Improvement of Parametric Variations Impact on the Performances of a UPFC System using a Decoupled Fuzzy Controller

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Abstract-**The instability problem in power system is of great importance in current studies. The static synchronous series compensator (UPFC) (Unified Power Flow Controller) is a FACTS device (Flexible Alternative Current Transmission Systems) for the stabilization of power systems with high efficiency. In this paper, we examine the performance of the UPFC device equipped first with a classical PI-D regulator, then with a FLC-D regulator. The static synchronous series compensator should be first stabilized. The results obtained with the regulator FLC-D are better than those obtained with classical control**

Mot clé : UPFC, PI-D , FLC-D. Improvement

I.INTRODUCTION [1][3][9]

The recent development of FACTS devices opens up new prospects for more effective use of networks by continuous and rapid action on the various parameters of the network (voltage, impedance…). Thus, the power flow will be better controlled and tensions better maintained, thus increasing the magnitude of nodal voltages or decrease losses in the lines. The UPFC (Unified Power Flow Controller) is a recent system FACTS device, which is capable of controlling the different parameters of the transmission line. It does not only accomplish the functions of STATCOM, SSSC, but also offers additional flexibility by combining some functions of these controllers.

II. STRUCTURE OF THE UNIVERSAL LOAD VARIATOR (UPFC) [2] [6] [7]

The UPFC consists of two transformers T_1 and T_2 used to provide galvanic isolation and adjust the voltage levels in the supply system. It is composed of two inverters with PWM control (Pulse Width Modulation), which are connected through a common continuous circuit. One is connected in parallel and the other in series with the transmission line, as illustrated by figure 1.

It is supposed that each inverter consists of six thyristors (GTO : Gate-Turn-Off) with corresponding anti -parallel diodes.

III. OPERATING PRINCIPLES OF THE UPFC

The UPFC is connected in a simplified transmission system as shown in Figure 1. It's installed at the end of the transmission line to which it's connected through the two transformers T1 and T2. In Figure 1, the voltages V_s and V_r represent respectively the sources of three-phase sinusoidal voltage of the transmission line departure and arrival. The UPFC consists of two inverters controlled PWM (Pulse Width Modulation) placed back-to-back and connected to a capacitor. The series inverter provides the compensation voltage V_c across the transformer series T_2 , while the parallel or shunt inverter provides or absorbs reactive power and active power demanded by the series inverter and regulates the voltage V_{dc} at the capacitor level. The active and reactive power are generated and absorbed independently by each inverter.

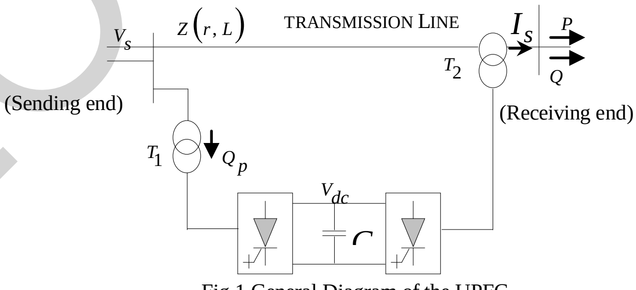


Fig 1.General Diagram of the UPFC

IV. MODELING OF UPFC [2] [3] [4]

The modelling process has enabled us to put in equations the different parameters of different parts of the system and allowed us to have according to PARK a suitable model, where we can show the parameters of such an appropriate setting.

The simplified circuit of the control system and UPFC compensation is shown in Figure 2.

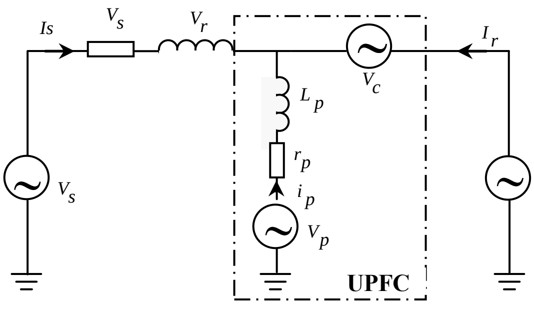


Fig. 2. Equivalent circuit of the UPFC

The dynamic equations of the UPFC are divided into three systems of equations: equations of the branch series, equations of the parallel branch and those of the circuit of D.C. current.
By applying Kirchhoff's laws we have the following equations for each branch.

A. MODELING OF SERIES BRANCH:

It is supposed that the inverters series and shunt are ideal controllable voltage sources.
Thus, from Figure .2, we can deduce the system of equation (1).
By applying Kirchhoff's laws on the UPFC series of Figure .2, we have the following equation

$$V_s - ri_s - L\frac{di_s}{dt} - V_c - V_r = 0$$
$$-ri_s - L\frac{di_s}{dt} = V_c + V_r - V_s$$
$$L\frac{di_s}{dt} = -ri_s + V_s - V_c - V_r$$

Where:

$$\frac{di_s}{dt} = -\frac{r}{L}i_s + \frac{1}{L}(V_s - V_c - V_r) \qquad (1)$$

We can write for the three phases:

$$\begin{cases} \dfrac{di_{sa}}{dt} = -\dfrac{r}{L}i_{sa} + \dfrac{1}{L}(V_{sa} - V_{ca} - V_{ra}) \\ \dfrac{di_{sb}}{dt} = -\dfrac{r}{L}i_{sb} + \dfrac{1}{L}(V_{sb} - V_{cb} - V_{rb}) \\ \dfrac{di_{sc}}{dt} = -\dfrac{r}{L}i_{sc} + \dfrac{1}{L}(V_{sc} - V_{cc} - V_{rc}) \end{cases} \qquad (2)$$

Where i_{sa}, i_{sb} and i_{sc} are the phase currents of the transmission line, r and L are respectively its resistance and inductance.

To simplify the calculations, the impedance transformer T_2 has been neglected. The series inverter generates the compensation voltage V_c at the arrival of the transmission line.

- TENSIONS OF COMPENSATION SERIES

The system of equation (2) can be rewritten by the expression:

$$\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \begin{bmatrix} r+s.L & 0 & 0 \\ 0 & r+s.L & 0 \\ 0 & 0 & r+s.L \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} + \begin{bmatrix} V_{ca}+V_{ra} \\ V_{cb}+V_{rb} \\ V_{cc}+V_{rc} \end{bmatrix} \qquad (3)$$

Or in matrix form:

$$[Vs_{abc}] = [r].[i_s] + [L].s.[i_s] + [Vc_{abc}] + [Vr_{abc}] \qquad (4)$$

Where V_{ca}, V_{cb} and V_{cc} are the series compensation voltages.
Using matrix representation on the axes a, b and c, the mathematical model of the UPFC can be described by the following equation:

$$\frac{d}{dt}\begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} = \begin{bmatrix} -r/l & 0 & 0 \\ 0 & -r/l & 0 \\ 0 & 0 & -r/l \end{bmatrix} . \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} + \frac{1}{L}\begin{bmatrix} V_{sa} - V_{ca} - V_{ra} \\ V_{sb} - V_{cb} - V_{rb} \\ V_{sc} - V_{cc} - V_{rc} \end{bmatrix} \qquad (5)$$

The voltage sources V_p and V_c represents respectively the series and shunt inverters of UPFC. The Park transformation of the three-phase currents i_{ra}, i_{rb} and i_{rc} and voltages V_{ra}, V_{rb}, and V_{rc} is given as follows:

$$\begin{bmatrix} x_d \\ x_q \\ x_o \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\omega t & \cos(\omega t - 2\pi/3) & \cos(\omega t - 4) \\ -\sin\omega t & -\sin(\omega t - 2\pi/3) & -\sin(\omega t - 4) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} \qquad (6)$$

Where x can either be a voltage or a current.

In our case, the x_o component is negligible because the power system is assumed symmetric. After the Park transformation, and considering the simplifying assumptions, the three voltages $V_{s\,abc}$ are given by the following matrix:

$$\begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} = \sqrt{\frac{2}{3}} V_s \begin{bmatrix} \cos\omega t \\ \cos(\omega t - 2\pi/3) \\ \cos(\omega t - 4\pi/3) \end{bmatrix} \qquad (7)$$

Where V_s is the voltage rms value.

Applying the Park transformation to the source voltages V_s and V_r leads to the following equation:

$$\frac{di_{sd}}{dt} = \omega i_{sq} - \frac{r}{L}i_{sd} + \frac{1}{L}(V_{sd} - V_{cd} - V_{rd}) \qquad (8)$$

$$\frac{di_{sq}}{dt} = -\omega i_{sd} - \frac{r}{L}i_{sq} + \frac{1}{L}(V_{sq} - V_{cq} - V_{rq}) \qquad (9)$$

The dq axis matrix form can be rewritten in the following form:

$$\frac{d}{dt}\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} = \begin{bmatrix} -r/L & \omega \\ -\omega & -r/L \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} + \frac{1}{L}\begin{bmatrix} V_{sd} - V_{cd} - V_{rd} \\ V_{sq} - V_{cq} - V_{rq} \end{bmatrix} \qquad (10)$$

The block diagram that can be adopted for the simulation of the transmission line with the series part of UPFC system according to reference mark X is given in figure 3.

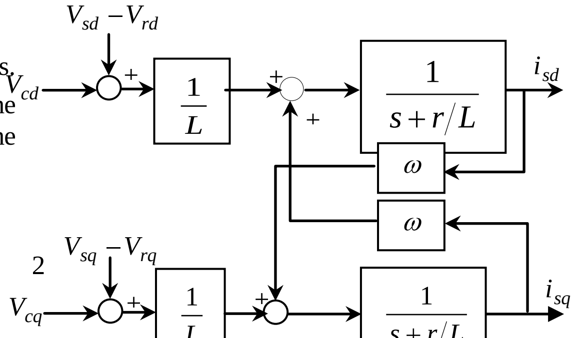


Fig. 3.Mathematical model of the UPFC series

Where

$$P_e = V_{ca}.i_{ra} + V_{cb}.i_{rb} + V_{cc}.i_{rc} \quad (11)$$

$$P_{ep} = V_{pa} i_{pa} + V_{pb} i_{pb} + V_{pc} i_{pc} \quad (12)$$

whith

P_e : The active power consumption of AC system

P_{ep} : The active power injected by the shunt inverter in AC system.

By applying the Park transformation, equation (5) to the equation (11), we obtain :

$$\frac{dV_{dc}}{dt} = \frac{3}{2.C \cdot V_{dc}}.\left(V_{pd}.i_{pd} + V_{pq}.i_{pq} - V_{cd}.i_{rd} + V_{cq}.i_{rq}\right) \quad (13)$$

The series and shunt UPFC are identical in every way. The controls used for the series inverter are the same as for the shunt inverter.

For the control application, the active and reactive power references (P^* et Q^*) are injected (used as inputs at the control system of UPFC) so to obtain the desired actual power P and Q. From equations (11) and (12), reference currents i_d^* and i_q^* can be calculated as follows:

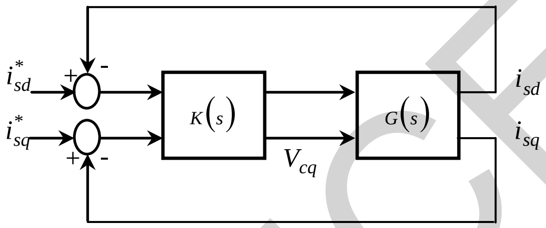


Fig4. Configuration of adjustment of the UPFC

$$i^*_{sd} = \frac{2}{3}\left(\frac{P^*.V_{sd} - Q^*.V_{sq}}{\Delta}\right) \quad (14)$$

$$i^*_{sq} = \frac{2}{3}\left(\frac{P^*.V_{sq} + Q^*.V_{sd}}{\Delta}\right) \quad (15)$$

Où :

$$\Delta = V_{rd}{}^2 + V_{rq}{}^2 \quad (16)$$

VI. UPFC ADJUSTMENT

Figure 8 represents the series UPFC control, $G(s)$ is the transfer function of the transmission line determined by:

$$G(s) = \frac{1}{s + r/L} \quad (17)$$

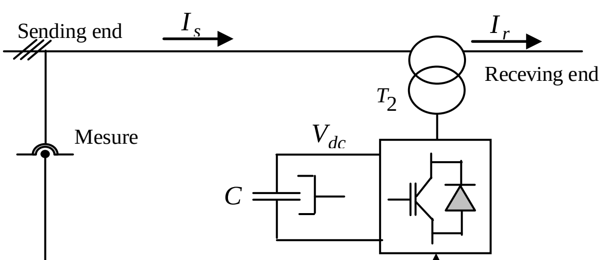


Fig. 8. Diagram of the series UPFC PI-D adjustment structure.

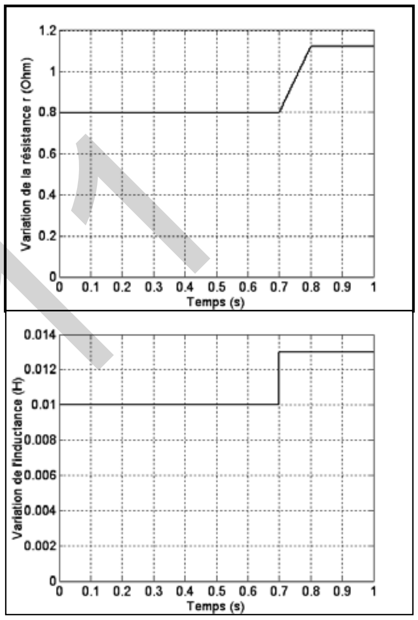


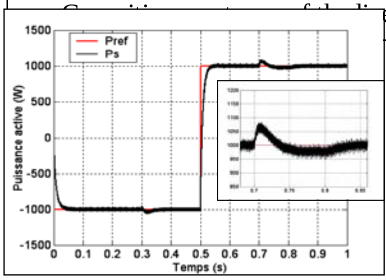
Figure 6: Resistance graduated variation between (t = 0.7s-0.8s) inductance step variation at t = 0.7s

V. SIMULATION RESULTS

After having carried out the synthesis of the regulator with classic and fuzzy logic, a transmission line of a simple power system with parameters given in Table 2 is simulated.

Table2. System parameters

Voltage of network	V_s =220V
Voltage of loads	V_r =220V
DC link voltage	V_{dc} =280V
Frequency	f =50 Hz
Resistance of the line (serie)	r =0.8 Ω
Resistance of the line (shunt)	r_p =0.4 Ω
Inductive reactance of the line (serie)	L =10 mH
Inductive reactance of the line(shunt)	L_p =10 mH
[illegible]	C =200 μF



(a) Results from the active power

From these figures, we can see that an increase in the line resistance has a remarkable influence on the quality of the response of active and reactive powers, the direct and quadrature current, and the phase currents.

These figures show also that the parametric variations have a remarkable influence on the performance of the UPFC adjustment system based on classical PI-D regulators.

Fuzzy regulator principle [1] [2]

The structure of the adaptive fuzzy controller that we propose here uses a solution that was applied to the UPFC nonlinear model.. The aim is to reduce the complexity of the regulator, while keeping, a high level of static and dynamic performance of the process whose modeling is difficult or its parameters are inaccessible.

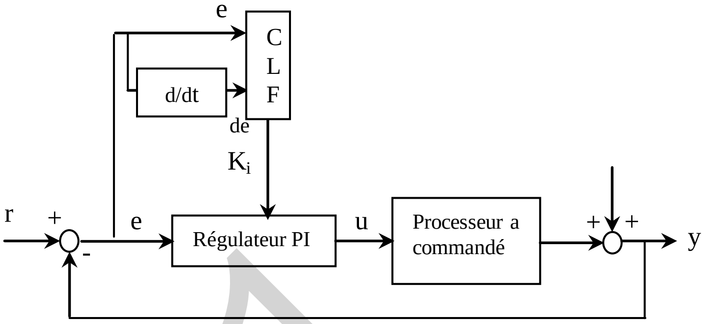
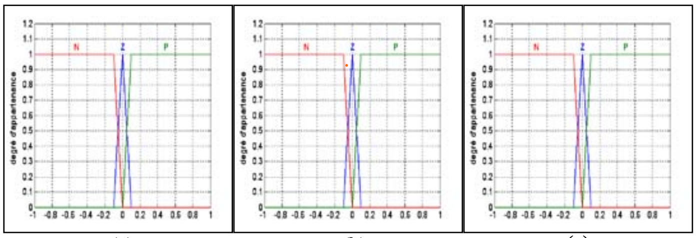


Figure 8 : Structure of fuzzy controller

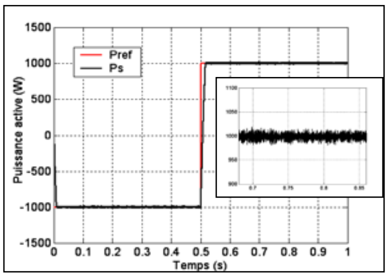
Table 1: FLC Rules

$\Delta\tilde{e}$ \ $\tilde{e}$	**NG**	**EZ**	**PG**
NG	NG	NG	EZ
EZ	NG	EZ	PG
PG	EZ	PG	PG

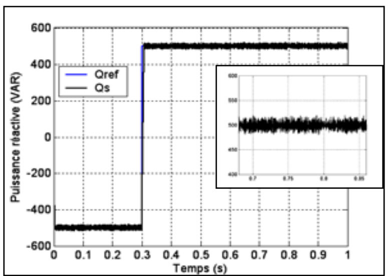


(a) (b) (c)

Figure 9: Fuzzy controller Input and output membership functions



(a) Results from the active power



It is clearly visible that the fuzzy control is more robust with comparison to the classical control. She provides a perfect tracking of the reference value in spite of the important variation that each parameter is subjected, and provides a good disturbance rejection.

VI CONCLUSION

In this paper, we tried to evaluate the performance of controllers based on the realization of fuzzy logic techniques. We began this evaluation by using a fuzzy controller, whose results are very satisfactory and the dynamics are improved compared to the classical controller shown above, which leads us to conclude that the fuzzy controllers give good performances, namely:

- A quick response to any variation in the input reference value
- A total absence of tolerance
- A perfect rejection of disturbances
- A zero static error

Fuzzy control allows the use of linguistic knowledge and possesses a wealth of possibility concerning the membership functions shape, fuzzification and défuzzification type as well as the inference type. The solution which we proposed is not unique.

The integration of fuzzy controller gave an improvement of the dynamic performances for the transient mode and decoupling was maintained.

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