

Optimization of an UPFC by using PSO Algorithm for Compensation the Reactive Power in the Electrical Grid

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Abstract— UPFC is an abbreviation of United Power Flow Controller. It is a typical FACTS (Flexible AC Transmission Systems) device that is capable of instantaneous control of transmission line parameters. This paper presents an optimization of UPFC for the compensation of the reactive power in grid system. The presented control system has the fast dynamic reaction and so is adequate for improving transient performance of power system. The presented simulation results demonstrate that the presented control acts properly in the steady and transient states. It is shown that by adding a supplementary optimization of the PIDs controllers by Particle Swarm Optimization (PSO) technique the height performing rejection parameters control when compared to conventional method design for tuning gains values of controllers.

Keywords— FACTS, UPFC, Power Flow, Grid System, Decoupled P-I, PSO.

I. INTRODUCTION

The elevated evaluation power electronic equipments have made it possible to consider new technologies such as FACTS for power flow control, secure loading and damping of power system oscillations [1]. UPFC enable to control the line voltage, impedance and phase angle with dynamic compensation of AC power system [2]. UPFC can full the functions of STATCOM (Static Compensator) [3], SSSC (Static Synchronous Series Compensator) [4] and phase shifter meeting many controls [2]. UPFC contains two "back to back" converters with a common DC link (Fig.1). The transmission line flows through series converter and for that reason; it exchanges the active and reactive power with the AC system. Since the converters are connected to a common DC link, they exchange only active power and there is no reactive power flow between them. Generally, this structure enables voltage control by the shunt inverter and independent active and reactive power flow control by the series inverter. In order to improve the interaction between the active and reactive power control, a so called decoupled P-I control based on $d-q$ axis theory was used [5]. Also, the conventional PID algorithm is the most popular feedbacks controllers used within the process industries. It is robust easily understood algorithm that can provide excellent control performance despite the varied dynamic characteristics of process plant. But the tuning of the PID controller parameters is not easy and does not give the optimal required response, especially with non-linear systems. In the last years emerged several new intelligent optimization techniques like PSO are anticipated to solve these problems.

This paper presents a complete UPFC model with closed loops PID. The presented control system is capable of controlling the line active and reactive power flows, regulation of the bus voltage and transient behavior enhancement of power system after a transient condition. The conventional methods of tuning PID controllers are represented as a point of comparison. The intelligent PSO technique is proposed on behalf of tuning the PID controllers. The simulation results show the performance and success of the presented control strategy.

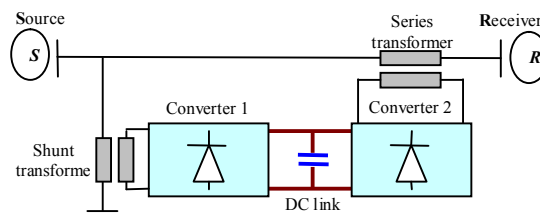


Fig. 1. General configuration of UPFC.

II. DETAILED MODEL OF UPFC

UPFC also called universal variable load, is one of the best performing components FACTS. In order to study the behavior of the system and synthesis of control laws it is necessary to establish an adequate model of the device. Modelling we allowed the presentation and simplification of the equations to address the control of our system in the coordinate of Park [6]. At the end we will develop a single setting by PI controller [7]. Circuit diagram of the control system and compensation UPFC is shown in Fig. 2 [8].

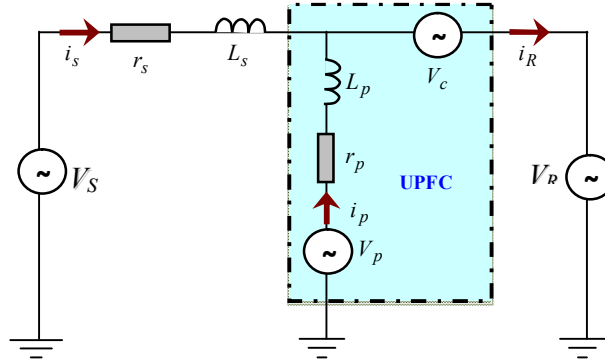


Fig. 2 Single phase equivalent UPFC system

The dynamic equations of the UPFC are divided into three sets of equations: Equations of the series branch, equations of the parallel branch and those of the direct current circuit.

A) Control System of Series Inverter

It assumes that the series and shunt inverters are ideal controllable voltage sources. So, from Fig. 2 we can deduce the equation system (1), (2):

$$V_S - r i_s - L \frac{di_s}{dt} - V_c - V_R = 0 \quad (1)$$

$$L \frac{di_s}{dt} = -r i_s + V_S - V_c - V_R \quad (2)$$

It can write for all three:

$$\begin{cases} \frac{di_{sa}}{dt} = -\frac{r}{L} i_{sa} + \frac{1}{L} (V_{sa} - V_{ca} - V_{Ra}) \\ \frac{di_{sb}}{dt} = -\frac{r}{L} i_{sb} + \frac{1}{L} (V_{sb} - V_{cb} - V_{Rb}) \\ \frac{di_{sc}}{dt} = -\frac{r}{L} i_{sc} + \frac{1}{L} (V_{sc} - V_{cc} - V_{Rc}) \end{cases} \quad (3)$$

Series inverter generates the compensation voltage V_c to the arrival of the transmission line. Equation (3) can be rewritten by the expression (4)

$$\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \begin{bmatrix} r+s.L & 0 & 0 \\ 0 & r+s.L & 0 \\ 0 & 0 & r+s.L \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} + \begin{bmatrix} V_{ca} + V_{Ra} \\ V_{cb} + V_{Rb} \\ V_{cc} + V_{Rc} \end{bmatrix} \quad (4)$$

By using the matrix representation of the system in a, b and c, axes the mathematical model of UPFC can be described by the following

$$\frac{d}{dt} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} = \begin{bmatrix} -r/L & 0 & 0 \\ 0 & -r/L & 0 \\ 0 & 0 & -r/L \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} + \frac{1}{L} \begin{bmatrix} V_{sa} - V_{ca} - V_{Ra} \\ V_{sb} - V_{cb} - V_{Rb} \\ V_{sc} - V_{cc} - V_{Rc} \end{bmatrix} \quad (5)$$

Park transformation of the phase currents $i_{R_a,b,c}$ and tension $V_{R_a,b,c}$ is given as follows.

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

x can be voltage or current. By applying Park transformation we gain the system

$$\frac{d}{dt} \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} = \begin{bmatrix} -r/L & \omega \\ -\omega & -r/L \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} + \frac{1}{L} \begin{bmatrix} V_{sd} - V_{cd} - V_{Rd} \\ V_{sq} - V_{cq} - V_{Rq} \end{bmatrix} \quad (7)$$

The block diagram that can be adopted for simulation of the transmission line with series part of UPFC by point of reference (d, q) of Park transformation is given by Fig. 3.

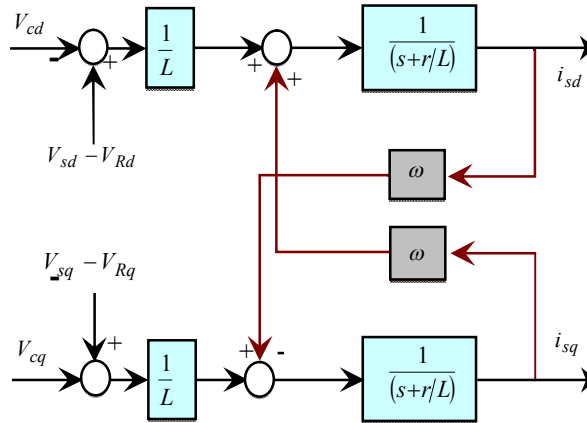


Fig. 3 Control system of series inverter

B) Control System of Shunt Inverter

The mathematical model of UPFC shunt can be written as follows:

$$\begin{cases} \frac{di_{pa}}{dt} = -\frac{r_p}{L_p} i_{pa} + \frac{1}{L} (V_{pa} - V_{ca} - V_{Ra}) \\ \frac{di_{pb}}{dt} = -\frac{r_p}{L} i_{pb} + \frac{1}{L} (V_{pb} - V_{cb} - V_{Rb}) \\ \frac{di_{pc}}{dt} = -\frac{r_p}{L} i_{pc} + \frac{1}{L} (V_{pc} - V_{cc} - V_{Rc}) \end{cases} \quad (8)$$

The system (8) can be rewritten in matrix form (9)

$$[V_{pabc}] = [r_p] [i_p] + [L_p] s [i_p] + [V_{cabc}] + [V_{Rabc}] \quad (9)$$

In the Park coordinate, we obtain the following transformation

$$\frac{d}{dt} \begin{bmatrix} i_{pd} \\ i_{pq} \end{bmatrix} = \begin{bmatrix} -r_p/L_p & \omega \\ -\omega & -r_p/L_p \end{bmatrix} \begin{bmatrix} i_{pd} \\ i_{pq} \end{bmatrix} + \frac{1}{L} \begin{bmatrix} V_{pd} - V_{cd} - V_{Rd} \\ V_{pq} - V_{cq} - V_{Rq} \end{bmatrix} \quad (10)$$

The shunt block diagram of UPFC is given in Fig. 4.

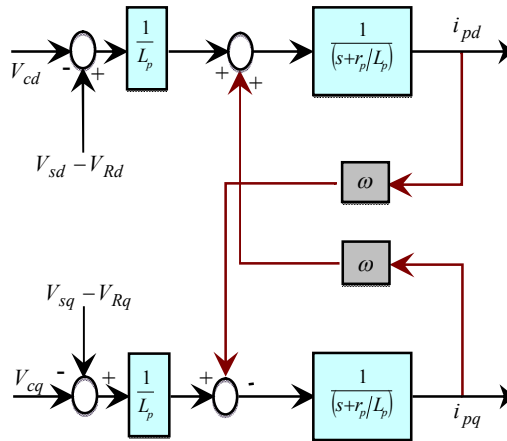


Fig.4 Control system of shunt inverter

C) Control System of branch continue of UPFC

Based on the principle of neglecting losses converters, the DC voltage V_{dc} is described by equation (11)

$$\left(\frac{1}{2}\right) \frac{dV_{dc}}{dt} = \frac{1}{C.V_{dc}} (P_e - P_{ep}) \tag{11}$$

Where:

$$P_e = V_{ca}.i_{Ra} + V_{cb}.i_{rb} + V_{cc}.i_{Rc} \tag{12}$$

$$P_{ep} = V_{pa}.i_{pa} + V_{pb}.i_{pb} + V_{pc}.i_{pc} \tag{13}$$

By applying Park transformation of equation (6) to equation (11) yields:

$$\frac{dV_{dc}}{dt} = \frac{3}{2.C.V_{dc}} (V_{pd}.i_{pd} + V_{pq}.i_{pq} - V_{cd}.i_{Rd} - V_{cq}.i_{Rq}) \tag{14}$$

III. CONTROL OF UPFC

The control system of UPFC consists of the parallel inverter with the control circuit, and the series inverter. The command type presented is evaluated as follows: Decoupled proportional-integral control (Decoupled PI)

[9]. P and Q are given by $P = \frac{3}{2} [V_d i_d + V_q i_q]$, $Q = \frac{3}{2} [V_d i_d - V_q i_q]$

For application to the control, the reference power and reactive are injected (used as input to the control system of the UPFC) to obtain the desired real power P and Q , from the equations (15) and (16). The reference currents and can be calculated as follows:

$$i_{sd}^* = \frac{2}{3} \left(\frac{P^* V_{sd} - Q^* V_{sq}}{\Delta} \right) \tag{15}$$

$$i_{sq}^* = \frac{2}{3} \left(\frac{P^* V_{sq} - Q^* V_{sd}}{\Delta} \right) \tag{16}$$

Or: $\Delta = V_{sd}^2 + V_{sq}^2$

The UPFC series and the UPFC shunt are identical in every respect. Commands for the inverter series are the same as for the inverter shunt. Where the components of the current receiver side is given by the following

$$\begin{cases} i_{Rd} = i_{sd} + i_{pd} \\ i_{Rq} = i_{sq} + i_{pq} \end{cases} \tag{17}$$

The interaction between current loops (i_d and i_q) is caused by the coupling term, the term is cut through against feedback, so the model of UPFC series are identical to the UPFC shunt. We can be rewritten as:

- According to the fig. 8 and 10 the errors of active and reactive power with optimised gains values controllers by PSO technique are small when compared to conventional PI controllers design.
- According to fig. 11, it is noted that a good pursue DC voltage of reference by means of a best rejection at instant to changing active and reactive power with PSO method design.

In general, its excites a best performing rejection regulation of UPFC control with Grid system obtunds by a means of using a Particle Swarm Optimization technique for tuned gains values of controllers when compared to conventional method.

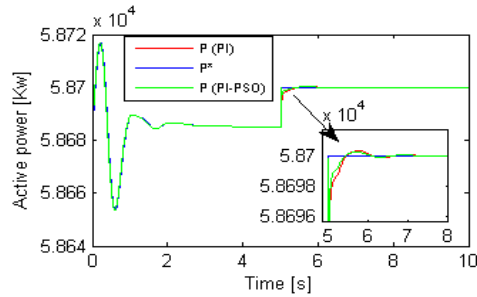


Fig. 7 Active power

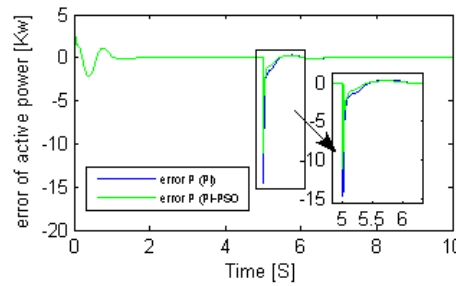


Fig. 8 The error of active power

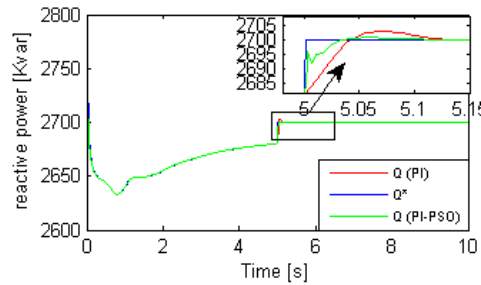


Fig. 9 Reactive power

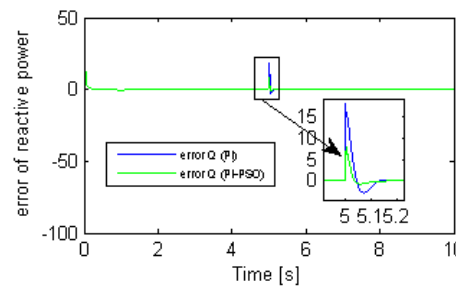


Fig. 10 The error of reactive power

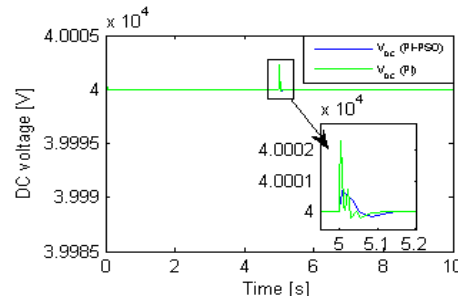


Fig. 11 DC Voltage

VI. CONCLUSIONS

This paper presents the brief model and control system of an optimal UPFC recorded in to Grid system. The presented system is optimized by PSO technique. The simulation results indicate the fast dynamic response, validity and effectiveness of the presented control system with a high-quality result obtunds by PSO technique for tuning gains values controllers when compared to conventional method. In this paper the power circuit, the used control strategy and the optimization of UPFC with Grid system are simulated by Matlab/Simulink.

APPENDIXES

Appendix A: Conventional method for tuning gains regulators

1- Series Part

Suitable value of the time constant of closed loop ($t \geq 5$ ms), K_p and K_i gains can be obtained as follows:

$$\begin{cases} K_p = \frac{1}{\tau} = \frac{1000}{10} = 100 \\ K_i = K_p \frac{r\omega}{L} = 100 \frac{2 \times 2 \times \pi \times 50}{101.44} = 3467 \end{cases}$$

2- Shunt Part

The same way as the shunt part, we can calculate K_p and K_i gains values controller for the shunt part:

$$\begin{cases} K_p = \frac{1}{\tau} = \frac{1000}{10} = 100 \\ K_i = K_p \frac{r_p \omega}{L_p} = 100 \frac{4 \times 2 \times \pi \times 50}{100} = 1256 \end{cases}$$

3- Continue Part

The gains controller continue branch of UPFC is estimates by the Ziegler-Nichols method, the K_p and K_i gains values controllers as the following

$$\begin{cases} K_p = 27 \\ K_i = 604 \end{cases}$$

Appendix B: Particle Swarm Optimization Algorithm design for tuning gains regulators

Based on (24), the optimization of the UPFC with Grid system is started for 10 running and the best rune is selected. Fig. 12 shows the convergence graph of the used Particle Swarm Optimization technique.

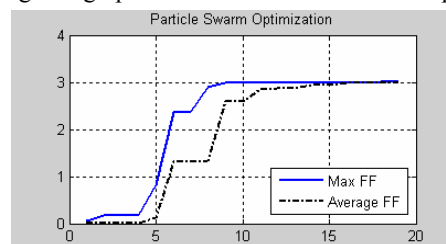


Fig. 12 Convergence graph in the PSO method

Where: $FF = \sum_1^n e(n)$. According to (24): $n = 3$

The best result gains values of PI controllers for 10 running PSO algorithm designed for optimized the UPFC with Grid system are indicates in the Table II.

TABLE III
THE BESTS GAINS PARAMETERS OF PIS OPTIMISED BY PSO

	Series part	Shunt Part	Continue part
K_p	126.1782	134.2595	39.1563
K_i	4015.1250	1705.8541	917.4357

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