ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 10, October 2015

A Transient Scheme for the Identification of Fault in HVDC Transmission Line

Sherin Tom[1], Jaimol Thomas[2]

PG Student [Power Systems], Dept. of EEE, Saintgits College of Engineering, Kottayam, Kerala, India[1]

Professor, Dept. of EEE, Saintgits College of Engineering, Kottayam, Kerala, India[2]

ABSTRACT: This paper presents a novel transient based protection for High Voltage Direct Current (HVDC) system. Behaviour of the HVDC system during internal and external fault is studied. Variation of transient energy and the relation between various parameters of the line are analysed during each fault. Based on that the transient protection principle 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 analysed to find out the type of DC line fault. The test system is modelled and analysed for various faults using MATLAB - SIMULINK package based on CIGRE HVDC benchmark system.

KEYWORDS: High Voltage Direct Current Transmission, Protection, Transmission lines, Fault identification

I. INTRODUCTION

High Voltage Direct Current (HVDC) technology is now commercially available, asynchronous and expected to be widely used due to its advantages, such as larger power transmission capability, longer transmission distance, fast and flexible control, and lower losses. These advantages make HVDC system more attractive than High Voltage Alternating Current (HVAC) system.

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 by computers, vulnerable to interference of external signals 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 [7]-[10].

A fault identification scheme is proposed in this paper. The test system is modelled in MATLAB based on CIGRE HVDC benchmark system.

II. LITERATURE SURVEY

HVDC system is usually meant for long distance large power transmission. Fault generating in an HVDC system can be internal fault or external fault. Internal faults are the DC line fault and external faults are the AC side fault. Chances of occurrence of line faults are more in HVDC since it is passing through complex terrain and is working under harsh weather conditions. For the satisfactory operation of HVDC system it is necessary to detect fault accurately with minimum time. Different fault detection methods are there. Most of the methods for the identification of fault in HVDC line are based on travelling wave. This method gives accurate results only if the wavehead is detected properly, which is somewhat difficult. Some other disadvantages of travelling wave method are given in [2]. So the result of travelling wave method cannot always be true and accurate. Along with the travelling wave method, some other methods of fault detection and identification are also there, like mathematical morphology, wavelet method etc [11]. Methods which are not based on travelling wave are really complex. They use some complex algorithms. Therefore the summary from the literature survey is, each existing method has its own advantages and disadvantages. A method which eliminates the disadvantages of all the methods needs to be proposed. This method should not be based on travelling wave. So the proposed method is based on transient data of the HVDC system. It is a simple and fast method.

III. TRANSIENT PRINCIPLE

In Fig.1 the main structure diagram of the typical HVDC transmission system is shown. Protection devices are installed at points A at the rectifier side and B at the inverter side. i_A and i_B are dc currents, v_A and v_B are dc voltages at A and B. The positive directions of currents and voltages are defined in the diagram.

The energy at the two points is given by,

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

The increment of the transient energy during any disturbance is,

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

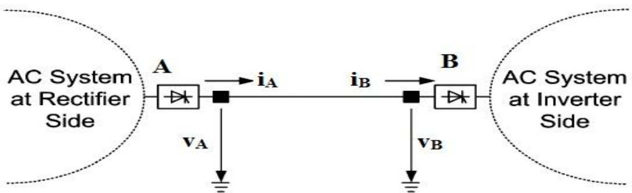

Fig.1. Typical structural diagram of HVDC system

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

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

At steady state conditions, $\Delta E_A = \Delta E_B = 0$. Then$\Delta E = 0$. But 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.

A. External fault

Fig.2 shows the lumped parameter model of dc transmission line. Here leakage conductance is neglected.

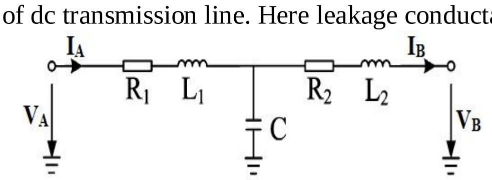

Fig.2. Lumped parameter model

Leakage conductance is neglected for simplicity. The increment of voltage and current caused by the distributed parameters of the transmission line can be described as follows:

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

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

Where,

$$v_L = v_A - v_B$$

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 10, October 2015

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.

(i). Effect of series inductance

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 Fig.3.

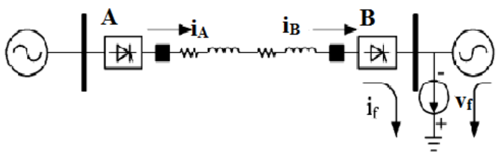

Fig.3. Effect of series inductance

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 Fig:4. Now the transient currents under fault F_1 at two ends of the dc transmission line can be obtained as follows

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

Substitute (6) in (4), then

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

And

$$v'_A - v'_B = v_L$$

Before F1, 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,

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

(ii) Effect of shunt capacitance

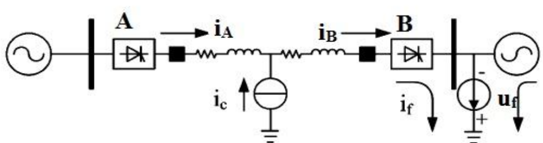

Fig. 4. Effect of shunt capacitance

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. 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 Fig. 4. The equivalent discharge current of the dc line is given in (6). Under the fault F_1, the transient currents in the dc lines are,

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

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 10, October 2015

Increments in two transient currents are,

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

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

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

Now

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

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

$\Delta P_A<0$ 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.

B. Internal fault

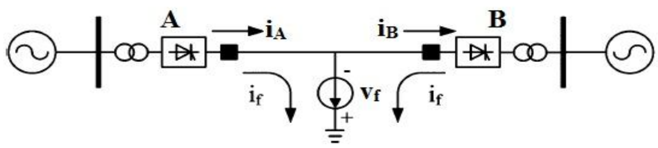

Fig.5. Internal fault

With the internal fault, the voltages at two ends of the dc line drop sharply. Fig. 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.

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.

IV. IDENTIFICATION OF TYPE OF DC LINE FAULT

The fault that occurs in a dc line can be of four 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.

1. Open Circuit

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 10, October 2015

Fig.6: Open circuit fault

Fig.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

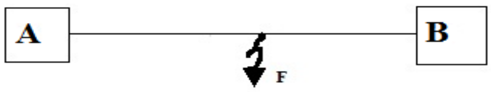

Fig.7: Pole to ground fault

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.

3. P-G fault with rectifier fault end grounded

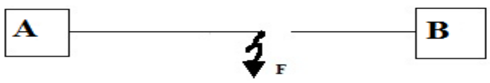

Fig.8: Pole to ground fault with rectifier end grounded

The third type of fault is also a pole to ground fault but only one faulted end will be grounded and the other end will be open. Here faulted end near to rectifier side, that is A side is shorted to ground and inverter side faulted end that is B side is open. Here I_A will be greater than zero and I_B will be equal to zero.

4. P-G fault with inverter side fault end is grounded

Fig .9: Pole to ground fault with inverter end grounded

The fourth type of fault is as same as the third type. The difference is that the inverter side faulted end that is B will be grounded and the other end that is A will be open. Here value of I_A will be zero and value of I_B will be greater than zero.

V. ALGORITHM

Step1: Measure the dc currents i_A and i_B and voltages v_A and v_B
Step2: Find out the increments in currents and voltages (Δi_A,Δi_B,Δv_A,Δv_B)
Step 3: Find out the change in power ΔP_A and ΔP_B
Step 4: Find out the transient energy difference ΔE_A and ΔE_B
Step 5: Find out the total change in transient energy ΔE
Step 6: Check whether ΔE is positive or negative at the starting of the fault, if positive go to step 7, else go to step 8
Step 7: Fault is identified as external. Go to step 14
Step 8: Fault is identified as internal. Go to step 9
Step 9: Measure the values of I_A and I_B. If I_A= 0 and I_B=0 go to step 10. If I_A~=0 and I_B~=0 go to step 11. If I_A~=0 and I_B=0 go to step 12. If I_A=0 and I_B~=0 go to step 13.
Step 10: Fault is Open circuit fault
Step 11: Fault is Pole to ground fault
Step 12: Fault is P-G fault with rectifier side fault end grounded.
Step 13: Fault is P-G fault with inverter side fault end grounded.
Step 14: End

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 10, October 2015

VI. RESULTS AND DISCUSSIONS

A. Result for internal and external fault

The transient energy during rectifier fault is shown in Fig. 10. From the figure it is clear that the transient energy is positive when the fault starts at the rectifier side. Rectifier side fault is an external fault. Therefore transient energy is positive when an external fault occurs.

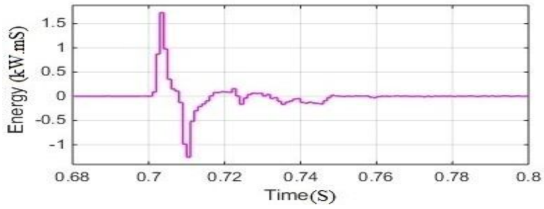

Fig.10. Transient energy during rectifier fault

Inverter side fault is also an external fault. Transient energy should be positive according to the proposed method. From Fig. 11 it is clear that at the beginning of inverter fault transient energy is positive.

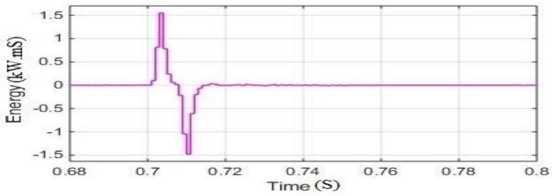

Fig.11. Transient energy during inverter fault

DC line fault is an internal fault. According to the proposed method transient energy should be positive during an internal fault. Fig.12 shows that transient energy is negative during internal fault.

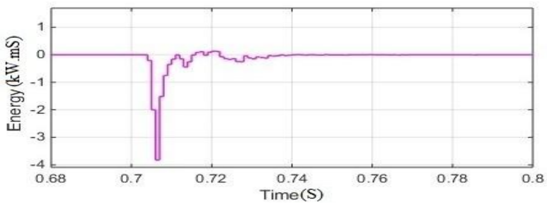

Fig.12. Transient energy during DC line fault

Thus the new method identifies internal and external faults correctly and quickly by analysing the transient energy data.

B. Results for type of internal fault

Type of line fault is identified by analysing the values of the DC current I_A and I_B. Results are shown in Table I. DC currents will be different for each fault. It means four different conditions are there for the four different faults in the DC transmission line. These conditions are checked during an internal fault to find out the type of fault that occurred in the transmission line. From the table it is clear that the type of dc line fault can be identified correctly and quickly by analysing the transient current data.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 10, October 2015

Table I
RESULT FOR LINE FAULT

Type of fault		
I_A	I_B	Fault
0	0	1
~= 0 and > In	~= 0	2
> 0	0	3
0	> 0	4

VII. CONCLUSION

An Algorithm 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. It can identify external fault, internal faults and type of internal fault correctly and quickly. Test system is modelled in MATLAB based on CIGRE HVDC benchmark system. All the fault conditions were simulated and the algorithm is found to be accurate. The proposed method is simple, reliable and fast.

REFERENCES

[1] Zheng-You He, Xiao-Peng Li, Sheng Lin, Jian-Wei Yang and Rui-Kun Mai, “Natural frequency based line fault location in HVDC lines,” IEEE transactions on power delivery, Vol. 29, NO. 2, APRIL 2014

[2] L. de Andrade, and T. Ponce de Leão, “Travelling Wave Based Fault Location Analysis for Transmission Lines,” EPJ Web of Conferences 33, 04005 (2012), DOI: 10.1051/epjconf/20123304005, Owned by the authors, published by EDP Sciences, 2012

[3] K. K. Li, C. Fan, W. L. Chan, and W. Y. Yu, “Study of protection scheme for transmission line based on wavelet transient energy,” Int. J.

[4] X. L. Liu, A. H. Osman, and O. P. Malik, “Real-time implementation of a hybrid protection scheme for bipolar HVDC line using FPGA,” IEEE Trans. Power Del., vol. 26, no. 1, pp. 101–108, Jan. 2011.

[5] M. O. Faruque, Y. Zhang, and V. Dinavahi, “Detailed modeling of CIGRE HVDC benchmark system using PSCAD/EMTDC and PSB/ SIMULINK,” IEEE Trans. Power Del., vol. 21, no. 1, pp. 378–387, Jan. 2006.

[6] G.WANG, J. B. LUO, H. F. LI, and Z. K LI, “Transient energy protection for 800 kv uhvdc transmission lines,” (in chinese) Autom. Elect. Power Syst., vol. 34, no. 1, pp. 28–31, Jan. 2010.

[7] Elect. Power Energy Syst., vol. 28, pp. 459–470, Feb. 2006. H. Takeda, H. Ayakawa, M. Tsumenaga, and M. Sanpei, “New protection method for HVDC lines including cables,” IEEE Trans. Power Del., vol. 10, no. 4, pp. 2035–2039, Oct. 1995

[8] B. Zhou and J. M. Zhao, “Steady-state stability analysis of systems HVDC considering capacitance of DC line,” (in Chinese) J. North China Elect. Power Univ., pp. 46–63, 1985.

[9] B. Wang, X. Z. Dong, Z. Q. Bo, and A. Perks, “RTDS environment development of ultra-high-voltage power system and relay protection test,” IEEE Trans. Power Del., vol. 23, no. 2, pp. 618–623, Apr. 2008.

[10] B. Wang, X. Z. Dong, Z. Q. Bo, and A. Klimek, “Residual compensation for ground impedance relay with applications in UHV transmission lines,” IEEE Trans. Power Del., vol. 24, no. 3, pp. 1072–1078, Jul. 2009.

[11] L.Shang, G.Herold; J. Jaeger, R.Krebs, A. Kumar, High Speed Fault Identification and Protection for HVDC Line usingWavelet Technique , Porto Power Tech, 2001

[12] J. L. Stewart, Circuit Analysis of Transmission Lines. New York: Wiley, 1958