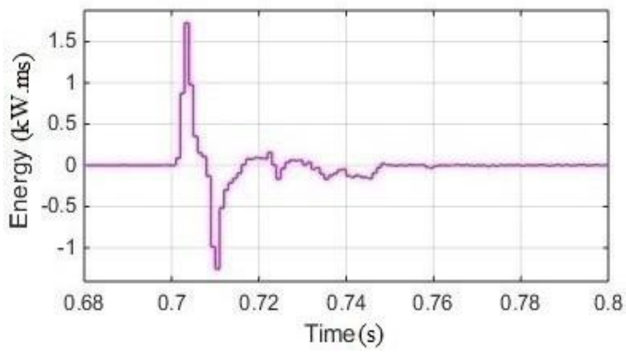

Figure 9: Transient energy curve during external fault

Transient energy during an internal fault is shown below in Figure 10. According to the proposed method transient energy should be negative during an internal fault. In the figure we can see that transient energy is negative.

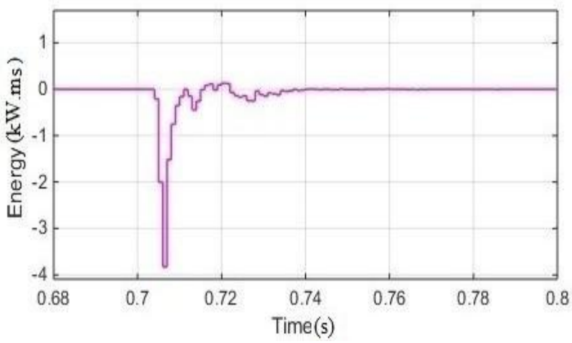

Figure 10: Transient energy during internal fault

Therefore it can be concluded that the new method identifies internal and external faults correctly and quickly.

6.2 Identification of type of external fault

Type of external fault is identified from the value of DC currents I_A and I_B during that fault. The current response of internal fault is shown below in Figure 11.

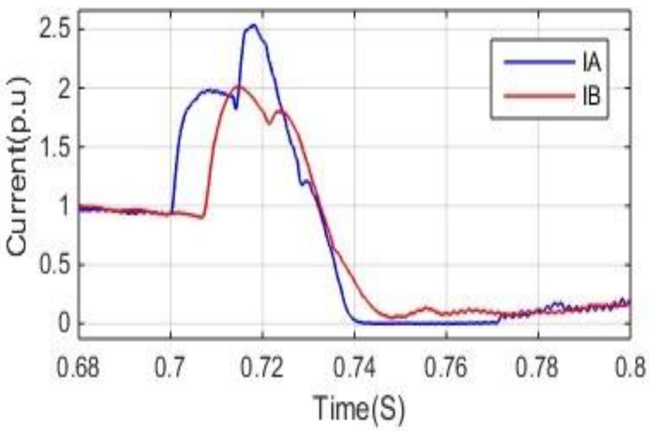

Figure 11: Current response during inverter fault

From the figure it is clear that, at the occurrence of fault both the current increases from their nominal value. It becomes greater than 1 pu.

Current response during rectifier fault is shown in Figure 12. For a rectifier fault the DC currents I_A and I_B at points A and B should be less than the nominal value 1 pu.

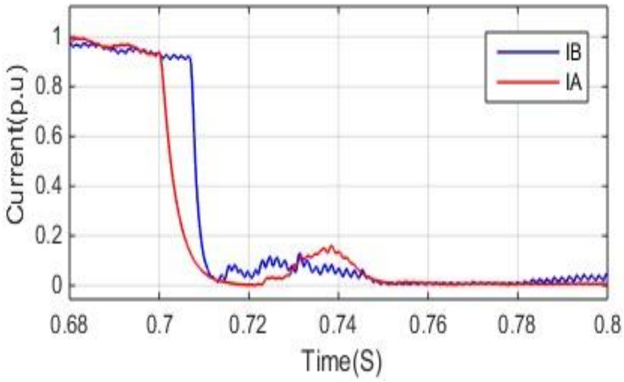

Figure 12: Current response during rectifier fault

From Figure 12 it is clear that when a fault occurs at the rectifier side both the current decline from their nominal value. They become less than 1 pu at the occurrence of rectifier fault.

Value of I_A and I_B is shown in Table 1.

Table 1: Type of external fault

I_A (pu)	I_B (pu)	Fault
0.0018	0.8004	Rectifier fault
1.936	1.033	Inverter fault

From Table 1 it is clear that during rectifier fault value of I_A and I_B are less than 1 pu and during inverter fault is is greater than 1 pu. So the new method identifies the type of external fault accurately.

6.3 Identification of type of internal fault

Type of internal fault is also found out from the value of I_A and I_B during that fault. It is shown in Table 2.

Table 2: Type of internal fault

I_A (pu)	I_B (pu)	Fault
0	0	Open circuit
~= 0 and > I_B	~= 0	Pole to ground fault

The values of I_A and I_B are different in each of the fault. It means there is a particular condition of I_A and I_B is there for both the internal faults. These condition are checked when an internal fault occurs and whenever a condition satisfies, corresponding fault will be the output. Thus the proposed method identifies the type of internal fault correctly.

7. Conclusion

A new method for fault identification, based on transients is proposed for HVDC transmission lines. This method is found to be better than the commonly used travelling wave methods. Test system is modeled in MATLAB based on CIGRE HVDC benchmark system. All the fault conditions were simulated and the proposed method is found to be accurate. The proposed method is simple, reliable and fast.

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