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SIMULATION OF VSC BASED HVDC TRANSMISSION SYSTEM FOR THE INTEGRATION OF WINDFARM INTO GRID

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Abstract - Wind energy has huge potential to become major source of renewable energy for the modern world. For integrating wind farms to the AC grid, HVDC transmission systems have several advantages over AC transmission systems. This paper presents the design and control of voltage source converter based HVDC system for integration of wind farms in to AC grid. The designed VSC-HVDC system performance under steady state conditions and various transient conditions are presented. The PSCAD/EMTDC software package is used for the simulation studies.

Keywords*-HVDC power transmission system,Voltage source converter, Windfarm,PSCAD/EMTDC.*

I. INTRODUCTION

Ever increasing energy demand and challenges like pollution, consumption of conventional energy sources, global climate changes etc have made renewable energy sources to penetrate into the grid. Renewable energy is sustainable as it is obtained from the sources that are inexhaustible. These energy sources include solar, wind, biomass, geothermal and hydro. Both wind and solar have tremendous potential to fulfill world's energy need. In this, wind energy connected with the utility grid is widely adopted. There are two ways to connect wind farms with the grid, with AC transmission lines or with HVDC system. For short distances up to 60km AC transmission is economical but beyond this distance HVDC transmission is more advantageous[1]. The connection of large wind farms over long distance with AC lines has technical, economical, environmental difficulties[4]. AC over head lines require large reactive power compensation and long distance cables requires large amounts of charging currents. Hence, HVDC transmission is more suitable and feasible. The HVDC link decouples the two networks which are on either side of its converters. Both the networks can operate at different voltage levels and frequencies. Apart from these, there are several advantages such as fast active power modulation, effective reactive power compensation, less voltage drop on an on shore substation etc. Moreover with HVDC link, disturbances at the grid are not transmitted to the wind farms. There are two types of HVDC topologies, line commutated HVDC system (LCC-HVDC) and voltage source converter based HVDC system (VSC-HVDC) which are used for off shore wind farms. A VSC-HVDC system needs no external voltage source for commutation and reactive power control is independent of real power control. These features make VSC-HVDC system more attractive for connection of renewable sources to grid, island networks and connection of weak AC systems [8].

Main objective of this paper is to develop a low rating VSC based HVDC transmission system for the integration of wind farm to the grid. This paper deals about the modeling of VSC based HVDC transmission system and its control.

II. VSC-HVDC SYSTEM

The block diagram of the VSC-HVDC system is shown in Fig. 1. The VSC-HVDC technology is based on voltage source converters. The converters convert AC power to DC power or DC power to AC power[2]. The converter station consists of an IGBT/GTO valve bridge operated with high frequency Pulse Width Modulation (PWM), the converter control, the phase reactor, DC capacitor, and an AC-filter as shown in Fig.2. Inductance of the transformer acts as phase reactor.The bridge, in its basic form is a two-level, three-phase topology with six valves and series connected IGBT's/GTO's in each valve. Every IGBT/GTO is provided with an anti parallel diode as in Fig. 2. Turn on/off of each single IGBT is controlled from the control equipment on ground potential.

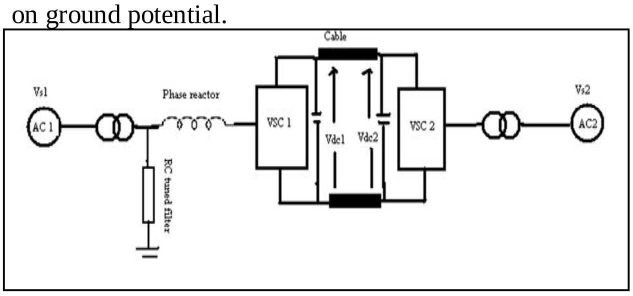

Fig. 1 Schematic diagram of VSC transmission system

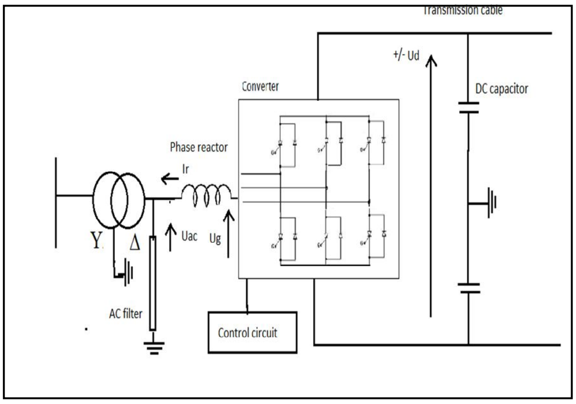

Fig. 2 Converter station

II. MODEL SYSTEM (VSC TRANSMISSION) AND CONTROL

A synchronous generator of 10MVA rating is connected to VSC1 via 13.8KV/62.5KVthree phase transformer as shown in Fig.1.VSC1, VSC2 are two six pulse converters connected through a cable of 100 Km length. Here, VSC1 is considered as rectifier and VSC2 as inverter. GTOs are used as switching devices of the converters. To reduce the harmonics at the input side, 1 MVAR- RC tuned damped filter is used and at the inverter AC bus 4MVAR filter is used. The DC voltage of the system is 120KV and current 0.18kA. Capacitors of each 500 µF is used at the rectifier and inverter end.

- Converter and inverter controls are independent with each other. The following are the control techniques which are adopted.
- Power flow can be controlled by adjusting the phase angle of ac side voltage of the sending end converter.
- DC voltage and AC voltage at the receiving end can be controlled by adjusting the phase angle of AC side voltage of the receiving end converter.
- Reactive power is held to a lower value by adjusting the magnitude of voltage at the sending end converter.

Control of DC voltage by inverter and control of power flow by rectifier is done by using PWM technique. Reference wave is compared with the carrier wave which is 33 times of fundamental frequency and generates the PWM pulses. The fundamental component of the inverter output voltage can be operated with the DC operating voltage by the following equation

$$U_{L-L} = \frac{\sqrt{3} * M * U_d}{2\sqrt{2}} \qquad (1)$$

Where,

U_{L-L} Fundamental component of line to line voltage

Ud DC Voltage

M Modulation index

The modulation index (M) is the ratio of triangular wave amplitude to sinusoidal reference wave amplitude. Fig 3. shows the carrier signal and reference signal for generation of triggering pulses of VSC using Sinusoidal Pulse Width Modulation (SPWM) technique.

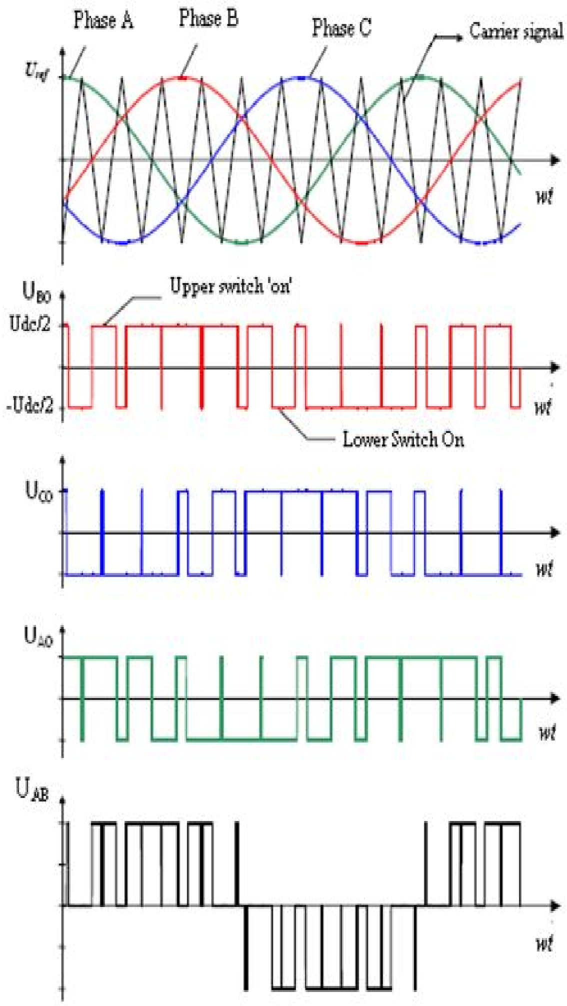

Fig. 3 AC output voltage of VSC using SPWM technique

Modulation index of the rectifier can be adjusted by comparing the system reactive power with reference reactive power. Pdc, mr ,Vrec are used as input to the sending end controller .Modulation index of the receiving end is varied by comparing the reference voltage and receiving end AC voltage of the system. Vac, mi, Vdc are the input parameters of the receiving end controller. By means of the sending, receiving end controller, output can be stabilized.Fig:4 represents the overall control diagram at sending end. Similar type of controller is developed at the receiving end to generate ON and OFF pulses. Instead of comparing the reactive power, It compares the reference voltage with the voltage at the inverter station. System controls are activated at one second.

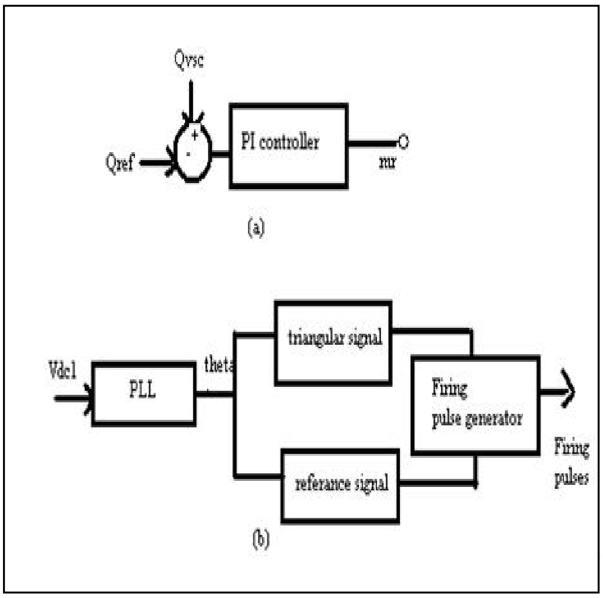

Fig.4. Control diagram at sending end-PWM Pulse generation

III. SIMULATION RESULTS OF VSC HVDC TRANSMISSION

The performance of the controllers and HVDC system are tested for steady state condition and for various transient conditions. Fig.5 gives the AC current harmonics at the sending end converter station. Fig.6 shows the DC voltage at rectifier and inverter under steady state and Fig. 7 shows the steady state DC current. Fig. 8 and 9 show the mi, mr and PU AC voltages at rectifier/inverter under steady conditions. The simulation is run for 5 seconds. The system response is tested for the following four different transient conditions

- DC line fault near rectifier station
- Three phase to ground fault at inverter AC bus
- Single phase to ground fault at inverter AC bus
- Double line to ground fault at inverter AC bus

The above mentioned faults are simulated at 2.2seconds for a duration of 2 ½ cycles.

Fig. 10 shows the DC voltage at rectifier and inverter under DC line fault near rectifier station. Fig. 11 shows DC voltage of the system for three phase to ground fault at inverter AC bus. Similarly, Fig. 12 and Fig. 13 shows the DC voltage under single line to ground fault and double line to ground fault at inverter AC bus respectively. Single phase to ground fault is created at inverter end to test the performance of mr, mi under normal and faulted conditions and also to test the PU AC voltage at rectifier and inverter end .Fig. 14 shows mr, mi when single phase to ground occurred at receiving end and Fig.15 shows PU AC voltages at rectifier and inverter for single phase to ground fault at inverter end

Simulation results gives us the change in the value of dc voltage,mi,mr,AC voltages for different types of faults. For all types of fault, VSC based transmission system gets effected for short duration and finally it is reaching its steady state value very fastly.

IV. INTEGRATION OF VSC WITH INDFARM

Proposed VSC based HVDC system is integrated with the windfarm as shown in Fig. 16 and tested the AC voltage at the rectifier end and DC voltage at rectifier/inverter end. Windfarm consists of five synchronous machines which are rated at 2 MVA. All the machines are operated by the wind turbine individually.

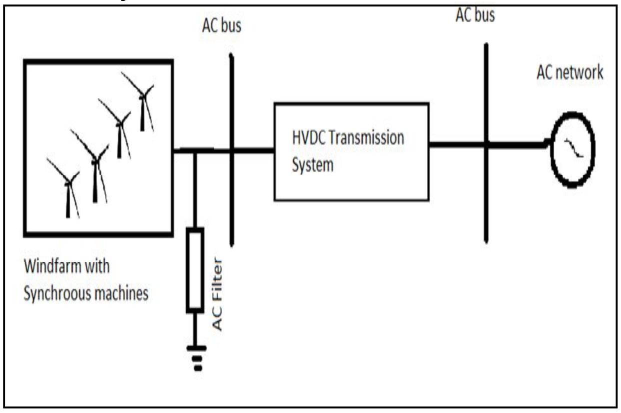

Fig.16: Integration of wind farm with the VSC based transmission system.

V. SIMULATION RESULTS OF WINDFARM WITH VSC HVDC SYSTEM

Performance of the integrated system is tested by the simulation result of DC voltage at inverter/rectifier and AC voltage at sending end. Fig.17 and 18 show the DC voltage at rectifier and inverter.Fig.19 shows the PU AC voltage at the sending end under steady state conditions..

VI. CONCLUSION AND FUTURE WORK

Performance of the proposed VSC-HVDC system under steady state and under various transient conditions are studied. The performance of the controllers is satisfactory as the HVDC system takes very less time to reach steady state after clearing of the fault. Proposed system is integrated with the wind farm to extract the wind energy and to supply the power to the grid and system response is checked with the help of DC voltage and AC voltage. Detailed analysis of this integrated system has to done.

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