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STUDY OF THE IMPACTS OF UPFC UPON DYNAMIC POWER QUALITY

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ABSTRACT

This paper designs the UPFC dynamic model after a briefly review to UPFC operating principles. Firstly, three-phase bridge full-controlled circuit is used to compose the converters, in which IGBT are employed as the switch components. Gate firing signals of IGBT are obtained using SPWM method. Secondly, whole UPFC model, together with a simple PI control rules, are accomplished after analyzing the transmission active and reactive power characteristics. Finally, the capabilities of the UPFC on enhancing transient stability, maintaining bus voltage and damping system oscillation are examed by simulation. Result graphics illustrate the unique capability of the UPFC to control the real and reactive power on a transmission line, while also regulating the local bus voltage simultaneously or independently.

Keywords: *UPFC EMTDC, dynamic model, simulation, dynamic power quality*

I. INTRODUCTION

UPFC (unified power flow controller) is one of the most powerful FACTS equipments, can perform the STATCOM (static synchronous compensator) and SSSC (static synchronous series compensator) functions simultaneously, by changing its control algorithm, can realize series compensation, shunt compensation and phase shifting simultaneously and deceptively, and then control the power flow and regulate the voltage. Using the EMTDC, this paper analysis and studies the impacts of UPFC upon the power quality detailed and system, the simulation results demonstrate that UPFC can enhance transient stability, control the power flow, maintain the bus voltage and damp the oscillation rapidly and effectively.

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2 EMTDC MODEL OF UPFC

2.1 WORKING PRINCIPLE OF UPFC

Fig1 is the theoretic diagram of UPFC. VSC1 (voltage-based converter) is connected into the system in shunt through the transformer Tsh, while VSC2 (voltage-based converter) connected into the system in series through the transformer Tse, the terminals of these two converters are connected through dc capacitor. VSC2 injects voltage Vse into the transmission line, and realizes series compensation, shunt compensation and phase shifting simultaneously or deceptively, VSC1 supplies the real power to the VSC2 through dc capacitor, and also exchanges reactive power with the transmission system to maintain the connected bus voltage at the reference level.

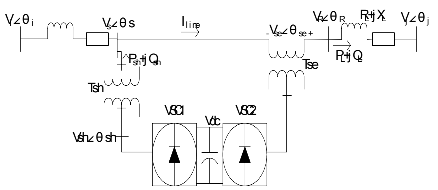

Figure1. Theoretic diagram of UPFC

2.2 UPFC MODEL

As shown in Fig2, UPFC model has four components, in which, Vs、V_R、P_L and Q_L are correspond to Fig1, Vdcref, V_{sref}、V_{Rref}、P_{Lref} and Q_{Lref} are the reference value, Vdc is the voltage across the dc capacitor. Three-phase bridge full-controlled circuits are used as the main circuits of VSC1 and VSC2. The switch device is IGBT, and its gating firing circuit is the block supplied by the EMTDC. In the circuit, the firing signal for IGBT is produced by SPWM method.

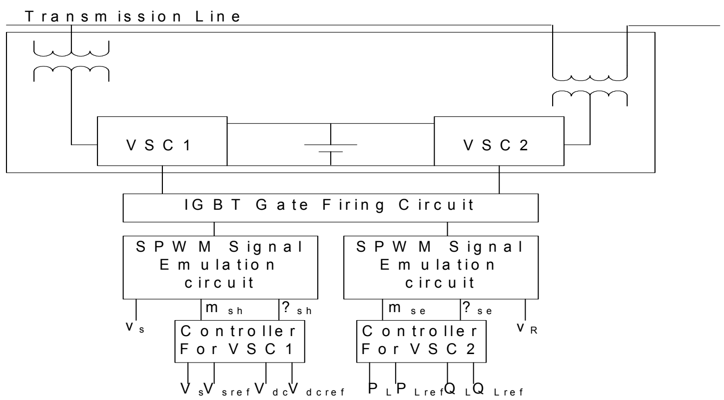

Figure 2. model of UPFC

The objectives of UPFC are to regulate the real and reactive power of the transmission line, bus voltage and dc capacitor voltage at the desired level. So the sending end voltage $\dot{V}_s$ and the dc capacitor voltage V_{dc} are taken as the feedback variables for the shunt converter control block, while, the real power and reactive powers of the transmission line are taken as the feedback variables for the series converter control block. the control blocks for shunt and series converters are described in detail as follows.

2.2.1 CONTROL BLOCK FOR SHUNT CONVERTER

As seen from Fig 1, the shunt side power emulated from transmission system is:

$$P_{sh} + jQ_{sh} = \dot{V}_s \times \left(\frac{\dot{V}_s - \dot{V}_{sh}}{jX_{Tsh}} \right)^*$$
$$= -\frac{V_{sh}V_s}{X_{Tsh}} \sin\theta_{sh} + j\frac{1}{X_{Tsh}}(V_s^2 - V_{sh}V_s\cos\theta_{sh}) \quad (1)$$

Where, X_{Tsh} is the equivalent reactance of transformer Tsh.

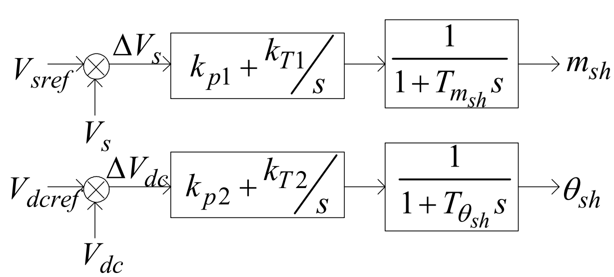

Figure 3. Control block of shunt inverter

From equitation (1), we can see the capacitance and flow direction of the real power P_{sh} depends on the phase of $\dot{V}_{sh}$; and the Q_{sh} exchanged between the system and the shunt converter mainly depends on the magnitude of $\dot{V}_{sh}$, therefore, the magnitude and phase of $\dot{V}_{sh}$ are choice as the output variables for the control block, the corresponding control criteria showed in Fig 3. In which, m_{sh} determines the magnitude of $\dot{V}_1$ and θsh determines the phase of $\dot{V}_1$.

2.2.2 CONTROL BLOCK FOR SERIES CONVERTER

As the similar fashion, according to Fig 1, the transmission line power when the UPFC connected into the system is

$$P_L + jQ_L = \dot{V}_k \times \left(\frac{\dot{V}_R - \dot{V}_j}{jX_{L2}} \right)^*$$

$$= j\frac{1}{X_{L2}} V_R \angle \theta_R \times (V_R \angle(-\theta_R) - V_j \angle(-\theta_j))$$

$$= \frac{V_j V_R}{X_{L2}} \sin(\theta_R - \theta_j)$$

$$+ j\frac{1}{X_{L2}} (V_R{}^2 - V_R V_j \cos(\theta_R - \theta_j)) \quad (2)$$

from this equation, we can see, when -90° < θ_R-θ_j < 90°, increasing V_R and θ_R-θ_j, the real power can be increased, and 0° < θ_R-θ_j < 180°, the reactive power can be increased by increasing V_R and θ_R-θ_j. The phase error of θR-θ_j determines the real power, while V_R determines the reactive power. So the magnitude and phase angle of $\dot{V}_R$ are choice as the control variables. The corresponding control block diagram for the series side converter showed in Fig 4.

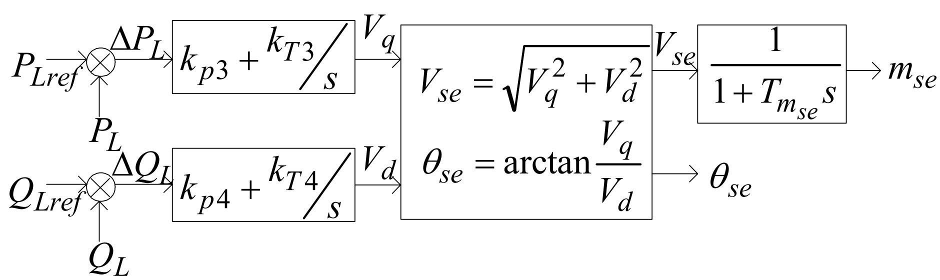

Figure 4. Control block of series inverter

3. SIMULATION OF UPFC AND THE RESULTS ANALYSIS

3.1 PARAMETERS SETTING FOR THE SYSTEM

The simulation system as shown in Fig 5. In which, the line voltage rms of generator F1 is 10.5kV, the initial phase is 0 degree, the line voltage rms of generator F2 is 10.5kV, the initial phase is -15 degrees. The two parallel transmission lines are 150km long, with 220kV rated voltage, and the overhead transmission conductor is LGJJ-400, and the corresponding zero sequence, positive sequence and negative sequence impedances are: Z_0 = 0.3620+j0.7589 Ω/km , Z_1 = Z_2 = 0.0745+j0.3562 Ω/km , C_0 = 0.00699 μF/km , C_1 = C_2 = 0.01001 μF/km。The transformer parameters set as in table 1.

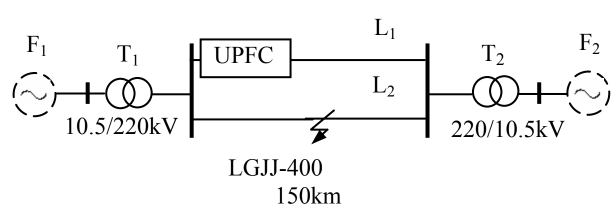

Figure 5. Diagram of simulation system

Table 1. Configuration of transformers

	Type	Rated capacity (MVA)	Connection type	(U%)	(I%)	Losses (kW)	
						With load	Without Load
T_1	SFP7-180000/220	180	d11, YN	14	0.8	510	160
T_2	SFP7-180000/220	180	YN, d11	14	0.8	510	160

In the block of UPFC, the parameters of the shunt coupling transformer are set as following: the ratio is 220kV/10kV, the capacitance is 100MVA, the leakage reactance is 10%, the connection type is Y/Δ - 11. The parameters of the series-coupling transformer are set as following: the ratio is 10kV/22kV, the capacitance is 100MVA, and the leakage reactance is 5%. In the dc capacitor: C_d=2000μF。

The controller parameters are: $k_{T1} = 0.1$, $k_{p1} = 3.5$; $k_{T2} = 0.1$, $k_{p2} = 0.25$; $k_{T3} = 0.05$, $k_{p3} = 2.6$; $k_{T4} = 0.05$, $k_{p4} = 1$ 。

In the simulation, the initial real and reactive power is: $P_L + jQ_L = 64.8\text{MW} + j35.8\text{M var}$; The bus voltage is $V_s = 1$ p.u.; the dc voltage is $V_{dc} = 34k\text{V}$ 。

3.2 SIMULATION FOR REGULATING THE REAL POWER

The objective of this simulation is to regulate the transmission real power, but maintain the transmission reactive power, the bus voltage and the dc capacitor voltage at the constant. At the time of 0.0s , 0.6s、1.2s and 1.8s set the real power as 65.8MW, 50MW, 30MW and 60MW, the corresponding transmission power flow, bus voltage and dc capacitor voltage shown in Fig 6.

From Fig 6, we can see the following phenomena, when the real power varied, it can reach the steady-state in 0.3s, and the reactive power maintains nearly at the constant; the bus voltage varied slightly around 1p.u.; and the dc capacitor voltage also varied in very small range, this due to the transmission line real power should be only supplied by dc capacitor, so there is a energy absorbing or dissipating process, image to voltage, this means the voltage magnitude varied.

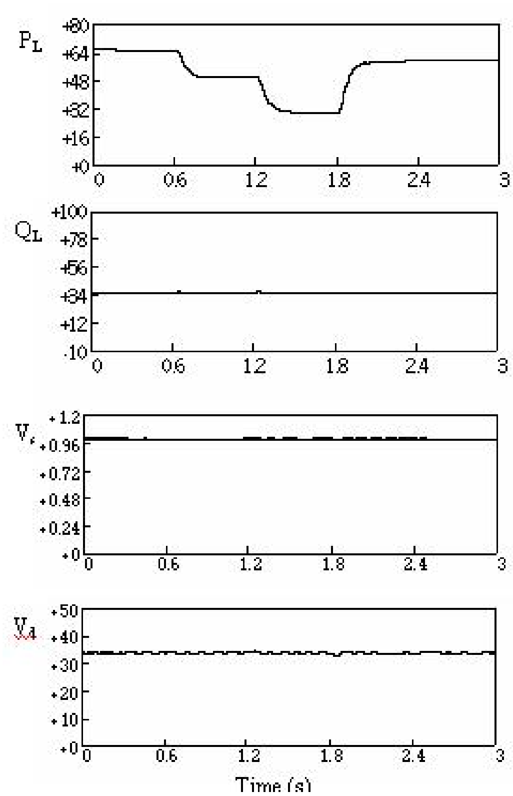

Figure 6. Simulation of changing real power

3.3 SIMULATION FOR TRANSMISSION REACTIVE POWER REGULATING

The objective of this simulation is to regulate the transmission line reactive power but maintain the real power, bus voltage and dc capacitor voltage at constant. Set the reactive power Q_L as 35.8Mvar, 25Mvar, 15Mvar and 30Mvar at 0.0s, 0.6s, 1.2s and 1.8s, and the corresponding power flow, bus voltage and dc capacitor voltage shown in Fig 7.

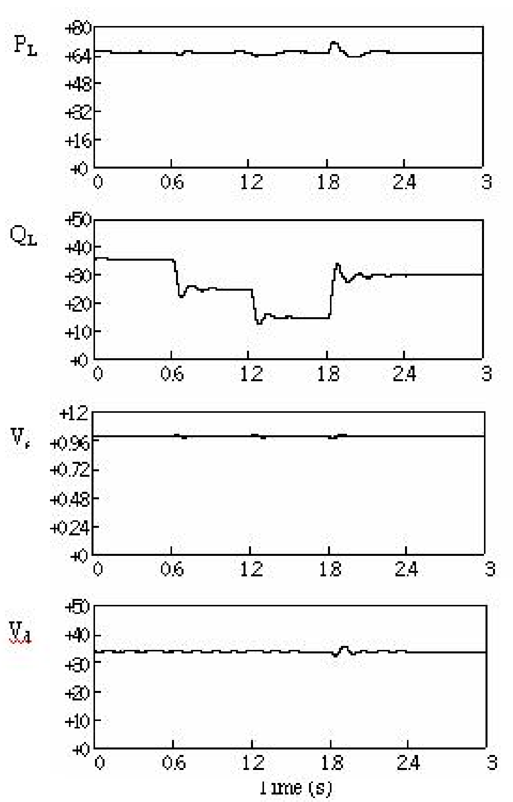

Figure 7. Simulation of changing reactive power

As the similar fashion to the transmission real power regulating, when change the transmission line reactive power only, it can reach the new steady-state in 0.3s, and this impacts on transmission line real power, bus voltage and dc capacitor voltage very slightly.

The aforementioned simulation results shown that, UPFC can regulate the power flow and the bus voltage rapidly and effectively, when there is acute power flow fluctuations, it need 0.3s to approach to the new steady-state, and the variations of transmission line power flow have very little impacts on the dc capacitor voltage and bus voltage.

3.4 TRANSIENT SIMULATION FOR SINGLE-PHASE GROUNDING FAULT

The objective of this simulation is to observe the capability of the UPFC to maintain the transmission real power and reactive power and to diminish the falloff of the bus voltage when there is a grounding fault in the transmission line.
In this simulation, as shown in Fig 1, c phase is connected to the ground in the line of L_2 at 1.0s, and the duration of the fault is 0.5s. Fig 8 displays both of the corresponding transmission line power flow and the bus voltage with and without UPFC.

When there has no the UPFC, the transmission real power from 65.8MW fall down to 52MW, the losses of real power is about 21%; the reactive power fall from 35.8Mvar down to 14Mvar, the losses of reactive power amount to 61%; bus voltage from 1.03p.u. full down to 0.88p.u., the losses of bus voltage is about 15%. While with UPFC, the real power fall from 65.8MW to 63MW, the losses is only 4%; the reactive power step from 35.8Mvar up to 40Mvar, the bias of reactive is 11%; the bus voltage fall from 1.0p.u. to 0.98p.u.. According to the foregoing phenomena, we can see that, UPFC can not only enhance the transient statability, but also diminish the low down of the voltage, and improve the dynamic power quality.

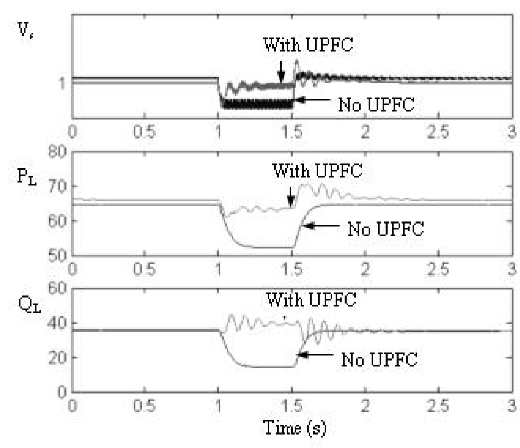

Figure 8. Load flow and bus voltage after a c-grounding fault

3.5 TRANSIENT SIMULATION FOR THE TRANSMISSION POWER OSCILLATION

The objective of this simulation is to observe the capability of UPFC to damp the power oscillation.

In Fig 9, the transmission line real power oscillated with 2Hz frequency. If without UPFC, the magnitude of the fluctuations of the real power is ±10MW, while with UPFC the fluctuation magnitude is decreased to ±3MW. So that, UPFC can damps the transmission line power oscillation effectively.

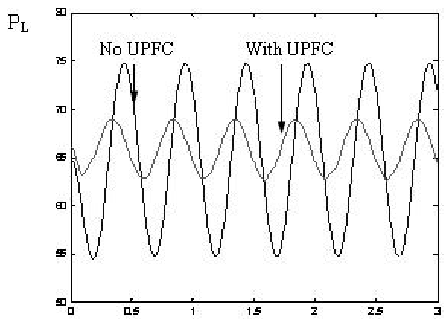

Figure 9. oscillation of the active power with and without UPFC

4. CONCLUSIONS

1) This paper made the power flow regulating, power oscillation damping and bus voltage maintaining simulations, the simulation results shows the UPFC implemented in this paper can enhance transient stability, control the power flow, maintain the bus voltage and damp the oscillation rapidly and effectively, so that can improve the dynamic power quality obviously.
2) Lots of simulation results shown that whether or not the UPFC can regulate power flow and bus voltage rapidly and effectively, depends on the designing of the control strategy and the control parameters of the UPFC controller, although UPFC is the so-called most powerful FACTS equipment. The improperly choice control strategy and control parameters will result in the breakdown of the power system, other than improve the stability of the power system.

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