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A Modified Grid Integration Technique of Large WindFarm and Synchronous Machine Using HVDC System

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Abstract—**Fluctuating power is the most common problem in grids. Many methods have been discovered to reduce the power fluctuation in power grids. But most of them fail when in the case of dynamic fluctuation of loads. With the penetration of renewable energy sources like wind farm which is connected to the same grid where conventional energy sources are connected, the problem further increases. HVDC systems with Line Commutated Converter (LCC-HVDC) have been used in High voltage transmission systems especially due to its high power capability. But the control of LCC-HVDC is somewhat complex when compared with more modern VSC technology. Voltage Source Converters improves system stability, helps in connecting wind farms to AC grids, enhances power quality, and reduces losses. In addition to them, they are less expensive, limit Short Circuit currents,providegrid access for weak AC networks, improve black start capability and dynamic performance.This project focuses on VSC-HVDC and its capabilities in enhancing the grid voltage. The study system consisting of an AC system, a VSC-HVDC transmission system, and an induction generator-based wind farm built in Matlab/SimPowersystems. The aim of the HVDC control system is to reduce the power fluctuation in the grid caused by fluctuating power of wind farm system.**

Index Terms—**Induction generator (IG), high-voltage direct current (HVDC).**

I. INTRODUCTION

High Voltage Direct Current (HVDC) technology is an efficient and flexible method to transmit power compared to conventional AC transmission [1], [2]. It uses power electronics technology with high power and voltage ratings. Using HVDC instead of High Voltage Alternative Current (HVAC) for high powertransmission is advantageous for long power transmissions, bulk power delivery, long submarine power crossing, and low line cost and losses [3], [4]. Further, HVDC offers an economical and reliable method for asynchronous interconnections between AC networks, renewable resources integration, fast and dynamic power flow control, and power system stability improvement [5], [6]. With the development of power electronics technologies, control equipment and techniques, a new generation of HVDC has been launched based on voltage source converters (VSC-HVDC). It is a new dc transmission system technology known as "HVDC Light" and "HVDC Plus" [8] by leading vendors (ABB and Siemens). VSC-HVDC converters include Insulated Gate Bipolar Transistors (IGBT'S) which are operated with high frequency Pulse Width Modulation (PWM) in order to get high speed control of both active and reactive power and to create the desired voltage waveform. As a result of using VSC technology and PWM, the VSC-HVDC has a number of potential features compared with classic HVDC (thyristor-based).

The VSC-HVDC is a mature technology; it provides several advantages over the classic HVDC such: improving system stability, connecting wind farms to an AC grid, enhancing power quality [9]-[11], lower losses, less expensive, limitation short circuit currents, grid access for weak AC networks, independent control for active and reactive power, supply of passive networks and black-start capability, high dynamic performance, low space requirements, long distance water crossing, and environmental reasons [12]-[22]. These features allows VSC-HVDC converters to be appropriate for a large range of applications related to power flow flexibility, fast response and recovery after the disturbances being cleared. Due to these merits, VSC-HVDC has been an area of a growing interest; it is expected that VSC-HVDC will play an important role in power systems; and it will be one of the most important components of power systems in the future. Therefore, modeling, control design and simulation are important for

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power system studies and interactions [22]-[31]. There are many topologies for voltage source converters (VSC) available for HVDC applications such as Two-level VSCs [22] and multilevel VSCs [23], cascadedmultilevel converters and modular multilevel VSC (MMC) [24]. The focus of this paper is on two levels VSC-HVDC and fast power routing capability of HVDC system using proposed control.

II. STUDY SYSTEM

A typical back to back VSC-HVDC system is presented in Fig.1. It consists of AC filters, transformers, converters, phase reactors and DC capacitors [23]-[25]. The main function of the VSC-HVDC is to transmit constant DC power from the rectifier to the inverter.

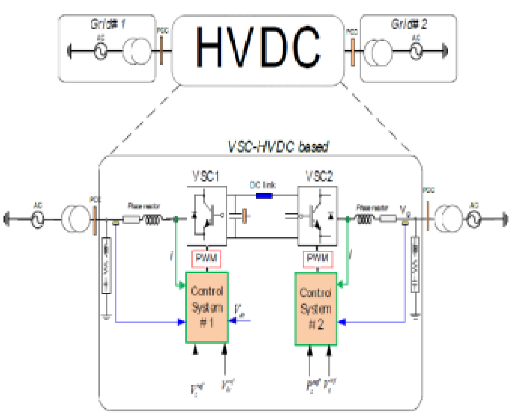

Fig. 1.Basic configuration of back to back HVDC system

The study system is shown in Fig. 2. The system consists ofa 1000-MW synchronous generator, a 100-MW wind farm, and anVSC-HVDC with a rated power at 1000 MW. The system is built in Matlab/SimPowerSystems. The HVDC link and the synchronous generator are built based on the models from SimPowerSystems examples. A 100-MW wind farm is made using induction generator based on type I wind farm. Power from the synchronous generator and the wind farm is transmitted to a 50-Hz grid through anVSC–HVDC connection. The HVDC is a1000-MW dc link.

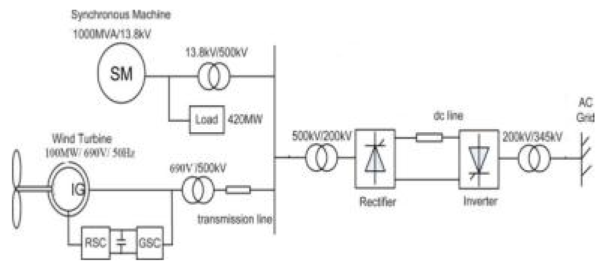

Fig. 2 .Study system

III. HVDC- CONTROL STRATEGY

There is several control methods used for VSC-HVDC systems. This section provides an overview of the three control strategies [24]. Vector current control is adopted in this paper. Vector current control of VSCs was first used at variable-speed drives, where the VSC is connected to an AC motor. In this method, with respect to the point of common coupling, by controlling the phase angle and the voltage magnitude of the VSC line current, the real and reactive power can be controlled. Further, this method can independently and precisely control active and reactive power through an inner-current control loop; and it has high dynamic performance. Fig. 3 shows the main-circuit and control block diagrams of a VSC-HVDC converter using vector current control. Christo Ananth et al.[7] presented a brief outline on Electronic Devices and Circuits which forms the basis of the Clampers and Diodes.

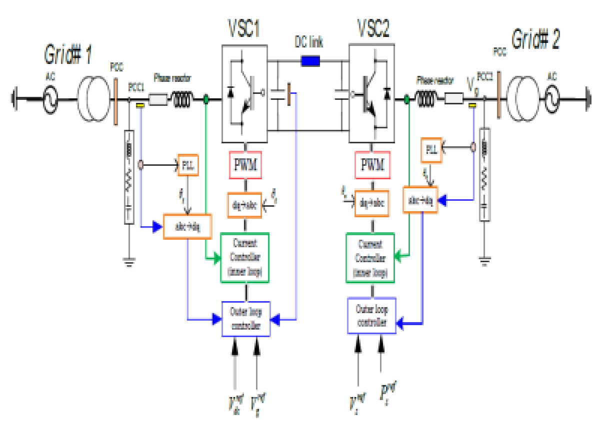

Fig. 3.Schematic diagram of VSC-HVDC system

A. *Control Design Procedure*

In HVDC systems, the active power of the grids is transmitted only over the DC link, whereas the

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reactive power is exchangeable only on the AC sides and cannot be exchanged through the DC-link. Normally, the one side of HVDC system is utilized to control the DC-voltage; and the other side converter is used to regulate the active power which is typically referred to as inverter and rectifier stations, respectively. The most common control implementation is the vector control, which gives the ability to control the active and reactive powers independently. Therefore, at both sides and in parallel to the DC and active power control, the converter can be designed to 1) control the voltage at the PCC, 2) control the reactive power or to 3) maintain the unity power factor. In this paper, the control voltage at the PCC at both stations is adopted; and the control arrangement is shown in Fig. 3. It shows the control circuit for the system under the study. VSC1 is used to control the DC-voltage (DC control), while VSC2 is used to control the active power (active power control). The control is implemented in *dq*-frame; and the well known controller, PI controller, is used. Fig. 4 shows the control loop structures.

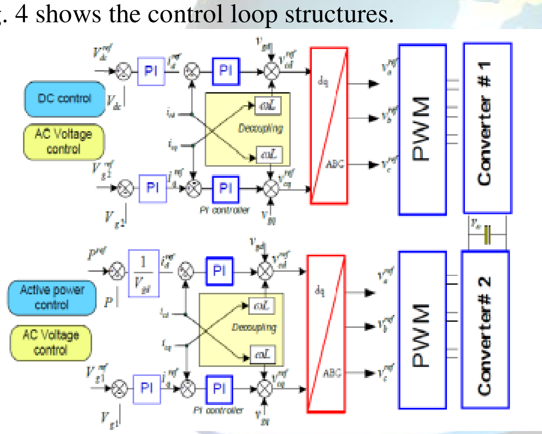

Fig. 4 . Control loops and structures of VSC-HVDC system

1) Inner current control loop

Fig. 5 shows the schematic diagram of the grid-side converter. The dynamic equations in a synchronous frame rotating with the grid voltage are:

$$V_{cd} = \left(R_{id} + \frac{Ld_{id}}{dt}\right) + \left(V_{gd} - wL_{iq}\right) \quad (1)$$

$$V_{cq} = \left(R_{iq} + \frac{Ld_{iq}}{dt}\right) + \left(V_{gq} - wL_{id}\right) \quad (2)$$

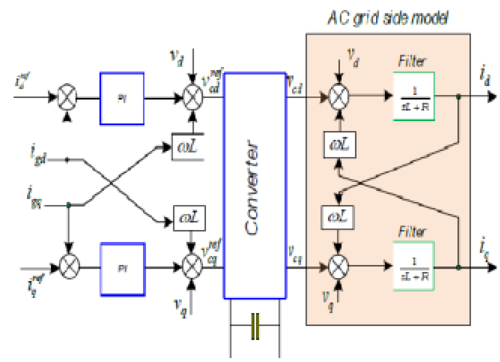

Fig. 5 . Control block diagram of a current-controlled VSC-HVDC system

PI controller is the most common type in *dq*-frame due to its ability to track DC and low frequency signals. By combining the current system and grid side dynamic, the closed loop system is:

$$F_{CC}(S) = \frac{(k_{p-cc}+k_{i-cc})\left(\frac{1}{L_s+R}\right)}{1+\left(k_{p-cc}+\frac{k_{i-cc}}{s}\right)\left(\frac{1}{L_s+R}\right)} \quad (3)$$

The gains of PI controller such as $k_{p-cc} = \frac{L}{\tau_{cc}}$ and $k_{i-cc} = \frac{L}{\tau_{cc}}$ are selected, where τ_{cc} is the time constant of the closed loop current controller. Equation (3) can be simplified by the first order transfer function:

$$F_{cc}(s) = \frac{1}{\tau_{cc}s+1} = \frac{\omega_{cc}}{s+\omega_{cc}}, \omega_{cc} = \frac{1}{\tau} \quad (4)$$

Where ω_{cc} is the bandwidth for the closed loop current controller. The switching frequency is chosen as 1980 Hz. The recommended bandwidth for the current controller is selected as one fifth of the switching frequency [32], [33]; and the bandwidth of current controller is selected to be 15% of the switch frequency (i.e. 1866 rad/s). With L= 0.031H and R=0.83Ω, the value of PI gains are calculated (k_p=60 and k_i=300000). This designed is for both converters.

2) DC outer loop

In *dq*-frame control, DC control is an outer loop Fig. 6 shows the DC control structure. For a stable cascaded control operation, the recommended bandwidth for the outer controller is at least five times lower than the inner loop [34]. The bandwidth of the DC controller loop is chosen to be slower than the inner loop, with a bandwidth 10% of the inner

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loop, which is equal to 186 rad/s. The dynamics of the current-control loop (F_{cc}) is much faster than the outer loops, so it is reasonable to assume that F_{cc}=1 within the bandwidth of the outer loops. The closed loops transfer function of DC control loop can be described by:

$$G_{dc} = \frac{{V_{dc}}^{ref^2}}{V_{dc}^2} = \frac{Sk_{p-dc}+k_{i-dc}}{0.5s^2C+sk_{p-dc}+k_{i-dc}} \quad (5)$$

The common second-order transfer function is ${\omega_n}^2=\frac{Ki_{dc}}{0.5C}$ and $2\zeta\omega_n=\frac{Kp_{PLL}}{0.5C}$; where ζ=1 and ω_n=0.67 pu yields k_{p-dC}=0.05 and k_{i-dc}=0.0454.

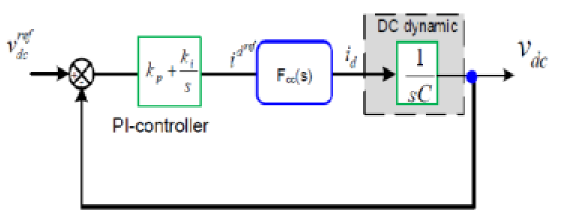

Fig. 6. Control block diagram of dc loop

3) *Active Power Outer Loop*

The power loop is a simple loop; it can be performed as shown in Fig. 7. The difference between the measured and the reference active power is used to generate the reference signal for current controller.

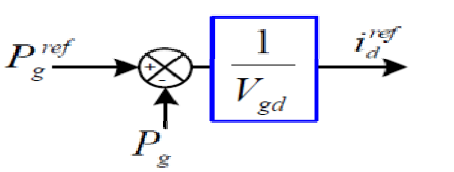

Fig. 7. Active power controller

IV. SIMULATION STUDIES

To demonstrate the fast power-routing capability of the HVDC, simulation studies are carried out in Matlab/SimPowerSystems. The main aim of this paper is to swiftly route the fluctuating power caused by wind farm in the grid. The term "fast power routing" refers to the capability of HVDC routing wind power fast enough to avoid local synchronous generators to pick up the power change. As the synchronous machine and wind farm is connected to the same grid, the fluctuating power has to be eliminated from the grid to reduce the load on synchronous machine. i.e.,to reduce the power fluctuation of synchronous machine. To demonstrate the capability of HVDC control system, the wind farm is fed with a variable wind speed initially.The power output of Synchronous machine (Fig. 8) and wind farm (Fig. 9), the power at sending end (Fig.11) and receiving ends (Fig. 12.) of HVDC,are also compared below. The voltages at sending end and receiving ends are shown by Fig. 12 and Fig. 13.

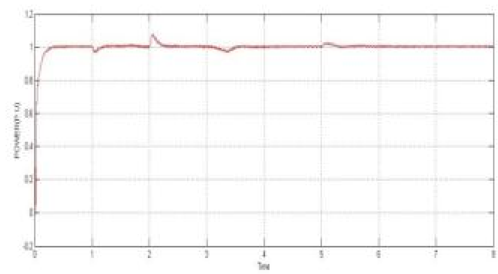

Fig. 8. Power output of synchronous machine

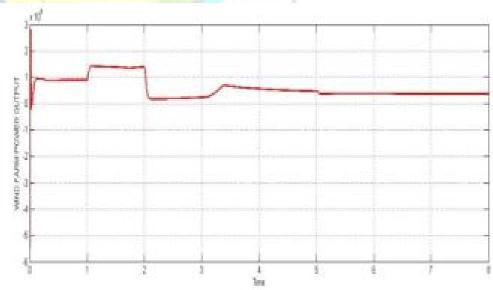

Fig. 9. Wind farm power output

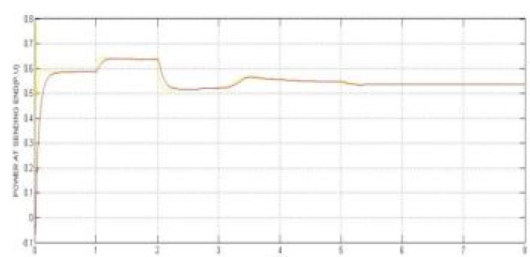

Fig. 10. Power at sending end in p.u.

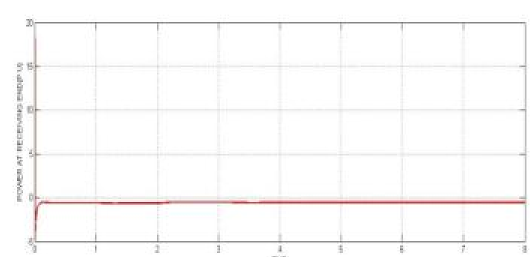

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Fig. 11. Power at receiving end in p.u

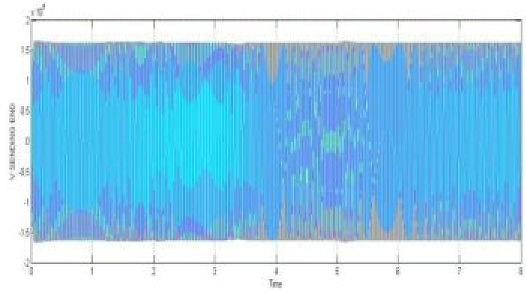

Fig. 12. Voltage at sending end

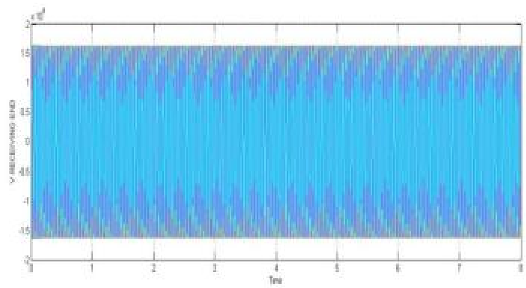

Fig. 13. Voltage at receiving end

Comparing the outputs of synchronous machine and wind farm, it can be seen that the fluctuations made by wind farm is not at all affected on the output of synchronous machine. This is same in the case of HVDC converter stations. The power output at inverter station is somewhat nearly constant and at rectifier station the power reaches the stable point after some time interval. Thus it is clear that the control of HVDC has effectively routed the fluctuating power of wind farm. In addition to it, looking at the voltage waveform, it is clear that the voltage at both converter stations has maintained except some losses in transmission.

V. CONCLUSION

This paper presents analysis, modeling and control of HVDC based on VSC. The operation principle and control strategies of VSC-HVDC are also explored and analyzed. Simulations for VSC-HVDC are conducted using MATLAB software. A new control technique is proposed and implemented on VSC based HVDC transmission system. Currently there are difficulties on connecting conventional power plants along with wind power plants in the same grid. This is due to the fluctuating power caused by wind farm which makes the output synchronous machines also fluctuating. This new proposed control technique helps to integrate large wind farm and synchronous machine in the same grid. Also the fluctuating power is eliminated by HVDC control by new control technique.

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