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# Rotor Angle Stability of VSC Based HVDC Power Transmission System with 9-Bus 3-Generators

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***Abstract*- High Voltage Direct Current (HVDC) system is a rising in utilization is recent times. It is essential to study the dynamics of HVDC power system. In our study, a Voltage Source Converter (VSC) based HVDC system is studied for stability analysis. Voltage Source Converter High Voltage Direct Current (VSC-HVDC) systems have the ability to control rapidly the transmitted active power and independently exchange a reactive power with transmissions systems.**

**The power system under study is modeled as a multivariable feedback control system model. The system is exposed to different types of fault to compare it with a general HVDC system is order to assess the stability of system**

***Keywords*- High Voltage Direct Current (HVDC), Voltage Source Converter (VSC), Power system stability.**

## I.INTRODUCTION

The HVDC power transfer system is thought out to be an excellent way for large volume power transfer at long distance range. Insulated Gate Bipolar Transistor (IGBT) [1] has led to the development of a new generation power electric converters. This device is fully controlled. The most common converters, which employ the self commutating, high voltage, high current, and high switching frequency power electronic devices, are the Voltage Source Converters (VSC). Voltage Source Converter (VSC)-based High-Voltage Direct Current (HVDC) schemes using insulated-gate bipolar transistors (IGBTs), known as VSC transmission, has attracted increasing attention. The main advantage of VSC power transmission is high controllability, the ability to control independently active and reactive power at each terminal and the possibility for linking with dead networks. These characteristics make VSC transmission attractive in applications like emerging interconnection with renewable sources. The known disadvantages are higher losses and capital cost compared with conventional HVDC [2, 3]. One requirement is the reduction of the power losses and the harmonic distortion generated by the converters, which allow the reduction of cooling and space requirements, also increasing system's operatingefficiency and reliability. The other need is to ensure system operates satisfactorily during abnormal conditions, such as during severe network unbalances.

The VSC-HVDC system consists of two VSC, one of which operates as a rectifier and the other asan inverter. The two converters are connected in two well implemented configurations, depending on application:

- Back-to-back Connection
- Joined by a DC cable

Its main function is to transmit a constant DC power from the rectifier station to the inverter station, with high controllability. The VSC-HVDC has several main advantages like [4, 5]:

- Independent control of the active and reactive power output from each terminal.
- Reduced requirements for harmonic filters.
- Improvements of the power quality and system stability
- Elimination of the requirement for a local power generation

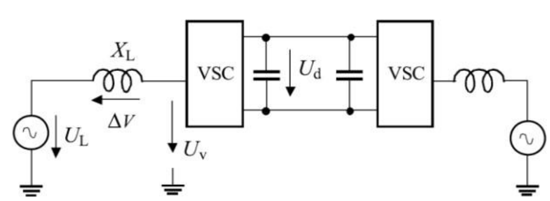


Fig 1-VSC Converter System

## II. PRINCIPLE OF VSC OPERATION

The fundamentals of VSC transmission operation can be understood by considering each terminal as a voltage source connected to the AC transmission network via a three-phase reactor. The two terminals are interconnected, as shown in Fig. 1.

The VSC converter can be represented as a variable AC voltage source where the amplitude, the phase and the frequency can be controlled independently of each other. It means that the VSC bridge can be seen as a very fast controllable synchronous machine with the instantaneous phase voltage, as described by the following equation:

$$U_V = \frac{1}{2} U_d m \sin(\omega t + \delta) + \text{harmonic terms}$$

Variables m and δ are adjusted independently by VSC controller gives combination of voltage magnitude and phase-shift in relation to the fundamental frequency voltage in AC system. As a result, the voltage drop across the reactor can be varied to control the active and reactive power flows. The active power flow between the converter and the network can be controlled by changing the phase angle (δ) between the fundamental frequency voltage generated by the converter ($U_{V(1)}$) and the voltage ($U_L$) on the bus. The power is calculated according to equation assuming a lossless reactor ($X_L$).

$$P = \frac{U_L U_V}{X_L} \sin\delta$$

The reactive power flow is determined by the amplitude of $U_{V(1)}$ which is controlled by the width of the pulses from the converter bridge. The reactive power is calculated according to equation below. The maximum fundamental voltage out from theconverter depends on the DC voltage.

$$Q = \frac{U_L(U_L - U_{V(1)}\cos\delta)}{X_L}$$

## III. SYSTEM MODELLING

Three synchronous generators with different values are interconnected over a long distance, the resultsare obtained for various faults (Three phase symmetrical and un-symmetrical) which are connected intermediate between various buses. Different case studies are taken for obtaining the result of the system that is as follows:

- Rotor angle stability without fault in 3 generator 9 bus system (Without VSC HVDC link)
- Rotor angle stability with three phase symmetrical fault in 3 generator 9 bus system (without VSC HVDC link)
- Rotor angle stability with L-G fault in 3 generator9 bus system (Without VSC HVDC link)
- Rotor angle stability L-L-G fault in 3 generator 9 bus system (Without VSC HVDC link)
- Rotor angle stability without fault in 3 generator 9 bus system (With VSC HVDC link)
- Rotor angle stability with three phase symmetrical fault in 3 generator 9 bus system (with VSC HVDC link)
- Rotor angle stability with L-G fault in 3 generator 9 bus system (With VSC HVDC link)
- Rotor angle stability L-L-G fault in 3 generator 9 bus system (With VSC HVDC link)

MATLAB simulation model of IEEE 9 bus 3 generator systems is used for study. Model consists of static area with the 3 synchronous generators, which are interconnected with number of buses. Specification of the Generator and load used in Simulink are:

1. Synchronous Generator 1- (247.5 MVA, 16.5 kV,180 rpm) swing bus
2. Synchronous Generator 2- (192 MVA, 18 kV,3600 rpm) PV bus
3. Synchronous Generator 3- (128 MVA, 13.8 kV,3600 rpm) PV bus
4. Load 1- 125 MW 50 MVAR/Three-Phase ParallelRLC Load
5. Load 2- 90 MW 30 MVAR/Three-Phase ParallelRLC Load
6. Load 3- 100 MW 35 MVAR/Three-Phase ParallelRLC Load

Synchronous machine is operated with constant value of mechanical power and reference voltage is generated by control system. Computation of Rotor angle uses the Forward Euler Integrator to ensure the better Accuracy. This machine is having swing bus, and used as reference for comparison of rotor angle and load angle of other machine.

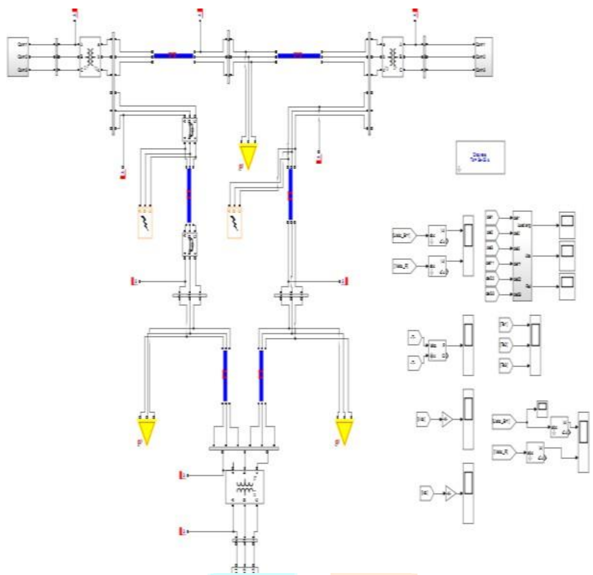

Fig 2– Simulink model of the system without VSC

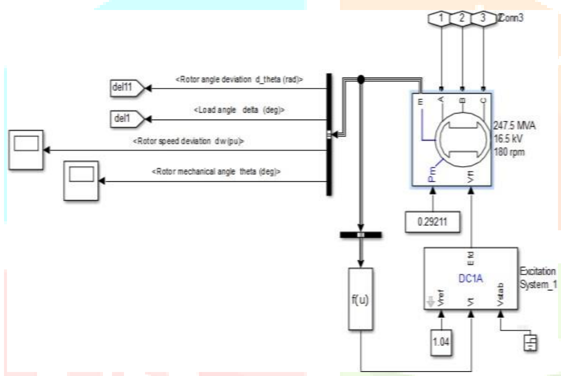


Fig 3- Synchronous machine connection

Figure 4 below shows the implementation of a fault (short-circuit) between line 5-7 and line 6-9 phase and the ground. When the external switching time mode is selected, a Simulink logical signal is used to control the fault operation.

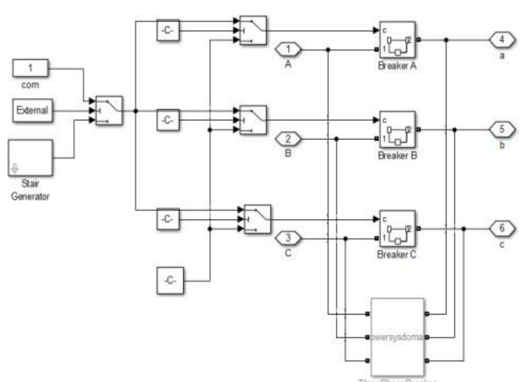


Fig 4 – Subsystem for fault condition

Three-phase parallel RLC load is shown in the figure 5 below which is major requirement of system to assure the system working normally.


Fig: 5-phase RLC Parallel Load

To measure the load angle and the rotor angle variation of the entire synchronous machine, synchronous frame of the reference is the well-known method is used the simulation; the modeling is given in figure below.

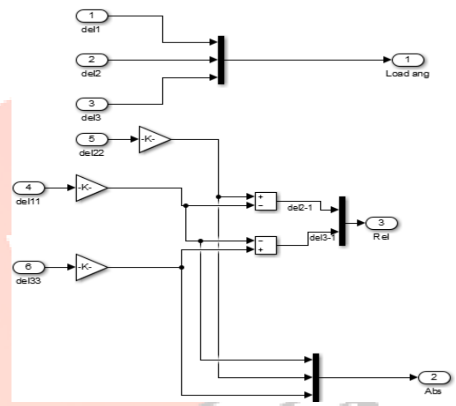


Fig 6- Synchronous reference frame model

The component of HVDC power system inducted in the power system under study is VSC Converter. The schematic diagram of VSC based HVDC system with long distance transmission line is shown in figure 7 below.

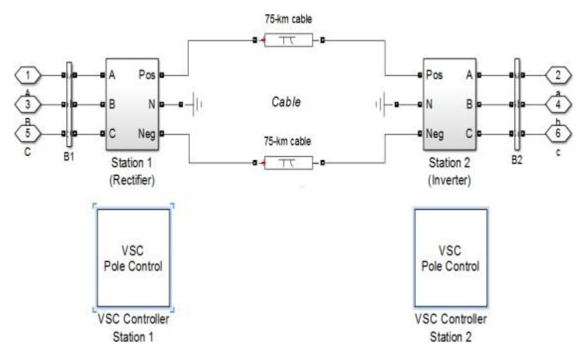


Fig 7- MATLAB model of VSC Converter

The two AC networks are connected with 75km long transmission line for power balance. The interfacing reactor and DC-link capacitor plays significant role for efficient power flow in HVDC transmission system. There is two converting station both at long distance, so the name as back-to-back VSC HVDC system.

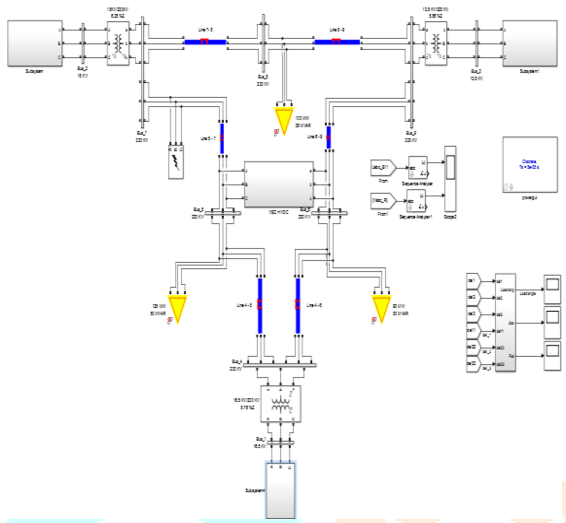

Fig 8- Simulink model of the system under study with VSC

The next stage of simulation needs a VSC converter that will serve the link between two buses. The simulation study will be treating all the cases of system disturbance to test the power system. MATLAB simulation model of 9-bus, 3 generator with VSC HVDC system is shown in figure above. Model consist Dynamic area connected in between line 5 and 6with the 3 synchronous generator, which are interconnected with the distance using 9 number of buses. The VSC controller station model is shown in the figure 9 below.

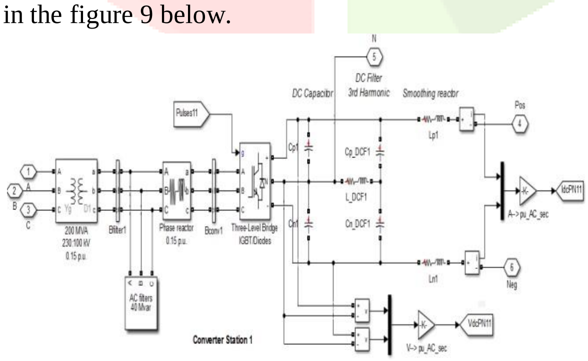


Fig 9-VSC Converter Control in MATLAB

IGBT's gate is used for the converter (AC to DC). The system under study is modeled with the 3-phase transformer, reactor, AC /DC filters and buses. 3-level-bridge of IGBT's and Diode requires pulse for the commutation. The pulse generation model with controller is modeled in MATLAB to provide the pulses. Discrete VSC controller is used, which compare the given three phase bus voltage and current, after it gives to the anti-aliasing filter for smoothing.

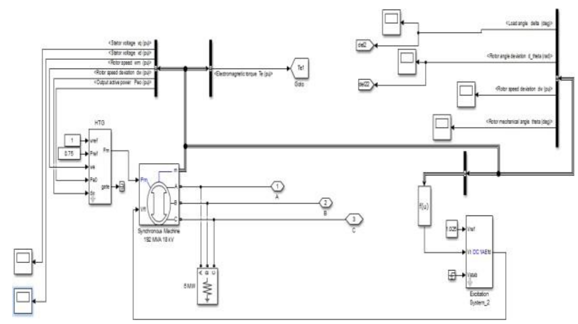

Fig 10- Synchronous machine connection in power system with VSC

## IV. RESULTS AND DISCUSSION

The simulation of 3 generator 9 bus system is carried out to confirm effectiveness of the model. The study has been differentiated into various cases as stated above. Let's go through them one by one. The MATLAB simulation results of Load angle variation in IEEE 9-bus without VSC HVDC converter is shown in figure below. The results suggest that the all three generator are running synchronously as machine 1 is reference model.

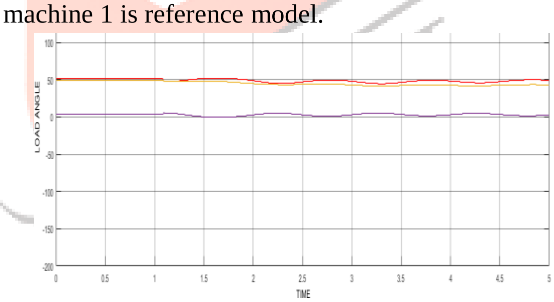


Fig 10- Generator response to step change in load angle without fault

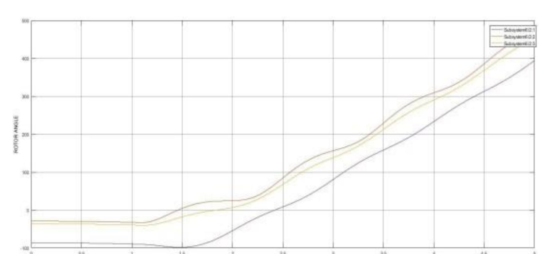

Fig 11- Generator rotor angle variation without fault

MATLAB simulation results of Load angle variation in IEEE 9 bus without VSC-HVDC converter is shown in figure 10. The 3- phase fault is in between line 5-7. As the synchronous machine 1 is used reference and having swing bus. Result shows that the all synchronous machine are in unstable condition due to the system faults.

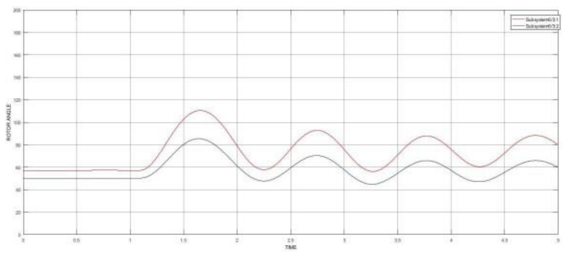


Fig 12- Generator rotor angle stability without fault

The synchronous frame of reference is used to identify the power system stability. MATLAB simulation results of Load angle variation in IEEE 9 bus without VSC HVDC converter is shown in figure above. Synchronous machine 1 is used as reference and having swing bus. Result shows that due to switching time the delta angle is in unstable condition.

MATLAB simulation Results of Load angle variation in IEEE 9 bus without VSC HVDC converter is shown in figure below. The 3-phase fault is in between line 5-7. Result shows that due to 3-phase fault, delta angle gets distorted after t=1.and load angle varies synchronously towards instability.

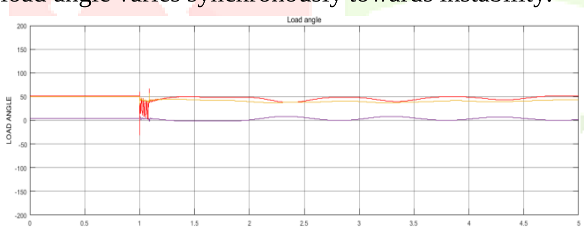


Fig 13- Generator responses to a step change in load angle with 3 phase fault

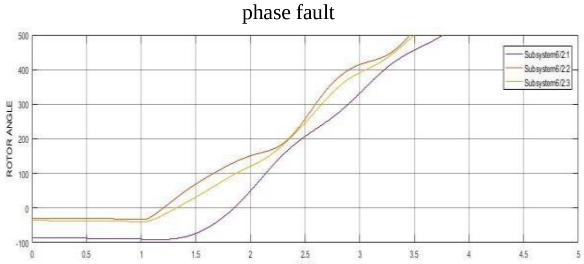


Fig 14- Generator rotor angle variation with fault in between bus5 and 7with synchronous method

Synchronous machine 1 has higher capacity. Due to 3- phase L-L-L Fault is present between line 5-7 and line 6-9, machine 1 tries to become stable but other i.e. synchronous machine 2 and 3 are become unstable .respective load angle variation is shown in the figure below.

With three phase fault in VSC HVDC system, load angle gets varied as shown in the figure below, where the entire three synchronous machine are varying load angle synchronously. The fault is at t=1, that is get cleared within of fraction with the used of circuit breaker.

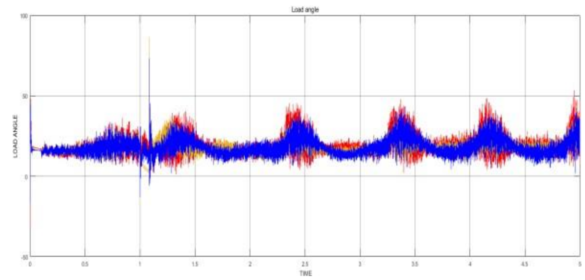


Fig 15- Generator response to step change in load angle without fault in VSC HVDC System

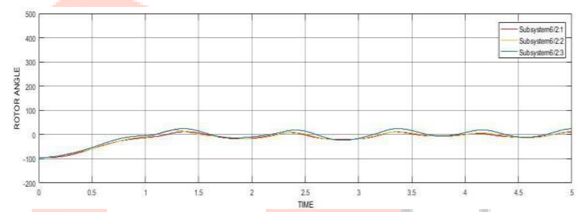


Fig 16- Generator rotor angle variation with 3 phase fault in system with VSC HVDC

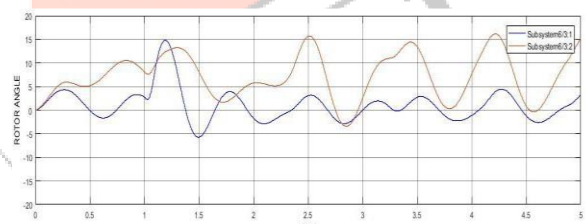


Fig 17- VSC HVDC system rotor angle stability by using synchronize method with 3 phase fault

Load angle of all three synchronous machine are varies linearly because all three generator having same specification. With the method of synchronous frame of reference the load angle of all three synchronous machines are compared and MATLAB simulation result is shown below.

## V. CONCLUSION

The voltage stability analyses are showcased here performed on integrated model of power system with VSC-HVDC transmission. Simulation results show the feasibility and effectiveness of the system and emphasize on need of power quality consideration under various transient conditions. The test carried out to check control of VSC HVDC system for back- to-back configuration. The rotor angle stability canbe achieved by using VSC HVDC system at the greatlevel.

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