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Unified Power Flow Controller and its Implementation On A WSCC System to Bring System in Synchronism after Fault Occurs.

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Abstract: **Unified Power Flow Controller is used to improve stability of a system. It can provide simultaneous control of all basic parameters of a power system i.e. transmission voltage, impedance and phase angle. Functions of reactive shunt compensation, series compensation and phase shifting can be fulfilled by UPFC thereby meeting multiple control objectives. Whenever a fault occurs in a system having multiple machines, the stability of a system is affected and it loses synchronism. The rotor angles of all machines get affected. In this paper a stability of a system having 3 machines 9 buses is improved by using UPFC by bringing the relative angular positions of all three machines in synchronism post fault occurrence.**

Keywords: UPFC, Control Scheme, WSCC System, Matlab Simulink, Relative angular position of rotors.

I. INTRODUCTION:

The purpose of UPFC is the insert a voltage in series with the line when required and is the most versatile FACTS equipment. Referring to the line voltage the voltage provided by UPFC can have any phase and magnitude. The UPFC consists of a parallel and a series branch, each consisting of a 3-phase transformer and a PWM converter. A common dc link with a dc storage capacitor operates both converters. Between the two ac branches the real power can flow freely in either direction. The reactive power at ac terminals at output can be independently generated or absorbed by each converter. To provide the desired series voltages and drawing the necessary shunt currents simultaneously, the gating signals are provided to the converter valves by controller.

A dc source with regenerative capabilities is required by the inverter in order to provide the required series injected voltage. To use the shunt inverter to support the dc bus voltage is one possible solution. To achieve a fast dynamic response, to provide a high quality output voltage and to reduce the size of required filter, the Pulse Width Modulation (PWM) technique is used. In order to provide a low THD voltage to the transformer, the second order filter attenuates the harmonics generated by the inverter. There are two switching converters in UPFC, and these are consider as voltage sourced inverters using gate thyristor valves in the implementations as illustrated in figure 1.

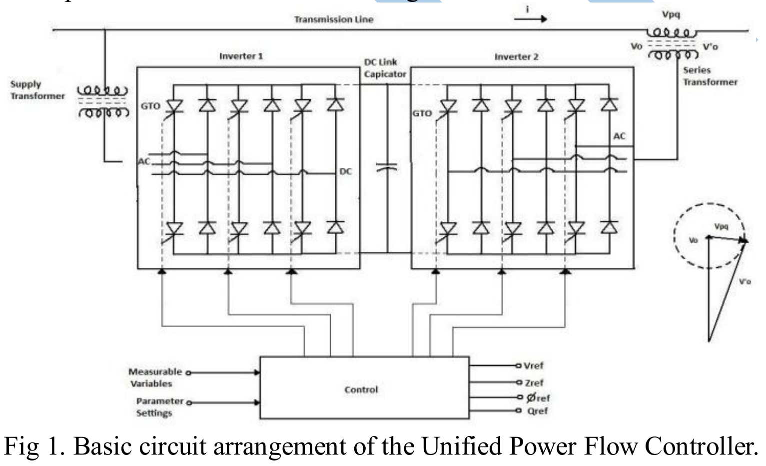

Fig 1. Basic circuit arrangement of the Unified Power Flow Controller.

A common dc link provided by dc storage capacitor operates these two inverters and these are labeled as "Inverter 1" and "Inverter 2" in the figure. Real power can flow freely in either direction between the ac terminals of the two converters due to the arrangements described above which functions as ideal auto ac converter. Reactive power can be generated at its own ac output terminal by each inverter independently. Real power can be exchanged with transmission line because series branch of UPFC can inject a voltage with variable magnitude and phase angle. Except for the power drawn to compensate for losses the real power can neither be supplied nor be absorbed by UPFC as a whole in steady state unless it has a power source at its dc terminals. To compensate losses and any real power drawn or supplied from the system by the series branch, shunt branch is required. The capacitor cannot remain at a constant voltage if the power balance is not maintained. Reactive power can be exchanged with the system independently by the shunt branch.

A voltage Vpq with controllable magnitude Vpq ($0\leq$ V$pq \leq$ Vo) and phase angle ($0\leq \rho \leq 360^0$) at power frequency by inverter 2 of the UPFC. This voltage is inserted with line via an insertion transformer. This injected voltage by UPFC can be considered essentially as a synchronous ac voltage source. Real and Reactive power exchanged between it and the ac system is because of the result of the transmission line current flowing through the voltage source of UPFC. The inverter converts the real power exchanged at the ac terminal which is actually terminal of insertion transformer into dc power, which appears at the dc link as positive or negative real power demand. The inverter internally generates the reactive power exchanged at the ac terminal. The basic function of Inverter 1 is to supply or absorb the real power demanded by Inverter 2 at the common dc link. Through a shunt connected transformer the power is coupled to the transmission line after the dc power link is converted back to ac. If it is desired then the controllable reactive power can also be generated or absorbed by the Inverter 1, thereby shunt reactive compensation for the line can be provided by it.

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

Based on reactive shunt compensation, series compensation and phase shifting the operation of UPFC was viewed from stand point of conventional power transmission. By adding the injected voltage Vpq, with suitable amplitude and phase angle, to terminal voltage Vo, the UPFC can meet multiple control objectives. The basic control of power flow functions of UPFC are shown in Fig 2.

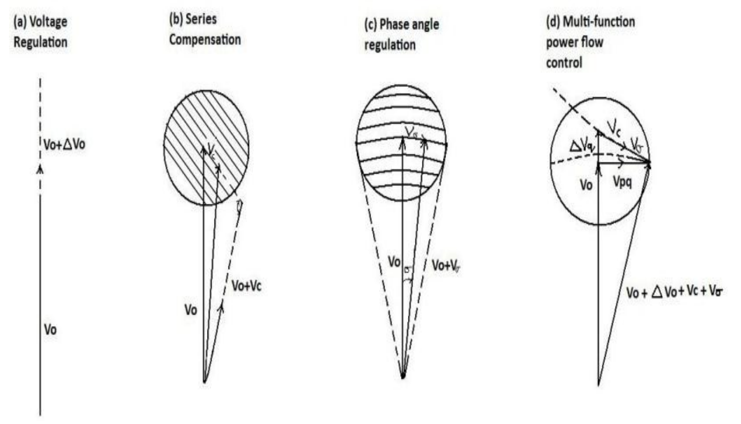

Fig 2 Basic UPFC control functions. (a) Voltage Regulation (b) Series Compensation (c) Angle Regulation (d) Multi Function Power Flow Controller.

Voltage regulation is shown in (a) where Vm = ΔV is injected in phase or anti phase with Vo and it is similar to that obtainable with a transformer tap changer having infinitely small steps. Series Compensation is shown in (b) in which Vp = Vc is injected in quadrature with the line current I. Phase Angle Regulation is shown in (c) where Vpq = Vσ is injected with an angular relationship with respect to Vo that achieves the desired σ phase shift which can be advance or retard but without change in magnitude. Multi Function power Flow Control is shown in (d) where Vpq = ΔV + Vc + Vσ and it is executed by simultaneous terminal voltage

regulation, series capacitive line compensation and phase shifting.
Above summarized capabilities of UPFC in terms of the conventional transmission control concepts, can be integrated into a generalized power flow controller. The prescribed real power P and reactive power Q in the line which are independently controllable are maintained by this controller. In order to maintain or vary the real and reactive power flow in the line to fulfill load demand and operating conditions of system the UPFC simply controls the magnitude and angular position of injected voltage in real time. Thus the conventional terms of series compensation, phase shifting etc becomes irrelevant.

II. CONTROL SCHEME:

There are several operating modes of UPFC. Shunt converter control and series converter control. Two control modes are possible for the shunt control:

1. VAR control mode: Inductive or capacitive VAR request is the reference input.
2. Automatic voltage control mode: To maintain the transmission line voltage at the connection point to a reference value is its main purpose.

The UPFC can be operated in four different ways by the control of series voltage:
Direct voltage injection mode: The magnitude and phase angle of the series voltage are directly the reference inputs.

1. Phase angle shifter emulation mode: Phase displacement between the sending end voltage and receiving end voltage is the reference input.
2. Line impedance emulation mode: Impedance value to insert in series with the line impedance is the reference input.
3. Automatic power flow control mode: The values of P and Q to maintain on the transmission line despite system changes are the reference inputs.

III. ADVANTAGES OF UPFC:

The advantages of UPFC are as following:

1. From technical point of view, by using solid state voltage sources exclusively instead of switched capacitors and reactors, or tap changing transformers, UPFC makes it possible to handle all power flow control and transmission line compensation problems uniformly.
2. The functional flexibility and operational performance which is generally not attainable by conventional thyristor controlled systems, is provided by the voltage source based universal power flow approach.
3. From the equipment and installation standpoints, this approach naturally lends itself to volume production, real estate and installation labour requirements are minimized, and make the overall capital cost primarily dependent on the cost of the solid state components, which historically exhibits the sharpest decreasing trend with technology advances.

IV. MULTI MACHINE MODELLING:

The popular Western System Coordinated Council (WSCC) 3-machine 9-bus practical power system is a widely used one and found very frequently in the relevant literature as presently appearing in references. A 3-machine 9-bus WSCC system is shown in Fig 3. The loads here have been assumed to be represented by constant impedance model.

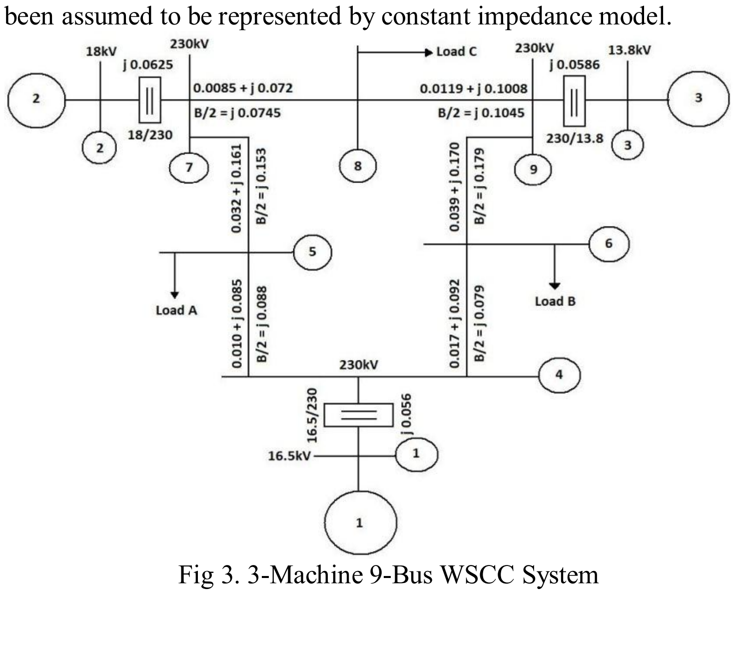

Fig 3. 3-Machine 9-Bus WSCC System

The base MVA of the system is 100, and the frequency of the system is 60 Hz. Table 1 shows the other data. By using MATLAB/Simulink Blocks the complete system with all the required components has been modelled.

Table 1

Specifications	Generator 1	Generator 2	Generator 3
Rated MVA	247.5	192.0	128.0
kV	16.5	18.0	13.8
H(s)	3.7	3.8	3.7
Power factor	1.0	0.85	0.85
Type	Hydro	Steam	Steam
Speed	180 r/min	3600 r/min	3600 r/min
x_d	1.305	1.305	1.305
x'_d	0.296	1.129	1.296
x_q	0.474	0.374	0.474
x'_q	0.243	0.243	0.243
x_l (leakage)	0.18	0.18	0.18
T_{do}	4.49	4.49	4.49
T'_{qo}	0.0513	0.0513	0.0513
Stored energy at rated speed	2364 MW	640 MW	301 MW

V. SIMULINK MODEL:

UPFC controller has been envisaged to be used for improvement of several performances of power system. These are improvement in the stability of the system, damping of power oscillations, prevention of voltage collapse and dynamic voltage control etc. Simulation of UPFC controller in MATLAB/Simulink (7.5 version) has been carried out in this chapter on Multi Machine (3 Machine 9 Bus) system. By varying the different system parameters the responses for the above cases were analyzed. The variation of rotor angle and its effect on the stability of a system are included in the investigations for analysis. The MATLAB/Simulink model of multi-machine (3-machine 9-bus) WSCC system, incorporated with a three phase fault is shown in Fig 4. The variation of relative angular positions of the generator with time has been analyzed for transient stability studies.

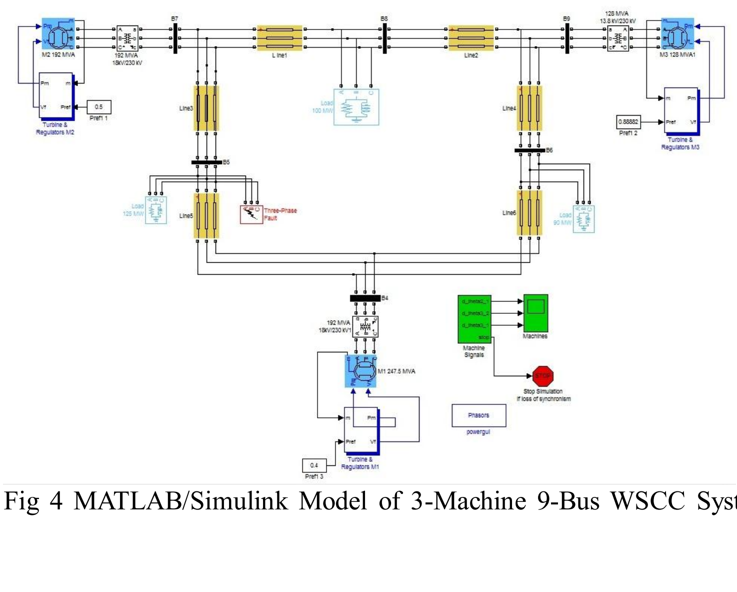

Fig 4 MATLAB/Simulink Model of 3-Machine 9-Bus WSCC System

incorporated with three phase fault.
The relative angular positions of the rotor are calculated as given below:
delt 2_1=delt 2-delt 1
delt 3_2=delt 3-delt 2
delt 3_1=delt 3-del 1
where delt 1, del 2 and del 3 are the rotor angle for generators M1, M2 and M3.
Variation of relative angular positions with time for 3-machine 9-bus system with a three phase fault between bus 5 and bus 4 is shown in Fig 5. The system goes to instability due to the fault. The total simulation time is 20 sec.

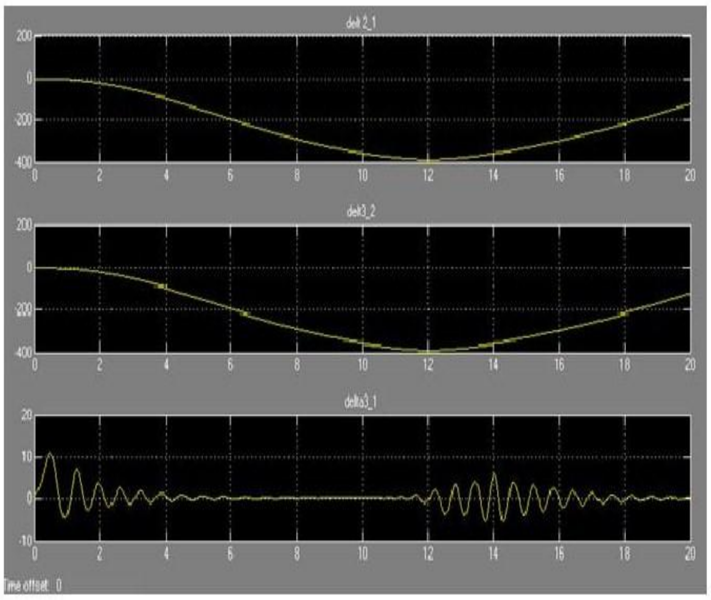

Fig 5. Variation of Relative Angular Position for delt2_1, delt3_2 and delt3_1 with time.

For fault which occurs between Bus 5 and Bus 4, analysis of the MATLAB/Simulink (7.5 version) model of 3-Machine 9-Bus WSCC system incorporated with UPFC has been done. The MATLAB/Simulink Model of 3-machine 9-bus WSCC system incorporated with UPFC and three phase fault occurring between Bus 5 and Bus 4 is shown in Fig 6.
Rating of the UPFC block has been set as follows:-
Nominal Voltage = 500 kV
Frequency = 60 Hz
Shunt Converter rating = 100e6
Shunt Converter Impedance = [0.22/30, 0.22]
Series Converter rating = [100e6, 0.1]
DC link nominal voltage = 40000 V
Capacitance = [750e-6] F
The relative angular positions for 3-machine 9-bus WSCC system incorporated with UPFC controller placed in the middle of bus 5 and bus 4 and three phase fault taking place between bus 5 and bus 4 is shown in Fig 7 and Fig 6 is MATLAB/Simulink Model of 3-Machine 9-Bus WSCC System incorporated with three phase fault between bus 5 and bus 4.

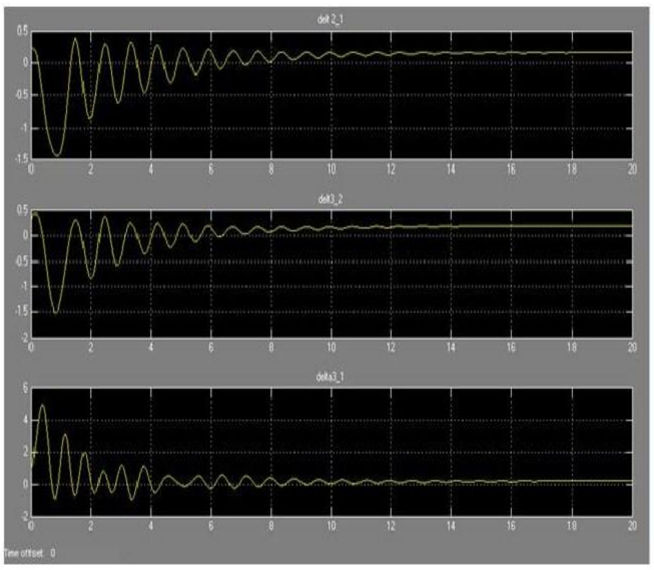

Fig 7. Variation of the Relative Angular Positions delt2_1, delt3_2 and delt1_3 with time

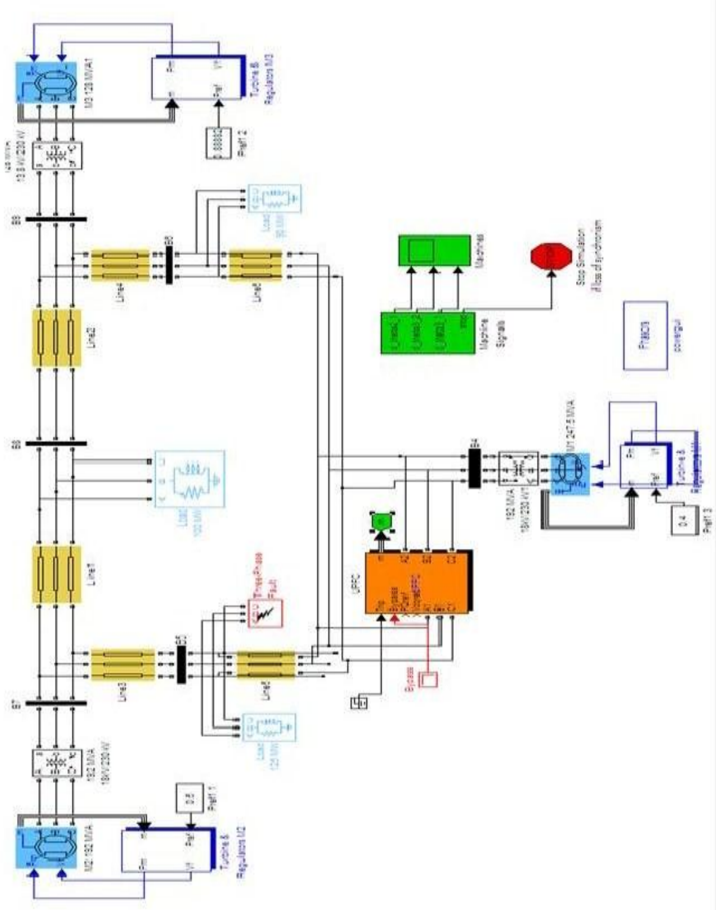

Fig 6. MATLAB/Simulink Model of 3-Machine 9-Bus WSCC System incorporated with UPFC in the middle of Bus 5 and Bus 4.

VI. CONCLUSION:

The following conclusions are revealed by the complete investigations:

- A voltage is injected in series by the UPFC controller that changes the reactive power which in turn affects the rotor angle and brings back the system into synchronism.
- From the above case, when a 3-phase fault occurs between bus 5 and bus 4, the system is brought back to synchronism by UPFC and stability is achieved very fast. Time taken to attain stability in the case of delt2_1, delt3_2 and delt1_3 are almost same as 14 seconds.

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