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Fractional Order PI Controlled UPFC for Transient Stability Improvement of Interconnected Power System

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Abstract : The loading capacity of the transmission link can be improved by using FACTS controllers. A consequence of this is to damp power oscillations in the transmission lines. To damp these low frequency power oscillations, one of the effective solutions is to use FACTS controllers. The gains of the FOPI controller are tuned by using TLBO optimization algoritham. The objective function in TLBO optimization is to minimize the power oscillations in the line where UPFC is placed. The dynamic performance of the power system with upfc is placed. The dynamic performance of the power system with UPFC is simulated in MATLAB/SIMULINK. The effectiveness of the proposed FOPI controller is compared with integer PI controller.

Keywords : Transient Stability, UPFC, Multi-Machine System, Power Oscillations, FOPI, TLBO.

1. INTRODUCTION

The demand of electric power is ever increasing. To meet the increased demands, FACTS controllers are used however the other aspect of the FACTS controllers is to damp the low frequency power oscillations. The series-shunt type FACTS device like UPFC is very effective in improving the transient stability of the power system. PI controllers have been used over years for UPFC. The reason for its popularity is its simple design and better performance. IN RECENT YEARS Fractional order PI controller applications are getting attention from researchers. In FOPI controllers, fractional power of s is used. Therefore the controller parameters in this controller are the gains K_p, K_I and other additional parameter is the power of s. the proposed controller parameters are tuned by using teaching and learning based optimization algoritham. The objective function in the TLBO algoritham is the change in the real power in the line where UPFC is placed.

UPFC

The UPFC is the most effective FACTS controller and is able to insert a voltage in series with the line. This voltage can have any magnitude and phase. The UPFC consists of a series and shunt branch, each consisting of a transformer and pwm inverter. Both convertors are operated from a common dc link[1]. The real power can freely flow in either direction between the two ac branches. Each converter can independently generate or absorb reactive power from the ac mains[2].

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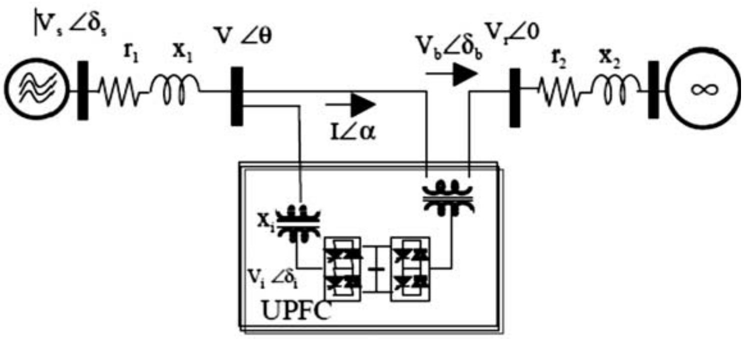


Fig. 1. UPFC connected to the Power System.

A. Generator Model : The synchronous generator is represented by second order model comprising of terminal voltage and electro mechanical swing equation[3].

$$\frac{d\delta}{dt} = \omega_b(\omega - 1) \tag{1}$$

$$\frac{d\omega}{dt} = \frac{T_m - T_e - D\,(\omega - 1)}{M} \tag{2}$$

The mechanical part of synchronous machine represented by

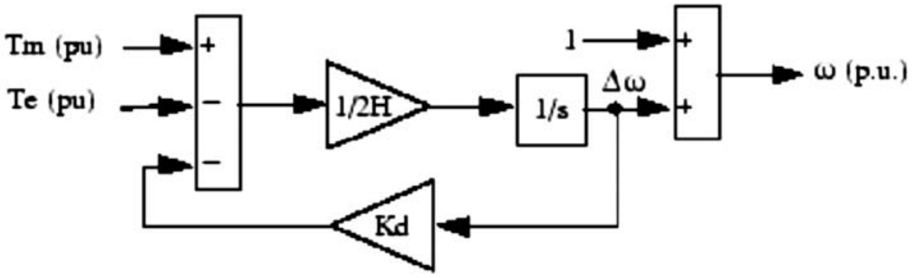


Fig. 2. Mechanical Part of Synchronous Machine.

B. Three phase transmission line model : A series R-L-C branch (with C value set to zero) and R-L-C parallel branch (with Rand L are set to infinity) with P-Q and voltage – current measurement blocks are used to develop π model of transmission line as shown in fig(3)

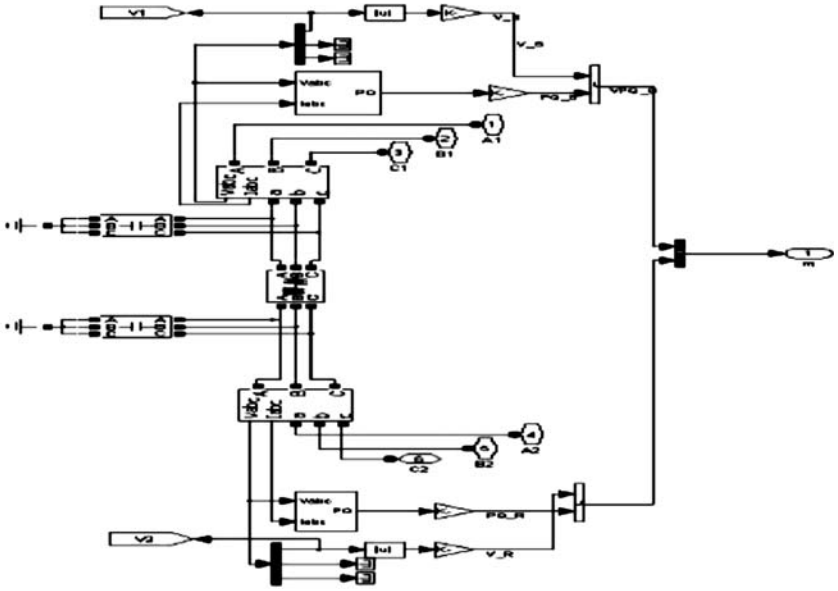


Fig. 3. SIMULINK Model for 3-phase Transmission Line.

C. Load Modelling : A parallel RLC load block with appropriate measurement blocks is represent load. The load active and reactive powers are proportional to square of the voltage.

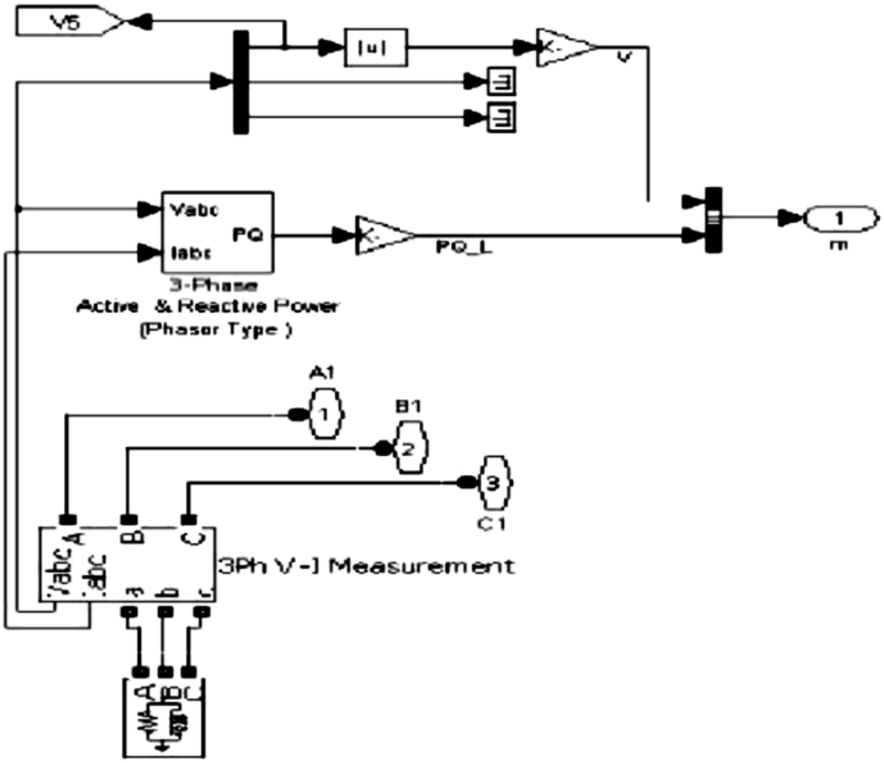


Fig. 4. SMULINK Model for 3-Phase R-L Load.

UPFC Model

In this study, UPFC is modelled as a a synchronous voltage source represented at fundamental (power systems) frequency by a voltage phasor with variable magnitude V_{se} and phase angle θ[5].

The real power and the reactive power transmitted between the two buses P and Q having voltages V_P and V_S as shown in fig is given by $P - JQ = V_r((V_s - V_R)/JX))^*$

With the inclusion of UPFC in the line as a synchronous voltage phasor the power flows in the line are

$$
\begin{aligned}
P - JQ &= V_r((V_s + V_{PE} - V_r)/JX)^* \\
P - JQ &= V_r((V_s - V_R)/JX))^* + ((V_r V_{PE}^*) / - JX) \\
P &= ((V_s V_r) /X)) \sin\delta - ((V_s V_{se}) /X)) \cos(\delta/2 + \theta) \\
P &= P_o + P_{sc} \\
Q &= ((V_s V_r) /X)) (1 - \cos\delta) - ((VV_{PE}) /X)) \sin(\delta/2 + \theta) \\
Q &= Q_o + Q_{sc}
\end{aligned}
$$

Where P_o and Q_o are real and reactive powers with out UPFC.

P, Q are real and reactive powers with UPFC

P_{sc} and Q_{sc} are the real and reactive powers supplied by UPFC.

The shunt converter improves voltage of the bus by varying reactive component of the current.

FOPID Controller

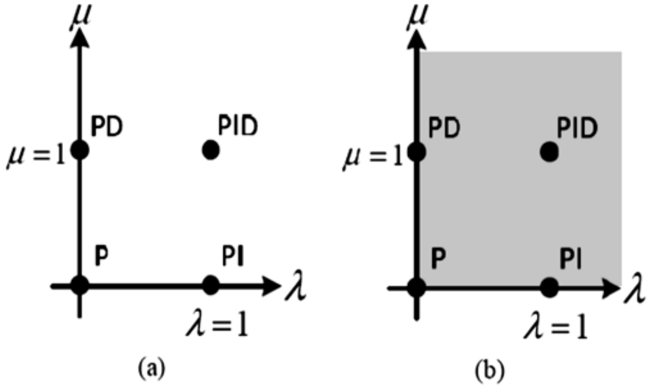
The mathematical model of the FOPID Controller described the following equation.

$$u(t) = K_p{}^{e}(t) + K_1 D_t^{-1} e(t) + K_D D_t^{\mu} e(t)$$

the La place transform of the above equation is given by

$$G(s) = K_p + K_I s^{-\lambda} + K_D s\mu \tag{5}$$

all the parameters K_P, K_I, K_D, λ and μ of FOPID controller which are not necessarily integers. The FOPID controller extends the conventional PI controller from point to plane.



(a) (b)

Fig. 5. FOPID *vs* Classical PID (*a*) integer-order controller and (*b*) factional-order controller.

F. **TLBO**

The gains of the controller need to be optimized for better performance of the power system[11].The optimization process has three steps,first one is objective function second one is search space (possible solutions) and third one is optimization algoritham. There are many nature followed optimization algorithms such as partical swarm optimization, (PSO), Artificial bee colony (ABC), ant colony optimization (ACO), etc working on the principles of different natural phenomena. These algorithms have been applied to many engineering optimization problems and proved effective in solving specific kinds of problems.

TLBO is one of the best known nature inspired optimization algoritham proposed to obtain acceptable solutions for continuous non-linear functions with less computational effort.TLBO gives solutions with high consistency[12]. The principle of this algoritham is based on the knowledge updation of a student in the class by his teacher and his fellow students. The teacher is generally considered as a highly learned person who shares his knowledge with learners. The quality of a teacher effects the outcome of the learners[14].

The process of TLBO is divided into two parts. The first part consist of ‘ Teaching Phase’ and second part consists of ‘Learning Phase’.

Teacher Phase

Let T_i and M_i be the teacher and mean value in any ith iteration.The teacher will try to move the mean of the student to his own level. The new mean is calculated [15] based on present mean and difference between the two recent means. The solution is updated according to the difference between existing and the new mean given by difference – mean $i = r_i(M_{New} - TF * M_i)$ the value of the mean to be updated is decided by the teaching factor TF and r_i is the random number in the range (0,1). The value of TF can be either 1 or 2 which is again a heuristic step and decodes randomly with equal probability on

$$TF = \text{round}\ [1 + \text{round}\ (0,1)\ \{2 - 1\}]$$

This difference modifier the existing solution according to the following expression

$$X_{New,}\ i = X_{old},\ i + \text{difference} - \text{mean}\ i$$

Learner Phase

The learners mean value is updated by two ways one through knowledge of the teacher and other through students with highest mean value. Randomly select two learner X_i and X_j where $i \neq j$

if $f(X_i) < f(X_j)$ then

$$X_{new}, i = X_{old\,,}\, j + r_j * (X_i - X_j)$$

Otherwise $$X_{new,\,i} = X_{old,\,i} + r_j * (X_j - X_i)$$

Problem formulation

The optimization problem is formulated based on power oscillation in the line where the UPFC is placed, the steady state power *i.e* pre fault power in the line is considered as reference power. The objective function is to minimize the integral square error of

$$J = \int_0^{tcr} (\text{pref} - \text{Pline})^2 dt$$

P_{ref} → Steady state Power flowing in the line where UPFC is placed.

P_{lien} →Power in the line when fault is on in the line where UPFC is placed. Subjected to

$$K_P \min \le K_P \le K_P \max$$
$$K_I \min \le K_I \le K_I \max$$
$$\lambda \min \le \lambda \le \lambda \max$$

The minimum and maximum values of K_P are 0.1 and 10, for K_I 3 and 40. The range of λ lies between 0 to 1.

Where *tcr* is fault clearing time. P line is the power in the line when fault is ON.

2. SIMULATION RESULTS:

The simulation of WSSC 3-machine 9-bus test system has been carried out in MATLAB/SIMULINK. A 3-phase fault is applied at bus 6 with a fault clearing time of 10 cycled. The relative rotor angles of generators 2-1 and 3-1 are plotted as a function of time as shown in fig(6). the power oscillations in the line are also given in fig(7).

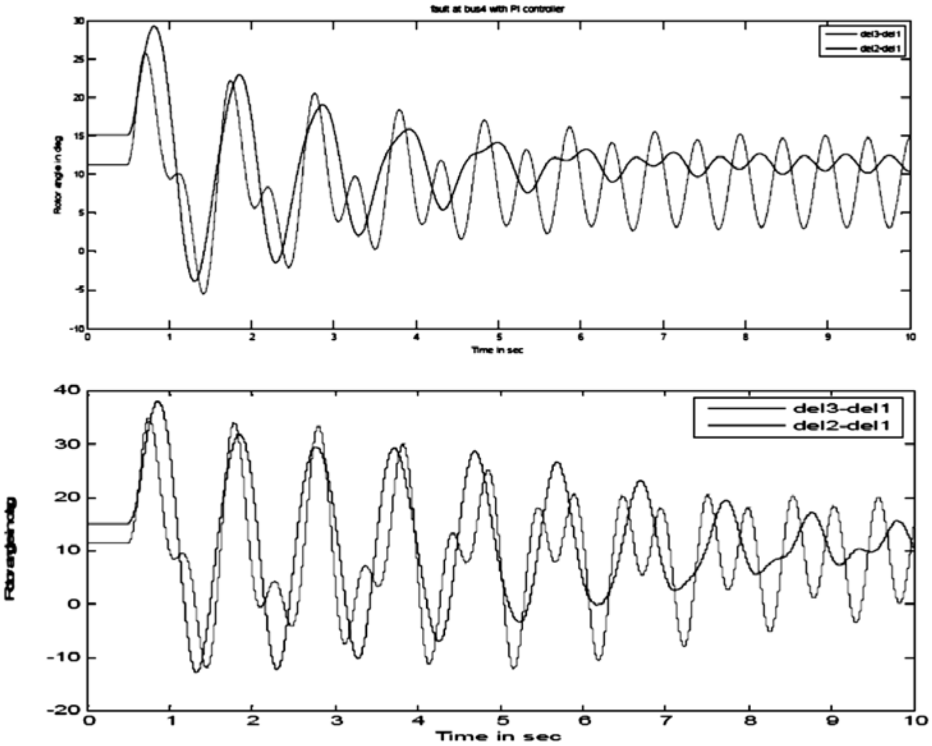


Fig. 6. Rotor angle variations for FOPI and PI controllers.

The simulation results of Fig (6) clearly indicate that the proposed FOPI controller improves the stability in terms of reduction in first swing and also consecutive swings. Therefore it provides better damping compared to integral PI controller.

The table gives the optimal controller parameters obtained by TLBO optimization algoritham.

Table 1.

S.No	*Parameter*	*Value*
1.	K_P	0.9
2.	K_i	7.6
3.	Λ	0.5

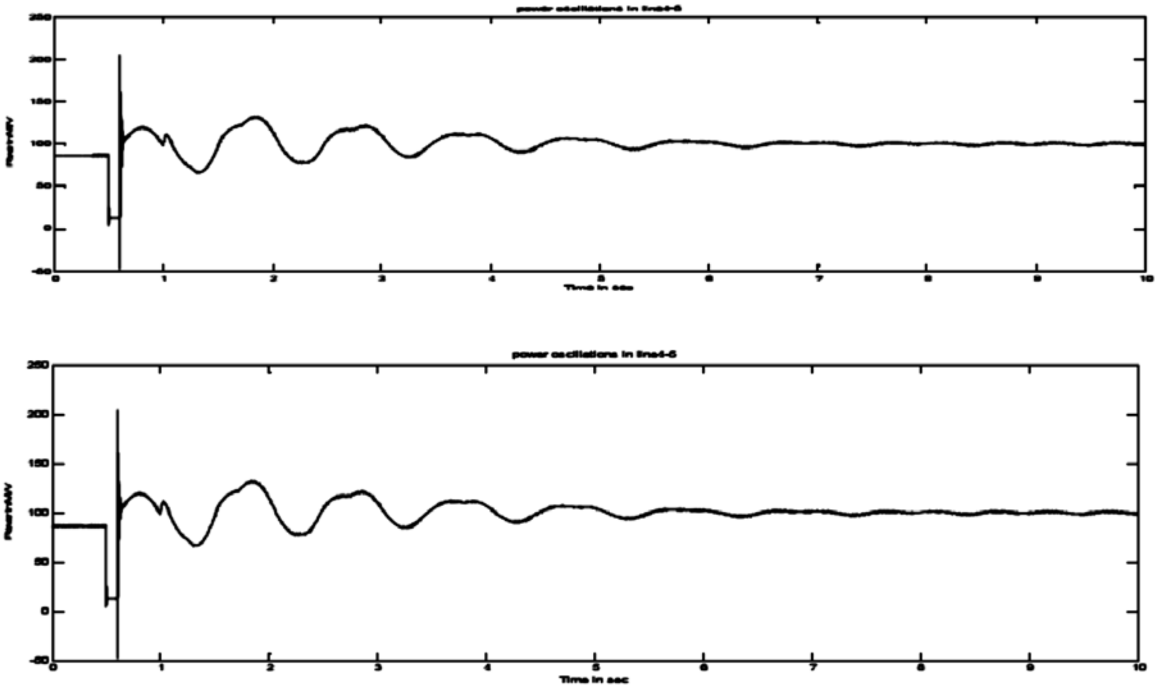


Fig. 7. Power oscillations with FOPI and PI Controllers.

3. CONCLUSION

This paper has considered the implementation of FOPI controller to the UPFC. The parameters of the controller are tuned by TLBO optimization algoritham. The proposed controller has been tested on a WSSC 3-machine 9-bus standard test system. A Three phase fault is applied at different locations and withdifferent fault clearing time. The simulation results shows the proposed FOPI controller has better performance compared to integer order PI controller and the optimum values of controller parameters give better performance compared to any other values of parameters.

4. APPENDIX

(*i*) Generators data :

Table 2.

Generator	X_d'	*H*
1.	0.0608	23.64
2.	0.1198	6.4
3.	0.1813	3.01

(*iv*) Bus Data :

Table 3.

Bus No.	P_{GEN}	P_D	Q_D	V_{ip}
1.	0.0	0.0	0.0	1.04
2.	1.63	0.0	0.0	1.026
3.	0.85	0.0	0.0	1.025
4.	0.0	0.0	0.0	...
5.	0.0	0.9	0.5	...
6.	0.0	0.9	0.3	...
7.	0.0	0.0	0.0	...
8.	0.0	1.0	0.35	...
9.	0.0	0.0	0.0	...

Test power system :

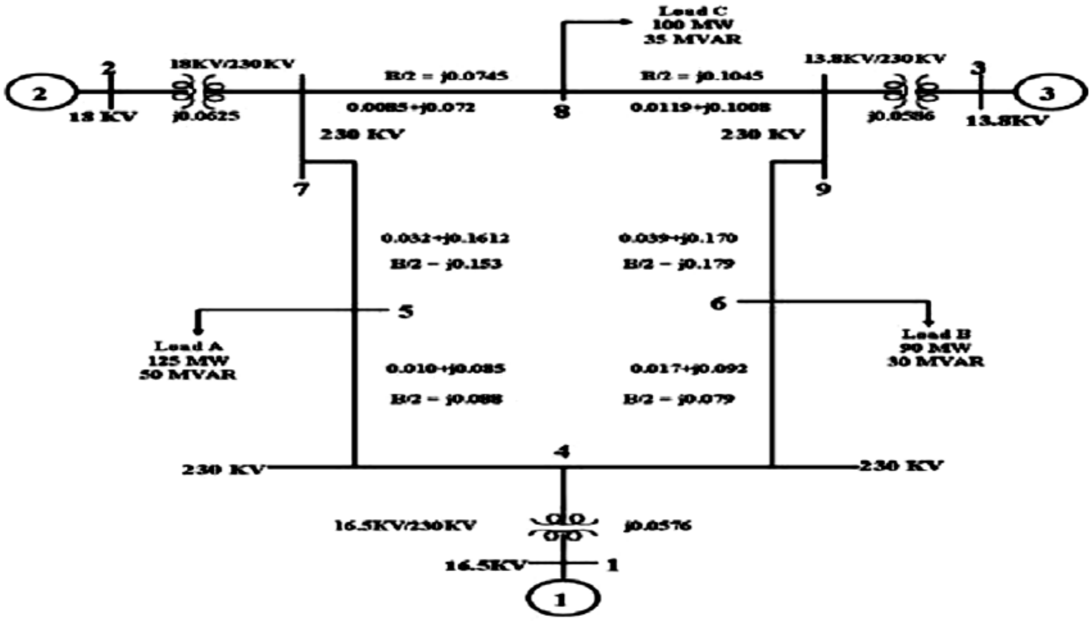


Fig. 8.

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