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The use of Facts devices in disturbed Power Systems-Modeling, Interface, and Case Study

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***Abstract*— This paper describes the theory and simulation by matlab of flexible Alternative Current Transmission Systems (FACTS) devices used in the disturbed power systems. One of these devices, Unified Power Flow Controller (UPFC) will be chosen for a specific application, detailed in this paper.**

Simulation investigate the effect of UPFC on the voltage of the related bus, it's also considers the effect on the amount active and reactive power flowing through the transmission system.

Finally simulation results have been presented to indicate the improvement in the performance of the UPFC to control voltage in disturbed power systems.

***Index Terms*— Facts, UPFC, Power Systems, disturbances, Interface, Modelling, Controls.**

I. Introduction

The power electronic based flexible AC transmission systems (FACTS) have been developed and used as economical and efficient means to control the power transfer in the interconnected AC transmission systems [1]. This allows forcing the power transit in the lines with higher transmission capacity [2], [3].

Among the FACTS components, Unified Power Flow Controller (UPFC), is the most complete. It is able to control independently the throughput active and reactive powers. The UPFC is capable to act over three basic electrical system parameters [4]: line voltage, line impedance, and phase angle, which determine the transmitted power.

Power Flow through an alternative current line is a function of the line impedance, the magnitude of the sending-end and receiving-end voltage and the phase angle between these voltages [4]. The power flow can be increased, firstly by decreasing the line impedance with a capacitive reactance, secondly by increasing the voltages and finally by increasing the phase angle between these voltages.

In our work, the power flow is controlled by controlling the sending and receiving bus voltage.

Also, the control of the shunt and series element of the UPFC will be studied in this paper.

II. Types of Facts Devices

The types of FACTS devices currently available can be categorized into devices that control certain electrical parameters. For example the UPFC can used to control active and reactive line flows (P, Q).

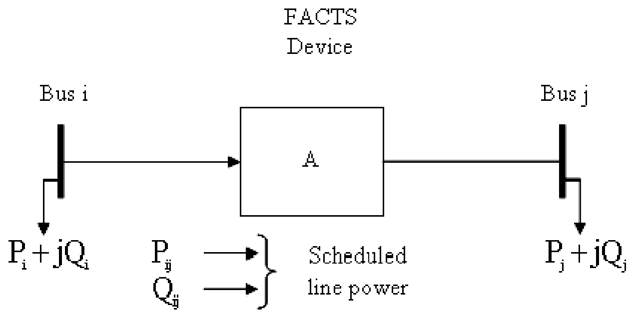
The phase angle regulator type can be used to control active power flow.

Table (1) lists the several types of existing and proposed FACTS devices. These types are termed A, B, and C here for convenience. [5]

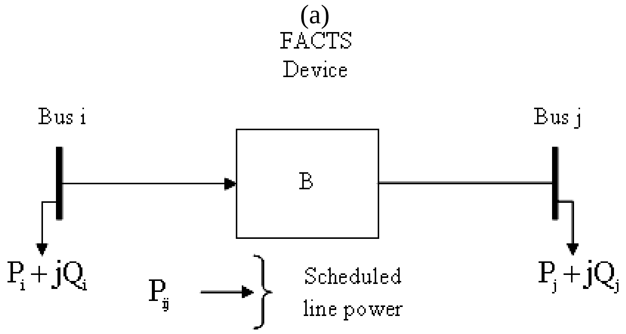
Table I: Types of FACTS device models

Type designation	Parameter controlled	FACTS devices
Type A	Series P and Q	UPFC
Type B	Series P	TCSC, phase angle regulator
Type C	Series Q	SVC, STATCON

These figures show types (a), (b), and (c) FACTS devices

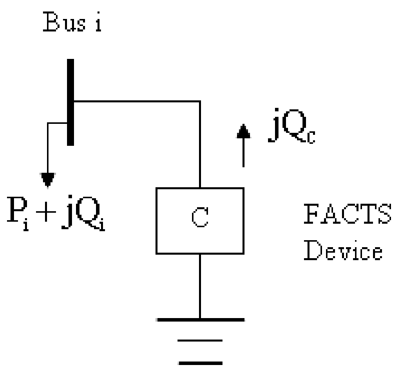


(a)



(b)

Mechanic's Department Skikda University
Electro mechanic's Department Annaba University
Electronics Department Annaba University.



(c)

Fig. 1 Models of a Type (a), (b), and (c) FACTS devices

III. UNIFIED POWER FLOW (UPFC) CONCEPT

The UPFC configuration is shown in fig2.

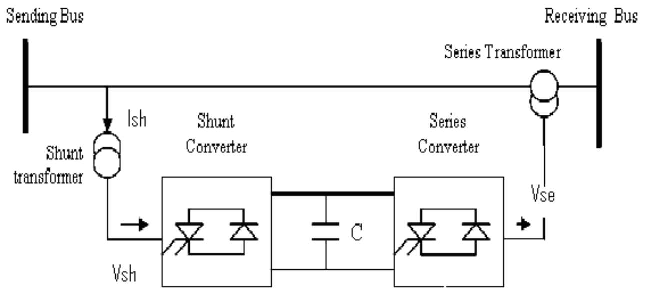


Fig.2 Basic Structure of an UPFC

It can be seen. That the UPFC consists of a series and a shunt converter is connected back-to-back through a common dc link. The shunt converter is connected also in parallel with the line transmission by transformer, allows controls the UPFC bus Voltage/shunt reactive power and the dc capacitor voltage [6].

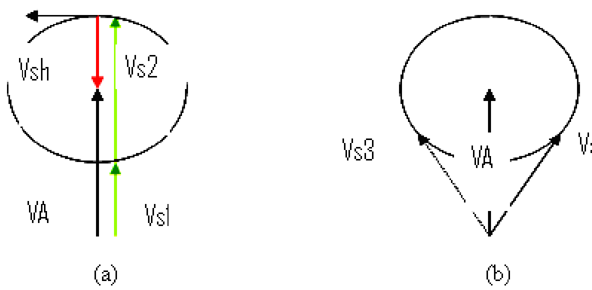


Fig.3. Power exchange of the Shunt Converter

Figure 3a shows the exchange of the reactive power between the UPFC and the electrical system. The shunt converter generates a voltage Vs1 in phase with VA but with variable magnitude. If Vs=Vs1. The UPFC injects some reactive power, if Vs=Vs2 the UPFC absorbs some reactive power and no reactive power is exchanged for Vs=VA. [7].

In order to compensate the series converter losses, figure 3b shows very clearly. That the active power is exchanged between UPFC and the electrical system. The Voltage generated by shunt converter is no it in phase with the voltage of the system but of the same magnitude [7]. Whereas the series converter of the UPFC controls the transmission line real/reactive power flows by injecting a series voltage of adjustable magnitude and phase angle. The UPFC can provide multiple power flow control functions by adding the injected voltage phasor with appropriate magnitude Vse and phase angle Ө to the sending-end-voltage phasor [8].

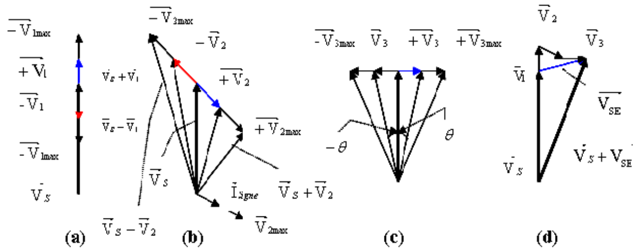


Fig. 4 Series Voltage Injected Phasor diagrams.

As illustrate in figure 4, by the appropriate choice (control) of phasor Vse, the three customary power flow control functions:

1) Voltage regulation
2) Series reactive compensation.
3) Phase Shift.

Simultaneous control of terminal voltage, line impedance and phase angle allows the UPFC to perform multifunctional power flow control.

IV. UPFC MATHEMATICAL MODEL

In order to simulate a power system that contains a UPFC, the UPFC needs to be modelled. Fig shows a diagram for UPFC; all the variables used in UPFC model are denoted in fig with bold fonts representing phasors [9].

Per unit system and MKS units are jointly used in modelling. The ac system uses par unit system with its variables calculated based on the system-side SB and VB, while the dc variables are expressed in MKS units. We first consider the UPFC dc link capacitor charging dynamics.

The current Id1, Id2 (see fig .5.) and the capacitor voltage and current have the following relation with harmonics neglected [10]:

$$I_d = C\frac{dV_d}{dt}$$

$$I_d = I_{d1} + I_{d2} \quad (1)$$

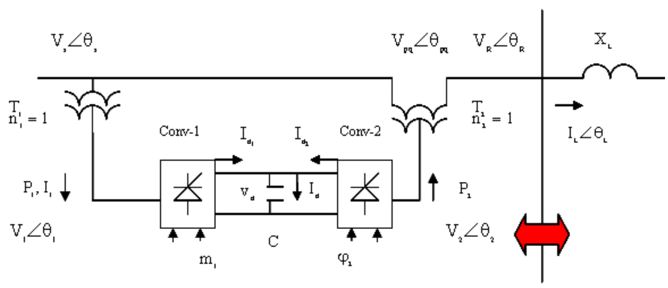


Fig. 5 Transmission line with UPFC installed

If we assume the inverters are ideal, the real power exchange with the ac system will be (P_1 and P_2 are in p.u.):

$$P_1 = \frac{V_d I_{d1}}{S_B}$$

$$P_2 = -\frac{V_d I_{d2}}{S_B} \quad (2)$$

From equation (1) and (2), we have:

$$CC_d = -\frac{dV_d}{dt}(P_1 - P_2)S_B \quad (3)$$

From ac system, we know that P_1 and P_2 calculated by:

$$\mathbf{P_1} = \mathbf{R_e}\left(V_1 I_1^*\right) = \mathbf{R_e}\left(V_1\left(\frac{n_1 V_s - V_1}{jX_{t1}}\right)^*\right) \quad (4)$$

$$\mathbf{P_2} = \mathbf{R_e}\left(V_{pq} I_L^*\right) = \mathbf{R_e}\left(V_{pq}\left(\frac{V_S + V_{pq} - V_R}{jX_{t2}}\right)^*\right)$$

Applying modern PWM control technique [10] two the two voltage source converters, the relations between the inverter dc-and ac-side voltages can be expressed by:

$$V_1 = m_1 \frac{V_d}{V_B}$$

$$V_2 = m_2 \frac{V_d}{V_B} \quad (5)$$

Where coefficient m_1 and m_2 represent the PWM control effects in order to maintain desired inverter ac-side voltages V_1 and V_2 respectively. The desired m_1 and m_2 are UPFC main control outputs. V_1 and V_2 are in p.u. and V_B is the ac system base voltage.

The phase angle of (V_1) and (V_2) are denoted as (Θ_1) and (Θ_2) respectively. They are controlled through firing angle (φ_1) and (φ_2) of two converters:

$$\theta_1 = \theta_s - \varphi_1$$
$$\theta_2 = \theta_s - \varphi_2 \quad (6)$$

The desired φ_1 and φ_2 are UPFC main control outputs.

Finally, taking series transformer ratio into consideration, and rewriting equations (1) to (6), the UPFC power frequency model used in dynamic study will be:

$$CV_d = -\frac{dV_d}{dt}(P_1 - P_2)S_B \quad (7)$$

Where:

$$\mathbf{P_1} = \mathbf{R_e}\left(V_1\left(\frac{n_1 V_s - V_1}{jX_{t1}}\right)^*\right)$$

$$\mathbf{P_2} = \mathbf{R_e}\left(V_{pq}\left(\frac{V_S + V_{pq} - V_R}{jX_{t2}}\right)^*\right) \quad (8)$$

$$V_1 = m_1 \frac{V_d}{V_B}$$

$$\theta_1 = \theta_s - \varphi_1 \quad (9)$$

$$V_{pq} = m_2 \frac{V_d}{V_B / n_2}$$

$$\theta_{pq} = \theta_s - \varphi_2$$

The desired m_1, φ_1, m_2 ***and*** φ_2 can be obtained from UPFC main control system, therefore based on equation (9) together with UPFC control system equations and ac network interface equation.

V. INTERFACE OF UPFC TO THE AC NETWORK

The interface calculation of UPFC to ac network will have significant impacts on transient stability [10].

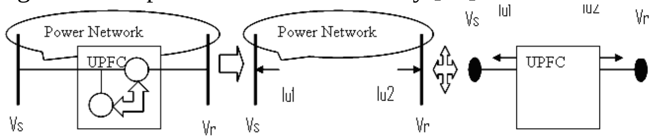


Fig. 6 The Interface of the UPFC to the network

In the interface calculation we assume that the bus admittance matrix has been reduced to generator internal buses with UPFC ac terminal buses remained. The corresponding reduced bus admittance matrix takes the form:

$$\begin{bmatrix} \mathbf{Y}_{GG} & Y_{GU} \\ Y_{UG} & Y_{UU} \end{bmatrix} \begin{bmatrix} E_G \\ V_U \end{bmatrix} = \begin{bmatrix} I_G \\ I_U \end{bmatrix} \quad (10)$$

Where:

E_G : Generator internal voltage.

I_G : Generator internal voltage.

V_U : ac terminal bus voltages of the UPFC.

The UPFC currents injecting to the ac network can be expressed by:

$$I_{U_1} = -\frac{n_1 V_S - V_1}{jX_{t_1}} n_1 - \frac{V_S + Vpq - V_R}{jX_{t_2}} \quad (11)$$

$$I_{U_2} = \frac{V_S + Vpq - V_R}{jX_{t_2}}$$

It is clear that in equation (11), though the UPFC output voltage magnitudes V_1 and V_{pq} can be known from control output and equation (3), (4), and (9).

The phase angles of V_1 and V_{pq} are unknown since they depend on the phase angle of V_s. the phase angle of V_s is unknown that should be obtained from the network solution. Therefore an iteration approach is required to obtain the network solution.

Substituting equation (11) into equation (10), and rearranging the second equation of equation (10), we finally have:

$$I_{1G}+I_{2G}+\left(Y_{SS}+Y_{RS}+\frac{n_1^2}{jx_{t_1}}\right)V_S+\left(Y_{SR}+Y_{RR}\right)V_R=\frac{n_1}{jx_{t1}}V_1$$

$$I_{2G}+\left(Y_{RS}-\frac{1}{jx_{t_2}}\right)V_S+\left(Y_{RR}+\frac{1}{jx_{t2}}\right)V_R=\frac{1}{jx_{t2}}V_{pq} \qquad (12)$$

Where:

$$\begin{bmatrix} Y_{SS} Y_{SR} \\ Y_{RS} Y_{RR} \end{bmatrix} = Y_{UU} \text{and} \begin{bmatrix} I_{1G} \\ I_{2G} \end{bmatrix} = Y_{UG}\, E_G$$

If we define a constant matrix:

$$Y_{UU}=\begin{bmatrix} \left(Y_{SS}+Y_{RS}+\frac{n_1^2}{jx_{t1}}\right) & \left(Y_{SR}+Y_{RR}\right) \\ \left(Y_{RS}-\frac{1}{jx_{t2}}\right) & \left(Y_{RR}+\frac{1}{jx_{t2}}\right) \end{bmatrix}$$

$$I_U=\begin{bmatrix} \frac{n_1}{jx_{t1}}V_1-\left(I_{1G}+I_{2G}\right) \\ \frac{1}{jx_{t2}}V_{pq}-I_{2G} \end{bmatrix} \qquad (13)$$

We have:

$$Y_{UU}V_U = I_U \qquad (14)$$

The equations from (13) to (14) are used for iteration of UPFC network interface as follows:

A. STEP 1:

Estimates the initials voltages of sending and receiving buses and calculate current based in equations (13) and (9).

B .STEP 2:

Solve equation (14) for difference of the initials voltages values. If the difference is less than the given tolerance for new value of sending and receiving voltages are considered as the solution of equation (12). Otherwise go to step 3.

C. STEP 3:

Update initial voltages and repeat steps 1 and 2 till convergence is reached.

VI. CASE STUDY

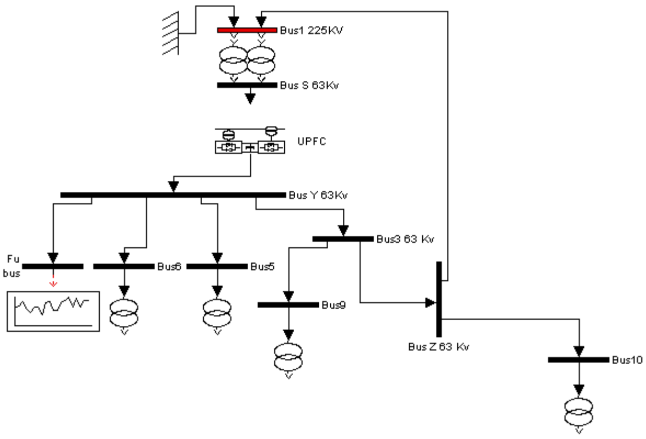


Fig.7 the Algerian ELHadjar’s Complex Power System.

A. Disturbances Simulation

The simulated system is an MV Electrical Network of EL-Hadjar Steel-making complex in Algeria. The system is shown in Fig.7. This latter functions with a lot such problems: Flicker, Harmonics and Asymmetric currents. These latters are due to the presence of furnaces in the complex.

To simulate the effect of the UPFC on power system, we have used Matlab. The UPFC was installed between buses (S) and (Y), and the shunt branch was connected to the bus S. the effect of the series branch of the UPFC on the transmission power between buses (S) and (Y).

First of all, we have to choose the references:

- Voltage in buses (S) and (Y): V= 1 p.u.
- Real and reactive Power in furnace bus:

P=0.8 p.u./Q=0.6 p.u.

To the instant t=2s, we changed the references in furnace Bus, so that they become: P=0.2 p.u./Q=1.2 p.u.

Then, to the instant t=3s we put back the initial references.

VII. SIMULATION RESULTS

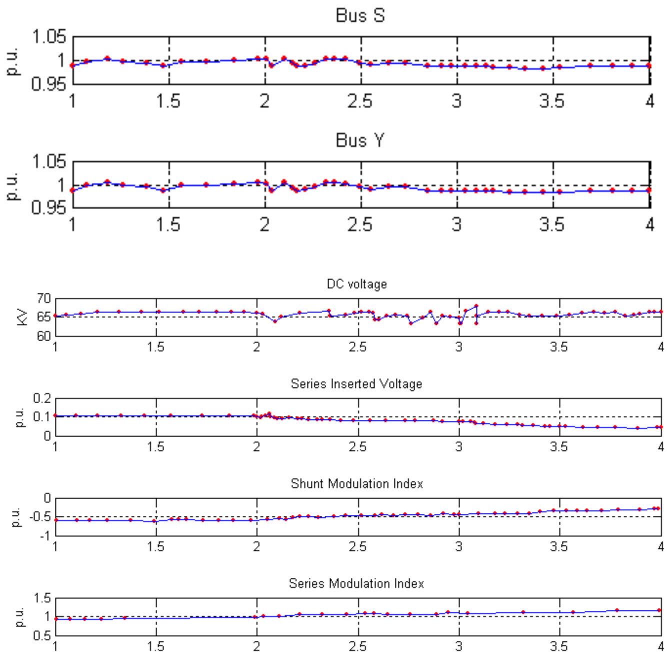


Fig. 8 Disturbances simulation results

We notice that the voltages at buses (Y) and (S) follow their order even the disturbances that happened at furnace buses.

VIII. CONCLUSION

In this paper, the compensation of an electrical system by using UPFC-FACTS device has been studied.

Two important coordination problems have been addressed in this paper related to UPFC control. One, the problem of real power coordination between the series and the shunt converter control system. Second, the problem of excessive UPFC bus voltage excursions during reactive power transfers requiring reactive power coordination.

The simulation results, obtained by Matlab show the efficiency of UPFC, in controlling line both active and reactive power flow.

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