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Power system stability enhancement using tilt-integral-derivative controller (Tid)

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Abstract

This paper considers the stabilization of a synchronous machine connected to an infinite bus via a TID. The TID parameters are tuned using Optimum Tuning Algorithm. Simulation results are introduced with and without the proposed controller. Also, a comparison study is introduced when using classical PID and the results show that using of TID Controller is capable of guaranteeing the stability and performance of the power system better than the classical PID.

Keywords: PID Controller, SMIB System, Tilt-Integral-derivative controller (TID)

1. Introduction

The electrical energy is a primary prerequisite for economic growth. The demand for electrical energy has greatly increased due to large-scale industrialization. Modern power system operates under much stressed conditions because of growth in demand and deregulation of electric power system. This leads to many problems associated with operation and control of power systems. The economics of power generation has a major concern for the power utilities. Therefore, the power utilities always need new technology to solve its problems [1].

The complexity of power systems is continuously growing due to the increasing number of generation plants and load demand. Power systems are becoming heavily stressed due to the increased loading of the transmission lines and due to the difficulty of constructing new transmission systems as well as the difficulty of building new generating plants near the load centers. All of these problems lead to the voltage stability problem in the system [2].

An interconnected power system basically consists of several essential components. They are namely the generating units, the transmission lines and the loads.

During the operation of the generators, there may be some disturbances such as sustained oscillations in the speed or periodic variations in the torque that is applied to the generator. These disturbances may result in voltage or frequency fluctuation that may affect the other parts of the interconnected power system. External factors, such as lightning, can also cause disturbances to the power system. All these disturbances are termed as faults. When a fault occurs, it causes the generators to lose synchronism. With these factors in mind, the basic condition for a power system with stability is synchronism. Besides this condition, there are other important conditions such as steady-state stability, transient stability, harmonics and disturbance, collapse of voltage and the loss of reactive power [3].

The stability of a system is defined as the tendency and ability of the power system to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium [4]. There are many major blackouts caused by instability of a power system which illustrates the importance of this phenomenon [5]. The stability has been acknowledged as an important problem for secure system operation since the 1920‟s [6].

Damping of power system oscillation between interconnected areas is very important for the system secure operation. Power system stabilizer (PSS) is the most widely used device for resolving oscillatory stability problems [7], and to enhance the power system damping. Traditionally, lead-lag structures have been used as power system stabilizers. Many researches had been published explaining the ways of tuning the parameters of the lead lag controller. The methods used for tuning range from pole placement, to the more recent one using the heuristic optimization techniques such as Genetic Algorithms (GAs) [8], Tabu Search Algorithm (TSA) [9], Simulated Annealing (SA) [10], Particle Swarm Optimization (PSO) [11], and Bacteria Foraging Algorithm (BFA) [12].

The PID controller is a well-established type of controller and has been in use for a long time. Tuning PID controllers are traditionally tuned using standard techniques such as the root locus, and classical PID controllers which tuned by "Ziegler-Nichols" methods [13].

This paper produces a design method for the stability enhancement of a single machine infinite bus power system using TID which its parameters are tuned by Optimum tuning algorithm. The advantage of tuning the parameters of the optimum controller is that the possibility of including time-domain specifications such as rise time, maximum overshoot, damping ratio, and steady-state error.

2. Synchronous machine model

The system under study in this work considered as a single machine connected to an infinite bus system through a transmission line as shown in Fig. 1.

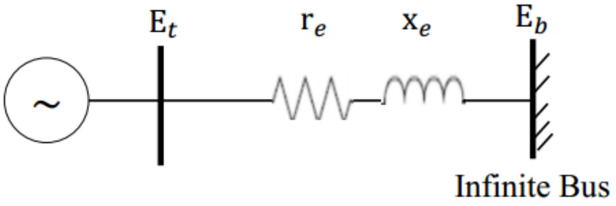

Fig 1: A single machine infinite bus power system

Fig. 2 shows the block diagram model of the system. This model is known as Heffron-Phillips model [14]. In this model, the synchronous machine is described by a 4th –order model. The relations in the block diagram apply to a two-axis machine representation with a field circuit in the direct axis but without damper windings. The interaction between the speed and voltage control equations of the machine is expressed in terms of six constants K1- K6 which depend on the real and reactive loading of the machine except for K3. The linearized equations describing the system of Fig.1 are given below:

$$\Delta\dot{\delta} = \omega_0 \Delta\omega$$

$$\Delta\dot{\omega} = \frac{1}{M}\left(-K_1\Delta\delta - D\Delta\omega - K_2\Delta\grave{E}_q\right)$$

$$\Delta\dot{\grave{E}}_q = \frac{1}{\acute{T}_{d0}}\left(-K_4\Delta\delta - \frac{\Delta\grave{E}_q}{K_3} + \Delta E_{fd}\right)$$

$$\Delta\dot{E}_{fd} = \frac{1}{T_e}\left(-k_e k_5\Delta\delta - k_e k_6\Delta\grave{E}_q - \Delta E_{fd} + k_e u\right) \quad (1)$$

Equation (1) can be rewritten in the state space form as given below:

$$\dot{x} = Ax + Bu \qquad (2)$$

Where A is the system matrix and B is the input matrix. The model of the system in the state space form without any controllers is obtained in the equation (3)

$$\begin{bmatrix}\Delta\dot{\delta}\\ \Delta\dot{\omega}\\ \Delta\dot{E}_q\\ \Delta\dot{E}_{fd}\end{bmatrix} = \begin{bmatrix} 0 & \omega_0 & 0 & 0\\ \frac{-K_1}{M} & 0 & \frac{-K_2}{M} & 0\\ \frac{-K_4}{T_{d\grave{0}}} & 0 & \frac{-1}{K_3 T_{d\grave{0}}} & \frac{1}{T_{d\grave{0}}}\\ \frac{K_e K_5}{T_e} & 0 & \frac{-K_e K_6}{T_e} & \frac{-1}{T_e}\end{bmatrix} \times \begin{bmatrix}\Delta\delta\\ \Delta\omega\\ \Delta E_q\\ \Delta E_{fd}\end{bmatrix} +$$

$$\begin{bmatrix} 0 & 0\\ \frac{1}{M} & 0\\ 0 & 0\\ 0 & \frac{K_e}{T_e}\end{bmatrix} \times \begin{bmatrix}\Delta P_m\\ \Delta V_{ref}\end{bmatrix} \qquad (3)$$

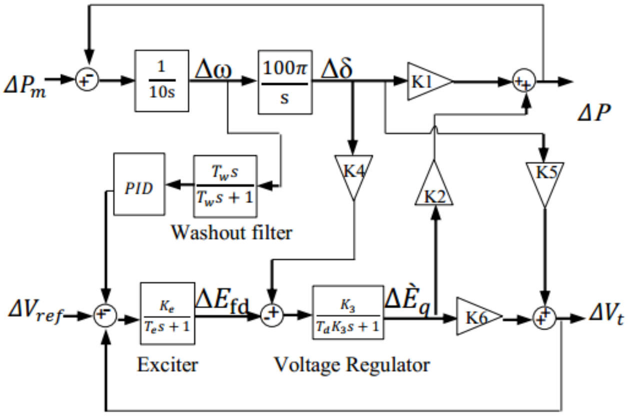

Fig 2: Heffron-Phillips block diagrom

3. Tilt-Integral-Derivative Controller (Tid)

It consists of three components tunable feedback loop control system which includes a PID compensator. The only difference from the conventional controller is that the proportional compensating part of the system is replaced with a more suitable compensator which is having a transfer function. The term 'Tilt' implies that it can provide a feedback gain as a frequency function which is shaped or tilted with respect to gain frequency of conventional compensation unit. The TID transfer function can be written as:

$$G(s) = K_t\,(1/s\,)^{1/n} + \frac{K_i}{s} + sK_d$$

Where, n is a nonzero real number. It is preferable to use 'n' as 2. The mathematical model of the above transfer function is shown in fig 3.

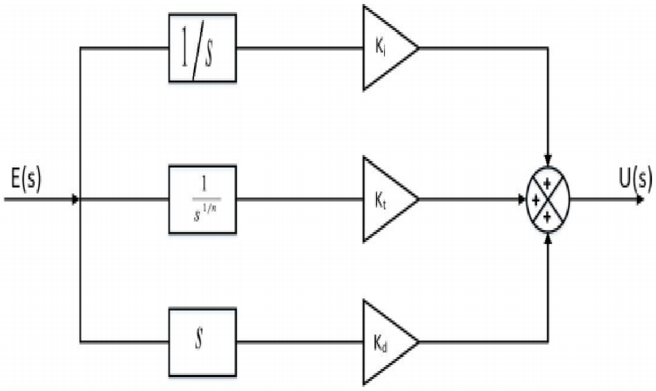

Fig 3: Mathematical model of TID

The effects of TID compensator can be summarized as:

- Simple Tuning
- Feedback control is improved
- Disturbance rejection ratio is improved
- Plant parameter variation has less effect on closed loop response

Optimum tuning algorithm is used for tuning the TID controller for stabilizing the frequency deviation response. The main parameter for tuning in TID controller is the tunable coefficient "n" and the other parameters (K_i and K_d) are the same as we used in conventional PID controller. Thus, the most optimum value of "n" is obtained by this technique for the lower percent of under/overshoot, settling time and steady state error.

4. Simulation Results

The proposed approach is implemented on the power system shown in Fig. 1. The comparative simulation results of the system for the deviations in the speed and the angle for a step disturbance in the mechanical input is shown in Fig. 4 and Fig. 5 without controller, with PID controller and with the proposed TID controller.

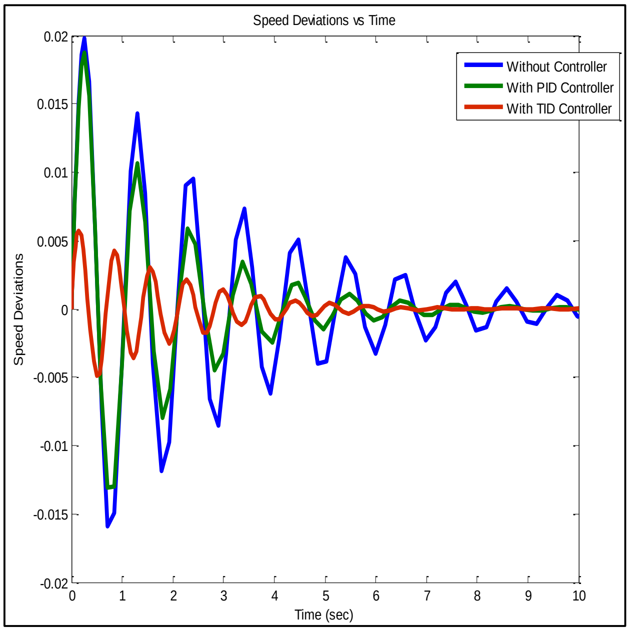

Fig 4: Speed Deviations for different controllers

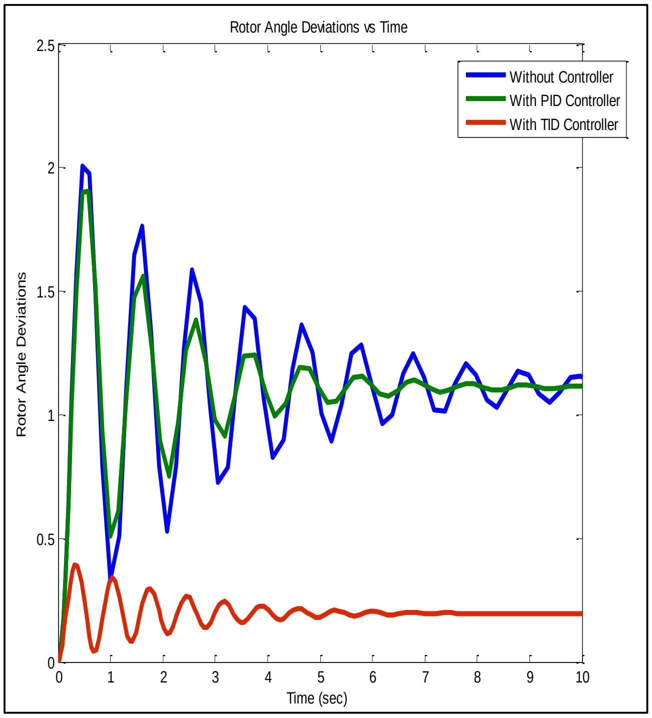

Fig 5: Rotor Angle Deviations for different controllers

5. Conclusion

In this paper the TID controller has an excellent response with small oscillation, while the PID controller response shows ripples and some oscillation before reaching the steady-state. TID controller shows the better control performance in terms of settling time and damping effect. Therefore it can be concluded that the performance of TID controller is better than conventional PID controller.

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