Study of electric power system oscillation damping

D Daryanto*, M Rif'an and G Purwanto
Electrical Engineering Education Study Program, Faculty of Engineering, Universitas Negeri Jakarta, Jakarta, Indonesia
*daryanto@unj.ac.id

Abstract. Operation of an electric power system through a transmission network that has limited capacity can cause system instability when the system is disturbance. This study aims to investigate the influence of dynamic loads on the electric power system oscillation damping. The interaction between the electric power system and dynamic load after and before interference is simulated through Simulink Matlab. Dynamic load models are developed from the Hill model based on load power responses due to voltage changes. While the electric power system model is based on a model developed by Demello, which is a Single Machine Infinite Bus System. Based on the two models, an overall block diagram is made that illustrates the interaction between dynamic loads and the electric power system. The results showed that there was an increase in the stability of the electric power system with dynamic load feedback and a decrease in the rotor angle and increase in voltage. So that it can be concluded that changes in dynamic load parameters affect the stability of the electric power system. This study can be used as a basis for studying the behavior of electrical power systems that experience greater disturbance with load feedback.

1. Introduction
The limited capacity of the transmission line to transmit electricity from the center of the power plant to the load centers can cause the steady state to be disturbed if the power system is disrupted. Milanovic in his study concluded that the poor reduction of electromechanical oscillations in electrical power systems was due to the existence of a number of synchronous generators connected to the rows and each swinging [1]. The stability of the power system is basically related to rotor angle oscillation. Fetissi Selwa examines the stability of the rotor angle based on simulation of power system for different values of fault clearing times. In the case of a default, the electrical power drops to zero as we explained previously. In this time, the circuit breaker opened the circuit was then closed again to clear the fault [2]. Whereas M. Chandra Prasad et al., examined the effect of response to nonlinearity on the dynamic stability of a single machine connected to an infinite bus (Single Machine Infinite Bus System) [3]. Research related to PSS has been carried out by researchers, as was done by Atabak Kolabi and Saeed Sofalgar who examined the performance of PSS by simulating it with Simulink [4], as well as Sidharta Panda using Simulink to model a single machine infinite-bus with TCSC for study stability of the electric power system [5]. According to Padiyar the change in generator output power is determined by the conditions of the transmission, distribution, and load installed on the electric power system [6]. This study investigates the effect of dynamic load changes on the reduction of the oscillation of the electric power system which is simulated by the Simulink program from Matlab for small disturbances. The results of this study can be used as a basis for regulating the electricity load on the consumer side and
the development of similar research for large disturbances in electric power systems with dynamic load feedback.

2. Method
The electric power system model in this study is a dynamic load model and synchronous generator model. Dynamic load models are developed from the Hill model based on load power responses due to voltage changes. The mathematical formula that describes the interaction between voltage and load power is realized by first-order differential equations. While the electric power system model is based on a model developed by Demello [7], which is a single electric generator connected to an infinite bus. The synchronous machine in this model is obtained from the classical Park model by assuming that the condition is balanced [8]; the stator coil resistance is ignored; the influence of saturation is ignored; the transmission network is assumed to be zero; and the local load is assumed the voltage depends only on the real power. Based on the two models, an overall block diagram is made that illustrates the interaction between dynamic loads and the electric power system by Simulink. The data in this study are in the form of graphical data on rotor angles and generator terminal voltages taken before and after the electrical power system has a fault in the form of a reference voltage drop of 10%. To compare the effect of dynamic loads on power system stability, data retrieval is performed on power systems that use and that do not use dynamic load feedback. While to investigate the effect of dynamic loads on the stability of the power system, data is taken at certain dynamic load parameter values.

3. Results and discussion
The results showed that a decrease in the Vreff reference voltage (as a disturbance) caused a decrease in generator terminal voltage and an increase in the rotor angle. The complete block diagram of the electrical power system is shown in figure 1 below:

![Block diagram of the electric power system with dynamic load feedback.](image)

Graphical data that illustrates changes in rotor angle due to a decrease in reference voltage between electric power systems that do not use dynamic load feedback and can be seen in Figure 2 below.
power system without dynamic load feedback  

power system with dynamic load feedback

**Figure 2.** The rotor angle response for a 10% decrease in reference voltage.

Decreasing the reference voltage results in the voltage entering the AVR (i.e. $\Delta E_{fd}$) decreasing, so that the output voltage of the field windings $\Delta E'q$ decreases. Figure 3 below is a block diagram illustrating the effect of decreasing the reference voltage on the field twist voltage.

\[
\Delta \delta \rightarrow K_4 \rightarrow KA \rightarrow \frac{v_{reff} - \Delta vt}{\Delta E'q} \rightarrow E_{fd} \rightarrow K_3 \rightarrow \Delta \delta \rightarrow \Delta \delta
\]

**Figure 3.** Relationship between $v_{reff}$ and $E'q$.

While the increase in rotor angle resulted in the output of block $K_5$ rising and the reduction in output of block $K_6$ due to the effect of demagnetization due to the reaction of the anchor. Based on the equation $\Delta vt = K_5 \Delta \delta + K_6 \Delta E'q$, with $\Delta E'q$ which is negative and $K_6 > K_5$ (from the calculation of $K_5 = 0.1483$ and $K_6 = 0.5220$), the generator terminal voltage will decrease. Another result of the reduction in reference voltage ($E_{reff}$) is the increase in electric torque $\frac{\Delta T_T}{\Delta E'q}$ and rotor speed $\Delta \omega$. Based on the equation $\Delta \delta = \omega b (\Delta \omega - 1)$, the increase in rotor speed ($\Delta \omega$) will reduce synchronous torque so that the rotor angle will rise. Block diagram in Figure 4 below is the relationship between voltage field winding and rotor angle with the generator output voltage changes.

\[
\Delta \delta \rightarrow K_6 \rightarrow \Delta \delta \rightarrow \Delta v_T \rightarrow -\Delta E'q
\]

**Figure 4.** Relationship between $\Delta E'q$ and $\Delta \delta$ with $\Delta vt$. 
From the simulation results in this study, it turns out that in a power system that uses dynamic load feedback, oscillation is shorter than a power system that does not use dynamic load feedback. The stability of the power system is affected by changes in load parameters. Changes in dynamic load parameters cause the torque entering the mechanical loop consisting of synchronizing torque and dampers to change. The research of Ahmed Mohammed, Ishag and Eisa B. M. Tayeb found that the generator will remain stable if it supplies power with a power factor that matches its capabilities. While the machine delivers rated power at p.f., it is found to be stable. But when the power factor is slightly leading (0.985), the generator becomes dynamically unstable. But under light load condition (0.5 p.u. loading) the generator becomes dynamically stable [9].

The concept of synchronizing torque and dampers is based on an analysis of electric power systems assuming that the generator rotor oscillates in a sinusoidal manner, stabilizing torque opposite the rotor motion. The torque component that is in phase with the change in rotor speed or speed change is called synchronizing torque, while the torque component which is in phase with the slip \( \Delta \delta \) or \(-j\Delta \omega\) is called the torque damper. The behavior of synchronous machine oscillations basically follows small disturbances related to electric torque components with coefficients

\[
K_1 = \frac{\Delta T}{\Delta \delta} \Delta \delta; \quad K_2 = \frac{\Delta T}{\Delta \delta} \Delta \omega
\]

The parameter \( K_4 \) is generated by losses in field windings calculated based on demagnetization due to changes in the rotor angle. If the addition of the rotor angle causes an increase in the \( d \)-axis component anchor current and a reduction in the magnetic flux, the \( K_4 \) parameter becomes positive. The negative parameter \( K_4 \) occurs if \( \frac{di_d}{d\delta} \) negative, that is when the value

\[
\{v_{i0}^2 + (i_{d0}v_{q0} + i_{q0}v_{d0} + v_{i0}^2) \} \left( i_{d0}v_{d0} - i_{q0}v_{q0} \right)
\]

is negative. This results in the resulting torque not as fast as the speed and produces a negative attenuation. In this study the decrease in rotor angle and system oscillation of electric power is determined by the power of the accelerator. This is based on synchronous machine swing equations, namely:

\[
\frac{d^2 \delta}{dt^2} = T_a = T_m - T_e
\]

in fixed \( T_m \), the change in rotor angle is only determined by the electric torque that enters the rotor system. The smaller the accelerator torque the more stable the electric power system, as well as the smaller rotor angle. Additional signals coming from \( K_7 \Delta P_d \) will increase the electric torque \( \Delta T_e \), so that accelerator torque which is the difference between the torque produced by the governor and the electric torque \( (\Delta T_m - \Delta T_e) \) decreases. This accelerator torque reduction will cause the rotor angle to drop. Therefore, in a power system that utilizes dynamic loads as feedback, the oscillation and amplitude of the rotor angle will decrease. Decreasing the rotor angle results in a rise in the voltage generated by the generator so that the terminal voltage also rises. This is due to the effect of demagnetization due to decreased anchor reaction and an additional signal \( K_{11} \). Changes in torque from additional signals are determined by dynamic load parameters. The \( \text{nps} \) change results in a change in the amplitude and power response to reach a steady state. The addition of the \( \text{nps} \) value will add \( \Delta P_d \) so that the accelerator power will decrease and the ambush torque increase, this results in a reduced rotor angle. While the effect of \( \text{nps} \) on terminal generator voltage changes is based on the equation: \( \Delta v = K_5 \Delta \delta + K_6 \Delta E'q + K_{11} \Delta P_d \), the increase in \( \text{nps} \) will result in a reduced effect of demagnetization due to the reaction of the anchor, besides the signal decrease coming from block \( K_5 \Delta \delta \) and \( K_6 \Delta E'q \) and the increase in the signal from the \( K_{11} \Delta P_d \) block. The effect of \( \text{nps} \) changes on rotor oscillation is based on load response after a disturbance occurs. From the power response to the voltage change in the form of a step it turns out that to achieve steady state depends on the ratio of \( \text{npt} \) to \( \text{nps} \). Takata in his study concluded that changes in rotor angle are influenced by dynamic loads. Furthermore, dynamic loads can reduce the coupling coefficient and can
increase the demagnetization effect due to rotor angle deviation [10]. The stability of the voltage depends on the characteristics of the static load and for a constant load impedance, the power system will be stable at all points of work. Klein in his study concluded that nonlinear loads both static and dynamic affect the reduction of oscillation of electric power systems consisting of many synchronous machines [11]. Loading conditions will affect the damping torque. Furthermore it was concluded that the dampening torque produced by SVC increases linearly if the load conditions increase [12]. Load parameters in transient conditions (nq) affect the stability of the electric power system. At the peak load the increase in value of nq will cause a decrease in the stability of the electric power system. But for the condition of 80% of the peak load, the stability increases. The change in oscillation time also follows the change in nps, which is determined by the ratio of npt to nps. At a fixed nps value, the change in npt does not cause the rotor angle or terminal generator voltage to change. This is because the value in a steady state does not change. The behavior of the electric power system if the change lies in the time constant oscillating rotor angle and voltage terminal, while the amplitude remains. Based on the power response, the greater the Tp value the longer the power system reaches its steady state. The amplitude of the steady state is not affected by the change in time constant Tp. Determining the value of the time constant depends on the type of load. For loads that are dominated by induction machines, the range of Tp is up to a few seconds. While the tap changer load and other control equipment, range Tp to minutes and for a range of heating loads of up to several hours.

4. Conclusion

- Dynamic load parameters affect the stability of the electric power system.
- The longer the load takes (Tp) to return to a steady state, the longer the power system reaches its stability.
- The increase in the price of the voltage exponent in a steady state (nps) will decrease the rotor angle, but the terminal voltage rises.
- Changes in npt and Tp will not affect the amplitude of the rotor angle and terminal generator voltage.
- The stability of the power system for changes in dynamic load parameters is determined by comparison, the larger or the smaller the comparison the longer the electric power system reaches its stability.

References

[1] Milanović J V and Hiskens I A 1995 Effects of dynamic load model parameters on damping of oscillations in power systems *Electric Power Systems Research* 33(1) 53-61
[2] Selwa F 2015 The Transient Stability Study of a Synchronous Generator Based on the Rotor Angle Stability *International Journal of Electrical and Computer Engineering (IJECE)* 5(6) 1319–1327
[3] Prasad M C 2013 Effect Of Nonlinearity On Dynamic Stability Of A Single Machine Infinite Bus System *International Journal of Engineering Research & Technology (IJERT)* 2(3)
[4] Kolabi A and Sofalgar S 2012 Application of Sliding Mode Control in Single Machine Infinite Bus System (SMIB) *Australian Journal of Basic and Applied Sciences* 165-174
[5] Panda S and Padhy N P 2007 MATLAB/SIMULINK Based Model of SingleMachine Infinite-Bus with TCSC for Stability Studies and Tuning Employing GA *World Academy of Science, Engineering and Technology International Journal of Energy and Power Engineering* 1(3) 560-569
[6] Padiyar K R 2008 *Power System Dynamics Stability and Control* (BS Publications, Hyderabad)
[7] Demello F P 1969 Concepts of Synchronous Machine Stability as Affected by Exitation Control *IEEE Trans. Power System* 316-329
[8] Park R H 1929 Two-reaction Theory of Synchronous Machines –Generalized Method of Analysis – Part I *AIEE Trans.*, 716-727
[9] Ishag A M and Tayeb E B M 2017 Design of power system stabilizer for damping power system oscillations *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)*, 2278-1676

[10] Takata S 1981 Effects Of Induction Machine Load On Power System *IEEE Trans. Power Apparatus and System* 2555-2565

[11] Klein M 1991 A Fundamental Study Of Inter-Area Oscillations In Power Systems *IEEE Trans. Power System* 914-921

[12] Wang L 1993 A comparative study of damping schemes on damping generator oscillations *IEEE Trans. Power System* 613-619