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Study and Simulation for Protection of HVDC Line

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Abstract : Transient harmonic current occurs in line commutated converter situated HVDC transmission system. For the protection of system against these currents a novel protection method is suggest here. In this paper we are using boundary characteristics of DC transmission line. Using Discrete Fourier transform transient harmonic current at both end of the DC transmission line removed. Performance of the protection method is studied under various fault condition depending on location of fault. Matlab /simulink system is presented.

Keywords : Discrete Fourier transform (DFT) analysis, high voltage direct current (HVDC), test and result, transient harmonic current, transmission-line protection.

1. INTRODUCTION

Due to the number of disadvantages of HVAC transmission system HVDC transmission system is used. The advantages of HVDC line are that it is used for long distance and large capacity power transmission; it has ability for asynchronous interconnection and to abstract inattentive loop flows in a connected ac system. [1], [2] Due to these advantages application of HVDC transmission system is increased since some decades.

The conventional protection scheme for HVDC line repeatedly brings into use voltage along with its changing rate to find ground fault in DC link [3]. But it easily affected by fault impedance [4]. Travelling wave theory have been employed in HVDC line with expeditious improvement in microelectronic technology and microcomputer [5]. Although, travelling wave theory based protection scheme has some limitation such as unavailability of mathematical tool to describe travelling wave and sensitive to noise etc. [6][7] Now a days, depending on boundary characteristics of the HVDC line a novel protection method has been proposed [7]-[9]. However the disadvantages is that high frequency component from 10 to 50khz are required, which are not appropriate for sampling and calculation.

Under various fault condition, the response of representive transient features of harmonic current at end point of the DC line differ as a result of boundary characteristics. To determine an internal fault apart from an external fault the transient features of harmonic current can be used.

Here a novel transient harmonic current protection method has been described for mono polar HVDC link. The test system is modelled using MATLAB/simulink. Inclusive test result describing uncomplicated, stable and systematic protection method is given.

2. NEW TRANSIENT HARMONIC CURRENT PROTECTION

Harmonics which are integral multiple of fundamental frequency are generated in the system due to converters which operates at end terminals of the HVDC transmission system. This are basically due to power conversion process [10]. Normally 12 pulse converters generate 12^{th}, 24^{th}, and 36^{th} harmonics. In HVDC transmission line,

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at the time of conversion harmonics voltages are generated. In HVDC transmission systems, harmonic current are generated of the similar order to overlap direct voltage.

DC filter connected in shunt and smoothing reactor are used to overcome these difficulties in HVDC system.[10] For harmonic filtering, they are connected at both terminals of HVDC line[8].

A EXTERNAL FAULT

In Fig. 1, M and N relays are responsible for transient harmonics current protection of HVDC transmission line. Fault at rectifier side and fault at inverter side are considered as external faults. As shown in fig.1, fault F_1 occurs at rectifier side and generates harmonic current i_{kf} which flows in DC transmission line and simultaneously harmonic current i_{kcR} and i_{kcI} are generated due to the conversion process in converters. Due to the DC filter these harmonics are eliminated from external fault and hence do not arrive at protection unit.

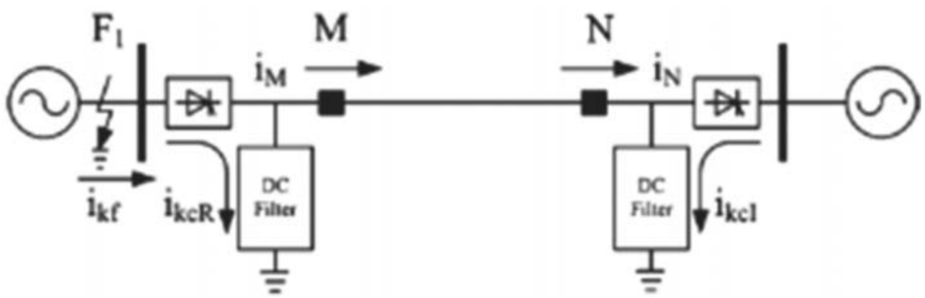


Fig. 1. Fault at rectifier side.

At inverter side fault F_2 occurs as given in Fig. 2 . Here i_{kf} is transient harmonic current that generates due to fault F_2 at inverter side and i_{kcR} and i_{kcI} generates due to conversion process in converters at each terminals of DC link. These harmonics are filtered by dc filter and hence harmonics do not arrive at protection unit. So characteristics of harmonic current can't be measured by transient harmonic protection scheme.

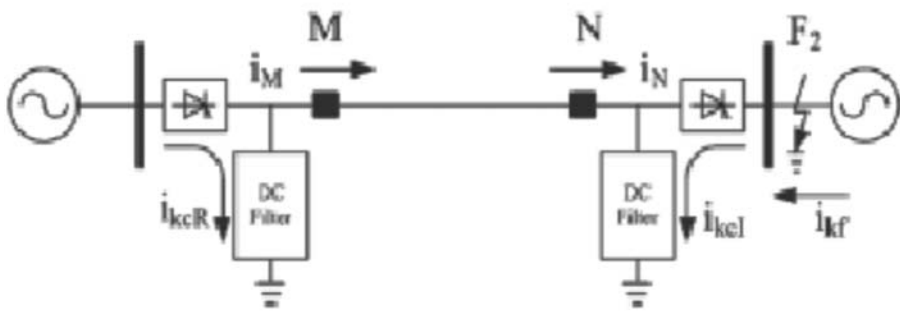


Fig. 2. Fault at inverter side.

B. INTERNAL FAULT

As shown in Fig.3, fault F_3 occurs on dc line and hence fault F_3 is internal fault. Due to occurrence of fault transient harmonic current *i.e.* i_{kf} is generated and i_{kcR} and i_{kcI} are generated by conversion process in converters at each end of DC link.

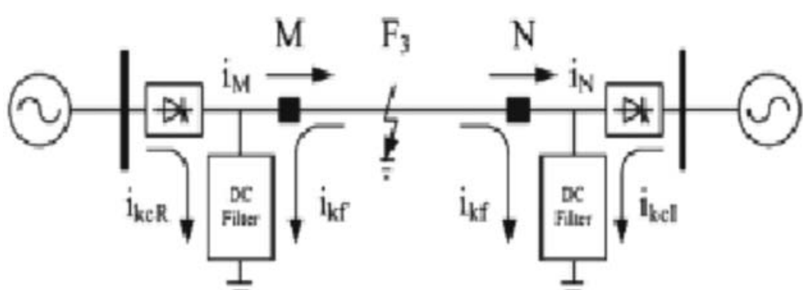


Fig. 3. Internal fault.

The harmonic current will pass through the DC link and they will be acquired by the transient harmonic current protection unit. These protection schemes will be active at each terminals of transmission link. During various fault conditions the transient harmonic currents differ from each other. Transient harmonic current protection unit will measure transients in harmonic current for internal fault. But during external fault these harmonic current will not be allowed to pass through transient harmonic protection unit.

3. DISCRETE FOURIER TRANSFORMATION

To inspect the signal and to find its harmonic content discrete Fourier transform (DFT) is used. A current waveform model $y(t)$ is given by

$$y(t) = Yc \cos \omega_0 t + \sin \omega_0 t$$

Where; Y_c and Y_s = actual numbers;

$y(t)$ = value of current signal at that instant;

ω_0 = significant frequency in rad/sec;

Rectangular form of the DFT is used which is useful to disintegrate the periodic signal into DC, the fundamental and harmonics.

4. NEW TRANSIENT HARMONIC CURRENT PROTECTION SCHEME FOR HVDC LINK

Set values of transient harmonic current protection are defined on basis of above analysis as below

$$I_{H.set} = k_{int} * k_{line} * k_{fault.r} * I_{H.set} \quad (3)$$

$$N_{n.set} = N_{n.inst} \quad (4)$$

where, k_{int} = correction coefficient considering the change of $I_{H.int}$;

k_{line} = correction coefficient considering transmission line length;

$k_{fault.r}$ = correction coefficient considering fault resistance;

$I_{H.int}$ = initial value of transient harmonic current;

$I_{H.Set}$ = setting value of transient harmonic current;

$N_{H.int}$ = initial harmonic pulse number in one cycle, n = 12,24,36. In this paper n = 12;

$N_{H.Set}$ = setting value of transient harmonic current protection for harmonic pulse number in one cycle.

$$I_{H.M} = k_{12} * l_{12.M} + k_{24} * l_{24.M} + k_{3e} * I_{36.M} \quad (5)$$

where $I_{H.M}$ = measured value of transient harmonic current;

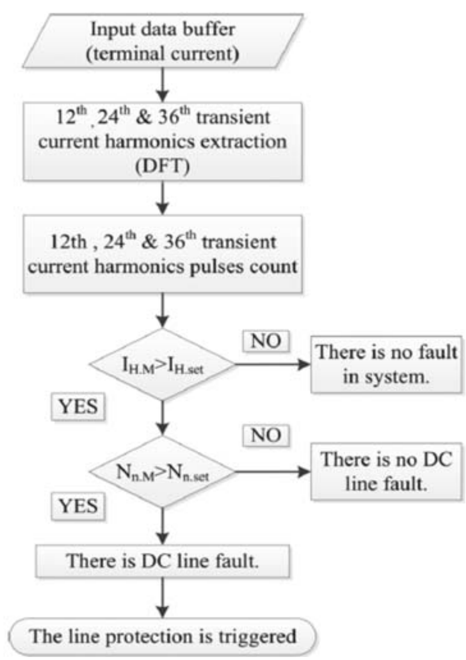


Fig. 4. shows the flowchart for transient harmonic current protection.

$k_{12,} k_{24,} k_{36}$, = correction coefficient for characteristic harmonic currents $I_{12.M}$, $I_{24.M}$, $I_{36.M}$;

$I_{12.M}$, $I_{24.M}$, $I_{36.M}$ = measured value of the 12th, 24th, and 36th characteristic harmonic currents.

Current is observed regularly at both end of HVDC transmission line.DFT is used to calculate transient harmonic current.

If $$I_{H.M} > I_{H.set}$$

When fault occurs in a system, transient harmonic current protection unit operates

The condition $$I_{H.M} > I_{H.set}$$
$$N_{n.M} > N_{n.set}$$

Above equations shows internal fault and hence protection unit is tripped instantly

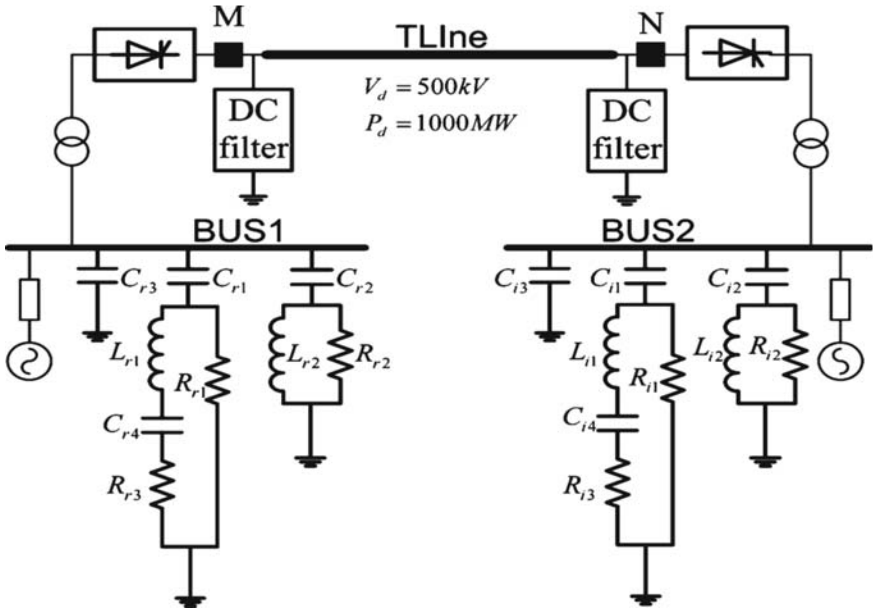


Fig. 5. Test system for HVDC protection scheme.

5. TEST SYSTEM

The model of the system is as shown in Fig.

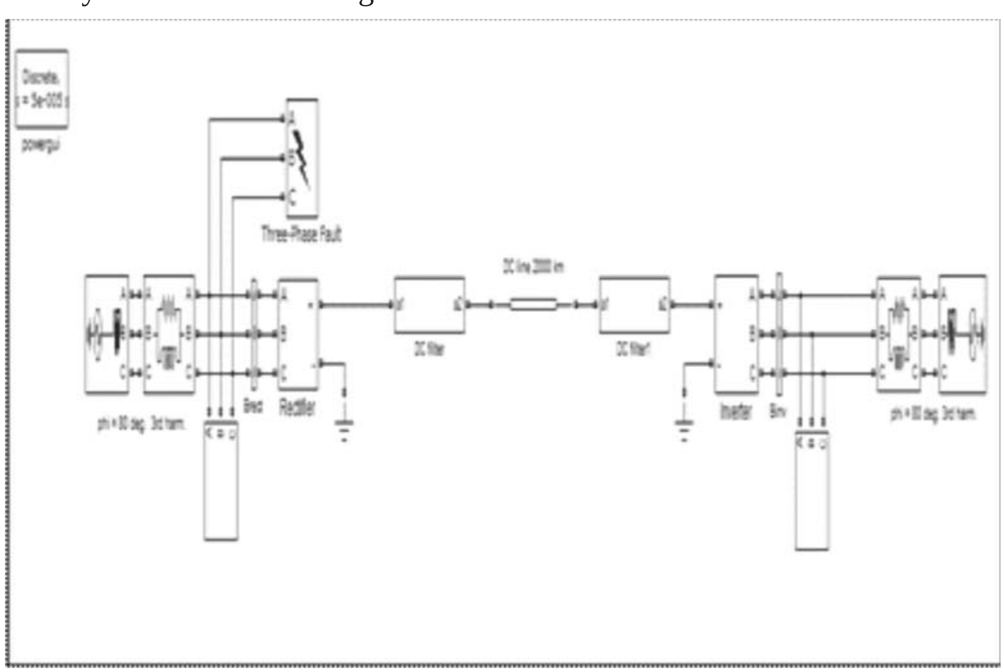


Fig. 6. Test system for fault at rectifier side

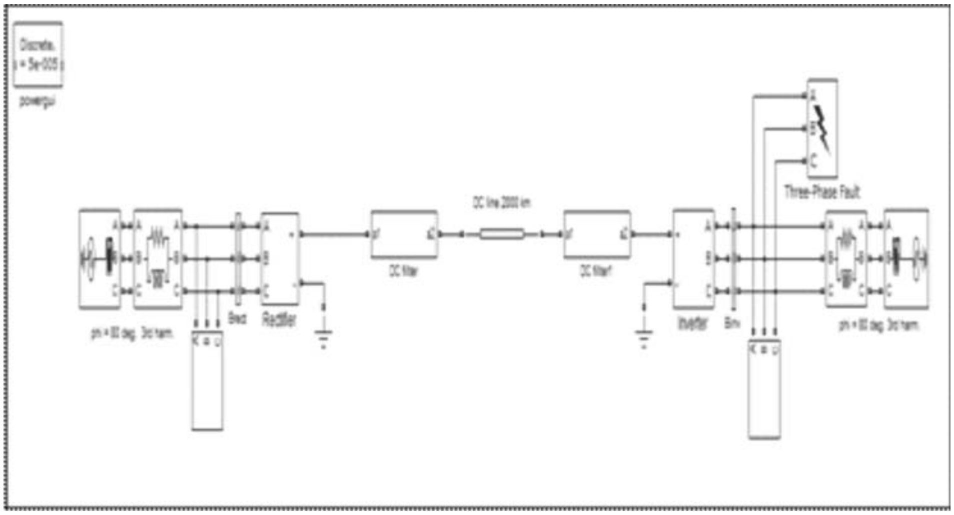


Fig. 7. Test system for fault at inverter side The length of the transmission line is 2000KM and it has 500kv voltage and 1000KW power. At both terminals sampling frequency is 4000 Hz.

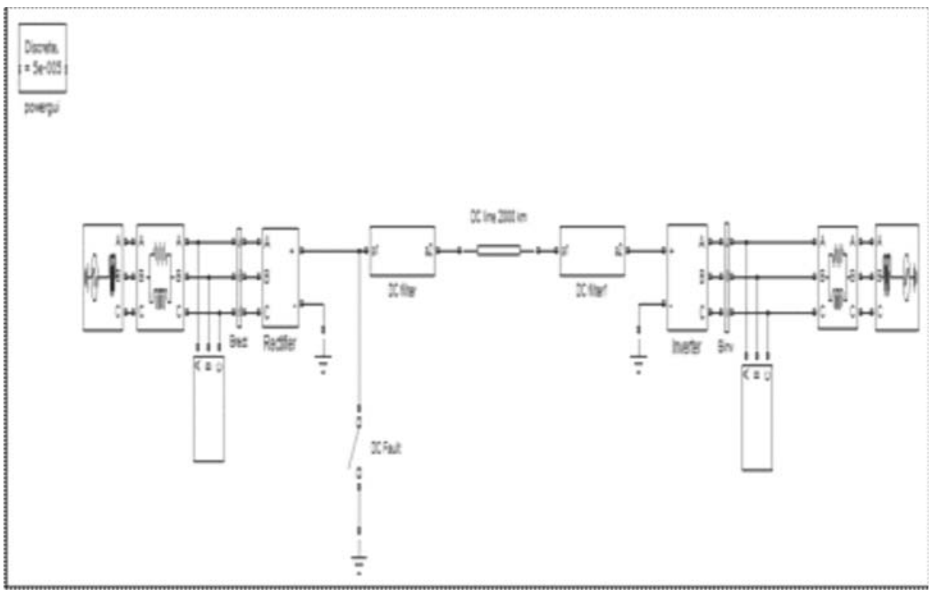


Fig. 8. Test system for fault on DC line side

6. SIMULATION AND TEST RESULT

A. RESULTS FOR FAULT AT RECTIFIER SIDE

Fig 8 shows the system responses for fault at rectifier side with a frequency of 50Hz which occurs at 0.5 sec. The waveform shows for 12th, 24th, and 36th DC harmonic current. In Fig 9 (a) its shows the DC harmonic current closer to rectifier side.

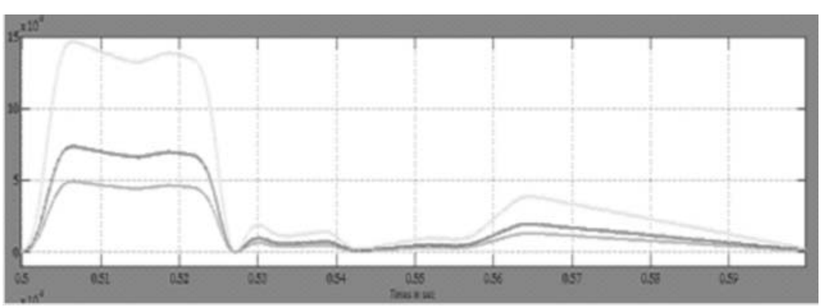


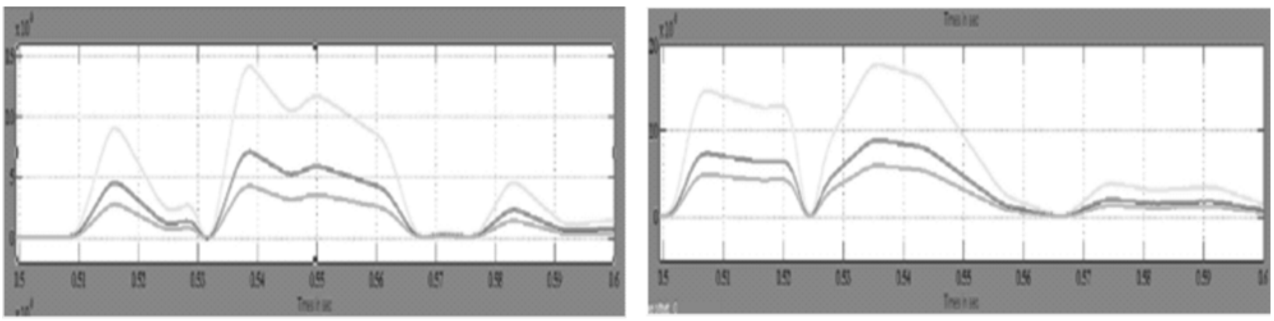
Fig 9 (*a*) the DC harmonic current neighbor to inverter side. (*b*)

Fig. 9. Response harmonic currents during the rectifier fault (*a*) Response harmonic currents at the rectifier terminal (*b*) Response harmonic currents at the inverter terminal

As in Fig. 9 shown, harmonic current set value $I_{H.set}$ is smaller than measured value $I_{H.M.}$ this shows the fault in the system. And we can see in Fig , In one cycle there is no periodic and continuous pulses in harmonic current so measured value of pulses $N_{n.M}$ is much less than $N_{n.Set}$ hence protection unit is not tripped.

B. RESULTS FOR FAULT AT INVETER SIDE

Fig 10 shows the system responses for 3 phase fault at inverter side with a 50Hz occurring at 0.5 sec. The waveform shows for 12th, 24th, and 36th DC harmonic current. In Fig 10(*a*) its shows the DC harmonic current closer to rectifier side and in Fig 10(*b*) the DC harmonic current neighbor to inverter side. As in Fig 10 shown, harmonic current set value $I_{H.set}$ is smaller than measured value $I_{H.M.}$ this shows the fault in the system. And we can see in fig , In one cycle there is no periodic and continuous pulses in harmonic current so measured value of pulses $N_{n.M}$ is much less than $N_{n.Set}$ hence protection unit is not tripped.



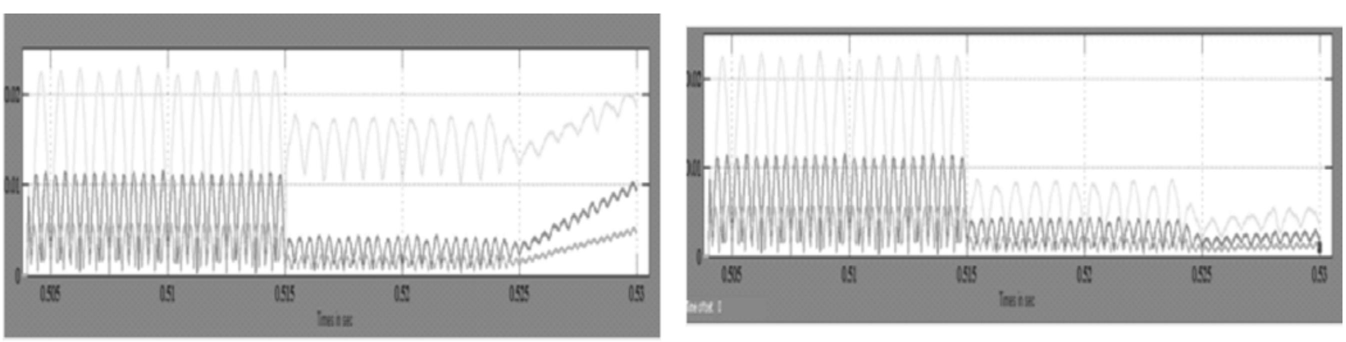
(*a*) (*b*)

Fig. 10. Response harmonic currents during the inverter fault. (*a*) Response harmonic currents at the rectifier terminal. (*b*) Response harmonic currents at the inverter terminal

C. RESULTS FOR DC LINE FAULT

Fig shows the system responses for DC line fault occurring at 0.5 sec. The waveform shows for 12th, 24th, and 36th DC harmonic current. In Fig 11(a) its shows the DC harmonic current closer to rectifier side and in Fig 11(b) the DC harmonic current neighbor to inverter side.

As shown in Fig , harmonic current set value $I_{H.set}$ is smaller than measured value $I_{H.M.}$ this shows the fault in the system. And we can see in fig , In one cycle there is periodic and continuous pulses in harmonic current so measured value of pulses $N_{n.M}$ is greater than $N_{n.Set}$ hence protection unit is tripped immediately.



(*a*) (*b*)

Fig. 11. Response of harmonic currents during the dc line fault. (*a*) Response of harmonic currents at the rectifier terminal. (*b*) Characteristic response of harmonic currents at the inverter terminal

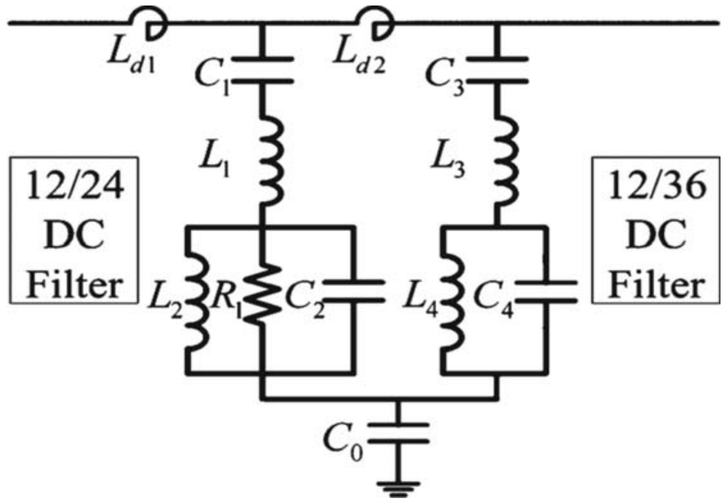


Fig. 12. DC filters structure of the HVDC transmission system.

At two terminals of the dc line the characteristic harmonic currents are $I_{12.M}$, $I_{24.M}$, $I_{36.M}$ and can be measured. According to (10), the transient harmonic $I_{H.M}$ current can be calculated. The count of the 12th harmonic $N_{12.M}$ current pulse and the time lag coefficient can also be obtained. In this simulation, the correction coefficient values of (8) are set as follows: k_{int} = 0.5,K_{line} =1, $k_{fault.r}$ = 0.2, $I_{H.int}$ = 0.01 p.u. So the setting value will be 0.001 p.u. after calculation The setting value of the 12th harmonic pulse number $N_{12.Set}$ is set as 11.

7. CONCLUSION

In this paper, new protection method is propounded for HVDC transmission link. The correspondence between fault response and features of proposed protection scheme has been observed. According to pulse numbers in harmonic current type of fault is determined. And protection scheme tripped to remove harmonics pulses. Above studies suggests that the operation of the transient harmonic current protection scheme is satisfactory. The protection scheme is accurately and instantaneously able to determine whether the fault is internal or external.

APPENDIX

DC filters parameters

L_{d1} = 0.15H, C_1= 0.9 μF, L_1 =0.03893H,
L_2 = 0.01922H, R_1 = 500 & Ω, C_2 = 1.81,
L_{d2} = 0.15H, C_3 =0.3 μF , L_3 = 0.07789H,
L_4 = 0.10295H , C_4 = 0.23 μF, C_0 = 6 μF

Rectifier ac system AC SCR = 2.5@84.0 deg 345.0*k*V 50HZ

filters parameters at the rectifier side

R_{r1} = 2.6187 & Ω, R_{r2} =83.32 & Ω, R_{r3} = 29.76 &Ω,
L_{r1} = 0.1364H, L_{r2} = 0.0136H,
C_{r1} = 6.685 μF, C_{r2}= 6.685 μF, C_{r3}= 3.342 μF,C_{r4}= 0.1364 μF

Inverter ac system AC SCR = 2.5@75.0 deg 230.0kV 50HZ

filters parameters at the inverter side

R_{i1} = 116.36 &!, R_{i2} =37.03&!, R_{i3} =13.23 &!,
L_{i1} = 0.0606H, L_{i2} = 0.0061H,
C_{i1} = 15.04 μF, C_{i2}= 15.04 μF, C_{i3}= 7.522 μF,C_{i4}=167.2μF

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