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TLBO Tuned Fractional Order PI Controlled TCSC For Improvement Of Transient Stability in Multi Machine Power System

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Abstract : The ever increasing demand for electric power can be met by enhancing loading capacity of the existing power lines. A consequence of this is to damp inter area power oscillations, In particular in multi machine power system. To damp the power oscillation s one of the effective solution is to use FACT Controllers besides controlling the steady state power flows in the lines also aids the damping of power oscillations. This paper gives The gains of Fractional order PI controller are optimized by using Teaching and learning based optimization algorithm. The objective function in optimization problem is the power flow in the line where TCSC is placed. The effectiveness of the proposed controller in damping of power oscillation and improvement in dynamic performance of the power system is demonstrated by compare with the conventional PI controller. MATLAB/Simulink is used to simulate the Power System and TCSC Controllers.

Keywords : Multi Machine System, FOPI controller, TCSC, TLBO,Transient stability, Power Oscillations.

1. INTRODUCTION

The demand of electrical power is continuously increasing. However the development of new power lines for generation of power and dispatch is confined due to environmental and economic reasons. Those result is effective utilization of existing infrastructure. To achieve this goal FACTS devices are used with effective controllers these devices help in improving the Power Transfer limits and to get higher operating efficiencies[1].

However the other aspect of these controllers is to damp the low frequency power oscillations during large disturbances.The series FACTS controllers like TCSC,SSSC are majorly used for low frequency power oscillation damping. A considerable attention has been given to investigate the effect of TCSC on improvement of dynamic performance of power system. PI controllers has beenused over years for TCSC. The reason for its popularity is its simple decision and better performance.

In recent years Fractional order PI controller applications are getting attention from researchers[2]. In fractional order PI controllers of integral operations of fractional order are used. Therefore the control parameters in these controllers are the gains Kpand KI and other additional parameter is the power of S.

In this paper an fractional order PI controlled TCSC is designed and implemented on a WSSC 9 bus 3 machine test system. The design of controller parameters is optimized by using Particle Swarm

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Optimization is used[5]. The objective function for optimization problem is change of power in the line where TCSC is placed.Thyristor Controlled Series Compensation (TCSC)-TCSC is a FACTS device, which is used to enhance power transfer capacity and the power oscillation damping. It consists of a Thyristor controlled reactor in shunt with a capacitor as shown in fig1. This configuration allows the capacitive reactance to be controlled over a wide range.

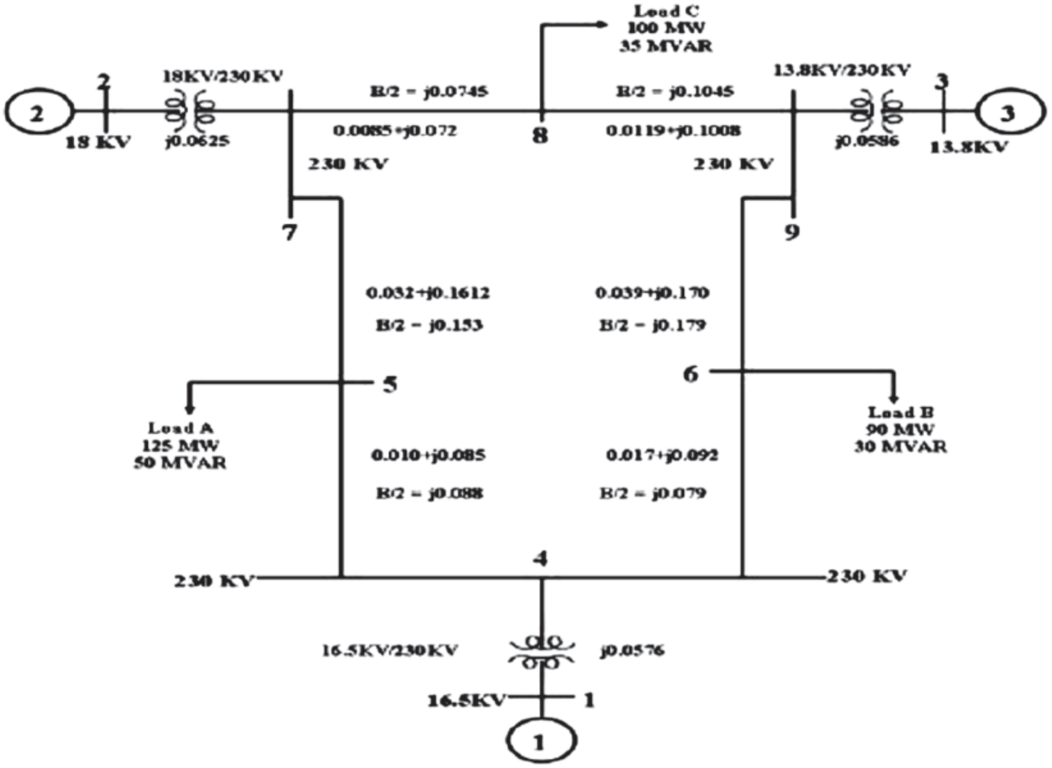


Fig. 1. Single line diagram of 3 machine 9 bus WSSC Power System.

2. MODELLING OF THE POWER SYSTEM

In this paper a 3 machine 9 bus WSSC test power system is considered as shown in fig1 with TCSC in one of the transmission lines. The main components of the system are Synchronous Generator, Transmission Lines, Loads and TCSC with FOPID. The modelling of each component is given in the following section.

A. Generator model : The synchronous generator is represented by a second order model with electro mechanical swing equation.

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

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

The mechanical part of the synchronous machine represented in fig2.

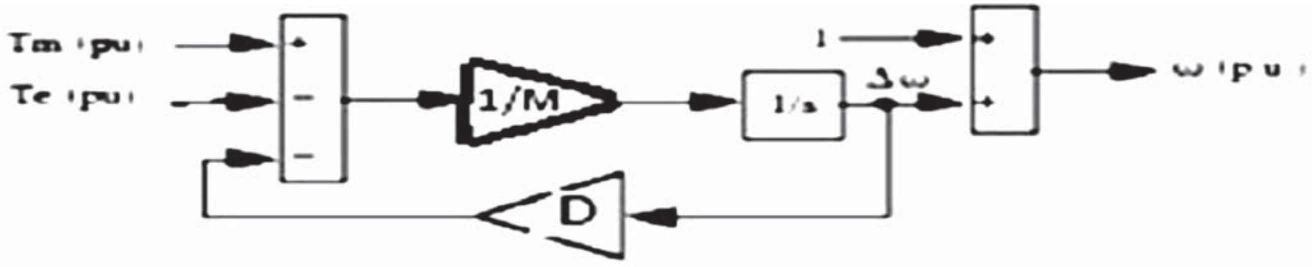


Fig. 2. Mechanical Part of Synchronous Machine.

B. Three phase Transmission Line Model : A series R-L-C branch (with C value set to zero) and a R-L-C parallel branch (with Rand L are set to infinity) along with P-Q and voltage – current measurement blocks are used to develop π model of transmission line as shown in fig3.

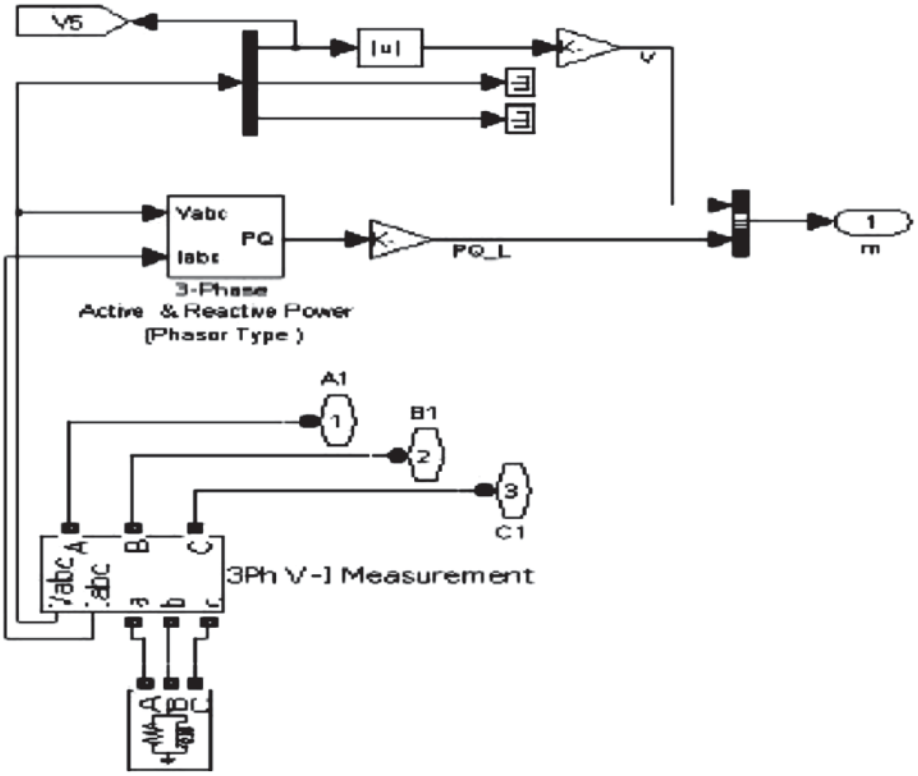


Fig. 3. SIMULINK Model for 3-phase Transmission Line.

C.Load Modelling : A parallel RLC load block with appropriate measurement blocks is used to represent load. The load active and reactive powers are proportional to square of the voltage. Fig 4 shows the SIMULINK Model of a 3-Phase Load.

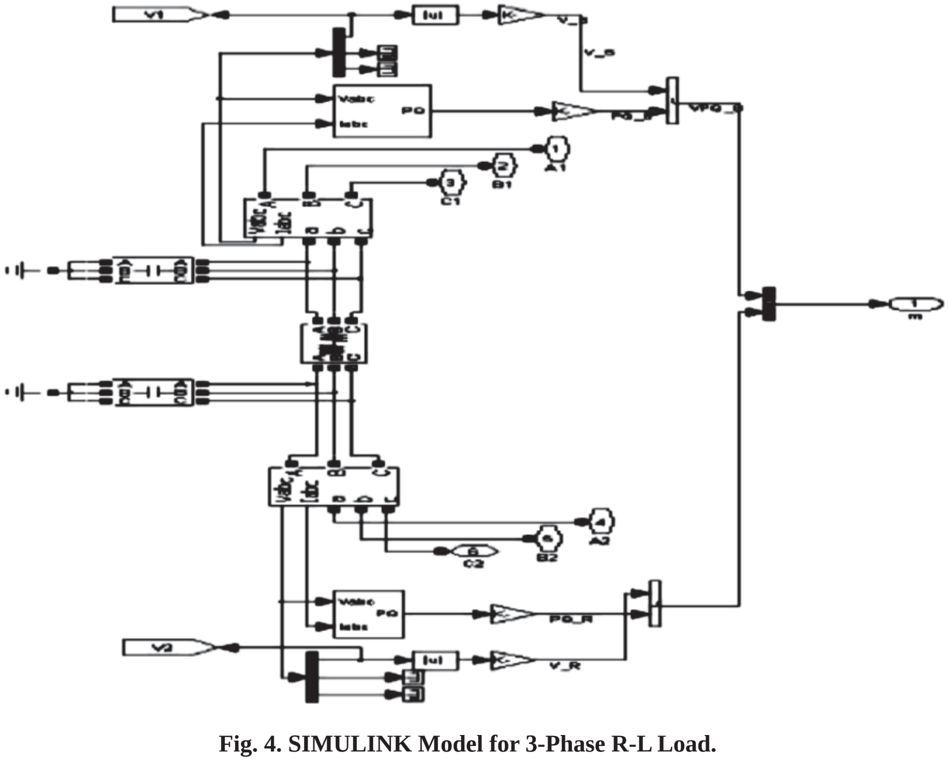


Fig. 4. SIMULINK Model for 3-Phase R-L Load.

D. TCSC Model : In this study TCSC is modelled as a variable reactance operated only in capacitive region. The following equations are used to calculate the fundamental dynamic reactance of the TCSC using firing angle α.The TCSC layout configuration is as shown in fig(5).

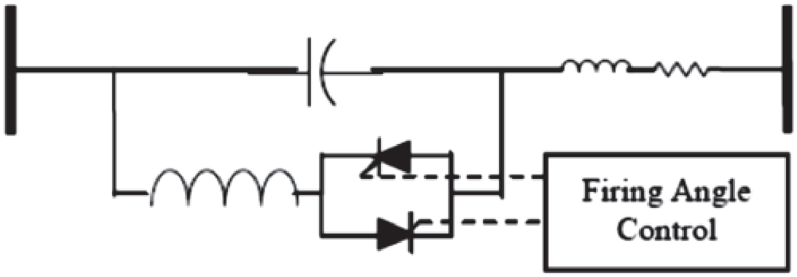


Fig. 5. TCSC Model.

$$X_C = \beta_1(X_{FC} + \beta_2) - \beta_4\beta_5 - X_{FC} \tag{3}$$

Where

$$\beta_1 = [2(\pi - \alpha) + \sin 2(\pi - \alpha)]/\pi,$$

$$\beta_2 = X_{FC}X_p/(X_{FC} - X_p),$$

$$\beta_3 = \surd(X_{FC}/ X_p),$$

$$\beta_4 = \beta_4 \tan[\beta 3(\pi - \alpha)] - \tan(\pi - \alpha)$$

and

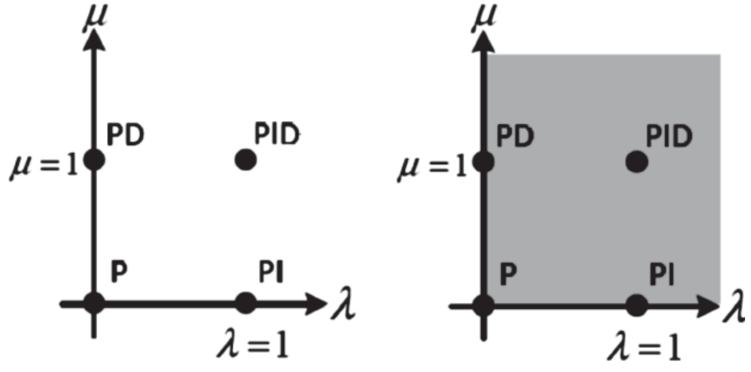
$$\beta_5 = 4\beta_2{}^2 \cos^2(\pi - \alpha)/(\pi X p)$$

E. FOPID Controller : The mathematical model of the FOPID Controller as described by the following equation.The Laplace Transform of the above equation is given by

$$u(t) = K_p e(t) + K_1 D_t^{-\lambda} e(t) + K_D D_t^{\mu} e(t) \tag{4}$$

$$u(s) = (K_P + K_I s^{-\lambda} + K_D s^{\mu})^* E(s) \tag{5}$$

The parameters K_P, K_I, and λ of FOPI controller are not necessarily integers. The FOPI controller extends the conventional PI controller from a point to plane as shown in fig6(*b*).



(a) (b)

Fig. 6. FOPID *vs* Classical PID (*a*) integer-order controller and (*b*) fractional-order controller.

F.TLBO : The parameters of the fractional order PI controller need to be optimized.

TLBO is proposed to obtain acceptable solutions for continuous non-linear functions with less computational effort.TLBO gives solutions with high consistency. The principle of TLBO method is based on the effect of the influence of a teacher on the output of student(learner) in the class. 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.

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

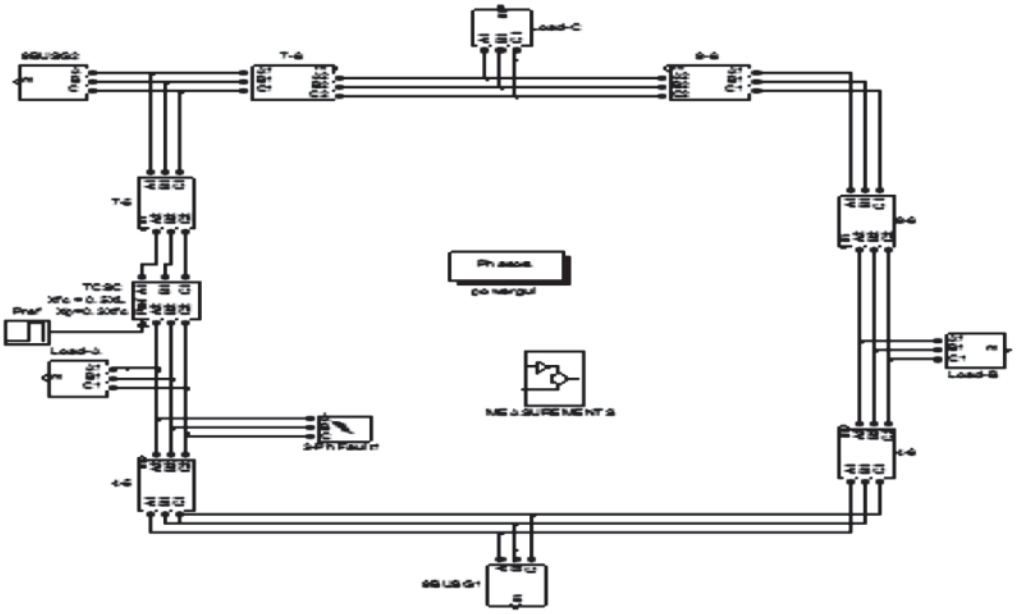


Fig.7.SIMULINK Model for 3machine 9 bus WSSC Power System

Teacher Phase: The teacher always try to move the mean of the student to his own level.In this phase the mean of the student is updated based teacher mean and present mean of the student.Let M and T be the mean and teacher and *i* be any iteration . The solution is updated according to the difference between existing and the new mean given by difference – mean $i = r_i(M_{New} - TF * M_i)$ where TF is the teaching factor that decides the value of the mean to be changed 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

$$X\ New,\ i = Xold,\ i + \text{difference} - \text{mean}\ i$$

Learner Phase : The knowledge of the learner is increased by two means one through input from the teacher and other through interaction among themselves. 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 on minimization of integral square error.The error is the difference of reference power which is the steadystate power before the fault and power when fault is on.The TCSC is placed in the line 4-5 and hence power oscillations in line 4-5 are considered to calculate the objective function. The objective function is

$$J = \int_0^{tr} (Pref - P\ line) \tag{6}$$

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

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

$$K_P min \leq K_P \leq K_P\ max$$

$$K_I\ min \leq K_I \leq K_I max$$

$$\lambda\ min \leq \lambda \leq \lambda\ max$$

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.

3. SIMULATION RESULTS

The simulation of WSSC 3 machine 9bus test Power System has been carried out in MATLAB/ Simulink. A three phase fault is simulated at bus 4 with fault clearing time of 0.5 sec. The TCSC with FOPI controller is placed in line 5-7.

The simulation results clearly indicate that the proposed controller design improves the system stability in terms of reduction in first swing and also consecutive swings also provides better damping compared to conventional PI controller.The optimal design of controller parameters is

Table 1.

S.No	*PARAMETER*	*VALUE*
1	K_P	0.9
2	K_I	7.8
3	Λ	0.7

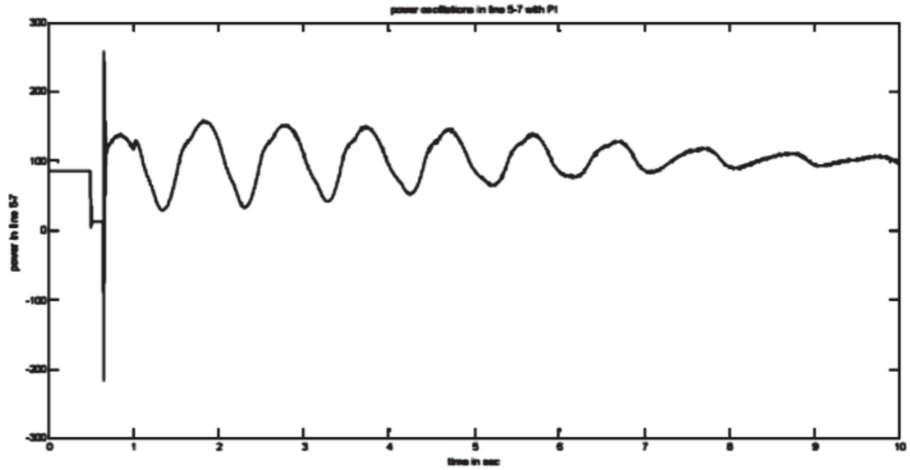


Fig. 8. Fault at bus 4 with PI and *tc* = 0.15sec.

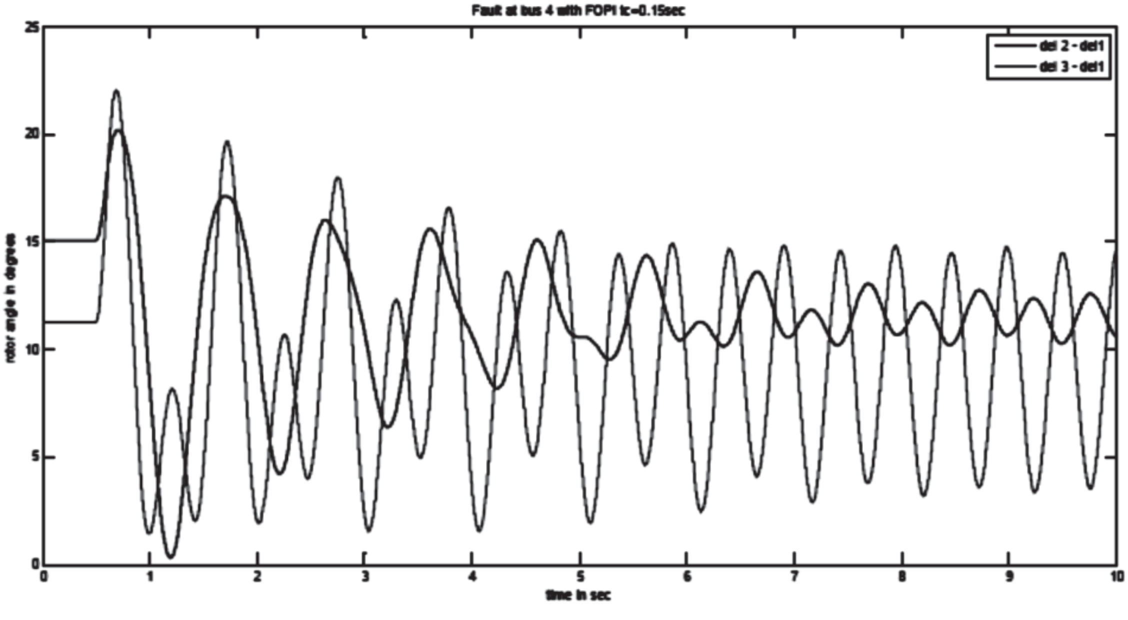


Fig. 9. Fault at bus 4 with FOPI and *tc* = 0.15sec.

PI and $tc = 0.15$ sec

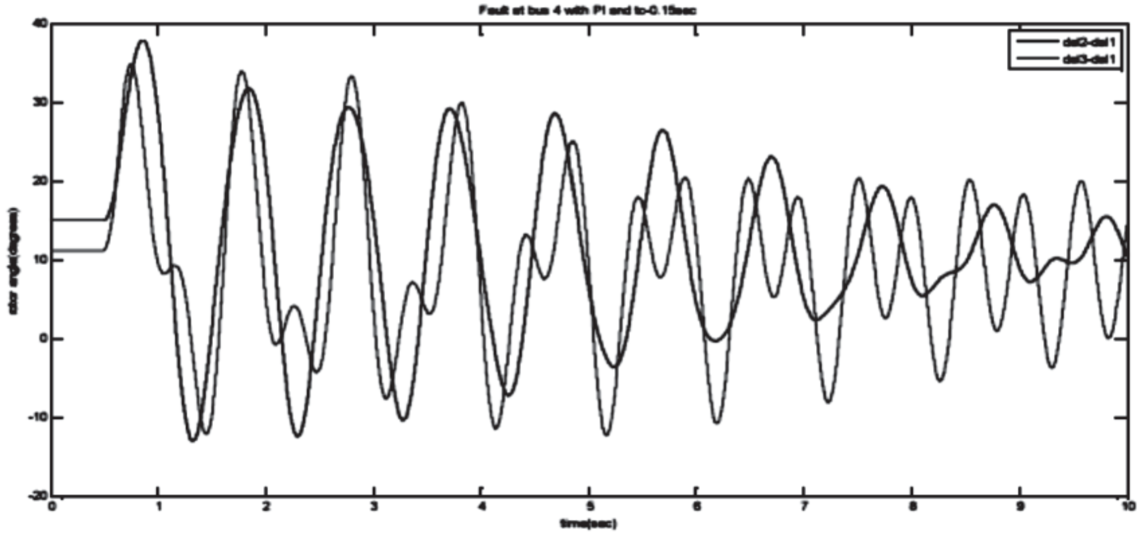


Fig.10. Power oscillations in line 5-7 with FOPI.

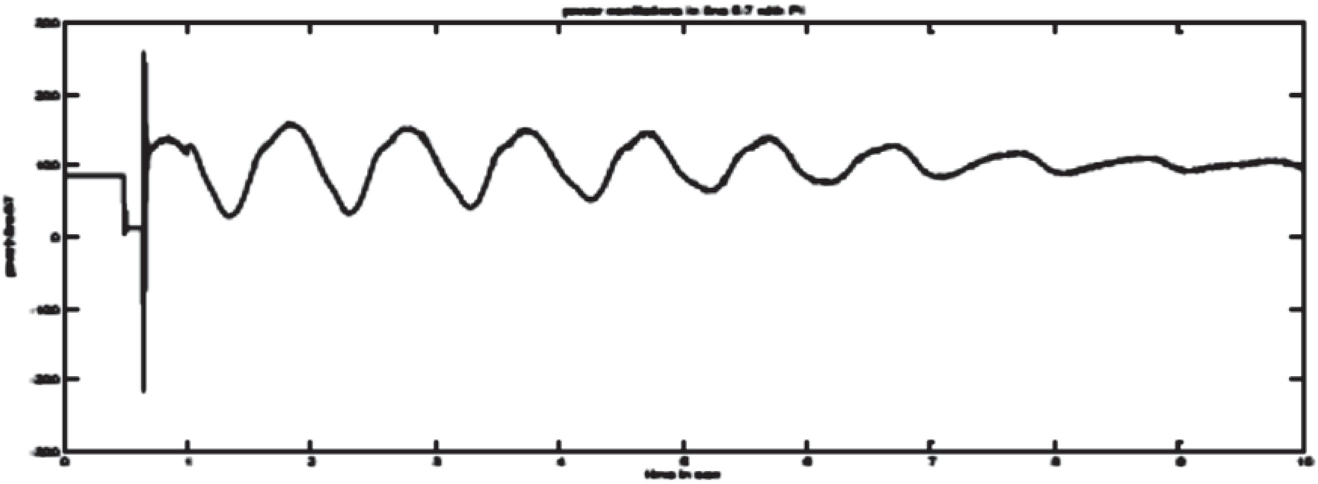


Fig. 11. Power oscillations in line 5-7 with PI.

The rotor angle variations of generator2 and generator3 with respect to first generator with PI controller is as shown in fig(8) and with fractional PI controller is as shown in fig(9).The power oscillations in the line 4-5 where TCSC is placed with PI controller is as shown in fig(10) and with FOPI controller is as shown in fig(11).

4. CONCLUSION

This paper has considered the implementation of fractional order PI controller to the TCSC for low frequency Power Oscillation Damping. The non-linear TCSC and generator model were implemented. The controller optimal design has been carried out using PSO. The proposed design has been tested on a WSSC 3 machine 9bus system under a severe disturbance at bus 4.

The TCSC is placed in the line 5-7. The results of the proposed controller were compared with conventional PI controller. The fractional order PI controller has better performance compared to integer order PI controller.The tuned parameters values gives good performance compared to any other values of parameters.

5. APPENDIX

1. Generator data

Generation	*Xd*	*H*
1.	0.0608	23.64
2.	0.1198	6.4
3.	0.1813	3.01

2. Transformer data

Generation	*X*
1.	0.0576
2.	0.0625
3.	0.586

3. Bus data

Bus No.	P_{GEN}	P_D	Q_D	V_p
1.	0.0	0.0	0.0	1.04
2.	1.63	0.0	0.0	1.025
3.	0.85	0.0	0.0	1.025
4.	0.0	0.0	0.0	1.025
5.	0.0	1.25	0.5	1.025
6.	0.0	0.9	0.3	1.025
7.	0.0	0.0	0.0	1.025
8.	0.0	1.0	0.35	1.025
9.	0.0	0.0	0.0	1.025

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