

POWER SYNCHRONIZATION CONTROL OF VSC-HVDC TRANSMISSION FOR WEAK AC SYSTEM

SEENA. K. R¹ & SINDHU.T.K²

^{1,2}Dept. of Electrical Engineering, National Institute Of Technology Calicut, Kerala – 673 601
E-mail : krseena@gmail.com & tk_sindhu@nitc.ac.in

Abstract- In this paper voltage source converter based HVDC transmission system is used for connecting two ac systems. The control method used is power synchronization control. This method is different from other control methods and it uses the internal synchronization mechanism in ac systems. It is applied for all grid connected VSC's especially for HVDC application. This control method gives strong voltage support to a weak ac system. It shows that the proposed control allows 0.86 p.u power to be transferred from a system with short circuit ratio of 1.2 to a system with an SCR of 1. The result is compared with the vector current control for the same ac system where it can transfer only 0.4 p.u. The simulations in MATLAB/Simulink are done to demonstrate the system and observe the system behavior under three phase AC faults.

Keywords: HVDC, Voltage source converter, power synchronization control, Short circuit ratio.

I. INTRODUCTION

High voltage DC transmission is a high power electronics technology used in electric power systems. It is an efficient, economic and flexible method to transmit large amounts of electrical power over long distances by overhead transmission lines or underground/submarine cables. Factors such as improved transient stability, dynamic damping of electrical system oscillations and possibility to interconnect two systems at different frequencies influence the selection of dc transmission over ac transmission. The HVDC transmission based on voltage source converters (VSC) is a comparatively new technology, where the valves are built by IGBTs (Insulated Gate Bipolar Transistors) and PWM (Pulse Width Modulation) is used to create the desired voltage waveform Compared to conventional line commutated HVDC systems. The principal characteristics of VSC transmission are it needs no external voltage source for commutation, it can independently control the reactive power flow at each ac network and reactive power control is independent of active power control. These features make VSC transmission technology very attractive for connecting weak ac systems, island networks, and renewable sources into a main grid.

Two existing methods for control of VSC-HVDC are power angle control and vector-current control. Power angle control is simple and straight forward to implement. In power angle control the active power is controlled by the phase angle shift between the VSC and the ac system, while the reactive power is controlled by varying the VSC voltage magnitude. The major disadvantage of power angle control is that the control system does not have the capability to limit the current flowing in to the converter.[1]

The vector current technology is the dominant control system for grid connected VSCs and it limits the

current flowing in to the converter. The basic principle is to control the active power and the reactive power independently through an inner-current control loop. By using a dq decomposition technique with the grid voltage as phase reference, the inner current control loop decouples the current into d and q components. The d component of current is used to control active power or direct voltage, and the q component to control reactive power or alternating voltage. The problems with vector control are the low-frequency resonance. This can interfere with the fast inner current control loop, thereby limiting the VSC control performance. All VSCs connected to the ac system uses a PLL to obtain an accurate synchronization. But the PLL dynamics might have a negative impact on the performance of VSC-HVDC in weak ac-system connections. The power synchronization control is the combination of power angle control and vector current control. In this no PLL is needed under normal system conditions. The problems such as the resonant peak at grid frequency and converter over-current limitation are properly treated in the proposed control.[1]

II. SYSTEM OUTLINE AND CONTROL

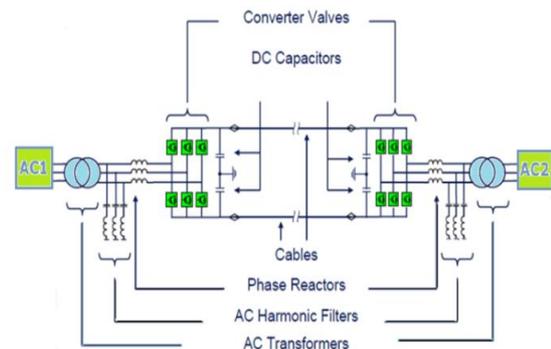


Fig.1 VSC-HVDC main circuit diagram

The schematic diagram of a VSC-HVDC transmission system connected between two ac systems is shown in fig.1. The ac source is a stiff constant frequency voltage source. The mathematical model of the VSC-HVDC can be written as shown below.[2]

$$L_c \frac{di_c}{dt} = v - u_f - R_c i_c - j\omega_1 L_c i_c \quad (1)$$

$$C_f \frac{du_f}{dt} = i_c - i_g - j\omega_1 C_f u_f \quad (2)$$

$$L_g \frac{di_g}{dt} = u_f - E - R_g i_g - j\omega_1 L_g i_g \quad (3)$$

Where L_c = The inductance of the phase reactor

R_c = Resistance of the phase reactor

E = Voltage vector of ac source

u_f = Voltage vector of filter bus

v = Voltage vector across VSC

L_g = Inductance of ac system

R_g = Resistance of ac system

P = Active power

Q = Reactive power

i_c = Current vector of phase reactor

i_g = Current vector to the ac source

ω_1 = Angular velocity of the ac system

The short circuit ratio (SCR) is defined as the ratio of the short circuit capacity of the ac system at the filter bus and the rated power of the HVDC link.

$$SCR = \frac{S_{ac}}{P_{dN}} \quad (4)$$

Where S_{ac} is the short circuit capacity of the ac system at the filter bus and P_{dN} is the rated power of the HVDC link.

Weak ac systems are those having SCR between 3.0 and 2.0, whereas very weak systems have a value lower than 2.0. The SCR can be regarded as an important reference for the design and operation of the HVDC system. It may cause the following problems in the HVDC system when connected to weak ac system: high temporary overvoltage, voltage instability, risk for harmonic oscillation and harmonic instability. [2]

III. CONCEPT OF POWER SYNCHRONIZATION CONTROL

The basic principle of power-synchronization control is similar to the operation of a synchronous machine. In an ac system the synchronous machines maintain synchronism by transient power transfer. This power

transfer involves a current which is unknown and is determined by the interconnecting network. Here the VSCs synchronize with the ac system through the active-power control instead of using a phase-locked loop (PLL) [1]

The active power output from the VSC is directly controlled by the power-synchronization loop and the reactive power (or alternating voltage) is controlled by adjusting the magnitude of the voltage. The power synchronization control law for VSCs is now proposed as[1]

$$\frac{d\Delta\theta}{dt} = K_p (P_{ref} - P) \quad (5)$$

Where

P_{ref} is the reference for the active power

P is the measured active power output,

K_p is the controller gain and $\Delta\theta$ is the output of the controller.

Here $\Delta\theta$ directly provides synchronization for the VSC. During normal operation an additional PLL is not necessary. The dynamic process of a VSC using power-synchronization control is very similar to that of interconnected synchronous machine. The transmitted power is increased or decreased by shifting the output voltage phasors of the VSC forwards or backwards. A simplified schematic diagram of the GSVSC control using power synchronization control system is shown in Fig.2.

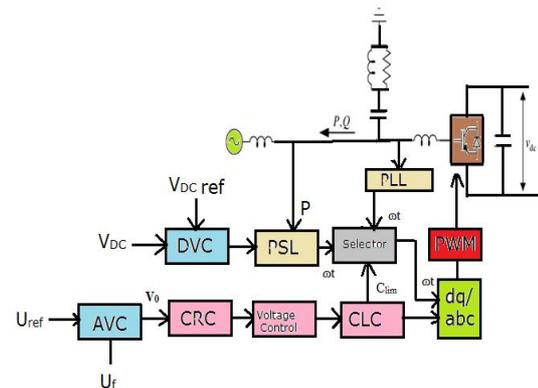


Fig.2 The schematic diagram of the GSVSC control using power synchronization control

A. Power Synchronization Control Loop(PSL)

PSL maintains synchronism between the VSC and the ac system. It is the active power control loop. The control law is given by equation 5. The power control error is converted to a frequency deviation, which is then integrated to an angle increment. The output of the PSL is used to transform the voltage reference from the converter dq frame to the stationary frame. The block diagram of PSL is shown in fig.3[1]

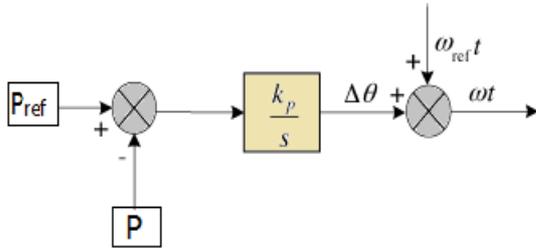


Fig.3. Power Synchronization Control Loop

B. Direct Voltage Control (DVC)

GSVSC has to keep the DC voltage constant to keep the balanced active power flow between the two sides. The control law is given as

$$P_{ref} = \left(K_{pd} + \frac{K_{id}}{s} \right) \frac{V_{dc}^{ref} - V_{dc}^2}{2} \quad (6)$$

C. Alternating-voltage control (AVC)

The function of alternating-voltage control mode is to keep the point of common coupling (PCC) voltage constant and control the active power to/from the PCC.

The control law is given by

$$\Delta V = \frac{K_u}{s} (U_{ref} - U_f) \quad (7)$$

D. Current Limitation Controller (CLC)

The current limitation controller is designed in such a way that under normal condition the voltage control law is

$$V_{ref}^c = V_0 - H_{HP}(s)i^c \quad (8)$$

Where $H_{HP}(s)$ is a high pass filter

$$H_{HP}(s) = \frac{K_v s}{s + \alpha_v} \quad (9)$$

During severe ac system fault if converter current exceeds the maximum current rating of the converter the control system has to be switched to vector current control given by

$$V_{ref}^c = \alpha_c L_c (i_{ref}^c - i^c) + j\omega_1 L_c i^c + u_f^c \quad (10)$$

And the reference value of the converter current I_{ref}^c is calculated by

$$i_{ref}^c = \frac{1}{\alpha_c L_c} [V_0 - u_f^c - j\omega_1 L_c i^c - H_{HP}(s)i^c] \quad (11)$$

During severe ac-system faults the VSC is blocked. The control system has to limit the current flowing into the converter valve. So the control system has to switch to a back up PLL during fault condition and after the fault is cleared, it has to switch back to PSL.[1]

IV. SIMULATION STUDIES

The VSC-HVDC transmission system model along with its controls is simulated in MATLAB/Simulink. The simulation set up contains a 400 kV ac system with a short circuit ratio of 1.0 at the receiving end (inverter station) while the sending end is having an SCR of 1.5.

A. Steady State Condition of VSC-HVDC system

Under normal condition the VSC-HVDC system transferring power between two ac system using power synchronization control is shown below. The DC voltage is set at 1 p.u and the active power is set at 0.8 p.u. The Grid side (Inverter side) Ac voltage, current, active power and the reference value of converter current are shown in fig.4.

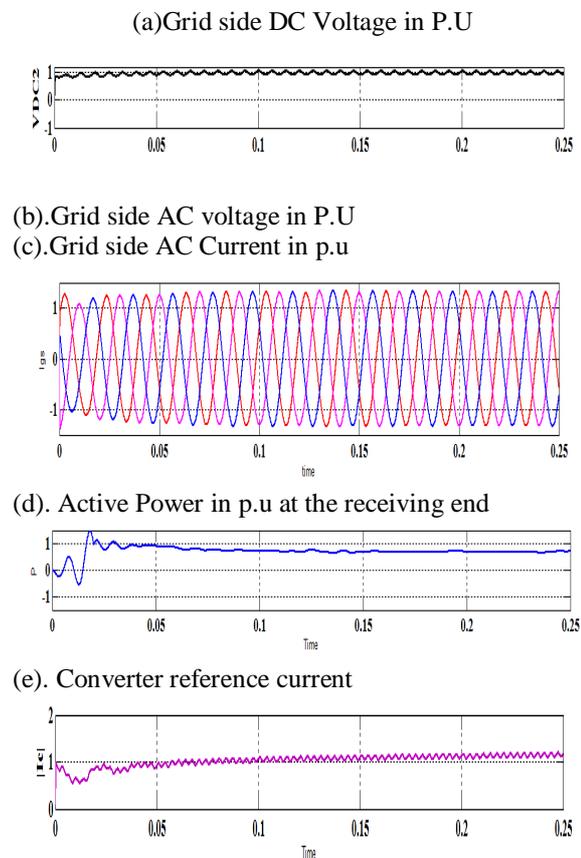
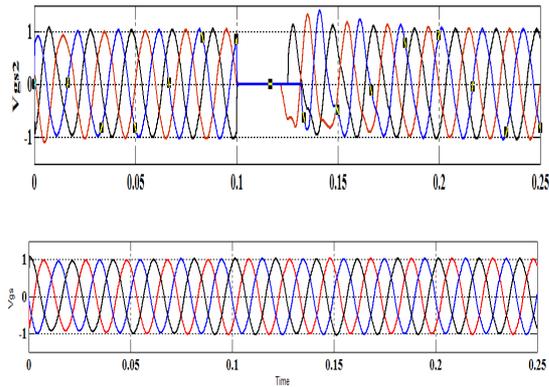


Fig.4. (a)DC Voltage. (b) AC voltage. (c)Current (d)Active Power and (e) converter reference current at the Inverter side (Grid side) during normal operation of the system using power synchronization control.

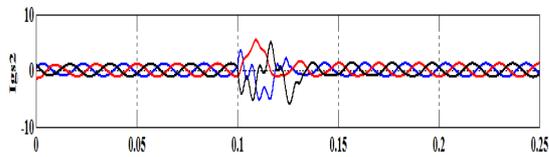
B. Three-phase ac system fault at the Grid side

The VSC-HVDC link is supposed to ride through ac-system faults without relying on communication between the two converter stations. In fig.5 a three phase ac fault is occurs at 0.1 s for a duration of 0.02s at the grid side. From the fig.5 it can be seen that the Dc voltage is increased to 1.4 and it is going to the normal value soon. Also during fault time the converter current I_c is increased to high value but the controller reduces the converter current to 1 p.u.

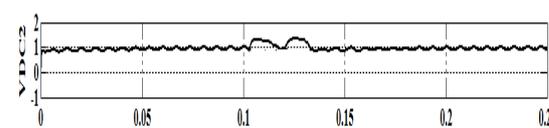
(a). AC voltage in p.u at the grid side during fault



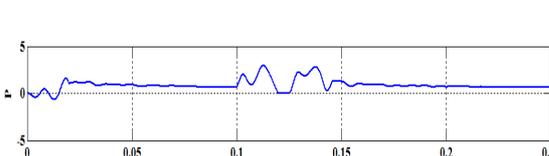
(b). AC Current in p.u at the grid side during fault



(c). DC voltage at the grid side in p.u during fault



(d).Active power in p.u at the grid side during fault



(d). Converter reference current at the grid side during fault

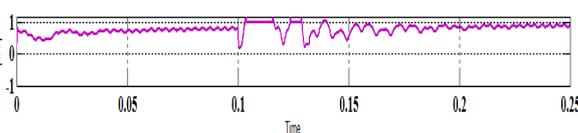
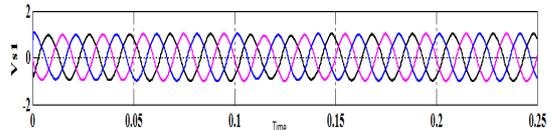


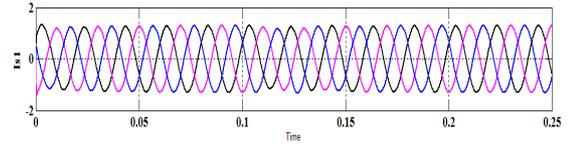
Fig.5(a)AC voltage.(b)Current(c)Dc voltage(d)Active Power and (e)converter reference current at the Inverter side (Grid side) during fault time.

The effect of fault at the sending end is shown in fig.6.The effect of fault at the grid side is less at the sending end.

(a). AC voltage in p.u at sending end during fault



(b)AC Current in p.u at sending end during fault



(c)Active Power at the rectifier side during fault

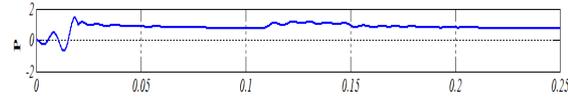
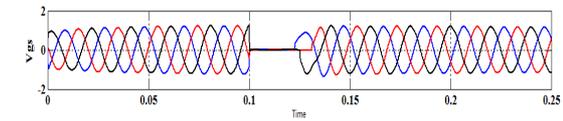


Fig.6(a)AC voltage.(b)Current(c)Active Power at the rectifier side (sending end side) when a three phase fault occurs at the inverter side while using power synchronization control.

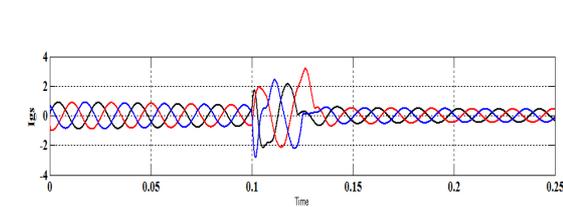
C. Comparison with the vector current control

To make comparison with the vector current control the fault analysis is shown in fig.7.Here 0.86 p.u power is transferred from a system with short circuit ratio of 1.2 to a system with an SCR of 1.The result is compared with the vector current control for the same ac system where it can transfer only 0.4 p.u.

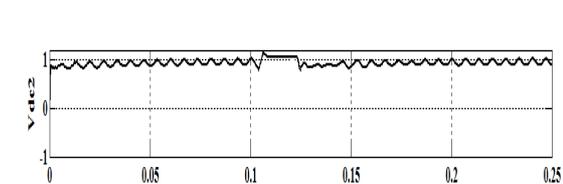
(a). AC voltage in p.u at the grid side during fault



(c). AC current in p.u at the grid side during fault



(c). DC voltage in p.u at the grid side during fault



(d). Active power in p.u at the grid side during fault

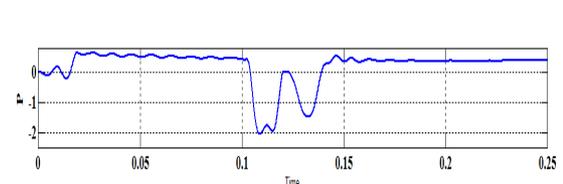


Fig.7 (a)AC voltage.(b)Current(c)Dc voltage and(d)Active Power (Grid side) during fault time for vector current control.

In vector current control also the DC voltage is set at 1 p.u. fault occurs at 0.1 p.u for 0.02 second. Here the active power transfer is only 0.4 p.u approximately. During fault time the variation of

active power Dc voltage, ac voltage and current is shown in fig.7.

IV. CONCLUSION

In this paper power synchronization control of VSC-HVDC is done for connecting two weak ac systems. From the simulation results it can be concluded that the system response is fast. It shows a very stiff DC link control. The control strategy is a combination of Vector current control and Power angle control. The control strategy is working well for keeping the grid side voltage constant. It can be seen that the very important property of power synchronization control is current limiting capability during ac system fault.

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