International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 6, June - 2013

Study Of Various Types Of Converter Station Faults

Himanshu Batra[1],Rintu Khanna[2]

[1]*M.tech, PEC University of Technology,Chandigarh,*
[2] *Asst. Prof, PEC University of Technology, Chandigarh*

Abstract—**This paper investigates about the various faults occurs at the converter station of a HVDC system and Controlling action for those faults. Most of the studies have been conducted on line faults. But faults on rectifier or inverter side of a HVDC system have great impact on system stability. Faults considered are fire-through, misfire, and short circuitacross the inverter station, flashover, and a three-phase short circuitin the ac system. These investigations are studied using matlabsimulink models and the resultsare presented in the form of typical time responses.**

Index Terms: **Fire – Through, Flashover, Misfire, Super Magnetic Energy System.**

I. Introduction

Studies Shows transmitting DC is more efficient than AC supply. As losses in HVDC are less than HVAC. But as we mostly generate AC supply hence we need converter stations to convert AC in to DC for efficient transmission. Mostly studies have been done on Transmission line faults or AC faults but Converter station faults or DC faults also cause the stressing of equipments due to overvoltage or current. As in AC system, the faults in DC system are caused by external sources such as lighting, pollution or internally due to failure of converter valves. Electrical disturbance in the power systemcan cause more torsional stressing on the turbine-generatorshafts of the system than in the case of a three-phase fault atthe generator terminals [1], [2]. Asturbine-generator shaft torsional systemscan interact with other power system stabilizers; static-varcompensators, high-voltage direct current (HVDC) systems,high-speed governor controls, and variable speed drive converters[3]–[5]. In most of the reported studies, attention hasbeen given to the interaction between HVDC systems and theturbine-generator shafts [6], [7]. Fewer studies have investigatedthe impact of HVDC faults on turbine-generator shafttorsional torques. In all these investigations, only dc line faultshave been considered and no attempt has been made to considerthe converter station faults [8]. This paper addresses the study of HVDC converter station faults such as fire-through, misfire,flashover, and a short circuit across the inverter and rectifier side.
A novel solution to eliminate the effect HVDC converter station fault is use of SMES (Super Magnetic Energy System).

II. Converter Faults

There are three basic types of faults that can occur at converter station:

1. Faults due to malfunctions of valves and controllers
(i) Arc backs (or back fire)
(ii) Arc trough (Fire through)
(iii) Misfire
(iv) Quenching or current extinction

2. Commutation Failures in inverters
3. Short circuits in a converter Station

The arc back is the failure of the valve to block in the reverse direction and result in the temporary destruction of the rectifying property of the valve due to conduction the reverse direction. This is a major fault in mercury arc valve and is of random nature. This is non self clearing fault and result in severe stresses on transformer windings as the incidence of arc backs is common.

Fortunately, thyristor don't suffer from arc back which has led to the exclusion of mercury arc valves from modern converter stations.

III. System under Study

Fig. 1 shows the system under study, which consists of a six-pulse ac/dc converter station connected to a synchronous machine at its terminals. In the system under investigation, a short transmission line is assumed to connect the converter station to an infinite bus bar. Also, a local ac load (purely resistive load) is connected to the ac bus of the converter station. A capacitor bank is connected to the converter ac bus bar to provide reactive power support to the system. Furthermore, it will filter the high-order harmonics of the ac line current.

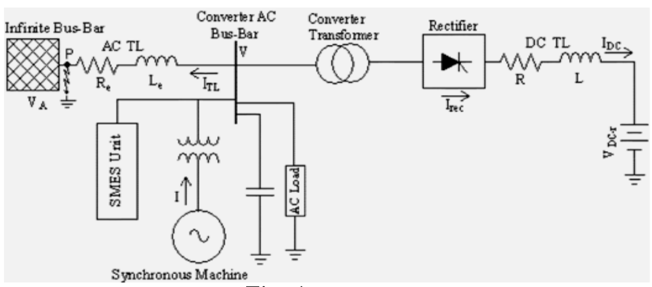


Fig .1

Fig 1 shows a complete HVDC system required for generation and transmission of AC supply. It's consist of Synchronous Machine, Mechanical System, Converter station, Transmission Network and also showing SMES unit required to improve power quality in case of converter station fault.

But as we study converter station Faults only in this paper. Hence we take converter station in detail only.

IV. Converter Station

The converter station is modelled as a three-phase, six-pulse bridge, as shown in Fig. 2. In the normal operation of this three phase bridge, either two or three valves are conducting simultaneously [11]. Therefore, 12 different modes of operation exist per cycle, as shown in Fig. 3.

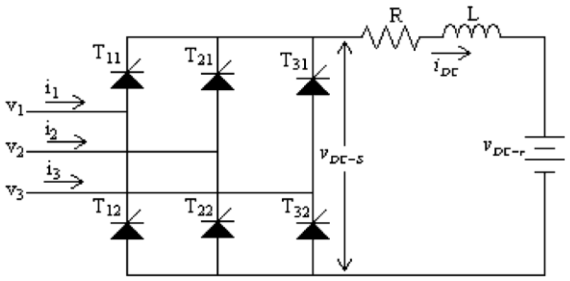


Fig 2 Bridge Control Rectifier

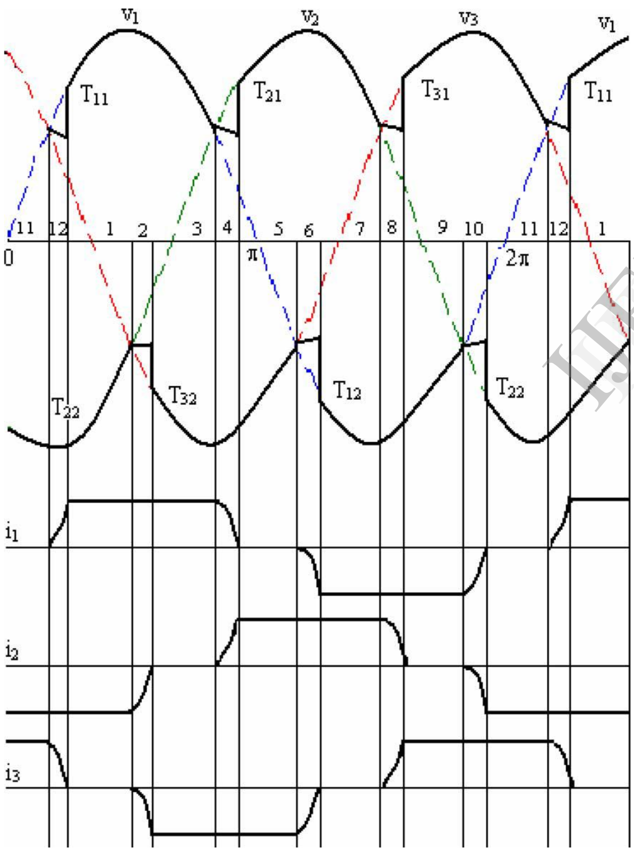


Fig 3. Normal operation of rectifier

Converter Station consists of a rectifier and inverter. Rectifier converts AC in to DC and generating side and this DC supply from rectifier is converted back to AC by inverter to supply load at distributing side.

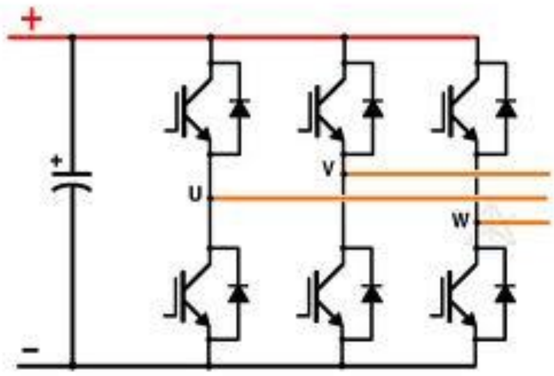


Fig 4 GTO based Inverter

Figure 4 showing a GTO based inverter used to study different type of converter station faults. DC supply is provided by rectifier at transmitting side and then this inverter converts that DC to AC to supply load. Normal condition Voltage waveform is shown in fig. 5

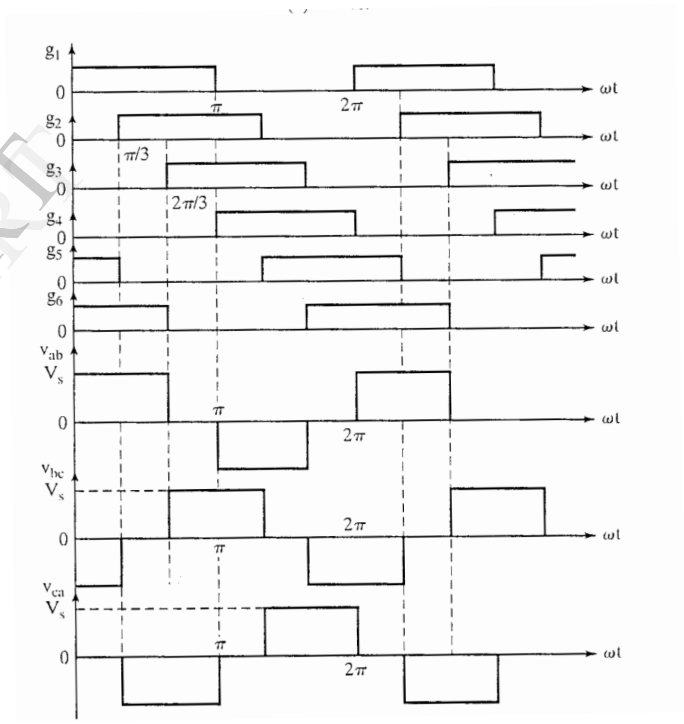


Figure.5 Voltage waveform for 180^{o} conduction mode inverter

Each Valve conducting for 180^{o} and their line to line voltage in normal condition is represent in fig.5

V. Detail of Faults

ISSN: 2278-0181
Vol. 2 Issue 6, June - 2013

A. Commutation Failure

This type of faults occurs in thyristor as they required a definite turn – off time so there is a need to maintain a minimum value of extinction angle defined by

$$\gamma = 180 - \alpha - u$$

Where the overlap angle (u) is a function of the commutation voltage and the DC current. The reduction in the voltage or increase in current or both can result in an increase in the overlap angle which can result in $\gamma<\gamma min$. This give rise to commutation failure.

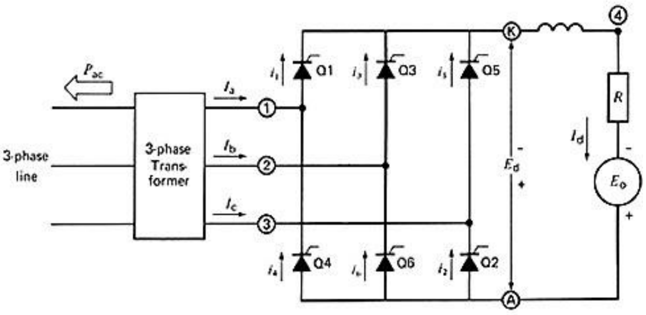


Fig.6 Thyristor based Rectifier

In the fig.6 If the current in the incoming valve (say valve Q_3) which starts conduct after valve Q_1 will diminish to zero and the outgoing valve (valve Q_1) will be left carrying the full sink current. As the firing of next valve in sequence is of valve Q_4 this will result in a short circuit of the bridges as both the valve $Q_1$and $Q_4$of the same arm will conduct. If the conduction from valve Q_2 to Q_4 is successful, only valve Q_1 and Q_4 are left conducting and this state continues until the valve Q_6 is fired. The firing of valve Q_6 is unsuccessful as the valve Q_5 is reverse biased at the time of firing.

If the commutation from valve Q4 to Q6 is successful, the conduction pattern returns to normal except the bridge voltages is negative at the instant where Q4 ceases conduction. If the causes which led to commutation failure in valve Q1 in the first instant have disappeared, the bridge operation returns to the normal state. Thus, a single commutation failure is said to be self clearing. The wave form of the bridge voltage and valve voltage are shown in fig. 7

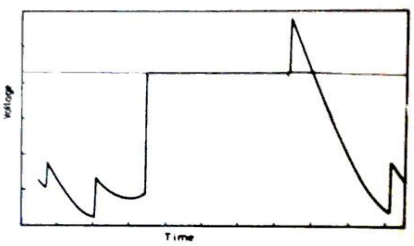


Fig 7 (a) Bridge Voltage

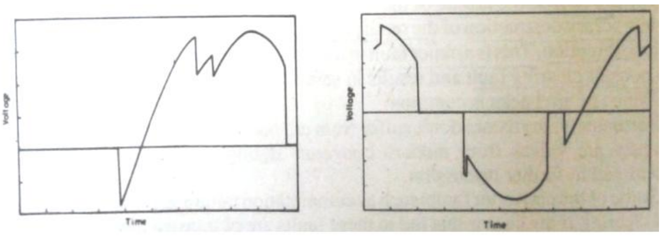


Fig 7 (b) Voltage across valves 2 and 3

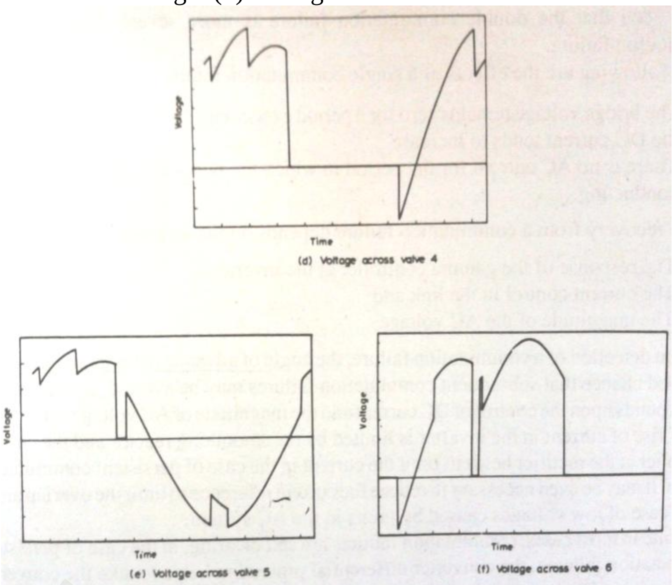


Fig 7(c) voltage across valves 4, 5 and 6

The failure of two successive commutations in the same cycle is called "double commutation failure". If the commutation failures occur when valve Q_4 is also fired the valves Q_1 and Q_2 are left in conducting state until the instant in the next cycle when valve Q_3will be fired. The bridge voltage waveform for this case is shown in fig 8 and it can be seen that the double commutation failure is more severe than the single commutation failure.

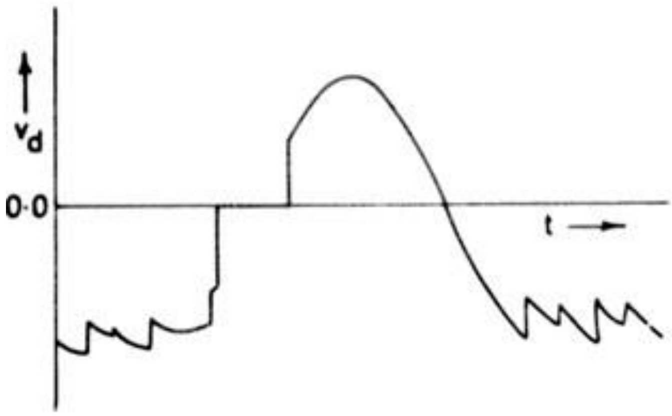


Fig 8 Bridge voltage waveform for a double commutation failure

The following are the effects of a single commutation failure

1. The bridge voltage remains zero for a period exceeding 1/3 of a cycle, during which the DC current tends to increase.
2. There is no AC current for the period in which the two valves in an arm left conducting.

The recovery from a commutation failure depends on the following factors:

1. The response of the gamma controller at the inverter
2. The current control in the link
3. The magnitude of the AC voltage

B. Arc Through

This is a fault likely to occur at the inverter station, where the valve voltages are positive most of the time (when they are not conducting). A malfunction in the gate pulse generator or the arrival of spurious pulse can fire a valve which is not supposed to conduct, but is forward biased. For such fault, the firing delay angle of the faulted valve is reduced from its normal value to a smaller value or zero. For example in a bridge, when valve 1 has successfully commutated its current valve 3, then initial current across it is a negative (for the duration of the extinction angle) and then become positive. If the valve 1 is fired at this time, the current will transfer back to valve 1 from valve 3. The effect of an arc through are similar to that of commutation failure – the voltage across the bridge falls as valve 4 is fired (with valve 1 is conducting) and the AC current goes to zero when valve 2 current goes to zero. The firing of valve 5 is unsuccessful and the bridge recovers to its normal operation after valve 6 is fired and the subsequent firings are according to the normal sequence. Such fault also introduces a significant increase in the harmonic contents of the turbine-generator shaft torsional torques.

C. Misfire

Misfire occurs when the required gate pulse is missing and the incoming valve is unable to fire. The probability of the occurrence of misfire is very small in modern converter stations because of duplicate converter controls, monitoring and protective firing of valves.

While misfire can occur in rectifier or inverter stations, the effects are more severe in the latter case. This is due to the fact that in inverters, persistent misfire leads to the average bridge voltage going to zero, while an AC voltage is injected in to the link. This result in large current and voltage oscillations in the DC link as it presents a lightly damped oscillatory circuit viewed from the converter. The DC current may even extinguish and result in large overvoltages across the valves. The waveform of the DC voltage and current in the link of persistent misfire in the inverter are shown in fig.9 Also such fault introduces significant distortion to the electromagnetic torque.

The effects of a single misfire are similar to those of commutation failure and arc through. When valve 3 in a bridge misfires, the valves 1 and 2 are still conducting until valve 4 is fired. However, at the end of cycle the normal sequence of valve firing is restored. Thus a single misfire is also self clearing.

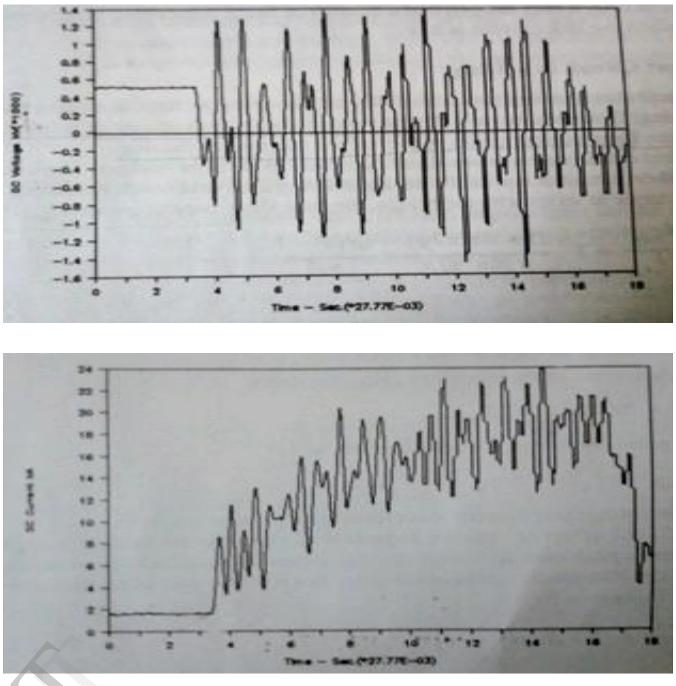


Figure 9 DC voltage and current persistent misfire

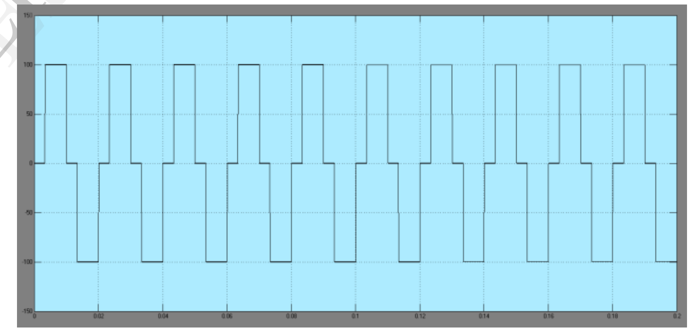


Fig 10(a) Normal output line to line voltage of an inverter

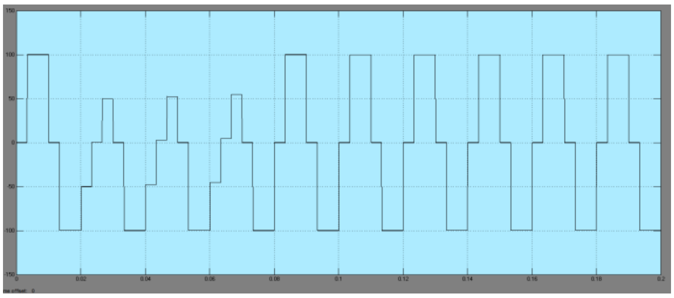


Fig. 10 (b) line to line output voltage of an inverter during misfire fault

It is clear from graph shown in fig 10(a) and 10(b) that output voltage of an inverter reduces during misfire fault. A misfire is done on valve 1 for the time interval T = 0.02 to T =0.08 sec to obtain the above shown result. After removal of misfire fault voltage become normal.

D. Current Extinction

The extinction of current can occur in a valve if the current through it falls below the holding current. This can arise at low value of the bridge currents when any transient can lead to current extinction. The current extinction can result in overvoltages across the valve due to current chopping in an oscillatory circuit formed by the smoothing reactor and the DC line capacitance.

The problem of current extinction is more severe in the case of short pulse firing method. However in modern converter stations, the return pulses coming from thyristors levels to the valve group control, indicate the build up of voltage across the thyristors and initiate fresh firing pulses when the valve is supposed to be conducting. It may happen that a number of firing pulses may be generated during a cycle when then current link is low.

E. Short Circuit in a Bridge

This fault also has very low probability as the valves are kept in a valve hall with air conditioning. However, bushing flashover can lead to a short circuit across the bridge and produce large peak currents in the valve that are conducting.

The short circuit currents are significant only in rectifier bridges. The worst case is when the short circuit occurs at the instant of firing a valve at $\alpha = 0^o$. Assuming that there is no inductance in series with the bridge, the peak short circuit current (i_{peak}) is given by

$$\frac{ipeak}{Is} = 3\,\frac{(1+\sin{}^{\pi}/_{p})}{psin{}^{\pi}/_{p}} + \frac{({}^{p}/_{3})-1}{{}^{p}/_{3}} * (\frac{ido}{Is}) .... (1)$$

Where
p = pulse number of the converter (6 or 12)
i_{do} = the dc current at the instant of firing the valve
$I_s = \sqrt{2}\, E_{LL} / 2\, X_c$
For a six pulse converter, the peak current is

$$i_{peak} = \frac{1}{2}\,[3\, I_s + i_{do}]$$

The bridge voltage and current waveform are shown in fig.11 In Eq. (1), the effect of network impedance in limiting the current is neglected.

The maximum peak current in a valve results when it is conducting in to a valve fault. For example the maximum current in valve 3, when it starts conducting with short circuit across valve 1, is given by

$$\frac{ipeak}{Is} = (1 + \cos\alpha) + (\frac{Id}{2Is})$$

The peak currents are of the order of 10 to 12 times the rated current and the thyristor valve must be having surge rating above this value. The fault clearing is performed by blocking the pulse when the fault current goes to zero. The detection of bridge or valve short circuit is also performed by comparing the AC and DC currents.

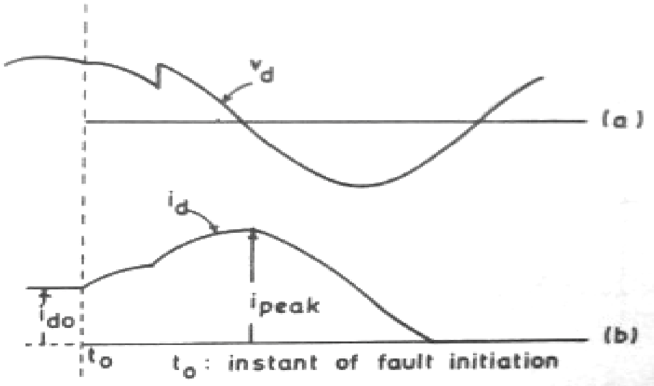


Fig 11 Bridge voltage and current waveform during short circuit

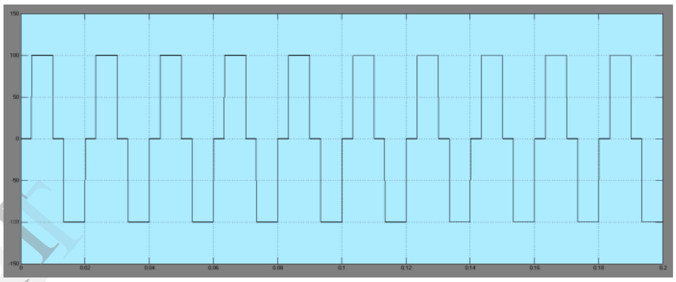
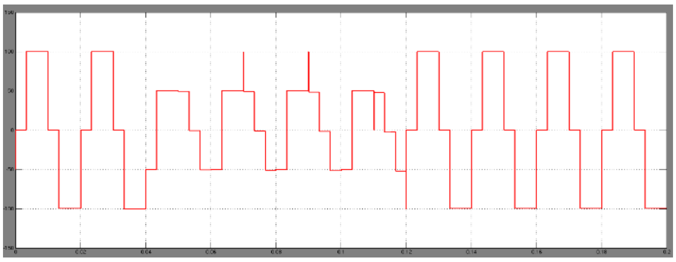


Fig 12 (a) Normal output line to line voltage of an inverterFig



12 (b) line to line voltage of an inverter during short circuit

Fig 12(a) and 12(b) shows the change in output voltage when short circuit faults occurs at inverter side of a converter station. Both the valve 1 and 4 of same arm conducting at same time to create a short circuit at arm.

VI. SMES (Super magnetic Energy System)

SMES unit works as a controller to control active and reactive power during the converter station faults to stabilize the output voltage and current.

Fig.13 shows the main configuration of the SMES unit. Theunit consists of a superconducting inductor which is consideredas the heart of the system, two-series six-pulse ac/dc convertersconnected to the three-phase ac power system via a Y - Δ / Y – Y step down transformer.

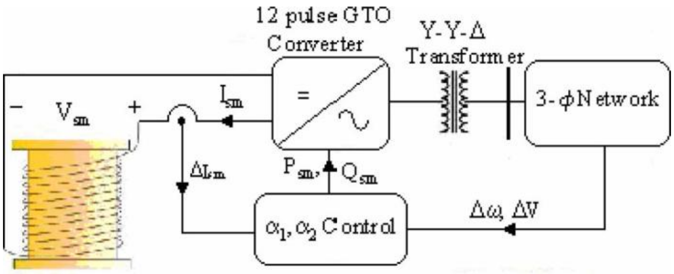


Fig 12 SMES UNIT

Above shown SMES unit control the firing angles of converter station rectifier and inverter unit. And hence by controlling their firing angle its control output voltage and active reactive power to reduce the effect of converter station faults.

VII Conclusion

In this paper various types of Converter station faults have been studied and their effect on output voltage and current of converter station is shown by various graphs and curves. And to control such type of faults a SMES unit is proposed which having supermagentic coil which controls the firing angle of converter station rectifier and inverter and reduces the adverse affects of faults.

REFRENCES

[1] Abu-Siadaand Islam: Application of SMES Unit in Improving the Performance of an AC/DC Power System, "IEEE Transactions on Sustainable Energy, VOL. 2, NO. 2, APRIL 2011"

[2] A. Abu-Siada, W. W. L. Keerthipala, E. A. Mohammed, and H. S.Khalil, "Simulation study of converter station faults on generator shafttorsional torques in HV system," in *Proc. 5th Int. Power EngineeringConf. (IPEC 2001)*, Singapore, May 17–19, 2001, pp. 134–139.

[3] A. M. El-Serafi and S. O. Farid, "Effect of HVDC converter stationfaults on turbine-generator shaft torsional torques," *IEEE Trans. PowerSyst.*, vol. 12, no. 2, pp. 875–881, May 1996.

[4] J. Arrillaga, *High Voltage Direct Current Transmission*. London, U.K.: Peter Peregrinus Ltd., 1983.

[5] K. R. Padiyar, *HVDC Power Transmission Systems*. New Delhi: Wiley Eastern Limited, 1992.

[6] K. E. W., *Direct Current Transmission*. Hoboken, NJ: Wiley Interscience, 1971, vol. 1.

[7] R. M. Mathur and S. A. M. , "Harmonics on the DC side in HVDCconversion," *IEEE Trans. Power App. Syst.*, vol. PAS-96, no. 5, pt. 1,pp. 1631–1683, Sep. 1977.

[8] A. Abu-Siada, "Effect of HVDC Harmonics on Synchronous MachineTransient and Dynamic Behaviour," M.Sc. Thesis, Ain Shams University, Cairo, Egypt, 1998.

[9] M. H. Ali, B. Wu, and R. A. Dougal, "An overview of SMES applicationsin power and energy systems," *IEEE Trans. Sustain. Energy*, vol.1, no. 1, pp. 38–47, Apr. 2010.

[11] A. M. El-Serafi and S. A. Shehata, "Digital simulation of an AC/DCsystem in direct phase quantities," *IEEE Trans. Power App. Syst.*, vol.PAS-95, no. 2, pt. 1, pp. 731–742, Mar. 1976.

[12] N. Mohan, T. M. Undeland, and W. P. Robbinsi, *Power ElectronicsConverters, Applications, and Design*, 2nd ed. Hoboken, NJ: Willey,1995.

[13] M. G. Rabbani, J. B. X. Devotta, and S. Elangovan, "Application of simultaneousactive and reactive power modulation of SMES unit under unequal -mode for power system stabilization," *IEEE Trans. PowerSyst.*, vol. 14, no. 2, pp. 547–552, May 1999.