PSO Tuned Fractional Order PI Controller for Improvement of Transient Stability Improvement 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 systems. To damp the power oscillations one of the effective solutions is to use FACT Controllers besides controlling the steady state power flows in the lines also aids in damping of power oscillations. This paper gives the gains of Fractional order PI controller are optimized by using Particle Swarm optimization 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 power oscillation improvement in dynamic performance of the power system is demonstrated by comparing with the conventional PI controller. MATLAB/Simulink is used to simulate the Power System and TCSC Controllers.

Keywords: FOPI Controller, Multi Machine System, PSO, Power Oscillations, TCSC, Transient Stability

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. These 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.

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 been used 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. In fractional order PI controllers of integral operations of fractional order are used. Therefore, the control parameters in these controllers are the gains $K_p$ and $K_i$, and other additional parameter is the power of $S$.

In this paper a 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 Optimization is used. 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.

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2. Modelling of the Power System

In this paper a 3 machine 9 bus WSSC test power system is considered as shown in Figure 1 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.

2.1 Generator Model

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

\[
\frac{d\delta}{dt} = \omega_b (\omega - 1)
\]

\[
\frac{d\omega}{dt} = \frac{T_m - T_e - D(\omega - 1)}{M}
\]

The mechanical part of the synchronous machine represented in Figure 2.

2.2 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 infin-

ity) along with P-Q and voltage – current measurement blocks are used to develop π model of transmission line as shown in Figure 3.

2.3 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. Figure 4 shows the SIMULINK Model of a 3-Phase Load.

2.4 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 \(\alpha\). The TCSC layout configuration is as shown in Figure 5.
The Laplace Transform of the above equation is given by
\[ u(s) = (K_P s^\mu + K_I s^\lambda + K_D s^\mu) E(s) \] (4)

\[ u(s) = (K_P + s^{\lambda} + s^{\mu}) E(s) \] (5)

The parameters \( K_P, K_I, \) and \( \lambda \) of FOPI controller are not necessarily integers. The FOPI controller extends the conventional PI controller from a point to plane as shown in Figure 6(b).

### 2.7 Problem Formulation

The optimization problem is formulated on minimization of integral square error. The objective function is

\[ J = \int_0^{\tau_r} (P_{ref} - P_{line})^2 + \int_0^{\tau_r} (\text{Pref} - P_{line})^2 \] (6)

\( P_{line} \rightarrow \) Steady state Power flowing in the line where TCSC is placed.

\( P_{line} \rightarrow \) Power in the line when fault is on in the line where TCC is placed. Subjected to

- \( K_P \) min \( \leq \) \( K_P \) max
- \( K_I \) min \( \leq \) \( K_I \) max
- \( \lambda \) min \( \leq \) \( \lambda \) max

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

### 3. Simulation Results

The simulation of WSSC 3 machine 9 bus test Power System has been carried out in MATLAB/Simulink.
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 shown in Table 1.

**Table 1.** Optimal design of controller parameters

| S.No | PARAMETER | VALUE  |
|------|-----------|--------|
| 1    | $K_p$     | 1.2    |
| 2    | $K_i$     | 8.5    |
| 3    | $\Lambda$ | 0.45   |

![Figure 8](image1.png) Fault at bus 4 with PI and tc=0.15sec.

![Figure 9](image2.png) Fault at bus 4 with FOPI and tc=0.15sec.

![Figure 10](image3.png) Power oscillations in line 5-7 with FOPI.

**Figure 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 Figure 8 and with fractional PI controller is as shown in Figure 9. The power oscillations in the line 4-5 where TCSC is placed with PI controller is as shown in Figure 10 and with FOPI controller is as shown in Figure 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**

**Table 2.** Generators data

| Generator | $K_p$ | $H$  |
|-----------|-------|------|
| 1         | 0.099 | 27.64|
| 2         | 0.119 | 4.4  |
| 3         | 0.183 | 7.01 |

**Table 3.** Transformers data

| Transformer | $X$   |
|-------------|-------|
| 1           | 0.0478|
| 2           | 0.0625|
| 3           | 0.0568|
Table 4. Bus data

| Bus No. | P_{ REF } | P_0 | Q_0 | V_{ sp } |
|---------|-----------|-----|-----|---------|
| 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 | --      |
| 5       | 0.0       | 1.25| 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 | --      |

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