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Dynamic Power Oscillation Reduction using PSOA-PI in UPFC

Ananda M.H, M.R. Shivakumar

Abstract: ***The power flow control is one the important part of power system to maintain power system stability. If the real power and reactive power can be controlled then the automatic control of the power system gives numerous possibilities. The Flexible AC Transmission System (FACTs) are the devices meant for this operation. There are series and shunt type of FACTs devices available. The Unified Power Flow Controller (UPFC) is one of the best devices in FACTs devices in AC power system. The power flows can be controlled in series and shunt connections using the two converters. The power oscillations are common in UPFC when the reference powers are changed. The PI controllers are replaced with PSOA tuned PI controller to reduces the power oscillations and reduces the settling time. The problem is formulated to minimize the settling time of the power value. The series and shunt controllers are tuned with particle swarm optimization algorithm (PSOA) to tune the PI controller parameters available in it. The MATLAB Simulink version 2017b is used here for the analysis and well known UPFC test system with three generators are used here for testing the proposed method. The results show PSOA tuned PI controller provides better oscillation damping with reduced settling time.***

Keywords: ***UPFC, PI controller, Particle Swarm Optimization.***

I. INTRODUCTION

The deregulation of power system changes the power system basic calculations like economic load dispatch, optimal power flow etc. while analyzing in steady state. In dynamic conditions also the limits of the generation and fault occurrences changed. Many damping controllers are used for damping the oscillations in the power system. Each of the damping controller work in different ways. The damping controller depends on the device which is used for the damping in the power system. Th power system may create the oscillation between 0.2 to 3.0Hz. A new control of STATCOM coordinated with PV is used to damp the oscillation in the system is presented in [1]. This article discusses that the oscillation damping is done and increases the power transfer. In [2] a unified model of FACTS devices for improving the stability and damping the oscillations are used.

The torque damping is done to minimize the oscillations. As discussed in [3] the UPFC is one of the finest devices in FACTS for controlling the real and reactive power. Here in [4] PSAT is used to model the power system and the UPFC model as power oscillation damper. Then the system is studied under faulty condition and the oscillations are also damped. This is based on the small signal stability. In [5] the Philips-Heffron model of STATCOM is modeled and the power system oscillations are damped. In [6] it is discussed that the DC voltage regulation affects the damping behavior of the FACTS. Compared to other FACTs devices the UPFC is one of the best devices to handle the damping [7]. In [8] author have introduced DC-DC converter to modulate the power of the SMES which is connected with the UPFC. And the multimachine system is compensated using this technique. It uses the non-linear adaptive control technique to perform the damping. The radial basis neural network-based controller for UPFC implemented to improve the damping performances as shown in [9]. The radial basis neural network performs better compared to PI controller. In a two area four machine system the mixed sensitivity design of damping with UPFC is done in [10]. In this paper the PSOA technique is used to tune the PI controller of the UPFC controller and the k_p and k_i parameters are optimized here to minimize the oscillations and reduce the settling time.

II. PSOA OPTIMIZED PI BASED CONTROLLER

Generally, the PI parameters are tuned to get better stability in the control systems. There are many techniques available for tuning purpose. Here the PSOA algorithm is used to tune the k_p and k_i parameters to obtain the reduced settling time in the system. The objective function is defined below.

Minimization of Settling Time

$$minimize\ \sum_{i=1}^{n}(Settling\ Time) \tag{1}$$

with respect to constraints

$$K_{p\ min} \le K_p \le K_{p\ max} \tag{2}$$

$$K_{i\ min} \le K_i \le K_{i\ max} \tag{3}$$

Where $K_{p\ min}$ and $K_{p\ max}$ are defined as the minimum and the maximum gains limits, $K_{i\ min}$ and $K_{i\ max}$ are defined as minimum and maximum gains of integral control obtained.

III. PARTICLE SWARM OPTIMIZATION

The particle swarm optimization works with the mathematics of the behavior of food searching found in animals.

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***** Correspondence Author

Ananda M.H*, School of Electrical & Electronics Engineering, REVA University/Research Scholar V.T.U, India.

M.R. Shivakumar, Sri Revana Siddeshwara Institute of Technology, V.T.U, India.

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It can be a swarm of bird or fishes. Each bird or a fish is known as particle. These particles are taken here as the vector of two variable of k_p and k_i. These values are selected based on the best reduced settling time which is known as food. This best location is shared to the neighborhood particle. The procedure in steps are given below.

Step 1: Arbitrarily the initial values of k_p and k_i are taken for random N numbers. It can be within 20 to 30 values.

Step 2: The initial k_p and k_i values are populated which is between the $K_{p\ min}$ and $K_{p\ max}$, $K_{i\ min}$ and $K_{i\ max}$

Step 3: Run the simulation for obtaining the reduced settling time.

Step 4: by using the velocity equation calculate the velocity of k_p and k_i.

$$V_j(i) = V_j(i-1) + c_1 r_1 [P_{best} - X_j(i-1)] + c_2 r_2 [G_{best} - X_j(i-1)] \quad (4)$$

Where j = 1,2,…N.

c1, c2= learning factor assumed as 2.

r1, r2 = 0 to1 any random number.

In j^{th} particle at the i^{th} iteration identify the positions again by updating the found velocities.

$$X_j(i) = X_j(i-1) + V_j(i) \quad (5)$$

Step 5: Find the local best k_p, k_i and global best k_p k_i values. And update the k_p and k_i with new velocity using the equation (14). Here X_j is the vector of k_p and k_i where the j is the number of particles.

Step 6: Do from step 3 till the final iteration reached.

IV. UPFC MODELLING

Fig. 1 shows the UPFC model connected to the bus system. There are two converters in the UPFC system. One converter is used for series connection and compensation another one is for shunt connection and compensation.

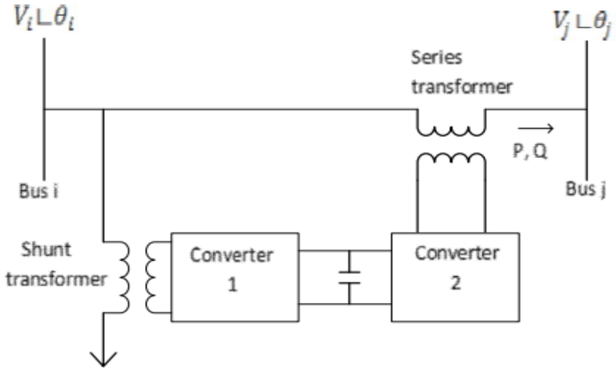

Fig. 1. UPFC model.

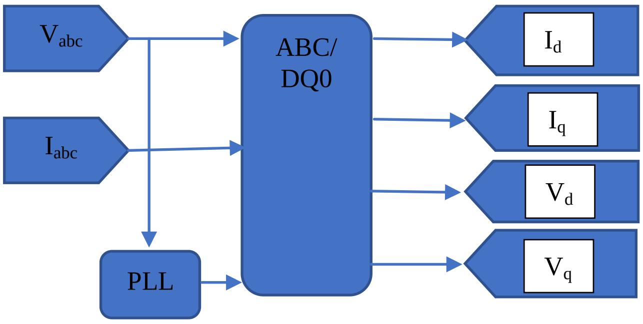

Fig. 2. ABC to DQ0 model.

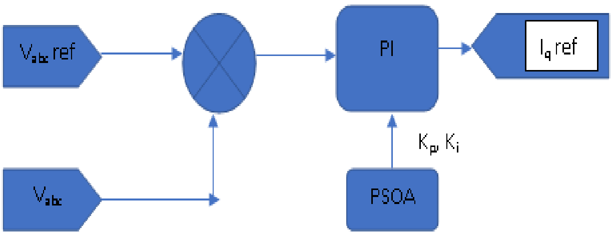

Fig. 3. Shunt current control.

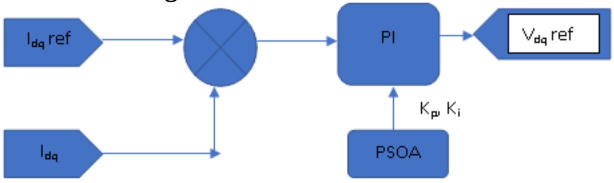

Fig. 4. Series voltage control.

The shunt compensator takes the I_{abc} and V_{abc}. Then it converts it into Idq0 and Vdq0. It is shown in Fig. 2. Measured voltage is compared with reference voltage. Then it is given to PI controller. The PI controller can be tuned with K_p and K_i. The output of the controller is $I_q$ref. It is the reactive power component of the shunt converter control. It is given in Fig. 3.The series compensator takes the I_{dq} values from Fig. 2. Then the measured and required Idq are compared and given to PI to convert it into V_{dq} reference. The series converter injects the required voltage to the system. This pi controller also tuned by PSOA algorithm which is shown in Fig. 4. For simplicity other controls like power to voltage, current and PWM controllers also are not discussion.

V. RESULTS AND DISCUSSION

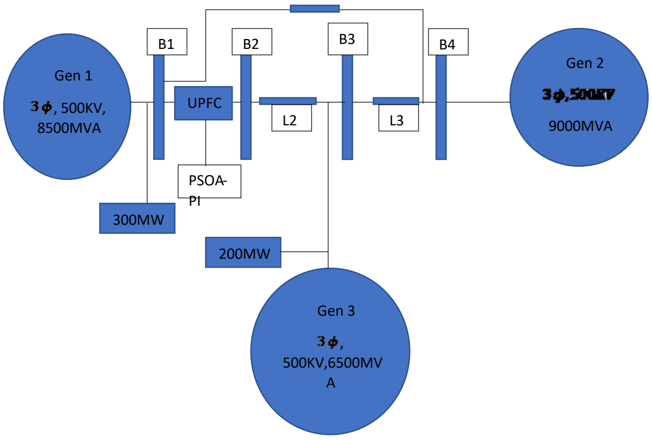

Fig. 5. Proposed system block diagram.

The Fig. 5 shows the complete block diagram there are three generating units the generator 1 is connected to bus 1. The bus 1 is connected to upfc then the other end of UPFC is connected to bus 2. From bus 2 is connected to the line number 2 then it is connected to bus 3. The bus 3 is connected to line 3 the other end connected to bus 4. The bus 4 is connected to generator 2. Then generator 3 is connected to bus 3. This system is used here as the test system.The simulation is run for 2.5 secs.

The initial real power reference given to UPFC is 8.7 and then at 1.25 secs it is increased to 9 p.u to check the dynamic performance. The reactive power reference given initial is -0.6 p.u then it is suddenly changed to 0.1.

Table- I: Comparison of methods

Parameters	PI	PSOA-PI
Rise Time (secs)	0.0024	0.0016
Settling Time (secs)	1.1974	0.1407
Settling Min %	8.466	8.6743
Settling Max %	9.2682	8.7362
Overshoot %	6.2619	0.3759
Undershoot %	0	0
Peak (MW)	9.2682	8.7362
Peak Time (secs)	0.3223	0.2938

Table- II: Controller parameters

Controllers	Shunt Controller		Series Controller	
	K_p	K_i	K_p	K_i
PI Controller	24	6000	0.05	3
PSOA-PI Controller	768.47	192118	1.70469	102.282

The PI controllers are tuned by running the UPFC system by PSOA algorithm. The fitness function is the power value of the UPFC which is the output parameter analyzed for the settling time. The power graphs are shown below. The table I shows the performance comparison between the PI and PSOA-PI. The rise time of the power is 0.0024 secs and the PSOA-PI delivers 0.0016 secs where the PSOA-PI gives better results. Then the main objective function setting time is 1.1974 secs and the PSOA-PI produces 0.1407 secs which is far better than the PI. So PSOA-PI succeed in settling time and the waveforms are given below. The other stability parameters are presented in the tabular column. The table II shows the Kp and Ki parameters used for and identified for normal PI and PSOA-PI.

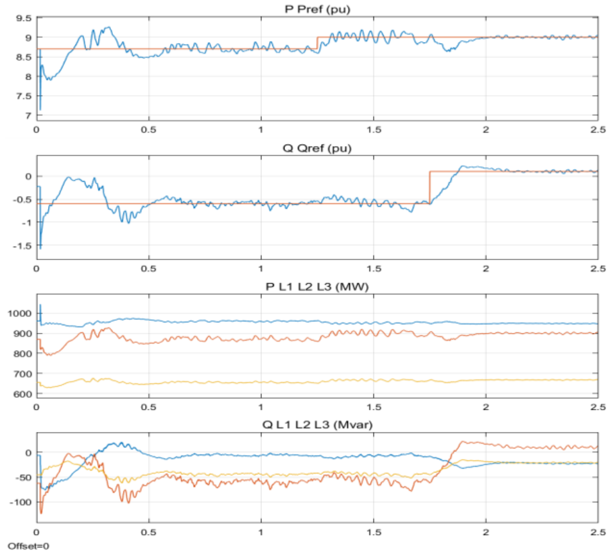

Fig. 6. Power curves using PI controller in shunt and series compensator.

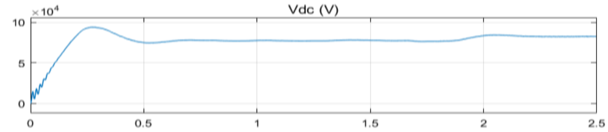

Fig. 7. DC link voltage with PI controller in shunt and series compensator.

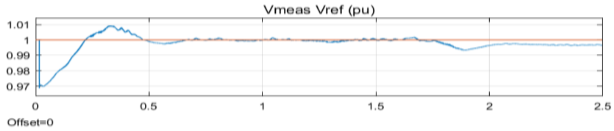

Fig. 8. Reference voltage and measured voltage with PI controller in shunt and series compensator.

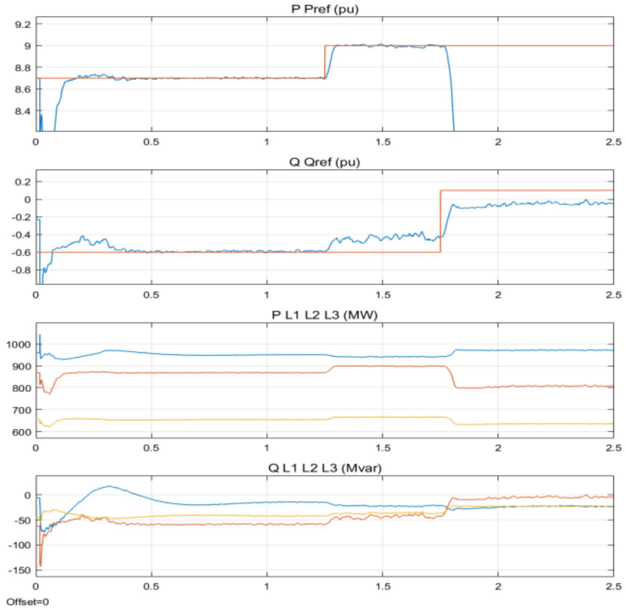

Fig. 9. Power curves using PSOA-PI controller in shunt and series compensator.

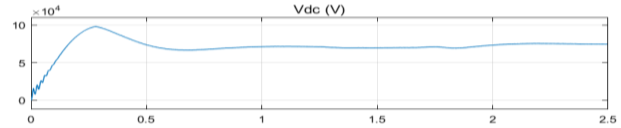

Fig. 10. DC link voltage with PSOA-PI controller in shunt and series compensator.

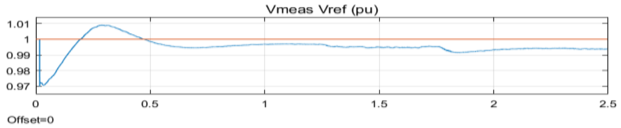

Fig. 11. Reference voltage and measured voltage with PSOA-PI controller in shunt and series compensator.

The Fig.6 shows the Power curves using PI controller in shunt and series compensator. The Fig.7 depicts the DC link voltage with PI controller in shunt and series compensator. The Fig.8 shows the Reference voltage and measured voltage with PI controller in shunt and series compensator. The

Fig.9 shows the Power curves using PSOA-PI controller in shunt and series compensator and it can be seen that the curves are clear and ripple free compared to PI controller. The Fig.10 depicts the DC link voltage with PSOA-PI controller in shunt and series compensator Fig.11 shows the Reference voltage and measured voltage with PSOA-PI controller in shunt and series compensator. The voltages are in stable conditions.

And it follows references in both the conditions. The real and reactive powers at line 1, line 2 and line 3 are measured and the deviation due to the change in power at the UPFC reference affects the real and reactive power at those lines.

VI. CONCLUSION

In this paper the UPFC is implemented in a test system and the real, reactive power are controlled using it. The particle swarm optimization algorithm (PSOA) technique is used to tune the PI controller of the UPFC. The k_p and k_i parameters are optimized here to minimize the oscillations and to reduce the settling time. The results are compared with PI controller and PSOA-PI controller. The PSOA algorithm-based PI controller performs well in settling time and other dynamic conditions. The results show power waveforms are stable in PSOA-PI compared to the PI controller, thus providing better power system stability and oscillation damping.

APPENDIX

Test system parameters considered for Simulation.

GEN 1	**Values**
Voltage in V	500e3*1.0491
Frequency in Hz	60
Phase in deg	9.2
VA rating	8.50E+09
X/R ratio	10
GEN 2	**Values**
Voltage in V	500e3*0.98
Frequency in Hz	60
Phase in deg	9.2-40
VA rating	9.00E+09
X/R ratio	10
GEN 3	**Values**
Voltage in V	5.00E+05
Frequency in Hz	60
Phase in deg	9.2-20
VA rating	6.50E+09
X/R ratio	10
LINE 1	**positive & zero sequence**
Resistance (Ohms/Km)	[0.01273*2 0.3864]
Inductance (H/Km)	[0.9337e-3 4.1264e-3]
Capacitor (F/Km)	[12.74e-9 7.751e-9]
Length in Km	200
LINE 2	**positive & zero sequence**
Resistance (Ohms/Km)	[0.01273*2 0.3864]
Inductance (H/Km)	[0.9337e-3 4.1264e-3]
Capacitor (F/Km)	[12.74e-9 7.751e-9]
Length in Km	75
LINE 3	**positive & zero sequence**
Resistance (Ohms/Km)	[0.01273*2 0.3864]
Inductance (H/Km)	[0.9337e-3 4.1264e-3]
Capacitor (F/Km)	[12.74e-9 7.751e-9]
Length in Km	180
UPFC	**Values**
Voltage	500kV
VA rating	1.00E+08
Loads	**Values**
at Bus 1	300 MW
at Bus 3	200MW

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AUTHORS PROFILE

Ananda M.H, Assistant Professor, School of Electrical and Electronics Engineering, REVA University, holds his B.E in Electrical & Electronics Engineering and M.Tech in Power Systems & Power Electronics. His employment experience includes 6 years of industry experience from ABB Ltd., DM-Power Electronics and 7 years of teaching experience.

He is Member of IAENG (International Association of Engineers), Member of IEI (Institution of Engineers India) and student member of IEEE. His special fields of interest included FACTS devices and their application to the power system, FOCS, Smart Grid, Micro Grid, Battery charging technology, Grid integration of renewable energy sources.

Dr. M.R. Shivakumar, Professor and Principal Sri Revana Siddeshwara Institute of Technology Bangalore is an Electrical power Engineering graduate from University of Mysore. Post graduate from Bangalore University and also a PhD holder in Electrical Engineering (Power Systems) from the same university. He has more than Three decades of teaching experience and guided the students for their Post graduate as well as doctorate degrees. He is a life member of The Indian Society for Technical Education, A Fellow of The Institution of Engineers (India), A member of Institution of Engineering and Technology MIET (UK). His field of interest includes power system stability, FACTS controllers, power electronics applications.