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HVDC TRANSMISSION LINE PROTECTION BASED ON TRANSIENT ENERGY AND TRANSIENT POWER: A SURVEY

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Abstract:

As the number of consumers of electricity increases the electric power generated required to serve the consumers increases. Due to the long distance transmission of the generated power the power system becomes complex. That is why HVDC transmission system used for long distance carriage of power. During transmission of HVDC system protection and security of the system is compulsory in order to minimize the overall losses. This review paper discusses the protection of HVDC line based on transient energy and transient power. The fault which is occurred on the system reflected on three main parts of the system. Using modified traveling wave algorithm the transient parameters are determined and the type and location of fault can be detected. The simulation is done using PSCAD/EMTDC, MATLAB/Simulink.

Motivation/Background: Due to the complication of a power system, HVDC power transmission system was chosen. But the system needs protection to secure the transportation of the needed amount of power.

Method: In this review paper a modified travelling wave algorithm is used to detect the faults.

Results: The result from the output of the algorithm shows the transient power and energy came to stability within short time.

Conclusions: By detecting the transient power and energy, it can easily be protect the system from severe problem.

Keywords: *HVDC; PSCAD; EMTDC; MATLAB/Simulink.*

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1. Introduction

The transmission lines act as very important elements in any power system as it is these components that carry electric power from the point of generation to the end user [1]. The more efficient the protection scheme in any system, the more reliable, economic and efficient the whole system would be. The series inductance offered to the fault current is very less in a DC line. Hence, the faulty section of the line needs to be detected and isolated as soon as possible to reduce the damage it would cause. This demands a fast and accurate fault detector and locator algorithm including the type of algorithm used in this review paper [2]. It is obvious that HVDC line carries huge amount of voltage. Due to this the HVDC line becomes complex and faces

problem which is fault if not kept secured. One of the safeguard securities of the system is controlling the transient power and energy to its limited value. This review paper points out the protection of the system based on the two transient parameters.
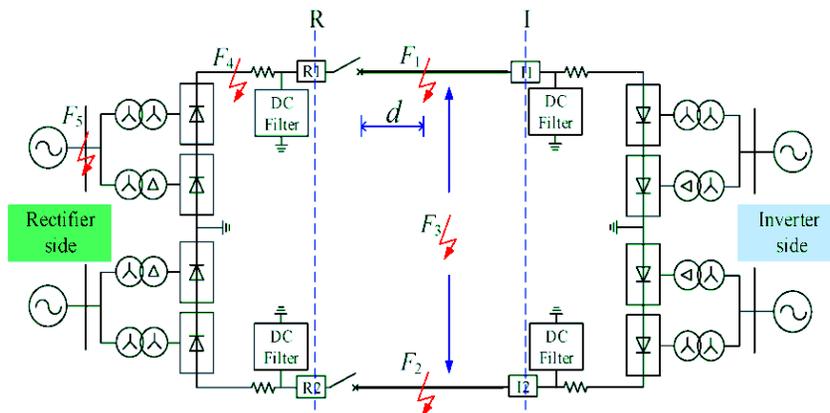
2. Basic HVDC Transmission Line Components

Figure 1: main components of HVDC transmission line

The main components of HVDC transmission line are:

Converters: The converters play an important role in HVDC Transmission system. It performs two operations at sending end and at receiving end such as conversion from AC to DC like rectifier and DC to AC like inverter respectively [12].

Transformers: The transformers connect the AC transmission network to the six-pulse valve bridge or twelve pulse Valve Bridge. The transformers adjust the AC voltage to a suitable level of the converters. The design of these transformers can be depending on the power to be transmitted in the system [12].

Filters for both AC and DC: The converters of HVDC transmission system produce harmonic currents on the AC side. In the process of conversion, the converters consume reactive power of the HVDC system. This reactive power is partly compensated in the filter banks and remaining is provided by capacitor banks connected in the HVDC transmission system [12].The converters of the HVDC transmission system produce ripple on the DC voltage. These voltage ripples cause the interference to telephone lines near the DC line. Tuned filters and active DC filters are commonly used on DC side of HVDC transmission system [12].

HVDC Overhead Transmission Lines or HVDC Cables: For submarine and underground transmission system normally HVDC cables are used. There is no length limitation exists for HVDC cables transmission system [12].

3. Faults in HVDC line

Mainly faults in HVDC transmission line can be classified as Internal and External faults. The transmission distance of HVDC system is particularly long, and this makes the probability of

HVDC line fault increased greatly. The actual data coming from electric power enterprises show that 50% faults happened in HVDC system belong to HVDC line faults [3]. And this becomes a serious threat to the power system operation safely and steadily. The operation of HVDC system is often affected by the AC system and the HVDC control system, and this makes its operation environment more complex. That is why the HVDC line are affected by different types of faults. At the same time, the process of HVDC line fault isn't analyzed clearly and the principles of it are also analyzed deficiently. All of these mentioned above make it difficult to the research of HVDC line protection. The actual operational data also show that the effect of the current HVDC line protection system is limited. So, it is necessary to study in depth the factors which are affecting the operation of HVDC line protection system. Faults in HVDC transmission line are various types. The study of these faults is very essential for reasonable protection design because fault will induce a significant influence on operation of HVDC transmission system. Especially for overhead DC transmission line, the problem in recovery process should be taken into account to ensure that the system can restore rapidly under temporary fault condition. The short-circuit fault is symmetrical and the ground fault is unsymmetrical. Faults on DC transmission line are generally caused by external mechanical stress [4]. The DC Line to Line fault and DC Line to Line fault are common types of fault which are permanent and required lengthy repairing process. For overhead DC transmission system faults are temporary and caused by lightning strikes and pollution. Some common types of AC fault occur on AC side in overhead HVDC transmission system such as Line to Line fault, Line to Ground fault and LL-L fault. In HVDC system, faults on rectifier side or inverter side have major effects on system stability. The various types of faults are considered in the HVDC system which causes due to malfunctions of valves and controllers, misfire and short circuit across the inverter station, flashover and three phase short circuit.

4. HVDC Transmission Line Protection Scheme

The traditional protection system for the HVDC transmission line often uses the voltage and its change rate to detect the ground fault in the dc line [5]. But it is affected easily by fault impedance. With the rapid advance of microelectronics technology and microcomputer protections, traveling-wave theory has been implemented and adopted in HVDC transmission lines successfully [6]. However, traveling-wave-based methods still have problems that limit their application, such as lacking mathematical tools to represent traveling wave, being easily influenced by noise, and so on [7], [8]. Recently, based on the characteristics of low-frequency differential transient energy at the two ends of the dc line, a new protection scheme for HVDC lines is proposed [9], [10]. However, this paper does not take into account the distributed parameters of the transmission line in detail. In fact, the typical characteristic of modern HVDC transmission systems is the long distance; thus, the effect of the distributed parameters cannot be ignored and may cause the improper operation of relay protection [11]–[14].

The present-day primary protection schemes for HVDC transmission lines employ travelling wave based methods, whereas the back-up protection is based on DC minimum voltage and DC line differential protection methods. The travelling wave algorithms estimate the fault location based on the time taken by the fault generated travelling wave to propagate along the transmission line [15]. In methods requiring two-terminal data, the global positioning system (GPS) is usually employed to keep the measurements synchronized. The travelling wave theory

follows that the transients that are generated as a result of faults or switching procedures are composed of travelling waves that continue to bounce back and forth between the fault point and the terminals until a post-fault steady state is reached. The signals intended to be used need to be synchronized before the travelling wave algorithm is applied. Once the signals have been synchronized, the travelling wave algorithm is used to estimate the travel time of forward and backward fault transients along the concerned transmission line between the fault point and the location of the relay. The fault location is then estimated using these travel times. Although these methods have fast response and high accuracy, the reliability is affected by the accuracy of detection of the surge arrival time. However, in methods requiring only single terminal data, there is no need of GPS and these methods are hence more economical. However, they require the detection of secondary reflection wave as well [16].

In fact, owing to the boundary characteristic, the responses of typical transient characteristic of energy and power on HVDC transmission line at two terminals of the dc line are different under various fault conditions. So the transient characteristic transient characteristic of energy and power can be employed to identify an internal fault from an external fault. A novel transient characteristic of energy and power protection scheme is proposed in this paper as a review. With PSCAD/EMTDC, the test system is modeled as a distributed parameter system [4]. Comprehensive test studies show that the proposed scheme is simple, reliable, and practical. It can provide correct responses under various fault conditions including high ground resistance faults. Finally, the main factors that affect performance of the protection, fault resistance, and fault reactance are also discussed. The relationships between the main factors and the sensitivity of transient characteristic of energy and power protection are also presented.

5. Literature Survey on Hvdc Line Protection Based on Transient Energy and Power

5.1. Principle of Protection

The protection mechanism is the comprised detection of different parameter on the HVDC line during fault occurred. The parameter includes; the line voltage, line current, line resistance, line reactance and line losses. In Fig.2 the main structural diagram of the typical HVDC transmission system is shown. Protection devices are installed at points X at the rectifier side and Y at the inverter side. I_x and I_y are dc currents, V_x and V_y are dc voltages at X and The positive directions of currents and voltages are defined in the diagram [7].

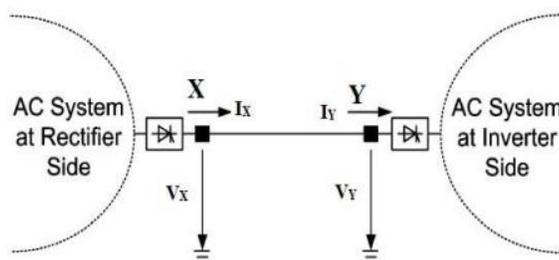Figure 2: main structural diagram of HVDC line

The power at the two points is given by, $P_x=I_xV_x$, $P_y=I_yV_y$. The increment of the transient power during any disturbance is given by: $\Delta P_x= \Delta I_x\Delta V_x$, $\Delta P_y= \Delta I_y\Delta V_y$. The transient energy is

the integral result of transient power [8]. Thus, the increment of transient power in the dc line is ΔP= Δpx-Δpy, Δpx=Δpy. If Δp=0 then, the system is at steady state condition [7]. When a fault occurs difference in transient power will no longer be zero. The value of Δp will depend on the type of the fault.

5.2. External Fault

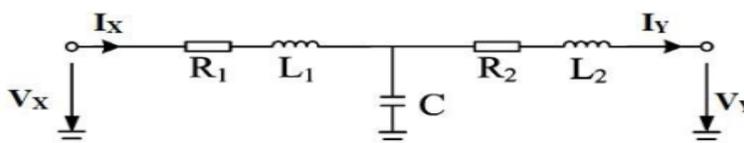The lumped parameter model of dc transmission line is shown in Fig. 3. Here leakage conductance is neglected [7].

Figure 3: lumped parameter model of HVDC line

VL=R1Ix+R2Iy+L1dIx/dt+L2dIy/dt, VL=Vx-Vy, Ic=C*dVc/dt
Where: R1, R2, L1, L2 and C are transmission line parameter.

The series inductance of dc transmission line has an effect on the protective relay during the external fault at the inverter side [7]. It is shown in Fig. 4.
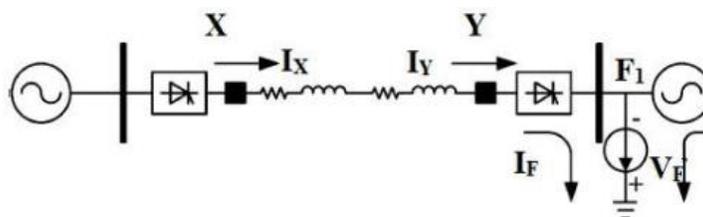

Figure 4: external fault on inverter side

A superimposed fault current If can be seen in Fig.4. Now the transient currents under fault F1at two ends of the dc transmission line can be obtained as follows [7].

Ix'=Ix+If,Iy'=Iy+If VL=R1Ix+R2Iy+(R1+R2)If+L1dIx'/dt+L2dIy'/dt
Line voltage becomes
VL=V'x-V'y
 Before fault (F1)   Vx-Vy=IxR1-IyR2
ΔVx-ΔVy= (R1+R2) If+L1dIx'/dt+L2dIy'/dt
ΔVx<0 and ΔVy<0
   /ΔVx/</Δvy

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 [7]. Effect of shunt capacitance during an external fault is shown in Fig. 5.
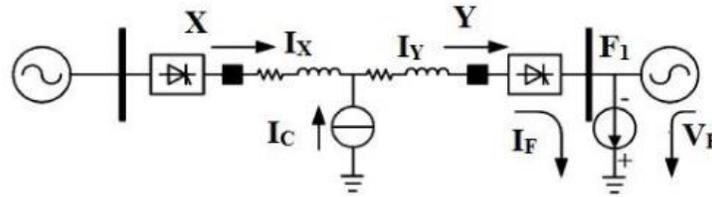
Figure 5: external fault on inverter side considering shunt capacitor

The equation becomes [3]

$$I_X' = I_X + I_F - \frac{1}{2}I_C$$

$$I_Y' = I_Y + I_F + \frac{1}{2}I_C$$

$$\Delta I_X = I_F - \frac{1}{2}I_C$$

$$\Delta I_Y = I_F + \frac{1}{2}I_C$$

$$\Delta I_X > 0 \text{ and } \Delta I_Y > 0$$

$$|\Delta I_X| < |\Delta I_Y|$$

$$\Delta P_X < 0 \text{ and } \Delta P_Y < 0$$

$$|\Delta P_X| < |\Delta P_Y|$$

$$\Delta P > 0$$

5.3. Internal Fault

With the internal fault, the voltages at two ends of the dc line drop sharply. Fig. 6 shows the superimposed circuit of the HVDC transmission system [3]. Vf and If are the additional fault voltage source and the additional fault current respectively. Therefore it is clear that in this condition, the current Ix always ascends while Iy descends.
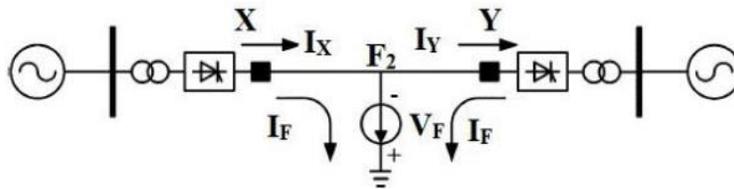

Figure 6: internal fault on DC component

The equation will be [4]

$$\Delta V_X < 0, \Delta V_Y < 0, \Delta \bar{I_X} > 0, \Delta I_Y < 0$$

$$\Delta P_X < 0$$

$$\Delta P_Y < 0$$

$$\Delta P < 0$$

6. Novel Algorithm for HVDC Line Protection Fault Detection Based on Transient Power and Transient Energy

The travelling wave algorithm for the protection of HVDC line based on transient power is described below
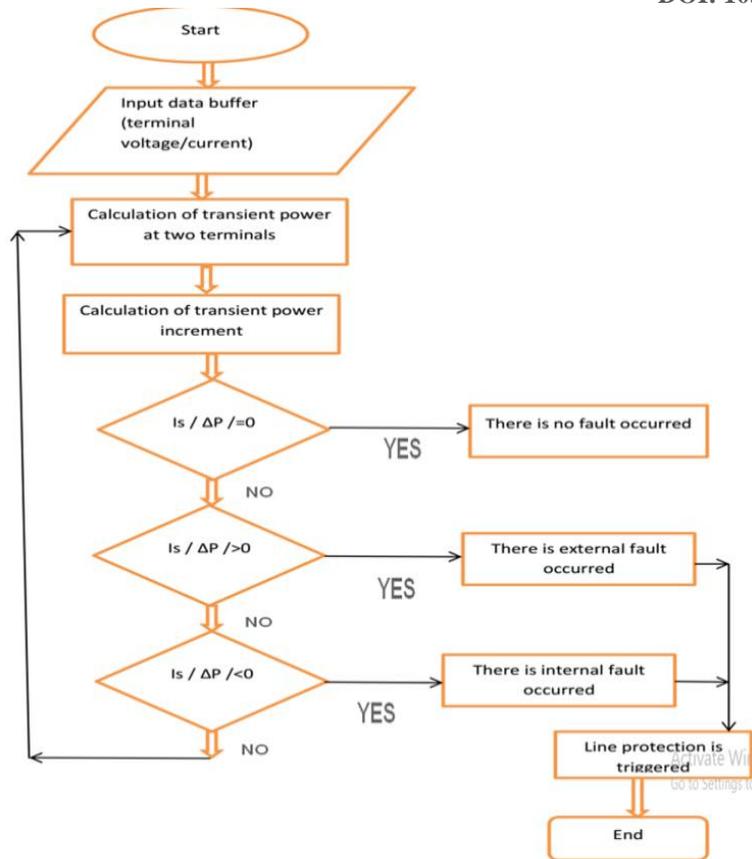

Figure 7: flow chart of traveling wave for transient power

The travelling wave algorithm for the protection of HVDC line based on transient energy is also described below [5]
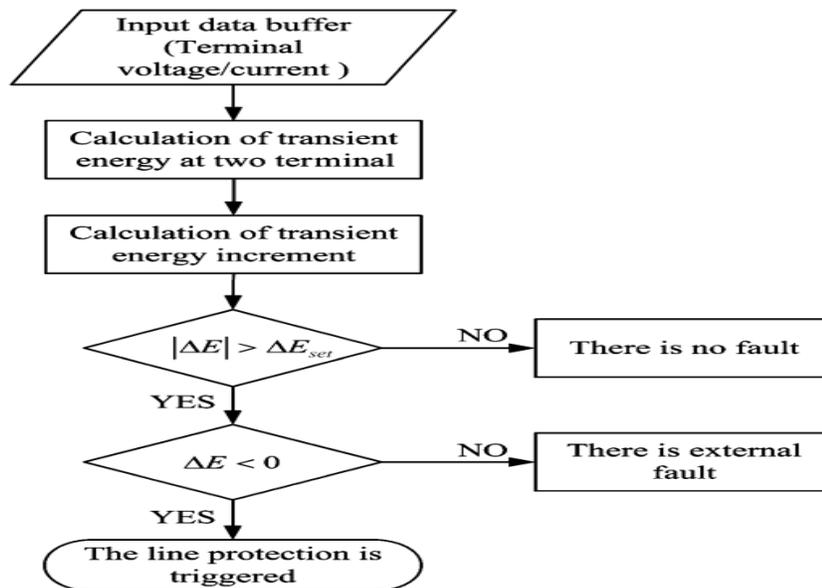

Figure 8: traveling wave algorithm for transient energy

7. MATLAB Simulink Model

7.1. MATLAB Simulink Model of HVDC Transmission Line

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. 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 of HVDC system is shown in fig 9 [7]
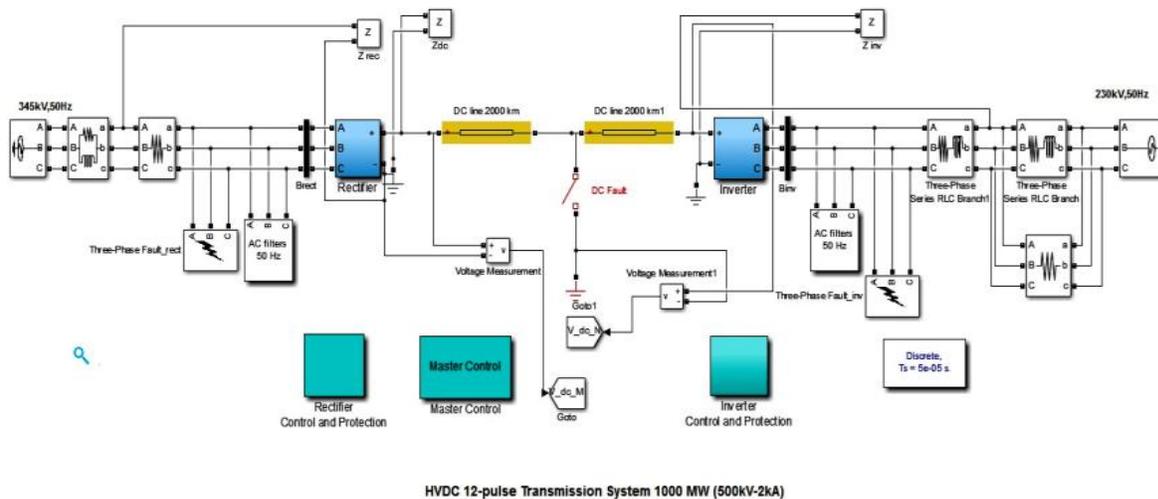

Fig 9 MATLAB/Simulink model of HVDC line

The HVDC transmission line protection scheme will be applied based on the transient power and energy considering the type of fault occurred on the above designed HVDC line on MALAB/Simulink. The transient energy and the transient power are related as one is the integral result of another and the other is the derivative result of the other. The transient energy and transient power can be related as [4]:

$$VEx = \int_{t2}^{t1} VPxdt \quad VEy = \int_{t2}^{t1} VPydt$$

8. Result

8.1. Result on External fault

At Inverter Side: The fault at the inverter starts at 0.7sec. It is a three phase fault. Ix and Vx in the dc line are near to the rectifier, Iy and Vy in the dc line are near to the inverter. When fault occurs at 0.7sec, big disturbance of the ac system causes a sudden increase in the dc current Ix

and Iy. During the transient process the shunt capacitance has an effect on the two dc currents. Due to this Ix is lower than Iy Variation of current is shown in fig 10.

The dc voltage Vx and Vy slump during any fault at the inverter ac side. Obviously the voltage Vx is higher than Vy at that time, as shown in Fig: 10.There is a transient power and energy difference between two terminals of the dc transmission line due to the difference in voltage and current [8]. The value of transient power and energy difference is positive at the initiation of the fault as shown in Fig.10. So the external fault can be identified easily by the proposed method [7].
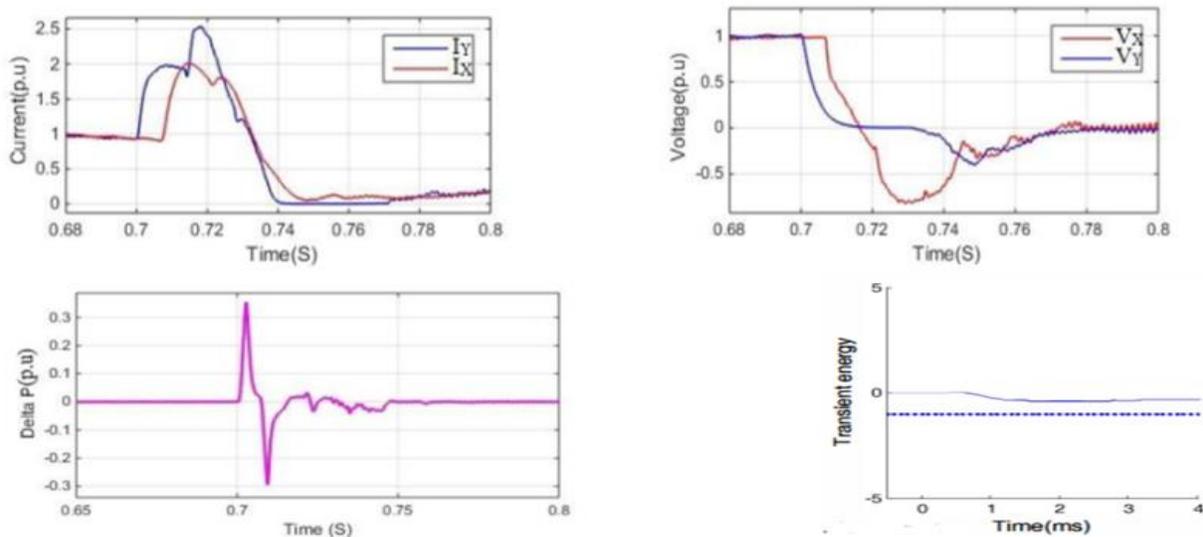

Figure 10: simulation result on inverter side of external fault

At Rectifier Side: The rectifier ac side fault occurs at 0.7 s. It is also a three phase to ground fault [8]. The dc currents Ix and IY will drop as soon as the fault is initiated. The currents drop is in such a way that Ix is smaller than Iy. It is because of the presence of equivalent shunt capacitance [7]. Current response during this transient period is shown in Fig: 11. The value of transient power and energy difference is positive at the initiation of the fault as shown in Fig.11.
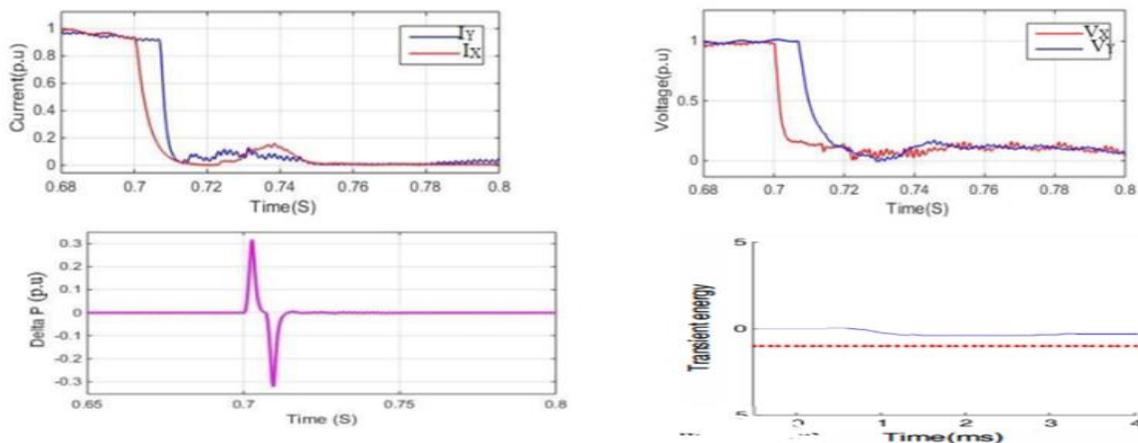

Figure 11: simulation result on rectifier side of external fault

Internal Fault: The internal fault is usually DC fault. The dc line fault is a pole to ground fault, occurs at 0.7 s. Fault occurs at the middle of the line. As soon as the fault occurs, dc current Iy drops and Ix increases suddenly as shown in Fig: 13 [7]. When a dc line fault occurs the voltages Vx and Vy decrease immediately as shown in Fig: 12. Due to the variation of voltage and current there will be a change in transient power and energy in the dc line. And the value is negative. It is shown in Fig: 12. So the internal fault can be easily identified by the proposed method [8].
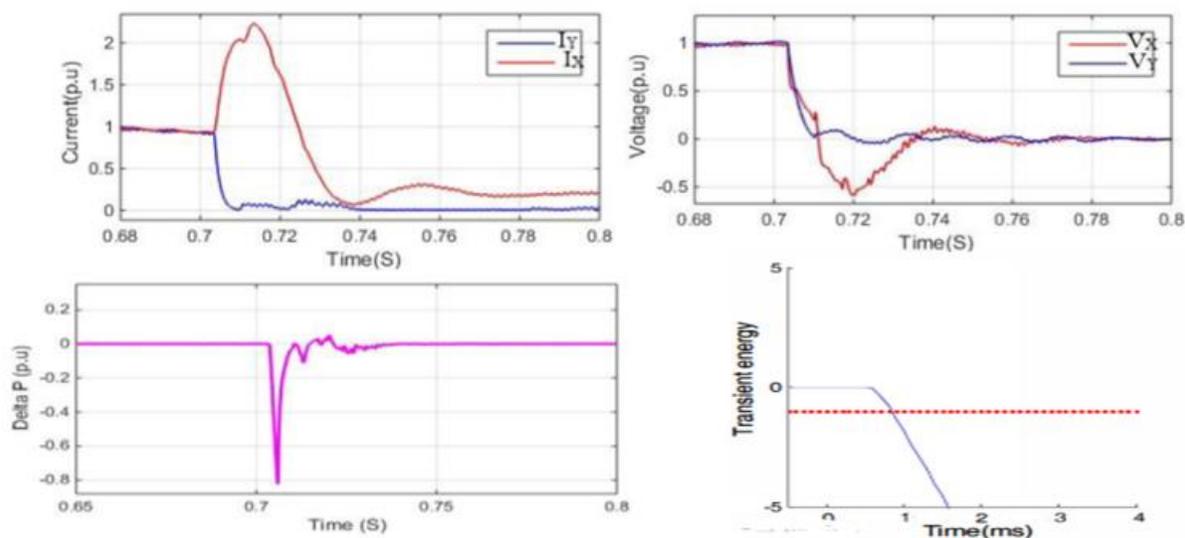

Figure 12: simulation result of HVDC line on an internal fault

9. Discussion

As it is shown from the above result of simulation of the designed sample of HVDC transmission line, the current, the voltage, the transient power and the transient energy are the result of the transmission line parameter. The result depends on the three location and types of faults which occur on the transmission line. The first graph of the above figure is the result for the fault occurrence on an inverter side of the HVDC line. The fault on the inverter side of HVDC line shows that the current and the voltage multiplied which result in transient power and on the other side the transient power integrated to yield transient energy. The wave form shows the parameter will tend to stable state within short time. The same principle applied for the fault occurred on the rectifier and the middle DC link side of the HVDC transmission line.

10. Conclusion

A novel Algorithm for fault identification and location, based on transient power is proposed for HVDC transmission lines. This method is found to be better than the commonly used travelling wave methods. Because it eliminates the disadvantages of travelling wave methods and gives output with minimum time possible. Test system is modeled in MATLAB based on CIGRE HVDC benchmark system. All the fault conditions were simulated and the result obtained is found to be accurate. The proposed method is simple, reliable and fast. For the secure protection of HVDC transmission line more modified algorithm has to be used for the future.

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