Scientific Journal of Impact Factor (SJIF): 4.14
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406
International Journal of Advance Engineering and Research Development
Volume 3, Issue 6, June -2016

Protection scheme for HVDC converters against DC side fault

[1]Atish Patel , [2]Prof. Muddapu Lohith

[1]PG Student at dept. of Electrical Engineering, Parul Institute of Engineering and Technology
[2]Asst. proff. At Electrical Engineering, Parul Institute of Engineering & Technology

Abstract:- *Improving the efficiency and operation of power transmission is important due to the continual increase in demand for electric power. In addition, many remote areas throughout the world lack sufficient access to electricity. Unfortunately, utilities cannot satisfy the high demand of power by building new power stations because of economic and environmental reasons. However, utilities can increase generation and transmission line efficiencies by controlling the power flow through their systems. One new attractive technology that enables the control of power flow in the system is Voltage-Source- Converter High Voltage Direct Current (VSC-HVDC) transmission. The contemplated protection scheme provides advantages, such as lower dv/dt stresses and lower voltage rating of thyristor switches in accumulation to providing full segregation between the converter semiconductor devices and ac grid during dc-side faults. A simulation case study has been carried out to reveals the effectiveness of the contemplated scheme.*

INTRODUCTION

WITH THE rapid increase in energy demand, grid integration of renewable energy sources has become essential. Among the different renewable energy sources, offshore wind energy benefits from HVDC technology for power transmission performance improvement.

Thanks to their substantial advantages, classical voltage source converter-based-HVDC (VSC-HVDC) and modular multilevel converter-based-HVDC (MMC-HVDC) systems are expected to be the technology of choice for efficient grid integration. Both types provide:

1) Fast and independent control of active and reactive power flow in both directions and
2) low harmonic generation hence the requirement of large filters is minimized. In addition, MMC-HVDC systems also have inherent salient features, such as low switching losses, low total harmonic distortion, modularity, and scalability (scalable to different power and voltage levels).

In HVDC systems, limiting fault currents is vital to protect the converter semiconductor devices, which are the most sensitive components in the system. Unfortunately, the classical VSCs and MMCs are defenseless against dc-side faults since their freewheeling diodes function as an uncontrolled rectifier bridge and feed the dc fault, even if the semiconductor devices are turned off. During the dc fault, the ac-side current contribution into the dc fault passes through the freewheeling diodes. As a result, the diodes may be damaged due to high fault current. This rectification mode of operation is shown in Fig. 1(a) and (b) for the two-level VSC and MMC during a dc-side fault.

.I. VSC-based HVDC system

VSCs utilize self-commutating switches, e.g. gate turn-off thyristors (GTOs) or insulated gate bipolar transistors (IGBTs), which can be turned on or off in a controlled manner. VSCs operate at high switching frequency utilizing Pulse-Width Modulation (PWM) technique. Generally, the new transmission technology has the following advantages compared to classic thyristor-based HVDC:

- Possibility to control the reactive power independent of the active power (to or from the converter) without any needs for extra compensating equipment;

- Little risk of commutation failures in the converter;

- Possibility to connect the VSC-HVDC system to a “weak” ac grid or even to one where no generation source is available and naturally the short-circuit level is very low;

- Faster dynamic response due to higher switching frequency operation (phase-controlled), which further results in reduced need for filtering and hence smaller filter size;

- Minimal environmental impact.

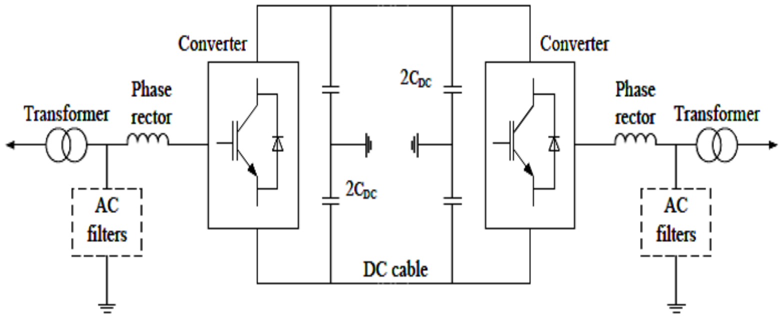


Figure 1 Typical VSC-HVDC system

VSC-based HVDC transmission system consists of two VSCs, transformers, phase reactors, ac filters, dc-link capacitors and dc cables.

The sending end and receiving end of VSC-HVDC have the similar configuration, one operating as a rectifier and another as an inverter. In this work the two converters are connected back-to-back. Normally, converters are connected to the ac system by means of transformers. The most important function of transformers is to transform the ac voltage level to the dc voltage level. Usually, they are single-phase three-winding type, but depending on the transportation requirements and the rated power, they can be arranged in other ways**.** The phase reactors are used for controlling active and reactive power flow by regulating currents through them. The reactors also serve as ac filters and therefore reduce the high frequency harmonic contents of the ac currents which are caused by the switching operation of the IGBTs. The dc side contains two equally-sized capacitors. The size of these capacitors depends on the required dc voltage. The primary objective of the dc capacitor is to provide a low inductive path for the turned-off current and energy storage to be able to control the power flow. The capacitor also reduces the voltage ripple on the dc side. Ac filters prevent the voltage harmonics entering the ac system. New type of dc cables is used in VSC-HVDC applications, where the insulation is made of an extruded polymer that is particularly resistant to dc voltage. Polymeric cables are the preferred choice for HVDC, mainly because of their mechanical strength, flexibility, and low weight**.** VSC on the ac side acts as a constant current source and therefore requires an inductor as its energy storage device. A small ac filter for harmonics elimination is also required on the ac side. On the dc side VSC acts as a constant voltage source and it requires a capacitor as its energy storage device. Energy storage capacitor here provides dc filtering capability. When compared to classic HVDC that are based on CSC, VSC-based HVDC has relatively high switching losses, but by using a soft-switching commutation scheme, the switching losses are considerably reduced**.**

The most relevant components of the HVDC system are the following:
- The thyristor or IGBT valves that realize the conversion from ac to dc and thus are the main components of any HVDC converter;
- The converter transformers transform the voltage level of the ac busbar to the required entry voltage level of the converter;
- The smoothing reactor, which has the main functions of prevention of the discontinuous current, limitation of the dc fault currents and prevention of resonance in the dc circuits;
- The ac harmonic filters, which absorb harmonic currents generated by the HVDC converter and supply reactive power;
- Dc transmission circuit consisting of dc transmission line, cable, dc switches and earth electrode.

II protection scheme

1) **i. Single-Thyristor Switch Scheme (STSS)**:- In the STSS, the thyristor is connected across the semiconductor device. During normal operating conditions, the voltage across semiconductor devices changes between 0 and Vsw. In case of a two-level VSC, Vsw is equal to the dc-link voltage Vdc, while it is equal to the voltage of each submodule's capacitor Vdc/n in case of the MMC; where is the number of submodules per arm. The dv/dt on the single-thyristor switch for the two-level VSC and MMC is given by (1) and (2), respectively

$$\left.\frac{dv}{dt}\right|_{\text{Single,VSC}} = \pm\frac{V_{sw}}{T_{\frac{\text{on}}{\text{off}}}} = \pm\frac{V_{\text{dc}}}{T_{\frac{\text{on}}{\text{off}}}} \qquad (1)$$

$$\left.\frac{dv}{dt}\right|_{\text{Single,MMC}} = \pm\frac{\left(\frac{V_{\text{dc}}}{n}\right)}{T_{\frac{\text{on}}{\text{off}}}} \qquad (2)$$

Where Ton/off is the time needed for the semiconductor device to change its state from ON to OFF or vice-versa. Six and 6n single-thyristor switches with a voltage rating of Vdc and Vdc/n will be needed for the two-level VSC andMMC configurations, respectively.

2) Double-Thyristor Switch Scheme (DTSS): In the DTSS, a back-to-back thyristor switch is also connected across each semiconductor device, that is, it will have the same dv/dt as the STSS as follows:

$$\left.\frac{dv}{dt}\right|_{\text{Double,VSC}} = \pm\frac{V_{sw}}{T_{\frac{\text{on}}{\text{off}}}} = \pm\frac{V_{\text{dc}}}{T_{\frac{\text{on}}{\text{off}}}} \qquad (3)$$

$$\left.\frac{dv}{dt}\right|_{\text{Double,MMC}} = \pm\frac{\left(\frac{V_{\text{dc}}}{n}\right)}{T_{\frac{\text{on}}{\text{off}}}}. \qquad (4)$$

Similarly, six and 6n double-thyristor switches with a voltage rating of Vdc and Vdc/n will be needed for two-level VSC and MMC configurations, respectively.

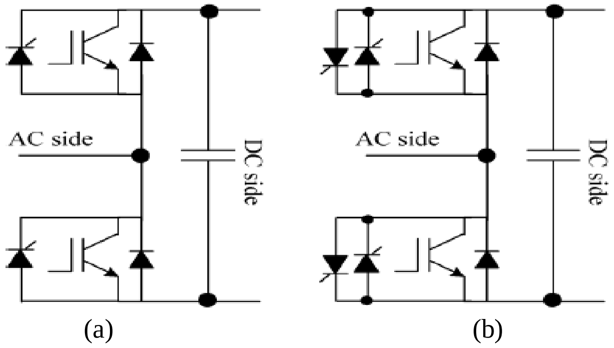


Fig. 3 (a) STSS for one leg of two level VSC topology and (b) DTSS for one leg of two-level VSC topology.

III CONTROL SYSTEM

Different control strategies have been developed for the control of VSC-HVDC. One of the methods for control of VSC-HVDC is known as the vector control method, which is transforming a three-phase system into a two-phase system by using dq-axis transformations. As shown in Figure 4.2, vector control works by transferring the vectors of AC currents and voltages to two-phase constant vectors in steady state and therefore static errors in the control system can be avoided by using PI controllers. Thus, vector control systems can be used to obtain independent control of the active and reactive powers.

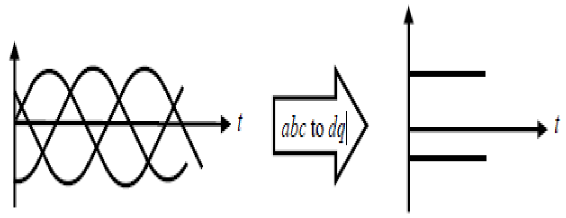


Fig. 2 DQ-axis Transformation Principle

For analysis of the VSC-HVDC, considering the converter system connected to AC network and the currents Iabc, are injected to the converter. The AC network voltages are defined as Vx, abc, and the converter input voltages Vr, abc, and resistance (R) and inductance (L) between the converter and the AC network, as shown in the system of Figure 4.1. The voltage at the AC network side of the converter can be expressed as:

$$V_{x,abc} = RL_{abc} + L\frac{DI_{abc}}{dt} + V_{r,abc} \qquad (1)$$

Applying the dq transformation equation (1) yields:

$$\frac{di_d}{dt} = \frac{V_{x,d} - V_{r,d}}{L} - \frac{R}{L}i_d + \omega i_q \qquad (2)$$

$$\frac{di_q}{dt} = \frac{V_{x,q} - V_{r,q}}{L} - \frac{R}{L}i_q + \omega i_d \qquad (3)$$

Where ω is frequency of the fundamental component in the AC network. The active power injected into or absorbed from the AC network is given by:

$$P_i = \frac{3}{2}(V_{x,d}I_d + V_{x,q}I_q) \qquad (4)$$

Inner Current Controllers. An inner current controller is developed based on equations (2) and (3) as shown in Figure 4. *Id** and *Iq** are reference currents for the *d*-axis and *q*-axis current controllers respectively.

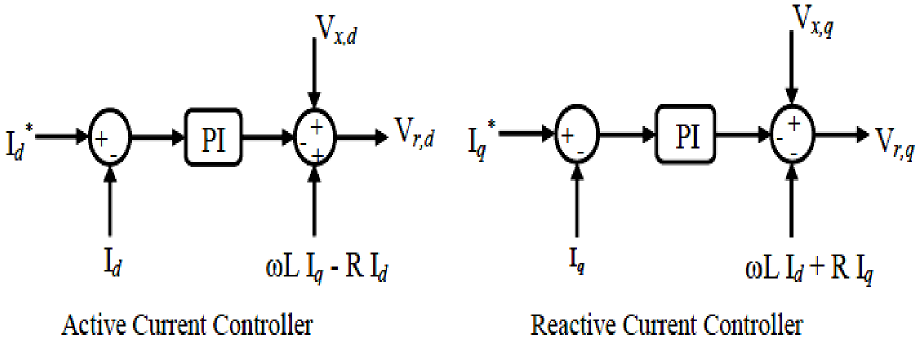


Figure 4 Inner Current Controllers

$V_{r,d}$ and $V_{r,q}$ are the dq reference frame voltages which are transferred to the abc frame and Vr,abc. Vr,abc are the reference voltages for the PWM.

Outer Controllers: The active current reference I_d^* can be used to control either the active power flow or the DC voltage level as will be illustrated in the next section.

Active power control:- The *dq* reference frame is selected in a direction such that the *d*-axis is in phase with the AC source voltage. This means that

$V_{xq} = 0$ (5)

Therefore, equation (4) can be rewritten as

$$P_i = \frac{3}{2} V_{x,d} I_d \qquad (6)$$

` Equation implies that the active power flow can be controlled by the active current "I_d. Therefore, the output of the active power controller will be the reference input to the active current controller I_d of the inner current controllers in Figure3. The active power controller is shown in Figure 5. Pi* is a reference active power flow.

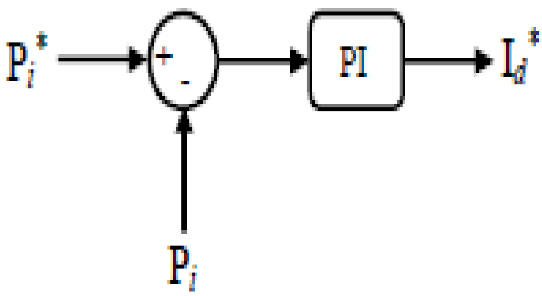


Figure 5 Active Current Controller

From the active power balance of the VSC-HVDC in Figure 3.4, the relation can be as following (ignoring the converter losses):

$P_i = P_{dc} + P_{cap}$ (7)

Where P_i refers to the power transferred from the AC source toward the DC lines, and P_{DC} and P_{cap} refer to the power flowing into the DC lines and the DC capacitor respectively.

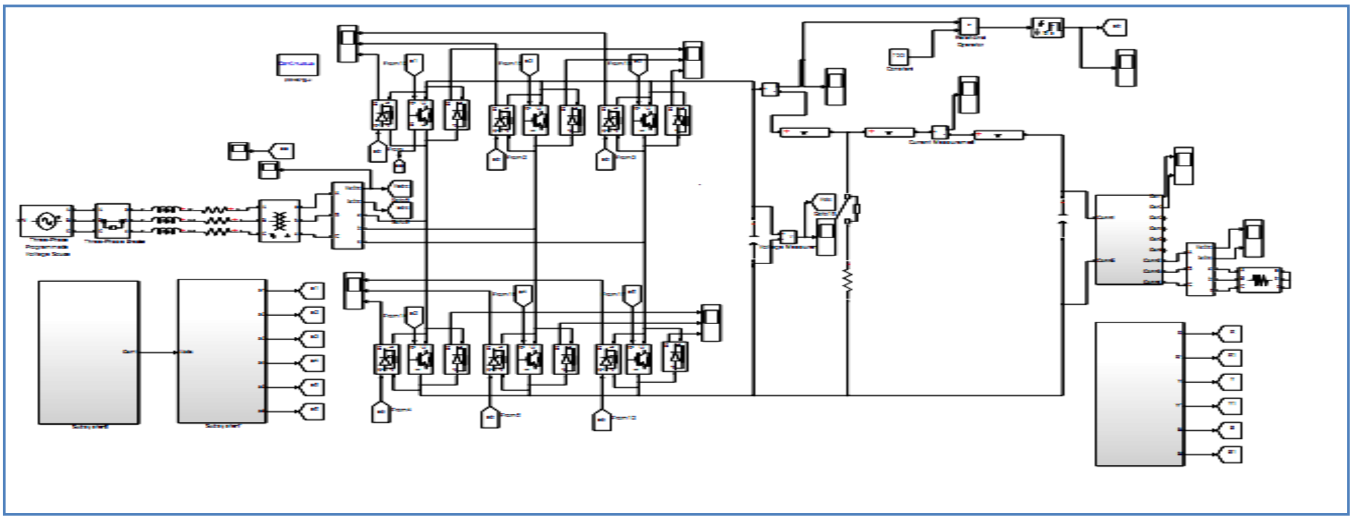
$P_{dc} = V_{dc} I_{dc}$ (8)

$P_{cap} = V_{dc} I_{cap}$ (9)

$I_{cap} = C \frac{dv_{dc}}{dt}$ (10)

IV SIMULATIONS AND RESULT

i. single thyristor switching scheme:-



From equations (8), (9), (10), (4.8) and (7), the differential equation for the DC voltage is:

$$C\frac{dv_{dc}}{dt} = \frac{3V_{x,d}I_d}{2V_{dc}} - I_{dc} \qquad (11)$$

Equation (11) indicates that the DC voltage can be controlled by the active current I_d. Although the IDC in equation (11) can be represented as a feed forward control in the DC voltage controller, the DC voltage can be controlled without a feed forward control loop because the PI controller has the ability to maintain the DC voltage constant. Thus, the DC voltage controller will be as shown in Figure 6.

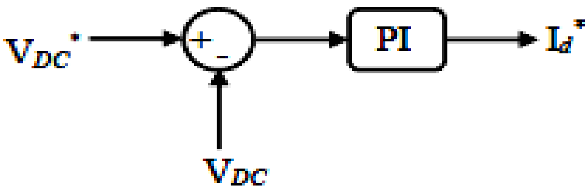
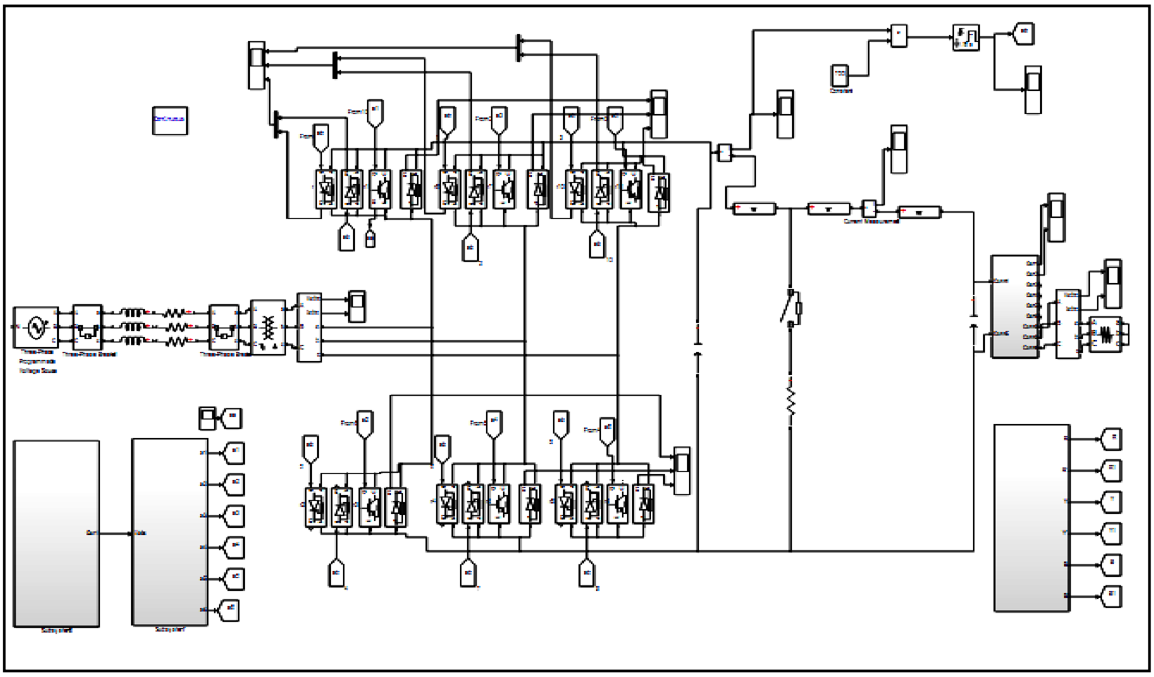


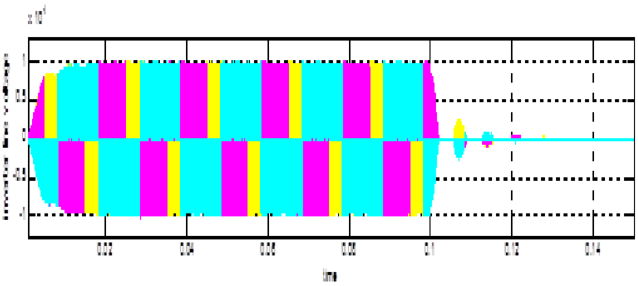
Fig.6. DC Voltage Controller

ii. double thyristor switching scheme

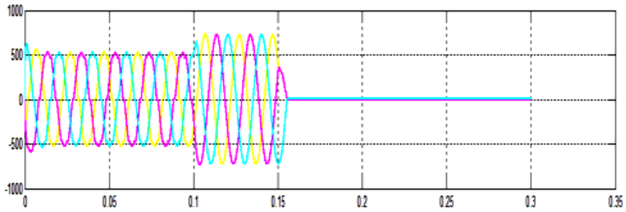


Results

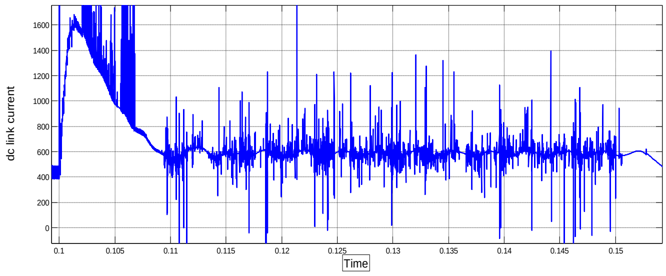
1. Inverter line voltage:-



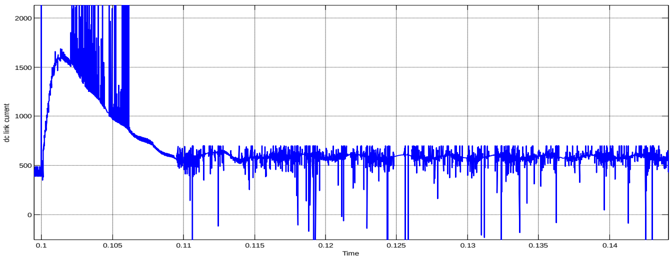
2. Greed phase current



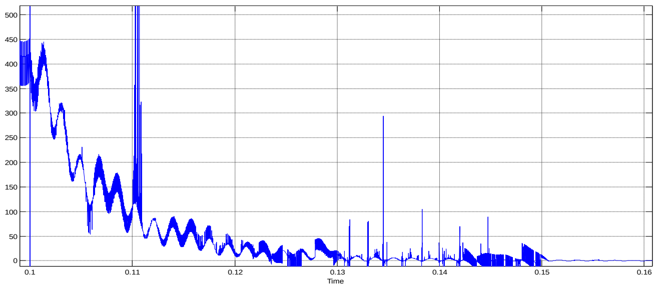
3. DC link current:-



Dc link current without any protection scheme is tends to be very high at the time of appearing the fault.

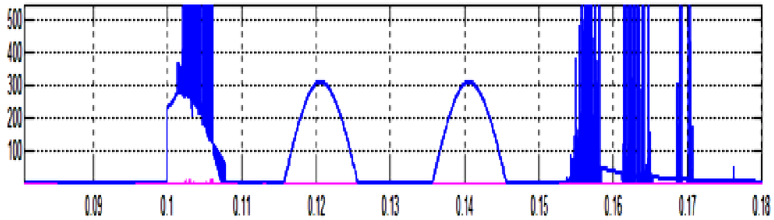


The waveform shows the DC link current during the STSS protection scheme. The results show that the current will decrease at the time of fault appearing.

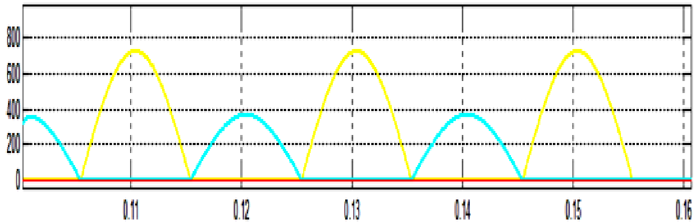


The waveform shows the DC link current during the DTSS protection scheme. The results show that the current will decrease much more compare to the STSS at the time of fault appearing.

4. Thyristor current:-

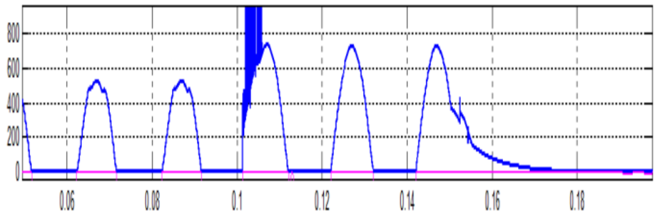


So when the fault appears as per our protection scheme the thyristor will turn on. The waveform shows that at the time of fault appearing the current is flowing from the thyristor, Which reduce the stress on both IGBT and the freewheeling diode.

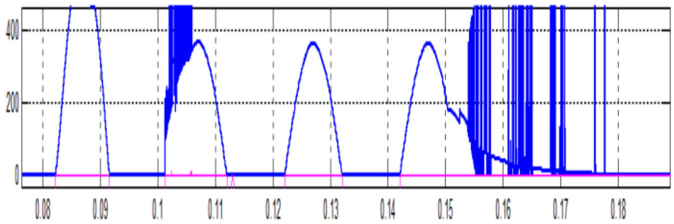


Same as STSS here in the DTSS the current will pass from the both thyristor. So the current passing from the igbt and freewheeling diode will much decreases. It will reduce the stress as well.

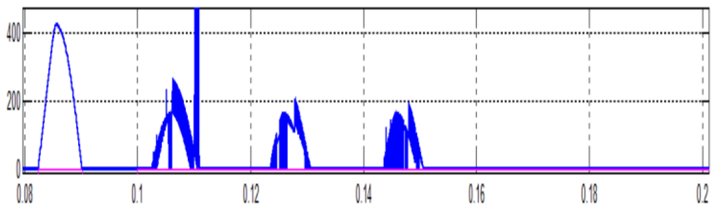
5. Diode current:-



The diode is the low resistance path for the current. So the current will pass from the freewheeling diode. We can see the current passing from the diode is too high.



But applying the protection scheme we can see that the current flowing from the diode is decreasing significantly.



By the second protection scheme we can see that the current flowing from the diode is decreasing more than the STSS method.

IV CONCLUSION

Depending on ac circuit breakers (ACCBs) to protect HVDC converters against dc-side faults is a risk since the full ac fault current is passing through the freewheeling diodes until tripping the ACCBs is achieved. Hence, the need for complex dc breakers has emerged as the alternative. In this paper, a protection scheme for HVDC converters (classical VSCs as well as MMCs) against dc-side faults is proposed. In this paper two schemes are presented which is STSS and DTSS. After the simulation we can conclude that the current from the dc side will divided between the freewheeling diode and the thyristors, which eventually reduce the stress on the IGBTs.

REFERENCES

[1] N. Flourentzou, V. G. Agelidis, and G. D. Demetriades, “VSC-based HVDC power transmission systems: An overview,” IEEE Trans. Power Electron., vol. 24, no. 3, pp. 592–602, Mar. 2009.

[2] P. Lundberg, M. Callavik, M. Bahrman, and P. Sandeberg, “High-voltage DC converters and cable technologies for offshore renewable integration and DC grid expansions,” IEEE Power Energy Mag., vol. 10, no. 6, pp. 30–38, Nov. 2012.

[3] L. Zhang et al., “Interconnection of two very weak ac systems by VSC-HVDC links using power-synchronization control,” IEEE Trans. Power Syst., vol. 26, no. 1, pp. 344–355, Feb. 2011.

[4] J. M. Espi and J. Castello, “Wind turbine generation system with optimized dc-link design and control,” IEEE Trans. Ind. Electron., vol. 60, no. 3, pp. 919–929, Mar. 2013.

[5] S. Cole and R. Belmans, “Transmission of bulk power,” IEEE Ind. Electron. Mag., vol. 3, no. 3, pp. 19–24, Sep. 2009.

[6] Y. Li, Z. W. Zhang, C. Rehtanz, L. F. Luo, S. Rüberg, and D. C. Yang, “A new voltage source converter-HVDC transmission system based on an inductive filtering method,” IET Gen. Transm. Distrib., vol. 5, no. 5, pp. 569–576, May 2011.

[7] L. Zhang, L. Harnefors, and H. P. Nee, “Modeling and control of VSCHVDC links connected to island systems,” IEEE Trans. Power Syst., vol. 26, no. 2, pp. 783–793, May 2011.

