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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 (Δδ) and the decrease of terminal voltage (ΔVt). If the ratio of transient exponential constant (n_{pt}) with the static exponential constant (n_{ps}) is equal to one, the curve of Δδ and ΔVt will not oscillate. If $n_{pt}/n_{ps} < 1$, Δδ curve will oscillate above the steady state value and ΔVt will oscillate below the steady state value. Furthermore, If $n_{pt}/n_{ps} > 1$, Δδ curve will oscillate below the steady state value and ΔVt will oscillate aboce the the steady state value. Moreover, the higher n_{ps}, the value of Δδ becomes higher and the value of ΔVt becomes smaller. The last point is that the higher T_p, the transition of Δδ and ΔVt 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 basicly 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. Meanwhlide, 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.

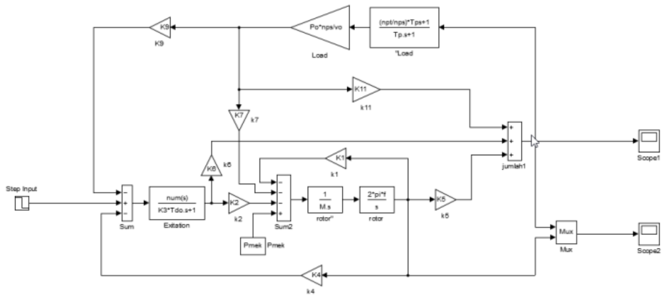

Fig. 1. Block diagram of dynamic load-SMIB interaction.

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.

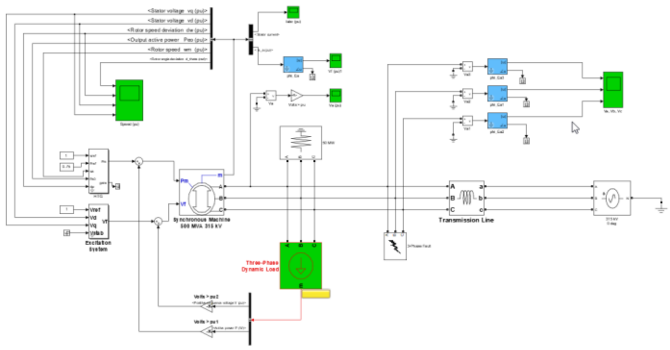

Fig. 2. The interaction between dynamic load with SMIB using Simulink.

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 Eq' field from the field winding in the stator, increasing the rotor angle. If the generator is not connected to a dynamic load, Δδ 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 Pe. Thus, the value of accelartion Pa 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 Pa 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 (Δδ) when the reference voltage is being dropped.

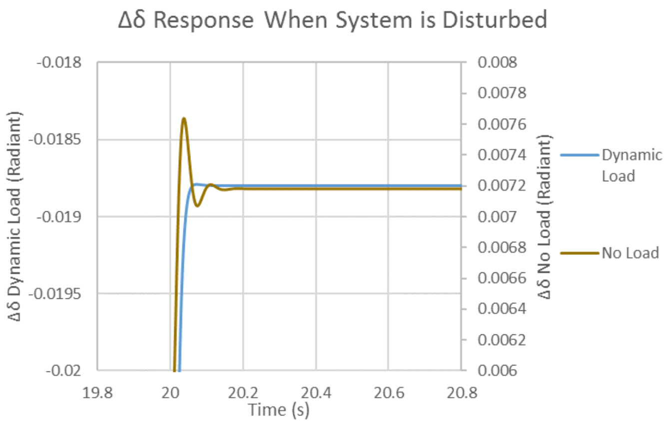

Fig. 3. The transition of Δδ on disturbance.

Meanwhile, Figure 4 shows the response of terminal voltage (ΔVt) on the drop of reference voltage.

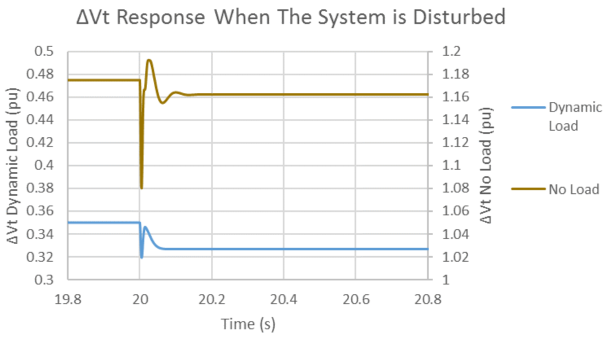

Fig. 4. The transition of ΔVt on disturbance.

A. *The Effect of n_{pt} 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 (Δδ) 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 Δδ graph on the oscillation point to the steady value.

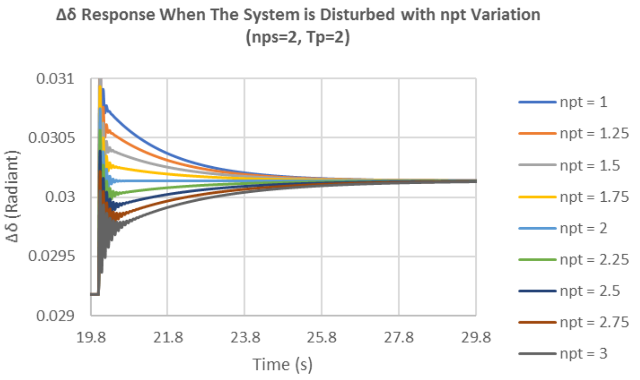

Fig. 5. The effect voltage reference drop on Δδ with npt variation.

Figure 6 is the terminal voltage response (ΔVt) when reference voltage drops with the variation of n_{pt} and the same value of other dynamic load parameters (n_{ps}=2 and T_p=2)

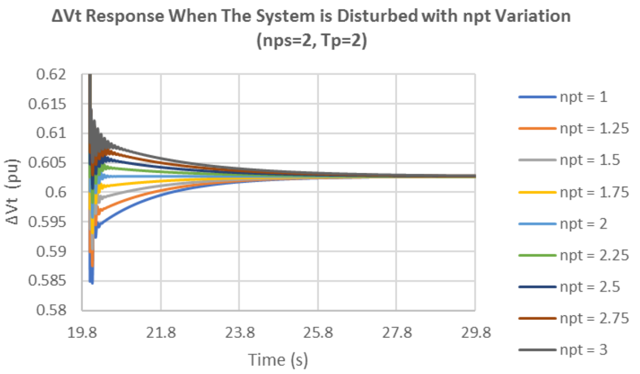

Fig. 6. The effect voltage reference drop on ΔVt with npt variation.

The opposite response happens in the case of ΔVt when in the case of npt/nps < 1, oscillation of ΔVt will stop below the steady value and will gradually increase. In the case of $n_{pt}/n_{ps} >$ 1, oscillation of ΔVt will stop above the steady value and will gradually decrease. The closer n_{pt}/n_{ps} into the value of 1, the closer the ΔVt graph on the oscillation point to the steady value.

In these simulation of n_{pt} variation, Δδ and ΔVt 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 Tp 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 (Δδ) 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).

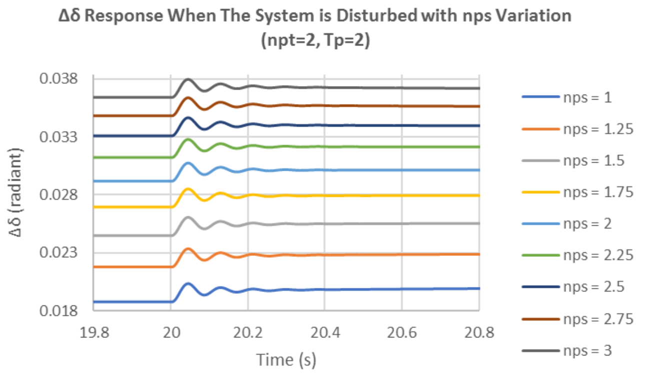

Fig. 7. The effect voltage reference drop on Δδ with n_{ps} variation.

The change of n_{ps} results in the overall shift of Δδ. 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 Δδ. 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 Δδ. The increase in Δδ gets smaller as the n_{ps} gets bigger.

Figure 8 shows the response of terminal voltage (ΔVt) 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).

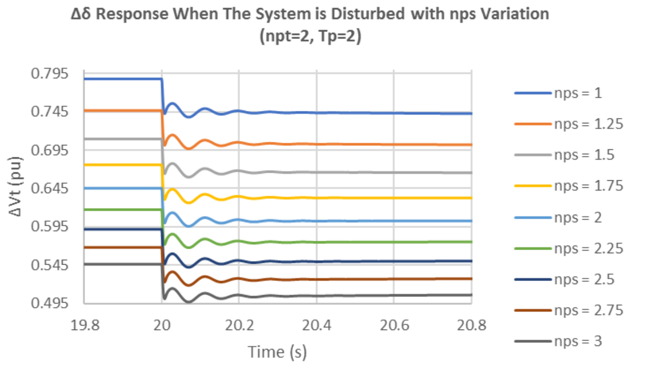

Fig. 8. The effect voltage reference drop on Δδ with n_{ps} variation.

The change of n_{ps} causes in the overall shift of ΔVt. This phenomenon occurs because dynamic load function has the variable of n_{ps} as a divider. Hence, the increase of n_{ps} decreases the value of ΔVt. The rise of n_{ps} 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_{ps} with the addition value of 0,25 in every case turns out to not giving the same decrease amount of ΔVt. The decrease in ΔVt gets smaller as the n_{ps} gets bigger.

C. The Effect of Tp Variation

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

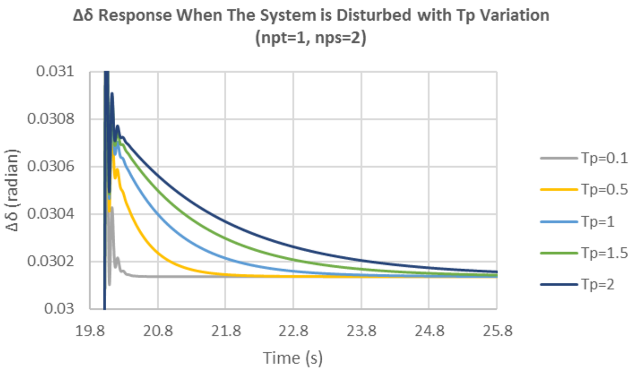

Fig. 9. The effect voltage reference drop on Δδ with Tp variation.

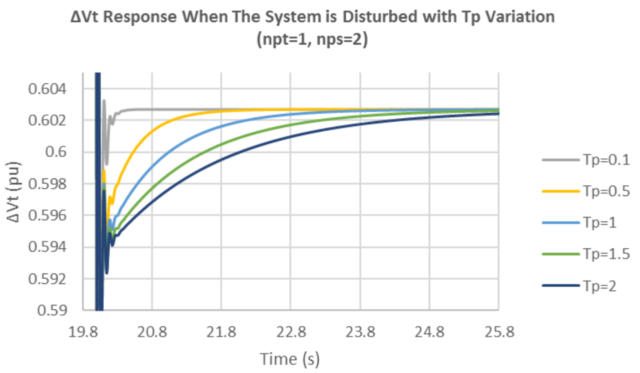

Fig. 10. The effect voltage reference drop on ΔVt with Tp variation.

As a time constant, Tp is defined as the time needed for Δδ and ΔVt to achieve steady state. On Figure 9 and 10, increasing the value of Tp makes the transient of Δδ dan ΔVt become slower. With the value of Tp=0,1, the transitions need less than 0.5 second while with the Tp=2, the transitions need more than 5 seconds to achieve steady state.

IV. CONCLUSION

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

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