Power System Oscillation Damping Model

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Abstract—Operating electrical power system in a large scale can disturb the stability of the rotor of the synchronous generator on the generating side which can result in failures. This research is intended to investigate the effect of dynamic load parameter on power system oscillation damping. The behavior of power system after the disturbance on various value of dynamic load parameter are shown with Simulink Matlab simulation. The developed power system oscillation model consists of a dynamic load and a synchronous generator. According to the model, a block diagram is created. Thus, it can depict the interaction between the dynamic load and the power system. The results of this research show that the drop of reference voltage results in the increase of rotor angle (\(\Delta \delta\)) and the decrease of terminal voltage (\(\Delta V_t\)). If the ratio of transient exponential constant (\(n_{ps}\)) with the static exponential constant (\(n_s\)) is equal to one, the curve of \(\Delta \delta\) and \(\Delta V_t\) will not oscillate. If \(n_{ps}/n_s < 1\), \(\Delta \delta\) curve will oscillate above the steady state value and \(\Delta V_t\) will oscillate below the steady state value. Furthermore, if \(n_{ps}/n_s > 1\), \(\Delta \delta\) curve will oscillate below the steady state value and \(\Delta V_t\) will oscillate above the steady state value. Moreover, the higher \(n_{ps}\) the value of \(\Delta \delta\) becomes higher and the value of \(\Delta V_t\) becomes smaller. The last point is that the higher \(T_p\), the transition of \(\Delta \delta\) and \(\Delta V_t\) into steady state become longer.

Keywords—oscillation damping, dynamic load parameter, power system, synchronous generator

I. INTRODUCTION

Operating electrical power system in a large scale can disturb the stability of the rotor of the synchronous generator on the generating side which can result in failures. The instability of synchronous generator’s rotor is basically resulted by a disturbance of connected synchronous generators. Several methods have been done to damp the oscillation, such as generator modelling, AVR addition, and governor installation. However, the effect of load addition to the power system stability has not been fully considered. Although it was proven that load affects on the analysis results, as shown on the research by Zhou [1]. His study concluded that load significantly affects oscillation. Takata [2], in his research, concluded that the shift of rotor angle is affected by dynamic load. Furthermore, dynamic load can decrease the value of synchronizing coefficient and can increase the effect of demagnetization because of the rotor angle shifting. Wang [3], said that voltage stability depends on static load characteristic. For loads with constant impedance, the power system is stable on every working point. Meanwhile, the research of Klein [4] concluded that nonlinear loads, static and dynamic loads, affect power system oscillation damping. Price [5] said that load parameter on transient condition (\(n_q\)) affects power system stability, especially on peak load. The research by Vournas [6] concluded that voltage stability depends on static load characteristic.

Power system stability is the dynamic of rotor angle that resulted from the disturbance emerging from input alteration in the form of the mechanical power from the prime mover, and the electrical power. Thus, the output power determines wether the rotor will accelerate, decelerate, or remain on its synchronous speed. Anderson [7] said that the change of power is determined by the condition of transmission line, distribution line, and the load connected on the power system. Therefore, a disturbance will change the output of the generator rapidly and will create electromagnetic transition. In this condition, load’s consumed power will affect the balance of generator and the load, affecting in the rotor angle shifting and the system swing stability. The electrical power flow is affected by load characteristic on the power system. This research will investigate the effect of dynamic load parameter on power system oscillation damping with Simulink Matlab simulation.

II. METHODS

The behaviour of power system after a disturbance on several value of dynamic load parameter is shown through a Simulink Matlab simulation. The developed model consists of a dynamic load and a Single Machine Infinite Bus (SMIB) system from the development by Demello [8] dan Park [9]. The mathematical model that depicts the interaction between dynamic load with the power system for the damping model is derived into a first order differential equation. Block diagram as shown in Figure 1 is created from the equation.
The behaviour of power system which is affected by dynamic load parameter changing is simulated with Simulink Matlab. Besides using a block diagram shown in Figure 1, a simulation with real condition can be done with a model in Figure 2.

III. RESULTS AND DISCUSSION

The drop of reference voltage results in the increase of rotor angle. This phenomenon happens because the drop of reference voltage causes the drop of $E_{fd}$ field from the exciter, decreasing $E_{q}'$ field from the field winding in the stator, increasing the rotor angle. If the generator is not connected to a dynamic load, $\Delta \delta$ will oscillate. However, the addition of dynamic load eliminates the oscillation and the rotor can achieve stability faster. In this case, according to David J. Hill [10], there two conditions, which are transient state and steady state. Those conditions happen because the dynamic load increases electric power $P_e$. Thus, the value of acceleration $P_a$ in the swing equation (1) decreases. This phenomenon matches with the statement from Padiyar [11] who said that the change of generator output power ($P_e$) is determined from transmission line, distribution line, and the load connected to the system. The decrease of $P_a$ decreases the shifting speed of rotor angle. This behaviour is realized into a feedback system from the dynamic load block diagram into the field winding, rotor, and exciter. The results of the study by Monsour et al. [12] found that a power system that does not use a power oscillation damper (POD) will decrease its dynamic stability, and the reverse will improves the dynamic performance of the system through increasing the system damping, decreasing the overshoots, and decreasing the settling time. In line with this, Hadi PS [13] concluded that POD has the potential to improve stability with a reduced response deviation of 66%, steady state time of 12 seconds (decreasing), although the rise time is longer by 700 ms. Erik [14] in his research concluded that loads influence the system damping differently depending on which characteristic the load. The static and dynamic load components in the composite load model provide the most accurate oscillation attenuation results among other load models [15].

Thus, the oscillation is damped. Figure 3 shows the response of rotor angle ($\Delta \delta$) when the reference voltage is being dropped.

Meanwhile, Figure 4 shows the response of terminal voltage ($\Delta V_t$) on the drop of reference voltage.

A. The Effect of $n_p$ Variation

The power system dynamic according to Anderson [16] is divided into two different phases, those are when the rotor is accelerated and decelerated. Meanwhile, the results of research by Nanang et al. found that the increase in system attenuation depends on the load regulation [17]. Asha Anu Kurian et al. [18] concluded that electromechanical oscillation damping
capability STATCOM-POD reduces system losses, improves system usage and increases the loadability of the system. The response of rotor angle ($\Delta \delta$) when the reference voltage drops with the variation of $n_{pt}$ and the same value of other parameters ($n_{ps}=2$ and $T_p=2$) is shown on Figure 5. The change of $n_{pt}$ changes the value of $n_{pt}/n_{ps}$. The rotor angle becomes stable instantly if the value of $n_{pt} = 2$, or we can say $n_{pt}/n_{ps}=1$. Meanwhile, the value of $n_{pt}/n_{ps} > 1$ makes the oscillation still happens and stops below the steady state. Then, it goes up into the steady value. If the value of $n_{pt}/n_{ps} < 1$, the oscillation will stop above the steady value and will go down into the steady value. The closer $n_{pt}/n_{ps}$ into the value of 1, the closer the $\Delta \delta$ graph on the oscillation point to the steady value.

In these simulation of $n_{pt}$ variation, $\Delta \delta$ and $\Delta V_t$ needs approximately 8 seconds to achieve stability with the value of $n_{pt}/n_{ps} \neq 1$. This phenomenon is related to the value of $T_p$ and will be discussed later. However, the small gap between the transient value and the steady state value makes this phenomenon insignificant.

B. The Effect of $n_{ps}$ Variation

Figure 7 shows the response of rotor angle ($\Delta \delta$) when a drop in reference voltage happens with the variation of $n_{ps}$ and the other parameters of dynamic load remains the same ($n_{pt}=2$ and $T_p=2$).

The change of $n_{ps}$ results in the overall shift of $\Delta \delta$. This phenomenon happens because dynamic load function has the variable of $n_{ps}$ as a multiplier. Hence, the increase of $n_{ps}$ raises the value of $\Delta \delta$. With the rise of $n_{ps}$, the value of stator field will be increased, therefore, increasing the rotor angle. The difference of $n_{ps}$ with the addition value of 0.25 in every case turns out to not giving the same increase amount of $\Delta \delta$. The increase in $\Delta \delta$ gets smaller as the $n_{ps}$ gets bigger.

Figure 8 shows the response of terminal voltage ($\Delta V_t$) when a drop in reference voltage happens with the variation of $n_{ps}$ and the other parameters of dynamic load remains the same ($n_{pt}=2$ and $T_p=2T_p=2$).
The change of $n_{pt}$ causes in the overall shift of $\Delta V_t$. This phenomenon occurs because dynamic load function has the variable of $n_{pt}$ as a divider. Hence, the increase of $n_{pt}$ decreases the value of $\Delta V_t$. The rise of $n_{pt}$ has a meaning of the increase of the load, increasing the load current. Hence, the power loss will increase and the value of terminal voltage will drop. The difference of $n_{pt}$ with the addition value of 0.25 in every case turns out to not giving the same decrease amount of $\Delta V_t$. The decrease in $\Delta V_t$ gets smaller as the $n_{pt}$ gets bigger.

C. The Effect of $T_p$ Variation

Figure 9 and 10 show the response of rotor angle ($\Delta \delta$) and terminal voltage ($\Delta V_t$) when a drop in voltage reference happens with the variation of $T_p$ and the same value of other dynamic load parameters ($n_{pt}=1$ and $n_{ps}=2$).

IV. CONCLUSION

The drop of reference voltage increases the rotor angle ($\Delta \delta$) and decreases the terminal voltage ($\Delta V_t$). The rotor angle and the terminal voltage become stable instantly if the value of $n_{pt}/n_{ps}=1$. Otherwise, $\Delta \delta$ and $\Delta V_t$ will oscillate. If the value of $n_{pt}/n_{ps} < 1$, the oscillation of $\Delta \delta$ and $\Delta V_t$ will stop, consecutively, above and below the steady value and gradually reach the steady value. If the value of $n_{pt}/n_{ps} > 1$, the oscillation of $\Delta \delta$ and $\Delta V_t$ will stop, consecutively, below and above the steady value and gradually reach the steady value. The increase in $n_{pt}$ will result in the rise of $\Delta \delta$ and the fall of $\Delta V_t$. Finally, the higher value of $T_p$ will make the transition of $\Delta \delta$ and $\Delta V_t$ into steady state become slower.

ACKNOWLEDGMENT

The authors wish to thank Faculty of Engineering in Universitas Negeri Jakarta for providing 2020 BLU POK Research Funds of this work.

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