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Analysis of Effect on Transient Stability of Interconnected Power System by Introduction of HVDC Link.

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ABSTRACT

Modern power employs HVDC links as a reliable and economical option for long EHVAC transmission line. The HVDC link in the power system behaves very differently than conventional HVAC lines during the disturbances in the power system. This paper analyses the effect of HVDC system on the transient stability of power system. Effect is studied on IEEE 24 bus reliability test system. A self-sufficient model developed in MATLAB Simulink has been given with full details, which can work as a basic structure for an advanced and detailed study.

Keywords – **Transient Stability, HVDC.**

I. INTRODUCTION

The improving reliability of supply is one of the objective to interconnect the generators located at large distances and the purpose is achieved by running the synchronous generators in parallel i.e. in synchronism and with adequate capacity to meet the load demand [1]. The stability problem is concerned with the behavior of the synchronous machines after they have been perturbed while operating in synchronism. If perturbation does not involve any net change in power, the machine should return to the original state. If unbalance between the supply and load is created by the change in load, in generation, or in network conditions, a new operating state is necessary. In any case all the interconnected synchronous machines should remain in synchronism if the system is to be kept stable [2].

Distinction should be made between sudden and major disturbances, which we shall call large impacts, and smaller and more normal random impacts. If one of these large impacts occurs, the study of system behavior following it is referred to as the transient stability problem [3]. The system response to such disturbances involves large excursions of generator rotor angles, power flows, bus voltages, and other system variables. The ability of the system to survive a certain disturbance depends on its precise operating condition at the time of the occurrence of disturbance. A change in the system loading, generation schedule, network interconnections, or type of circuit protection may give completely different results in a stability study for the same disturbance. Thus the transient stability study is a very specific one, from which the engineer concludes that under given system conditions and for a given impact the synchronous machines will or will not remain in synchronism [4].

The problem of interest is one where a power system operating under a steady load condition is perturbed, causing the readjustment of the voltage angles of the synchronous machines. Any unbalance between the generation and load initiates a transient that causes the rotors of the synchronous machines to “swing” because net accelerating (or decelerating) torques are exerted on these rotors. If these net torques are sufficiently large to cause some of the rotors to swing far enough so that one or more machines “slip a pole,” synchronism between the machines is lost [3].

The transient stability is affected by lots of components present in power system and its behavior during the disturbance, like excitation system of generators, reactive power compensating devices, circuit breakers and steam valves of turbine. In this paper the effect of adding the HVDC line in the power system has been studied. The HVDC line shows very different behavior under transients than the HVAC lines as the power flow in DC lines is independent upon the voltage angles at the both ends. To study its effect on the transient stability, 24-Bus IEEE Reliability test system has been simulated in the MATLAB- Simulink environment. The PMU have been simulated to collect the voltage angles at the generator terminals and the behavior of the system is studied from these measurements.

The paper is organized as follows. Section II details the simulated 24 bus system, Section III gives the details of PMU and its simulation, Section IV details HVDC system and its controls. Section V presents the simulation results, and Section VI concludes.

II. DESCRIPTION OF THE BENCHMARK POWER SYSTEM

This section first introduces the models of the different power system elements of the IEEE 24 bus system that is used for the simulations. The fig.1 shows the layout of it.

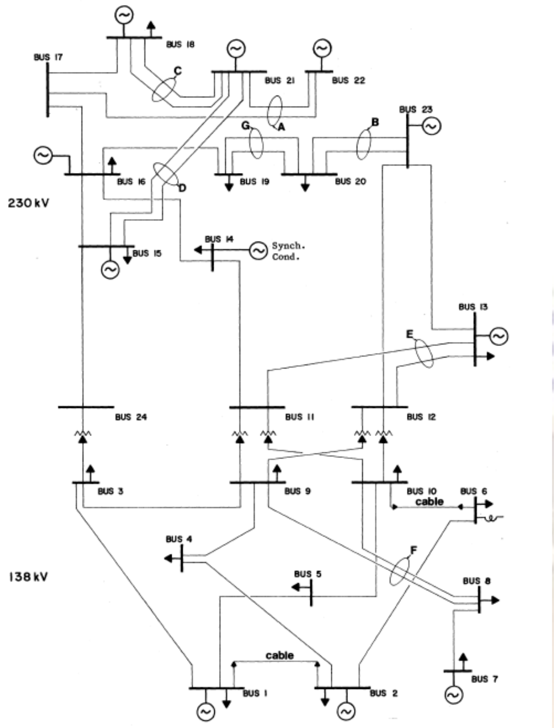

Fig. 1:-IEEE Reliability Test system

The system contains 10 plants, one synchronous condensers and a reactor [5]. They are interconnected by 230KV network and 138KV network, both of them are interconnected through the 5 two winding transformers as shown in fig.1. The generators inside the plants are assumed to be coherent generators and considered as a single unit in the system with capacity equal to addition of capacities of all units in the plant. The generators are equipped with AVR's and PSS. The plants are considered as the hydro power plants and hence hydraulic turbine and governor blocks in Simulink are used to supply mechanical power to it. Fig. 2 below gives the Simulink model of the subsystem simulated for the plants.

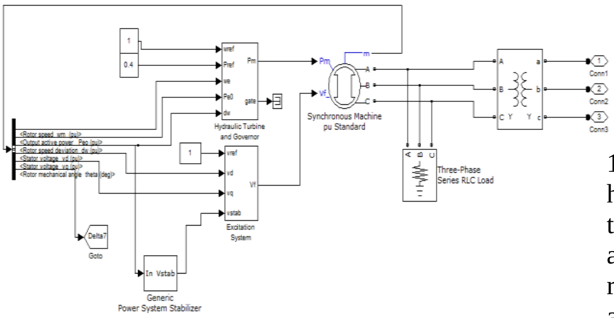

Fig. 2:- Synchronous machine, excitation and governor subsystem

Following table gives the loading of each generator –

TABLE 1: - GENERATOR OUTPUTS BEFORE DISTURBANCE.

Generator No.	Bus No.	Real Power (MW)	Reactive Power (MVAr)
1	1	200.02	325.26
2	2	174.98	223.17
3	3	224.96	261.01
4	13	175.22	-196.98
5	15	50.07	-45.35
6	16	50.06	-64.026
7	18	200.17	-31.11
8	21	150.13	-36.033
9	22	100.17	-22.295
10	23	327.86	-91.17

The loads are modeled as a constant impedance load and hence the power absorbed by them is proportional to the square of the voltage across them. System contains a reactor of capacity 100 MVAr at bus 6 and a synchronous condenser of capacity -200 to 50 MVAr at bus 14.

III. HVDC SYSTEM AND CONTROLLES

HVDC systems are employed in modern power systems because of numerous economical and technical advantages over AC transmission when line length is more. The behavior of the HVDC line during and after the disturbance is different than the HVAC line as the power flow of the AC line is dependent upon the voltage angles at both the ends of the line while in DC line the power flow dependent merely upon the AC voltage magnitude at both ends and can be explained from following circuit diagram

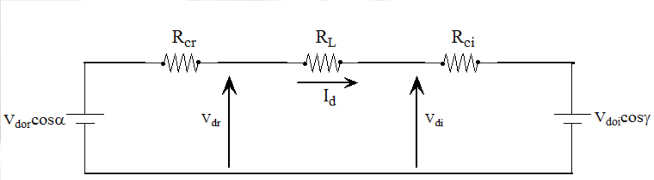

Fig.3:- Equivalent circuit of HVDC line

The power flow is governed by the equations

$$I = \frac{V_{dr} - V_{di}}{R} \qquad (1)$$

$$V_{d0} = \frac{3\sqrt{2}}{\pi} E_{LL} \qquad (2)$$

In the benchmark model one 200KV, 100MW, 100Km single pole CSC based HVDC line has been added in 230KV network between bus 18 to bus 11. Passive harmonic filters are employed to absorb the generated harmonics and to supply the required reactive power for the converter operations at the rectifier as well as inverter end. Terminal of the line connected to the bus 18 acts as a rectifier while connected to bus 11 acts as an inverter. Hence the line guides power flow from 230KV network to 138KV network.

Three modes of operation are designed to control the power injections from the end buses of each HVDC-link to desired value [6]. Under normal conditions, the HVDC-links operate in constant power mode when the rectifier operates in constant current control and the inverter operates in constant extinction angle control. During disturbances, when α reaches extreme values, the mode of operation changes. The control modes can be written as follows.

- Mode 1: Constant power/current control at the rectifier and constant extinction angle at the inverter.
- Mode 2: Minimum firing angle control at the rectifier and constant power/current control at the inverter.
- Mode 3: Minimum firing angle control at the rectifier, and constant extinction control at the inverter. This is the transition mode between Mode 1 and Mode 2.

HVDC link cannot be started abruptly as it may give a shock to existing system. The link is programmed to start and reach a steady state. Then steps are applied on the reference current of the rectifier and on the inverter reference voltage in order to execute the purpose. The converters are deblocked and started by ramping the rectifier and inverter reference current. At t = 0.02 s, the reference current is ramped to reach the minimum value of 0.1 pu in 0.3 s (0.033 pu/s). At the end of this first ramp (t = 0.32 s) the DC line is charged at its nominal voltage and DC voltage reaches steady-state. At t= 0.4 s, the reference current is ramped from 0.1 pu to 1 pu (500A) in 0.18 s (3 pu/s). At the end of this starting sequence (t=0.54 s) , the DC current reaches steady state.

IV. PMU IMPLEMENTATION IN SYSTEM

A Phasor Measurement Unit (PMU) is a device that provides synchrophasor and frequency measurements for one or more three phase AC voltage or current waveforms. The PMU takes reading throughout the system where it has been installed at the same time and hence we have the phasors from all across the system at same instant so it can be compared to study system behavior at that instant. The device uses CT and PT signals as an input and samples it N times per cycle of the 50 Hz (in this case) and by applying DFT we get the fundamental component of the phasor as

$$x_k = \frac{2}{N}\sum_{K=0}^{N-1} x_k e^{-j\frac{2\pi}{N}K} \qquad (4)$$

The conventional phasor representation of the phasor is releted to the fundamental component as

$$x = \frac{j*1}{\sqrt{2}} x_k \qquad (5)$$

The devices are simulated in the Simulink and the MATLAB code has been generated to calculate the phasors in Simulink model(Fig.5).

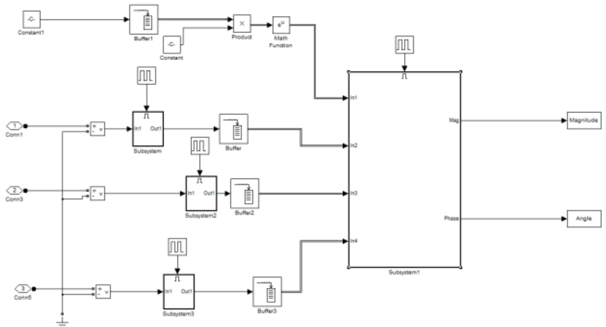

Fig.5:-Simulink model to simulate PMU

The devices are connected at each generator terminal hence we have the synchronized phasors of all generator terminals. PMU in this case gives 25 phasors per second as per reference (9). Because of implementation of DFT technique PMU gives output of phasor angles between -180^0 to +180^0 instead of 0^0 to 360^0 (7).

V. SIMULATION AND RESULTS

The Simulink model of the IEEE 24 bus reliability test system is given in Fig. 6. To study the transient stability of the model, the disturbance has been created by applying three phase to ground solid short circuit to various locations in the power system. The faults are cleared by opening the respective transmission lines and the critical clearing time of each fault for a particular operating condition of the power system has been noted. The same exercise is carried out for a system with and without HVDC link. The behavior of the system is studied by observing rotor angles of the synchronous machines. When angles of the machine moves away from each other by 180^0, it is considered that stability is lost. PMUs installed at the generator terminals gives us the voltage angles of the respective generator terminal voltage. The assumption have been made that the terminal voltage angle and rotor angles are same, and hence the PMUs gives us directly the rotor angles of the generators. As the time frame of interest in transient stability analysis is usually three to five seconds after the disturbance [1], this study is conducted to the first three seconds after the short-circuit inception.

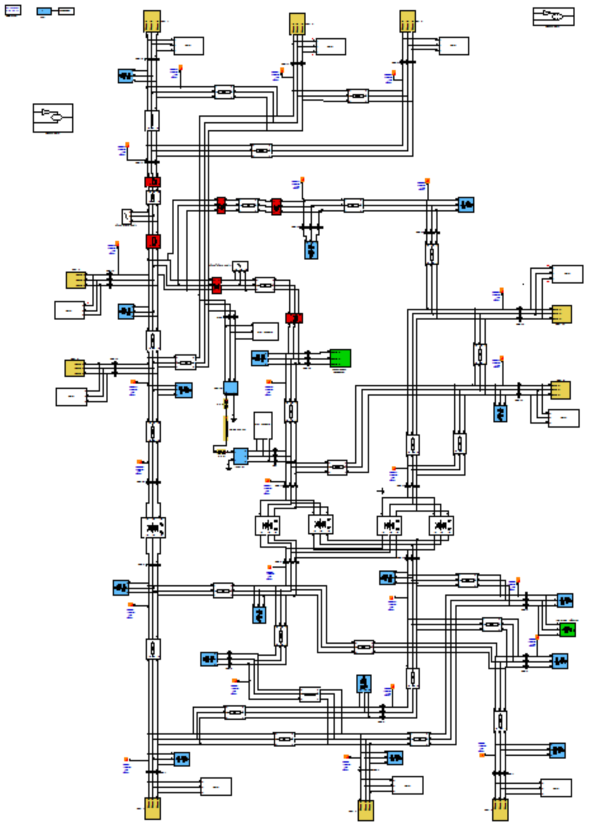

Fig. 6:- Simulink Model of IEEE 24 Bus Test System.

V.1. Illustrative Example

A three phase to ground fault is applied to bus 16 at t=1s, and the fault is cleared by tripping lines 16-14, at t=1.5sec and t=1.7sec without HVDC link. From the generator angles (Fig.7 and Fig.8) we can see the system loses synchronism for FCT 0.7sec, the generators 6, 7, 8 and 9 speeds up from rest of the system. Study is repeated after addition of HCDC link in Model and the generator rotor angle movement is observed for FCT 0.7sec (Fig. 9). Results shows that after inception of HVDC link, the system does not loses synchronism when fault cleared at 0.7sec.

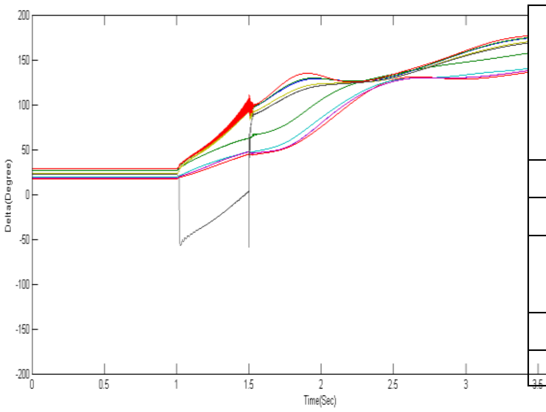

Fig.7:- Rotor angles for FCT 0.5 sec, without HVDC.

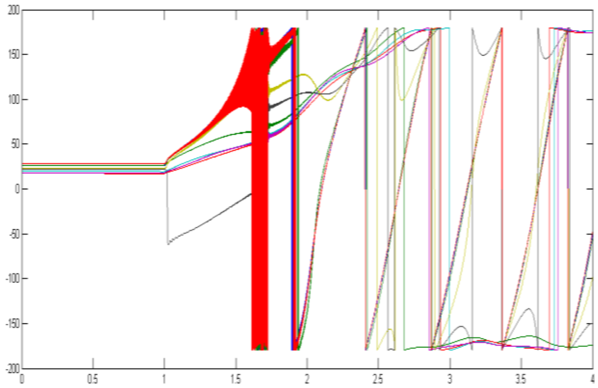

Fig.8:- Rotor angles for FCT 0.7 sec, without HVDC.

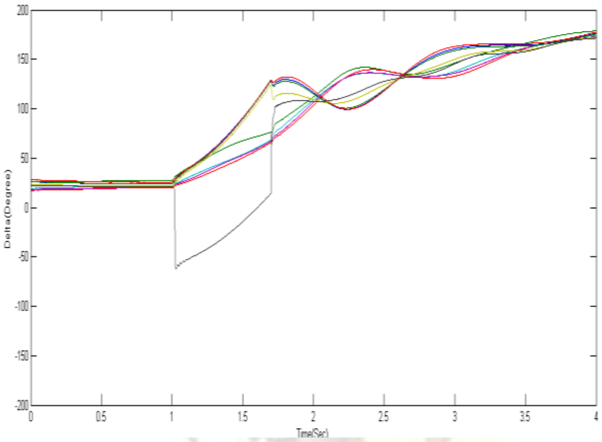

Fig.9:- Rotor angles for FCT 0.7 sec, with HVDC.

Same study has been conducted for faults at various locations in the system and the critical clearing time has been noted down in Table 2.

TABLE 2:- CRITICAL CLEARING TIME (IN SEC.) FOR DIFFERENT CONTINGENCIES

Fault Location	Line Opened	Critical FCT Without HVDC (Sec.)	Critical FCT with HVDC (Sec.)
Bus 16	16-17	0.7	1.4
Bus 16	16-14	0.68	1.6
Bus 16	16-17 & 16-14	0.6	2.0
Bus 14	14-11	0.932	3.0
Bus 21	15-21	0.32	0.9

VI. CONCLUSION

Transient stability of the interconnected power system gets improved with HVDC link introduced in it. A significant improvement in the critical fault clearing time is observed when HVDC link is present. The role of HVDC in transient stability improvement depends mainly upon the location and the power rating of HVDC transmission line. A complete model for transient stability study of a multi-machine power system was developed using Simulink. Thus a Simulink model is not only best suited for an analytical study of a typical power system network, but it can also incorporate the state-of-the-art tools for a detailed study and parameter optimization. A Simulink model is very user friendly, with tremendous interactive capacity and unlimited hierarchical model structure.

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BIOGRAPHIES

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