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. 5, Special Issue 8, November 2016

Role of Power Electronic Devices in HVDC System for Fault Mitigation and Harmonic Stability

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ABSTRACT: With the fast development of converters (rectifiers and inverters) at higher voltages and larger currents, D.C. transmission has become a major factor in the planning of the power transmission.The advantages of D.C transmission as compared to AC Transmission are that there is a fast controllability of power in DC lines through converter control.The control of HVDC transmission bridges by implementing the power electronics equipment like rectifier station at the AC-DC transmission and inverter at the DC-AC transmission. The voltage and power flow control is mainly done by controlling the firing angle of rectifier and extinction angle of inverter.AC & DC filters are introduced to reduce the telephone interferenceand to filter unwanted harmonicswhich would cause destabilization to HVDC system.

Fast Fourier Transform (FFT) and Short Circuit Ratio (SCR) test with variation of loads is carried outunder the simulation of MATLAB/ SIMULINK.

KEYWORDS: AC-DC Transmission, HVDC, Fast Fourier Transform(FFT), Total harmonic Distortion (THD)

I.INTRODUCTION

In the history of the electricity industry, that the first commercialelectricity generated (by Thomas Alva Edison) was direct current (DC) electrical power. The first electricity transmission systems were also direct current systems.Since the first commercial installation in 1954 a huge amount of HVDC transmission systems have been installed around the world. In today electricity industry, in view of theliberalization and increased effects to conserve the environment, HVDC solutions have become more desirable for the following reasons:

1. Environmental aspect
2. Economical
3. Asynchronous interconnections
4. Power flow control

Added benefits to the transmissionlike stability, power quality etc.[1].At the same insulation level, a DC line can carry as much power with two terminals ofpositive and negative conductors as compared over an AC lines . It saves about 67% of that for AC with the same current carrying capacity of conductors[2].The fast controllability of power in DC lines through converter control has brought several advantages that are not achievable with AC transmission system. It includes synchronous interconnections between two large AC systems, control of power flow and power modulation control to enhance system operation. Maintaining a stable and weak AC connection between two large and independent systems is technically difficult and almost impossible, but HVDC ties can overcome all these drawbacks. The asynchronous nature of a DC link allows interconnection with different nominal frequencies [3].

The main objective of this paper is to present basic voltage control system which is able to control the power flow between terminal DC links connecting the AC systems. The performance of power transmission was ascertained by tuning firing angles of the thyristor valves in HVDC bridge model circuit. Transformers with star-star and star-delta connections are emphasized in this paper.Fig.1.Illustrates a simplified single-line diagram of a two-terminal bipolar HVDC transmission system.

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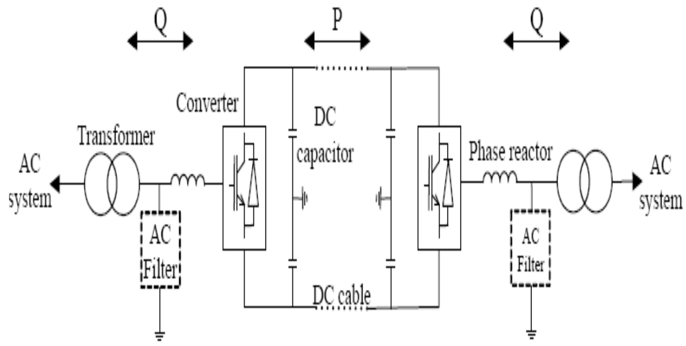

Fig.1.Single-Line diagram of a HVDC System.

II.THYRISTOR BASED HVDC CONTROLLER

Most HVDC schemes in commercial operation today employ line commutated thyristor valve converters. In a line commutated converter, the commutation is carried out by the ac system voltage.The line commutated converter based HVDC will continue to be used for bulk power HVDC transmission over several hundred MW, because this mature technology provides efficient, reliable and cost effective power transmission for many applications.

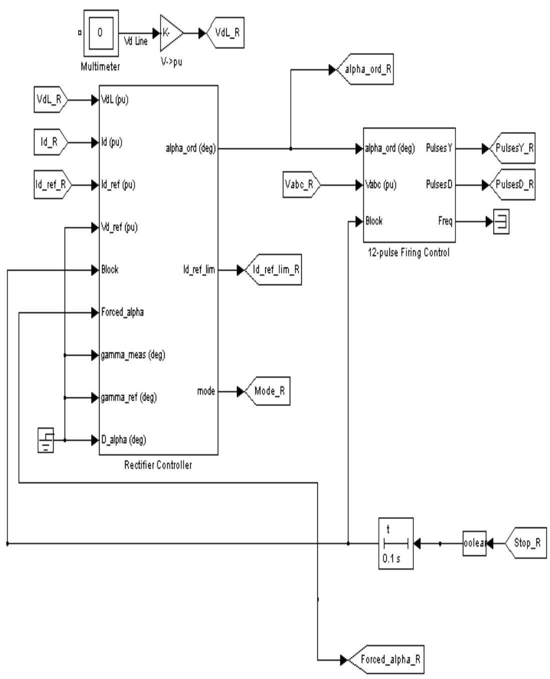

Fig.2.HVDC Controller in Rectifier Side

The control systems of the rectifier and of the inverter use the same discrete HVDC controller block from the discrete control.The system can operate in either rectifier or inverter mode. At the inverter, the Gamma Measurement block is

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used.The Master Control system generates the current reference for both converters and initiates the starting and stopping of the DC power transmission.Figure.2.shows HVDC controller in rectifier side and also Figure.3.shows HVDC controller connected to the inverter circuit used in this paper.

Inputs 1and 2 are the DC line voltage (V_{DL}) and current (I_d). Note that the measured DC currents voltages p.u.(1 p.u. current = 2 kA; 1 p.u. voltage = 500 kV) before they are used in the controllers.**Inputs 3 and 4** (I_{d_ref} and V_{d_ref}) are V_d and $I_d$reference values in p.u.**Input 5** (Blocked pulses) accepts a logical signal (0 or 1) used to block the converter when Block = 1.
Input 6 (Forced-alpha) is also a logical signal that can be used for protection purposes. If this signal is high (1), the firing angle is forced at the value defined in the block dialog box.**Input 7** (gamma_meas) is the measured minimum extinction angle of the converter 12 valves. It is obtained by combining the outputs of two 6-pulse Gamma Measurement blocks. **Input 8** (gamma_ref) is the extinction angle reference in degrees. To minimize the reactive power absorption, the reference is set to a minimum acceptable angle (e.g., 18 deg). **Input 9** (D_alpha) is a value that is subtracted from the delay angle maximum limit to increase the commutation margin during transients.

Table 1. Modes of HVDC Controller

Mode 0	Blocked pulses
Mode1	Current control
Mode2	Voltage control
Mode3	Alpha minimum limitation
Mode4	Alpha maximum limitation
Mode5	Forced or constant alpha
Mode6	Gamma control

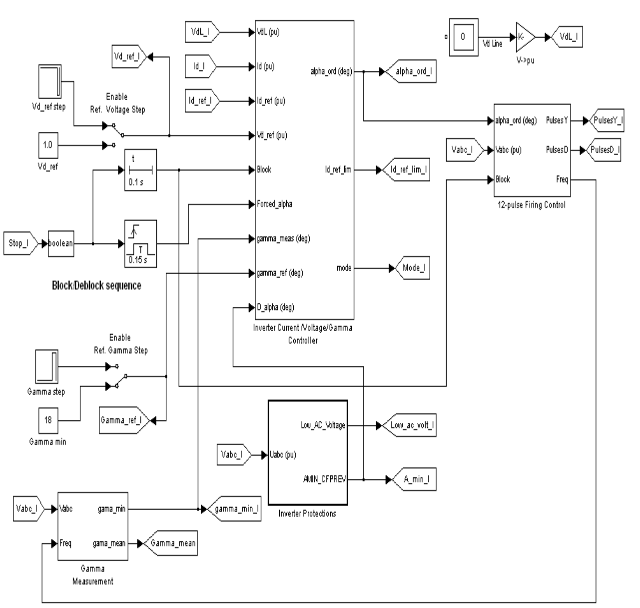

Fig.3. HVDC Controller Connected to the Inverter Circuit

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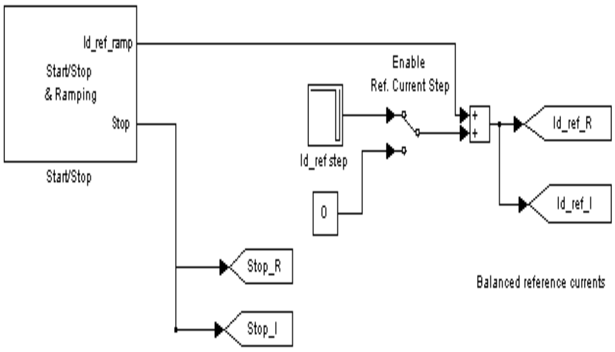

Fig.4. Master control unit for the circuit

The master controlcircuit, shown in fig.4, however, is usually system specific and individually designed. Depending on the requirements of the transmission, the control can be designed for constant current or constant power transmitted, or it can be designed to help stabilizing the frequency in one of the AC networks by varying the amount of active power transmitted. The control systems are normally identical in both converter systems in a transmission, but the master control is only active in the station selected to act as the master station, which controls the current command. The calculated current command is transmitted by a communication system to the slave converter station, where the pre-designed current margin is added if the slave is to act as rectifier, subtracted if it is to act as inverter.

III. METHODOLOGY OF IMPLEMENTED SCHEME

Two six pulse Graetz bridges are connected in series to form a 12-pulse converter. The two six pulse converter totally identical except there is an in phase shift of 30° for the AC supply voltages. Some of the harmonic effects are cancelled out with the presence of 30° phase shift. The harmonic reduction can be done with the help of filters.

The main equations governing the steady-state operation of the DC system are given here so that you can compare the theoretical values with the simulation results. The following expression relates the mean direct voltage V_d of a twelve pulse bridge to the direct current I_d and firing angle α (neglecting the ohmic losses in the transformer and thyristors):

$$V_d = 2\times(V_{do}\times\cos(\alpha) - R_c \times I_d) \quad \ldots\ldots\ldots \quad (1)$$

V_{d0} is the ideal no-load direct voltage for a six-pulse bridge

$$V_{do} = (3\sqrt{2}/\pi)\times V_c \quad \ldots\ldots\ldots \quad (2)$$

V_c Is the line-to-line RMS commutating voltage that is dependent on the AC system voltage and the transformer ratio.

R_c is the equivalent commutating resistance.

$$R_c = (3\sqrt{2}/\pi)\times X_c \quad \ldots\ldots \quad (3)$$

X_c is the commutating reactance or transformer reactance referred to the valve side. The voltage applied to the inverter is therefore boosted by a factor of 1/0.90.Therefore, this theoretical voltage corresponds well with the expected rectifier voltage calculated from the inverter voltage and the voltage drop in the DC line (R = 4.5 Ω) and in the rectifier smoothing reactor (R = 1 Ω):

$$V_d = V_{dl} + (R_{DC} + R)\times I_d \quad \ldots\ldots \quad (4)$$

$$V_d = 500kV + (4.5\Omega + 1\Omega)\times 2 = 511kV \quad \ldots. \quad (5)$$

The μ commutation or overlap angle can also be calculated. Its theoretical value depends on α, the DC current Id, and the commutation reactance X_c

$$V_{do} = (3\sqrt{2}/\pi)\times 213.3 = 288.1kV \quad \ldots\ldots \quad (6)$$

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$$R_c = (3/\pi)\times 9.874 = 9.429\Omega \quad \text{...........} \quad (7)$$

$$V_d = 2\times(288.1kV\times\cos(16.5^0) - 9.429\times 2) = 515kV \quad \text{......} \quad (8)$$

$$\mu = a\cos[\cos(\alpha) - \frac{X_c\times I_d\times\sqrt{2}}{V_c}] - \alpha \quad \text{......} \quad (9)$$

$$\mu = a\cos[\cos(16.5^0) - \frac{9.874\times 2\times\sqrt{2}}{213.3}] - 16.5^0 = 17.6^0 \quad \text{....} \quad (10)$$

Therefore, the steady-state current in the DC link can be calculated using the formulae given below.

$$I_d = \frac{(E_{dr} - E_{di})}{R_{cr} + R_d - R_{ci}} \quad \text{............} \quad (11)$$

$$I_d = \frac{(A_r E_r / T_r)\cos\alpha - (A_i E_i / T_i)\cos\gamma}{R_{cr} + R_d - R_{ci}} \quad \text{...} \quad (12)$$

Where, subscripts r, i and d stand for rectifier, inverter and DC link respectively,I_d is the DC link voltage, R_{on},$R_d$and R_{ci} are the resistances of rectifier, DC link and inverter respectively,

A_r and A_i are constants for voltage conversion

E_r and $E_i$are the AC line voltages at transformer primaries.T_r and $T_i$are the transformer off-terminal tap ratios.

IV.MATLAB/SIMULINK RESULTS

Figure.5.illustrates the main simulation of a complete 12-pulse HVDC transmission system.

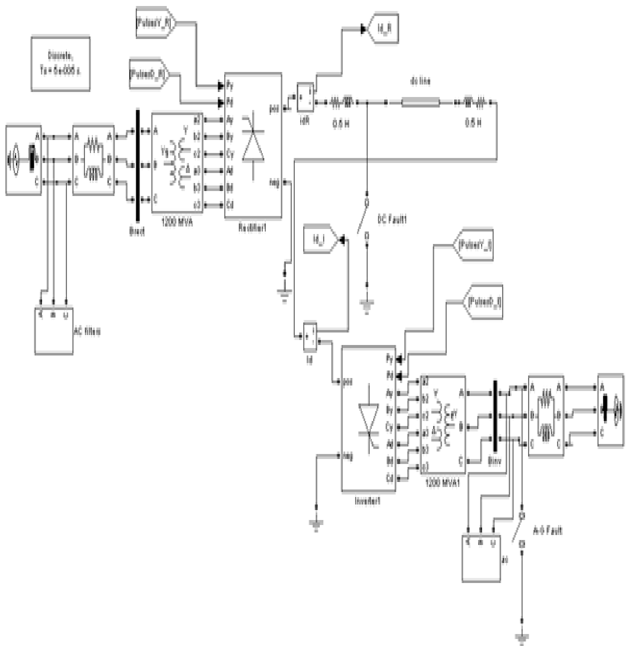

Fig.5. Simulink Diagram of HVDC Connected Main Circuit

The modeling of a high-voltage direct current (HVDC) transmission link using 12-pulse thyristor converters is presented. Perturbations are applied to examine the system performance.

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Table 2. Main DC Data Rating Summary

Power	300 MW,(300KV, 1KA)
Voltage	275KV(rectifier), 230KV(inverter)
Tap Changer	0.90(rectifier), 0.96(inverter)
α angle	18(rectifier), 0.96 (inverter)
γ angle	20(inverter)
Smoothing reactor	0.78H
Length	110Km

The circuit is simulated when the filters are placed and when the filters are removed, the output waveforms are observed as shown in fig. 6 and fig.7 respectively.

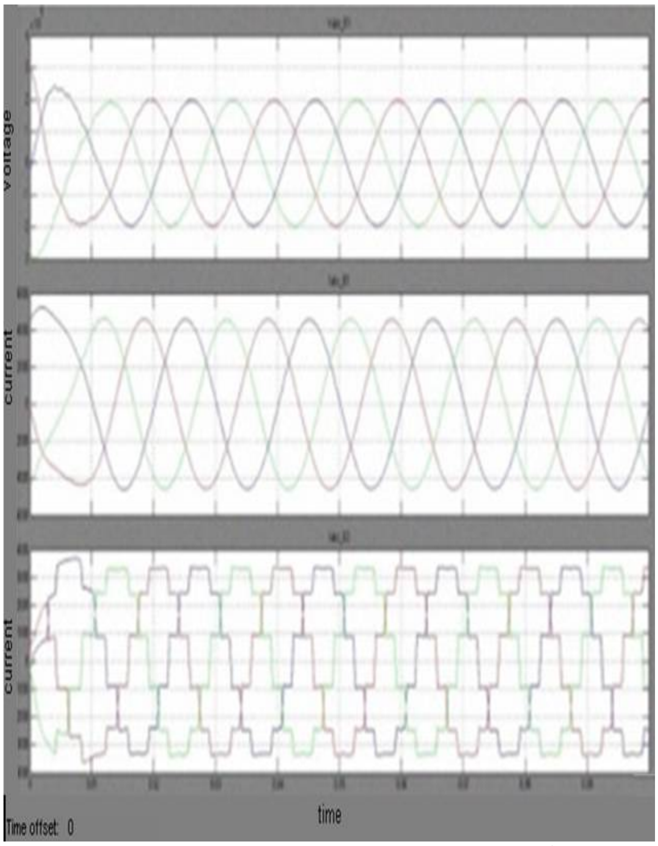

Fig.6. Three-phase voltage-current graph with filters

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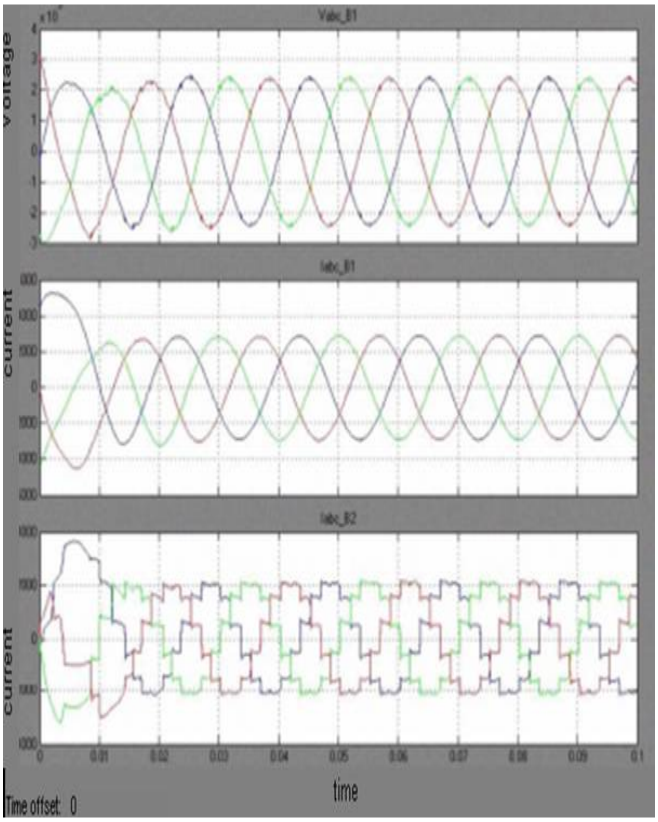

Fig.7. Three-Phase Voltage-Current Graph without Filters

There are two parts of graphs in Figure 8 & 9. For alpha angle equal to 18°, the systems took about 0.005 s to reach the steady state. The first graph shows a DC voltage of 275 kV (V_{abc}). Both the second graph (Iabc_Bl) and third graph (Iabc _ B2) show the current flows into bus with and without the existence of filter set.

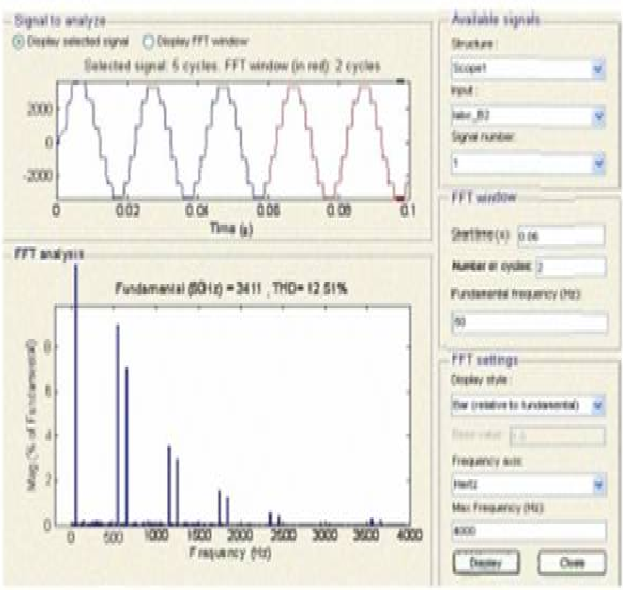

Fig.8. Single-Phase FFT Analysis for Current without Filter

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It can be seen that Iabc _ B2 graph is the normal steady state without any filters added in to the system. It is not a pure sinusoidal waveform.

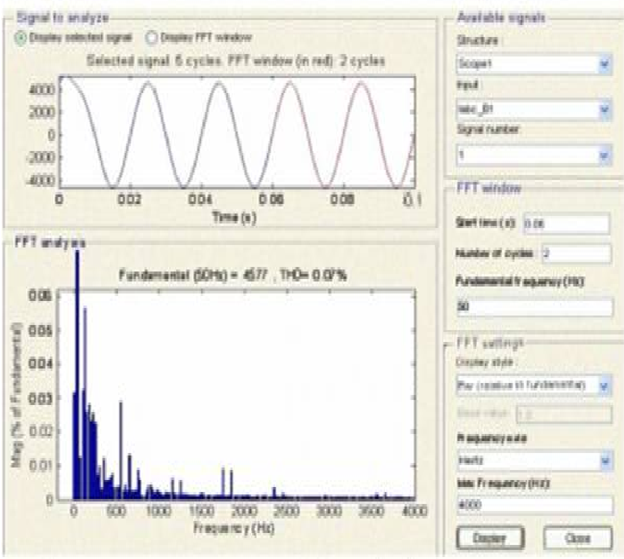

Fig.9. Single-Phase FFT Analysis for Current with Filter

Table.3.comparison of %THD

THD Analysis of current waveform	
Without filter	**With filter**
12.51%	**0.07%**

V.CONCLUSION

It is concluded thatit is more economical for the HVDC transmission system to transfer more power as the power factor is almost near to unity and the energy loss is low. The waveforms in the circuit have been analyzed with filter and without filter. DC filters and AC filters can not only eliminate the harmonic effects but also reduce the total harmonic distortion (THD) from 12.51% to 0.07%.

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