Case Study of a Four Machine Eleven Bus System Using U.P.F.C.

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Abstract: *The same assumptions used for a system of one machine connected to an infinite bus often assume valid for a multi machine system: Mechanical power input is constant. Damping or asynchronous power is negligible. Constant-voltage behind-transient model for the synchronous machines is valid. The mechanical rotor angle of a machine coincides with the angle of the voltage behind the transient reactance. Passive impedances represent loads. Now taking the cases when small signal perturbation at time instant 15 sec is there and also UPFC is there in the circuit. Hence the comparison of the cases with and without UPFC.*

Keywords - *PSS-Power System Stabilizer, FACT-Flexible Alternating Current Transmission, AVR-Automatic Voltage Regulator*.

I. Introduction

The Unified Power Flow Controller (UPFC) concept was proposed by Gyugyi in 1991. The UPFC was devised for the real time control and dynamic compensation of ac transmission systems, providing multifunctional flexibility The UPFC is the most versatile FACTS-equipment and is able to insert a voltage in series with the line. This voltage can have any phase and magnitude referred to the line voltage. The UPFC consists of a parallel and a series branch, each consisting of a three-phase transformer and a PWM converter. Both converters are operated from a common dc link with a dc storage capacitor. The real power can freely flow in either direction between the two-ac branches. Each converter can independently generate or absorb reactive power at the ac output terminals [3-4]. The controller provides the gating signals to the converter valves to provide the desired series voltages and simultaneously drawing the necessary shunt currents.

In order to provide the required series injected voltage, the inverter requires a dc source with regenerative capabilities. One possible solution is to use the shunt inverter to support the dc bus voltage.

The pulse width modulation (PWM) technique is used to provide a high-quality output voltage, to reduce the size of the required filter, and to achieve a fast dynamic response [1]. The harmonics generated by the inverter are attenuated by a second order filter, providing a low THD voltage to the transformer [6].

II. Unified Power Flow Controller

Steady state objectives (i.e. real and reactive power flows) should be readily achievable by setting the references of the controllers. Dynamic and transient stability improvement by appropriate modulation of the controller references. While the application of UPFC for load flow control and in stability improvement has been discussed in [3,4], a detailed discussion on control strategy for UPFC in which we control real power flow through the line, while regulating magnitudes of the voltages at its two ports.

Inverter 2 provides the main function of the UPFC by injecting a voltage Vpq with controllable magnitude V_{pq} ($0 \le Vpq \le Vpq$) and phase angle ρ ($0 \le \rho \le 360$ degree), at 360 degree), at the power frequency, insert with line via an insertion transformer. This injected voltage can be considered essentially as a synchronous ac voltage source.

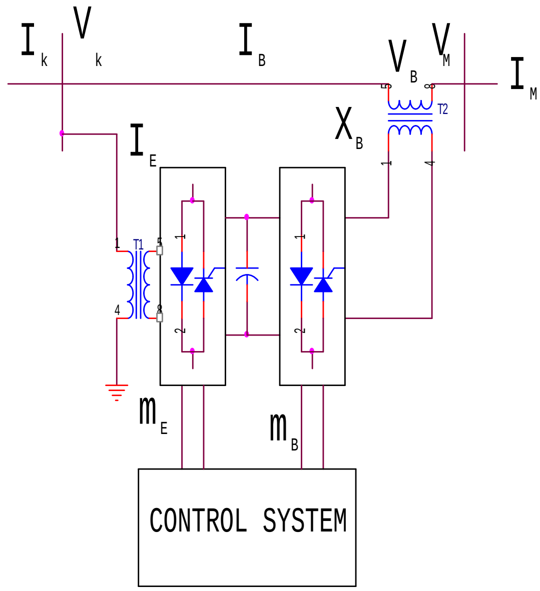

Fig. 1. Basic circuit arrangement of the Unified Power Flow Controller

Reactive power if it is desired, and thereby it can provide independent shunt reactive Compensation for the line. It is important to note that whereas there is a closed "direct" path for the real power negotiated by the action of series voltage injection through Inverters 1 and 2 back to the line, the corresponding reactive power exchanged is supplied or absorbed locally by Inverter 2 and therefore it does not flow through the line. Thus, Inverter 1 can be operated at a unity power factor or be controlled to have a reactive power exchange with the line independently of the reactive power exchanged by Inverter 2. This means that there is no continuous reactive power flow through the UPFC.

Here in the present chapter the design of UPFC controllers has done in a great detail, the system responses with and without fault has been shown and due to UPFC connected in to the system the stability has also been improved.

III. UPFC by two back to back voltage – sourced converters

In presently used practical implementation, the UPFC consists of two voltage sourced converters, as illustrated in fig. 2.

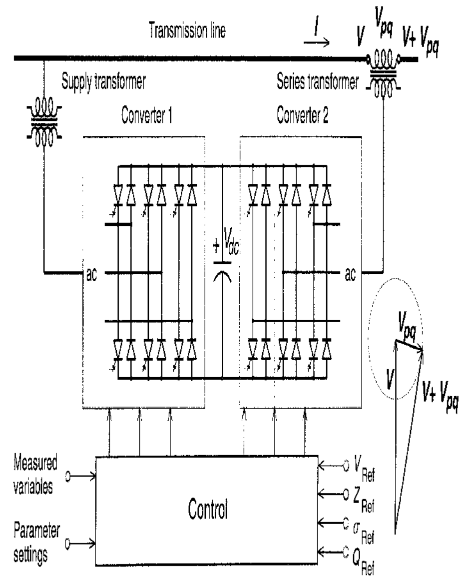

Fig. 2. Implementation of the UPFC by two back to back voltage – sourced converters

Converter 2 provides the main function of the UPFC by injecting a voltage V_{PQ} with controllable magnitude V_{PQ} and phase angle p in series with the line via an insertion transformer. This injected voltage acts, essentially as a synchronous ac voltage source. The transmission line current flows through this voltage source resulting in reactive.

Power and real power exchange between it and the ac system. The reactive power exchanged at the ac terminal (i.e. at the terminal of the series insertion transformer) is generated internally by the converter. The real power exchanged at the terminal is converted into dc power which appears at the dc ling as a positive or negative real power demand.

IV: UPFC Model

Instantaneous power flow delivered by a VSI into a power system

An inverter connected to a power system, which is able of power exchange between the power system and the dc storage capacitor, can be represented by a three symmetrical sinusoidal voltage sources.

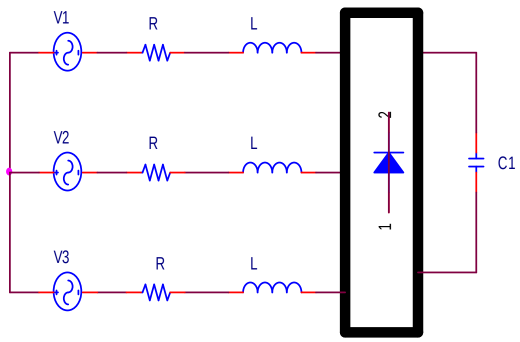

Fig. 3: Equivalent circuit of a VSI connected to a power system.

A symmetrical three – phase system can be transformed into a synchronously-rotating orthogonal system. A new co-ordinate system, having the axes rotating at the synchronous angular speed of the fundamental network voltage ω is defined on the basic of the d-q transformation. In the Fig 2.4 A VSI is supplied by a voltage system V_{ia}, V_{ex}, V_{ex}, R and L are respectively the transformer equivalent resistance and inductances. The d-q transformation of the supply voltage system Vx is made using the following equations:

$$\begin{pmatrix} V_{xds} \\ x_{sqs} \\ o \end{pmatrix} = \frac{2}{3}\begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix}\begin{pmatrix} V_{xd} \\ V_{xb} \\ V_{xc} \end{pmatrix} \quad \theta = \tan^{-1}\left(\frac{V_{xqs}}{V_{xds}}\right) \text{.............1}$$

$$\begin{pmatrix} V_{xd} \\ V_{xq} \\ o \end{pmatrix} = \frac{2}{3}\begin{pmatrix} \cos\theta & \cos(\theta-\frac{1}{2}\pi) & \cos(\theta-\frac{2}{3}\pi) \\ -\sin\theta & -\sin(\theta-\frac{2}{3}\pi) & -\sin(\theta+\frac{2}{3}\pi) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix}\begin{pmatrix} V_{xd} \\ V_{xb} \\ V_{xc} \end{pmatrix} \text{ ....2}$$

On the basis of this d-q transformation, the instantaneous active and reactive power flowing into the power system delivered by the VSI, neglecting transformer losses and assuming fundamental frequency and balanced conditions, and $V_{xd} = |V_{xa}|, V_{xq} = 0 \ are \ eqn \ 3.4$

$$P_x(t) = \frac{3}{2} {}^{*}Vxd \ {}^{*}i_{xd}$$

$$q_x(t) = \frac{3}{2} {}^{*}Vxd \ {}^{*}i_{xd} \text{ ....3}$$

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The same assumptions used for a system of one machine connected to an infinite bus often assume valid for a multi machine system:

1. Mechanical power input is constant.

2. Damping or asynchronous power is negligible.

3. Constant-voltage-behind-transient-reactance model for the synchronous machines is valid.

4. The mechanical rotor angle of a machine coincides with the angle of the voltage behind the transient reactance.

5. Passive impedances represent loads.

This model is useful foe stability analysis but is limited to the study of transients for only the "first swing" or for periods on the order of one second.

V. System Investigated:

For studying transient stability performance of multi-machine power system the model shown in Figure 1 is considered [10] Each synchronous generator of the multimachine system and UPFC are simulated. The text system consists of two fully symmetrical areas linked together by two 220 kv lines of 220 km length. It is specially designed to study low frequency electromechanical oscillations in large interconnected power systems. Despite its small size, it mimcs very closely the behavior of typical systems in actual operation. Each area is equipped with two identical round rotor generators ratcd 20kV/900MVA.

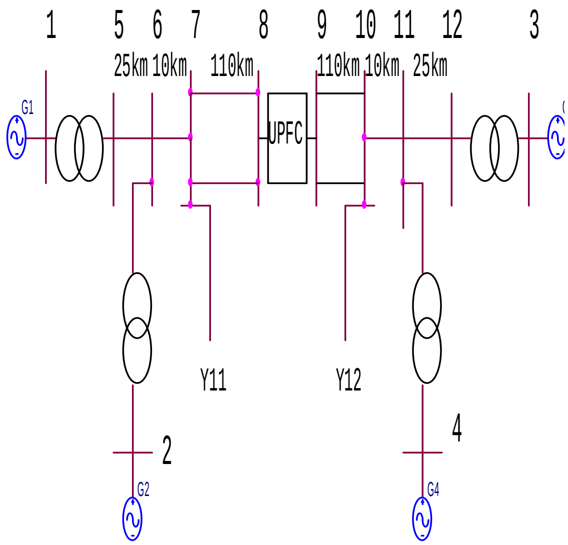


Fig. 4. System Model.

For this purpose MATLAB simulation software package version 7.6 is used, A typical 4 generator 11 bus test system chosen to model which consists of generators, loads, three phase transmission lines, and three phase two winding transformers.

Test system with and without UPFC for the large perturbation

The MATLAB simulation result of the power system is shown in the figure given below. First taking the case when UPFC is not connected in the system and hence when fault is there, system is going to unstable region. The following curves show the behavior of the system without UPFC. Fig 2 is acceleration power, fig. 2 show the power transfer from area B1 to area B2, Fig 2 show the terminal voltage of all four synchronous generators and fig 2 show the angular speed of all synchronous generators. These are the four curves for the without UPFC case.

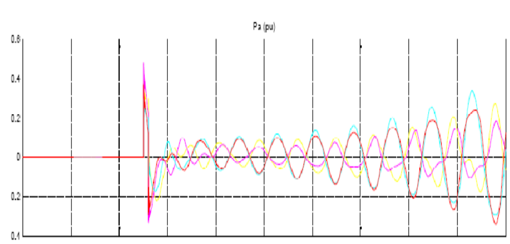


Fig: 5.1(a) acceleration power of all generators

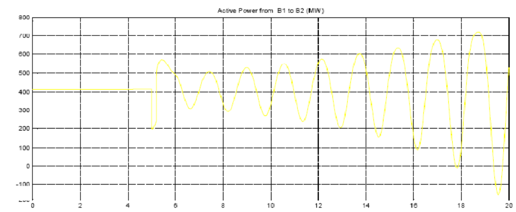


Fig: 5.1(b) Power transfer from area B1 to are B2

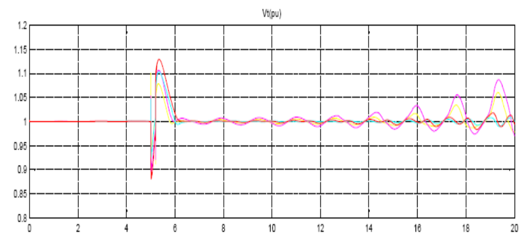
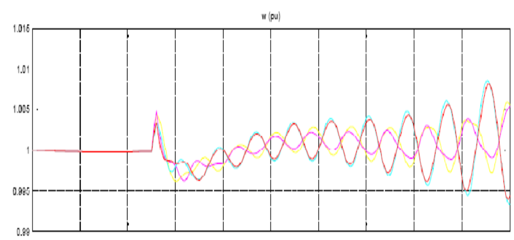


Fig : 5.1(c): Terminal voltages of all four synchronous generators



These were the results of the system when UPFC was not connected in the system, now for the case when UPFC is connected in to system, here the comparison has been shown between the cases with and without UPFC.

VI. Conclusion

Here in the present chapter the design of UPFC controllers has done in a great detail, the system responses with and without fault has been shown and due to UPFC connected in to the system the stability has also been improved.

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