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Lab VIEW Based Simulation of UPFC incorporated on Multi-Machine System

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ABSTRACT : *A number of Flexible AC Transmission System (FACTS) controllers based on the rapid development of high power electronics technology have been proposed in recent years for better utilization of existing transmission facilities. FACTS devices have shown very encouraging results for improvement of power system steady state performance. Unified Power Flow Controller (UPFC) is a versatile FACTS device which has the ability to adjust the three control parameters, i.e. the bus voltage, the transmission line reactance, and the phase-angle between two buses.*

During transients, it can be used to improve the damping rate of low frequency oscillations. Multi-Machine (3-machines 9-Bus) electrical power system incorporated with UPFC has been simulated in the present work with the aim of analyzing the response of the device for enhancing transient stability of the electrical power system. LabVIEW tool has been used for the simulation purposes. LabVIEW is a new research tool which is capable of representing dynamic systems in block diagram form, along with a provision of simulation of system behavior in total. Results obtained are encouraging and indicate that the proposed simulation model is very near to the physical simulation.

Keywords- *LabVIEW, FACTS, Transient Stability, UPFC.*

I. INTRODUCTION

As power transfer grows higher, the power system becomes increasingly more complex to operate and becomes less secured for rising through major outages. It may lead to large power flow with inadequate control, excessive reactive power in various parts of the system, large dynamic swings between different parts of the system and hence full potential of the transmission interconnection may not be utilized. Power system stability issues and thermal constraints limit transmission capacity. In order to meet the increasing load demand and also satisfy the stability and reliability criteria, either the existing transmission or generation facilities be utilized more efficiently or new facilities may be added to the system. But building new transmission lines and expanding existing transmission systems are not feasible due to economic and ecological reasons. As such it is necessary to utilize the existing power transmission system at its maximum capacity and efficiency to meet increasing demand of electrical energy. All these problems can be eased if sufficient margins in the power system are maintained. The required safe operating margins can be reduced by introducing fast dynamic control over reactive and active power using high power electronic controllers. This fast dynamic control can provide flexibility in ac transmission network to adapt to changing conditions caused by contingencies and load variations. Such a transmission system is known as Flexible AC Transmission System (FACTS).

II. FACTS CONTROLLERS

FACTS Controller may be defined as “A high power electronics-based system and other static equipment that can provide control of one or more ac transmission system parameters” [1].FACTS Controllers not only provide the same benefits as conventional compensators with mechanically controlled switches in steady state but also improve the dynamic and transient performance of the power system. FACTS Controllers control the interrelated parameters including series impedance, current, voltage, phase angle and the rate of damping of oscillations at various frequency, that govern the operation of transmission system.

III. UNIFIED POWER FLOW CONTROLLER

Unified Power Flow Controller (UPFC) is the most versatile but a complex FACTS device that has emerged for the control and optimization of power flow in power transmission systems [2]. It has the combined features of series converter as well as shunt converter based FACTS devices, and is capable of realizing voltage regulation, series compensation, and phase-angle regulation simultaneously. The UPFC is thus capable of independently controlling active as well as reactive power on the compensated transmission line.

Series converter is connected in series with the transmission line through a series transformer. Since the series branch of the UPFC can inject a voltage of variable magnitude and phase-angle, it can exchange real power with the transmission line. The shunt converter is connected in parallel with the line through a shunt transformer. Its main function is to provide real power required by the series converter plus the losses by regulating the dc bus voltage at a desired value. The shunt inverter demands the real power needed by the series converter from the line. Meanwhile, the shunt inverter also exchanges (capacitive or inductive) reactive power with the bus. The common dc capacitor C_{dc} provides a direct voltage support for the converter operation and also functions as an energy storage. UPFC is the most promising device in the FACTS concept. It has the ability to adjust three control parameters, i.e. bus voltage, transmission line reactance, and phase-angle between the two buses. Major function of UPFC is to redistribute power flow among transmission lines during steady state. During transient state, it can be used to improve the damping of low frequency oscillations. UPFC needs to be equipped with a power flow controller, dc voltage regulator, and a supplementary damping controller in order to perform these tasks [3].

IV. MULTI-MACHINE SYSTEM MODELING

The popular Western System Coordinated Council (WSCC) 3-machincs 9-bus practical power system with loads assumed to be represented by constant impedance model has been considered as a test case. WSCC system is widely used system [3,4]. Fig.1 shows the WSCC 3-machines 9-bus system.

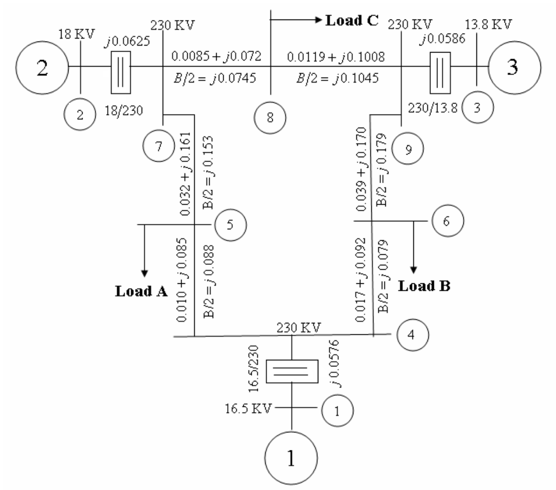


Fig. 1 WSCC 3-Machines 9-bus system

For the power system under study, the disturbance initiating the transient is a three-phase fault occurring near bus 7 at the end of the line 5-7 and the UPFC is located at bus number 5 because VAR compensation is used for voltage regulation at the midpoint (or some intermediate point) to segment the transmission line and at the end of the line in order to prevent voltage instability, as well as for obtaining dynamic voltage control to increase transient stability by damping power swings and oscillations. The reduced matrices are calculated. The resultant Y matrices of the system before, and during fault conditions are worked out and are given as Y_{Rpf} and Y_{Rdf} respectively.

Reduced Y matrix for Pre-fault Network Y_{Rpf} is:

$$Y_{RPf} = \begin{bmatrix} 0.8455 - j2.9883 & 0.2871 + j1.5129 & 0.2096 + j1.2256 \\ 0.2871 + j1.5129 & 0.4200 - j2.7239 & 0.2133 + j1.0879 \\ 0.2096 + j1.2256 & 0.2133 + j1.0879 & 0.2770 - j2.3681 \end{bmatrix}$$

Reduced Y matrix for the Network during fault Y_{Rdf} is:

$$Y_{Rdf} = \begin{bmatrix} 0.6568 - j3.8160 & 0 & 0.0701 + j0.6306 \\ 0 & 0 - j5.4855 & 0 \\ 0.0701 + j0.6306 & 0 & 0.1740 - j2.7959 \end{bmatrix}$$

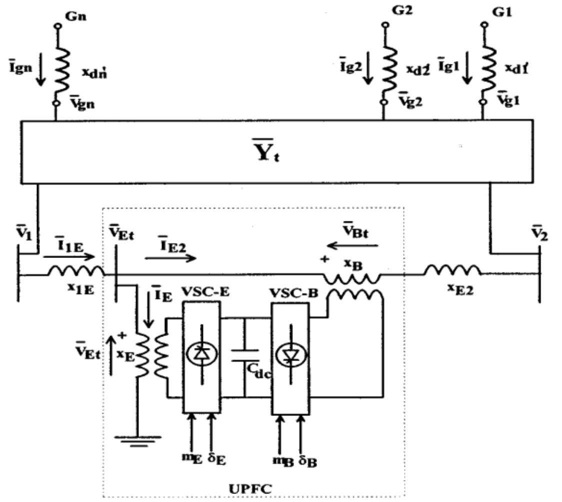


Fig.2 An n-machine power system with UPFC installed

Referring Fig.2, UPFC can be modeled by means of voltages and currents of E_T and B_T as follows [5,6,7]:

$$\frac{dV_{dc}}{dt} = \frac{3m_E}{4C_{dc}} \begin{bmatrix} \cos\delta_E & \sin\delta_E \end{bmatrix} \begin{bmatrix} I_{Ed} \\ I_{Eq} \end{bmatrix} + \frac{3m_B}{4C_{dc}} \begin{bmatrix} \cos\delta_B & \sin\delta_B \end{bmatrix} \begin{bmatrix} I_{Bd} \\ I_{Bq} \end{bmatrix} \quad (1)$$

$$I_{Ed1} = \frac{X_{BB}}{X_{d1\Sigma}} E'_{q_1} - \frac{m_E \sin\delta_E V_{dc} X_{Bd1}}{2X_{d1\Sigma}} + \frac{X_{dE1}}{X_{d1\Sigma}} \left(V_b \cos\delta_1 + \frac{m_B \sin\delta_B V_{dc}}{2} \right) \quad (2)$$

$$I_{Eq1} = \frac{m_E \cos\delta_E V_{dc} X_{Bq1}}{2X_{q1\Sigma}} - \frac{X_{qE1}}{X_{q1\Sigma}} \left(\frac{m_B \cos\delta_B V_{dc}}{2} + V_b \sin\delta_1 \right) (3)$$

$$I_{Bd1} = -\frac{X_{dt1}}{X_{d\Sigma 1}} \left(V_b \cos\delta_1 + \frac{m_B \sin\delta_B V_{dc}}{2} \right) + \frac{X_{dE1}}{X_{d\Sigma 1}} \frac{m_E \sin\delta_E V_{dc}}{2} - \frac{X_E}{X_{d\Sigma 1}} E'_{q1} \quad (4)$$

$$I_{Bq1} = -\frac{m_E \cos\delta_E V_{dc} x_{qE1}}{2x_{q1\Sigma}} - \frac{x_{qt1}}{x_{q1\Sigma}} \left(\frac{m_B \cos\delta_B v_{dc}}{2} + V_b \sin\delta_1 \right) \quad (5)$$

Terminal voltages of generators can be expressed as

$$V_{g_1} = E'_{q_1} - jX'_{d1} I_{g_1} - j\left(X_{q_1} - X'_{d1}\right) I_{q_1} (6)$$

Internal voltages of generators can be expressed as

$$\dot{E}_{q1} = (E_{fd1} - (X_{d1} - X'_{d1}) I_{d1} - E'_{q1}) / \mathrm{T}_{d01} (7)$$

The electrical power output of machine 1, machine 2 and machine 3 can be expressed as :

$$P_{e1} = (((V_{g_1}{}^{2} G_{11}) + (V_{g_1} V_{g_2} Y_{12} \cos(\theta_{12} - \delta_1 + \delta_2)) + (V_{g_1} V_{g_3} Y_{13} \cos(\theta_{13} - \delta_1 + \delta_3))) \qquad (8)$$

The rotor angle for machine 1, machine 2 and machine 3 can be expressed as :

$$\frac{2H_1}{\omega_R} \frac{d\omega_1}{dt} + D_1 \omega_1 = P_{m1} - P_{e1} \qquad (9)$$

$$\frac{d\delta_i}{dt} = \omega_i - \omega_r \qquad (10)$$

i=1, 2, 3….

LabVIEW based Model of Multi-Machine System Equipped with UPFC

LabVIEW, the short form for Laboratory Virtual Instrumentation Engineering Workbench, is a programming environment in which one can create programs using graphical notations. LabVIEW is specifically designed to take measurements, analyze data, and present results to the user. It is also ideal for simulations, presentations of ideas, general programming, or even teaching basic programming concepts [8]. Fig. 3 shows LabVIEW based model of multi-machine system equipped with UPFC Controller.

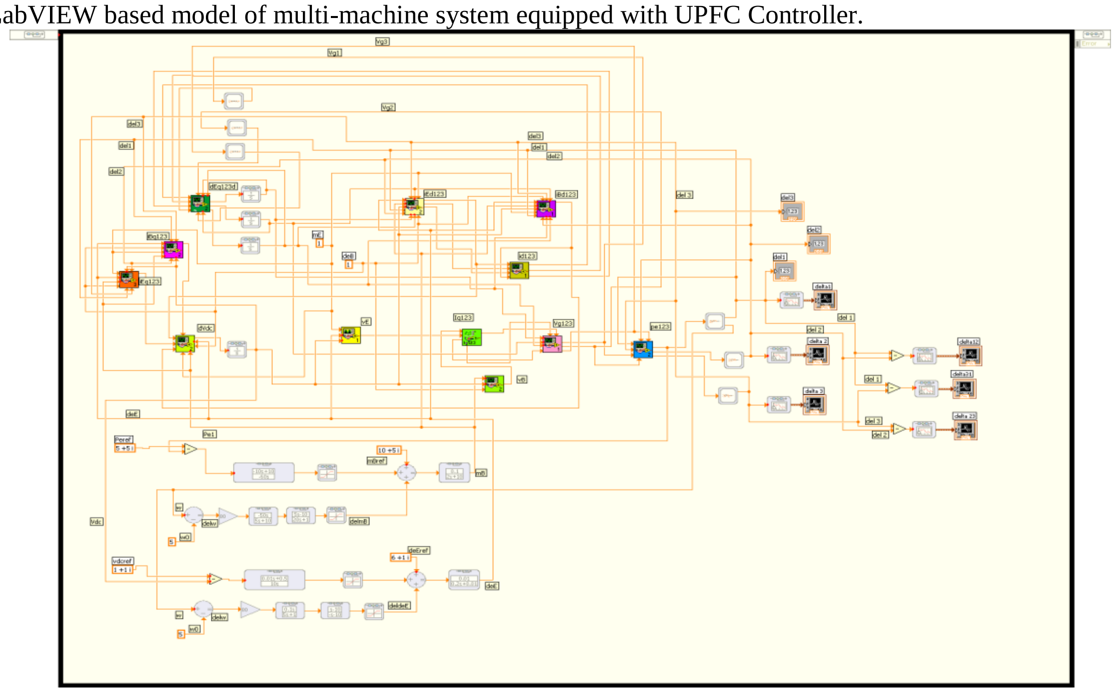
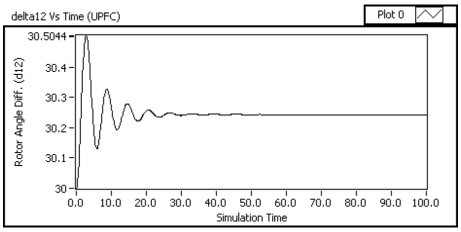


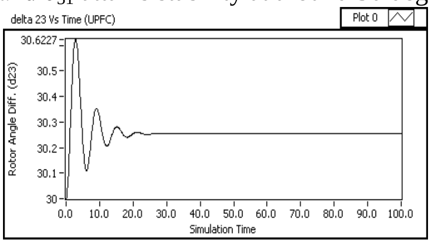
Fig. 3 LabVIEW based Model of multi-machine System Equipped with UPFC

V. SIMULATION RESULTS

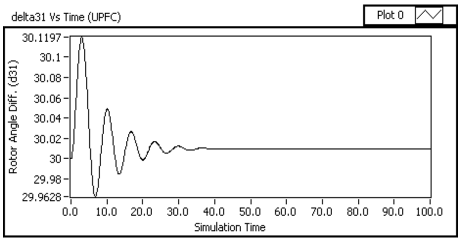
Fig. 4 (a), (b) and (c) represent the rotor-angle versus time curves for damping constant D1 = 10, D2 = 10 and D3 = 17. From these curves, it has been analyzed that at t = 0.2 sec, δ_{12} reaches its maximum value to 30.5044 degrees, δ_{23} reaches to 32.6227 degrees and δ_{31} reaches to 30.1197 degrees. At this point of time the system becomes unstable. The system is back to its stable condition by the effects of δ_E and m_B. By modulating the phase-angle of the ET voltage δ_E, dc voltage is controlled and by modulating the amplitude of the BT voltage m_B, the power flow is controlled. In order to maintain the power balance between the series and the shunt converters, a dc voltage regulator has been incorporated and to dispatch the power flow among transmission lines, a power flow controller has been included. Inclusion of these controllers resulted in decrease of relative angular position δ_{12} to 30.27 degrees at the instant of 20 sec, and finally between the period 25 to 30 sec, δ_{12} attains stability at around 30.24 degrees, δ_{23} attain stability at around 30.25 degrees and δ_{31} attains stability at around 30 degrees.



(a) δ_{12}



(b) δ_{23}



(c) δ_{31}

Fig. 4 Variations of Relative Angular Positions δ_{12}, δ_{23} and δ_{31} with Time for D1=10, D2=10 and D3=17

Same response as in fig.4 has been obtained at different values of damping constant D1 ,D2 and D3 which are tabulated in Table1, Table2 and Table3 respectively.

Table 1: Stability Details Regarding Relative Angular Positions δ_{12}, δ_{23} and δ_{31} with varying values of D1, keeping D2 =10 and D3 =17.

*D C D1	Stable value of Relative Angular Positions (degrees)			Time taken to Attain stability (sec)		
	δ_{12}	δ_{23}	δ_{31}	δ_{12}	δ_{23}	δ_{31}
4	29.7818	30.2647	30.4828	40 – 50	40 – 50	45 – 55
6	29.9614	30.2586	30.2971	30 – 40	20 – 30	35 – 45
9	30.1798	30.2543	30.0745	20 – 30	18 – 25	30 – 40
12	30.3635	30.2535	29.89	20 – 30	18 – 25	25 – 35

***D C: damping constant**

Table 2: Stability Details Regarding Relative Angular Positions δ_{12}, δ_{23} and δ_{31} with varying values of D2, keeping D1 =10 and D3 =17.

*D C D_2	Stable value of Relative Angular Positions (degrees)			Time taken to Attain stability (sec)		
	δ_{12}	δ_{23}	δ_{31}	δ_{12}	δ_{23}	δ_{31}
5	30.6378	30.6455	30.0076	35 – 45	30 – 45	45 – 55
9	30.3073	30.3166	30.0093	25 – 35	20 – 25	30 – 40
13	30.0795	30.0906	30.0111	20 – 30	12 – 20	28 – 38
17	29.8998	29.9127	30.0124	20 – 30	12 – 20	28 – 38

Table 3: Stability Details Regarding Relative Angular Positions δ_{12}, δ_{23} and δ_{31} with varying values of D3, keeping D1 =10 and D2 =10

*D C D_3	Stable value of Relative Angular Positions (degrees)			Time taken to Attain stability (sec)		
	δ_{12}	δ_{23}	δ_{31}	δ_{12}	δ_{23}	δ_{31}
15	30.2464	30.1787	29.9322	25 – 32	18 – 25	30 – 40
20	30.2418	30.3543	30.1125	25 – 32	18 – 25	28 – 35
24	30.2408	30.4717	30.231	25 – 32	15 – 21	22 – 32
27	30.2411	30.5507	30.3096	25 – 32	15 – 21	22 – 30

It is seen from Table1, Table2 and Table3 that with the increasing values of D1, D2 and D3, time taken to attain stability for δ_{12}, δ_{23} and δ_{31} decreases.

VI. CONCLUSION

The proposed LabVIEW based simulation has been successfully incorporated. The Complete investigations revealed the following conclusions:

i. Simulation of UPFC implementation in MM system were successfully carried out and the controllers performance in enhancing power system transient stability was investigated.
ii. Simulation results are quite encouraging and show the effectiveness of UPFC.
iii. Investigations also reveal that with the increasing value of damping constant D, oscillations starts reducing in MM system.
iv. UPFC has been found to be versatile FACTS Controller as it has the unique capability of controlling simultaneously/selectively all the parameters affecting power flow in transmission line viz., voltage, impedance and phase-angle. It is also seen that UPFC can independently control both real and reactive power flow in transmission line.
v. Simulation of UPFC using LabVIEW software almost serves the purpose of physical simulation.

REFERENCES

[1] G. Hingorani, L. Gyugyi, "Understanding FACTS Concepts Technology of Flexible AC Transmission Systems", IEEE Press, New York, 2000.
[2] S.Tara Kalyani, G.Tulasiram Das, "Simulation of Real and Reactive Power Flow Control with UPFC Connected to a Transmission Line", Journal of Theoretical and Applied Information Technology, pp 16-22, 2008.
[3] M.L.Kothari and N. Tambey, "Design of UPFC Controllers for a Multimachine system", IEEE PES Power System Conference and Exposition, Vol.3, pp 1483-1488, 2004.

[4] R.Patel, T.S.Patel and D.P. Kothari, "Matlab/Simulink-based transient stability analysis of a multimachine power system", International Journal of Electrical Engineering Education 39/4, pp 320-336.

[5] H. Wang, "A Unified Model for the Analysis of FACTS Devices in Damping Power System Oscillations-Part3: Unified Power Flow Controller", IEEE Transactions on Power Delivery, Vol.15, No.3, pp 978-983, July, 2000.

[6] Wang H.F. "Applications of Modelling UPFC into Multi-Machine Power Systems", IEE Proceedings on Generation and Distribution Vol.146, No.3, pp 306-312, May1999.

[7] Abido M.A., Al-Awami,A.T., Abdel-Magid Y.L.,"Simultaneous Design of Damping Controllers and Internal Controllers of a UPFC", IEEE Power Engineering Society General Meeting, pp1-8, June, 2006.

[8] Travis. J., Kring. J., LabVIEW for Everyone: Graphical Programming Made Easy and Fun, Third Edition, Pearson Education, 2007.

[9] R. K. Pandey, N. K. Singh, "An Approach for Optimal Power Oscil lation Damping with UPFC", IEEE Power and Energy Society General meeting-Conversion and Delivery of Electrical Energy in the 21st Century. pp 1-9, July, 2008.

[10] Z. Huang, Y. Ni, C.M.Shen, F. F.Wu, S. Chen, B.Zhang, "Application of Unified Power Flow Controller in Interconnected Power Systems - Modeling, Interface, Control Strategy, and Case Study", IEEE Transactions on Power System, Vol.15, No.2, pp 817-824 May, 2000.