INVESTIGATION ON TRANSIENT RESPONSE OF SYNCHRONOUS MACHINE

Hazwani binti Arshad
Faculty of Electrical Engineering
Universiti Teknologi MARA (UiTM)
40450 Shah Alam, Malaysia
hazwaniarshad@gmail.com

Abstract – **This paper presents the investigation on transient response and stability of higher orders model of synchronous machine in a typical power system by using the PID controller. The PID controller aims to improve the dynamic response as well as to reduce or eliminate the steady-state error in the machine. The other factors such as using different types of turbines and various component parts within the power system are briefly discussed. A transfer function simulation model is developed by using the MATLAB Simulink software. The fourth orders of synchronous machine model are implemented for better understanding of the machine response under sudden large disturbances during transient conditions. Simulation results are presented in order to get stable system of synchronous machine by using the designed controller.**

Keywords - ***PID controller, AVR system, AGC system, excitation system, transfer function***

I. INTRODUCTION

The problem of the maintenance of constant voltage covers an extremely large field, from the control of the busbar voltage of a power station to the supply of constant voltage to small electronic instruments [1]. The overall accuracy of a system is primarily decided by how correctly the synchronous machines within the system are modeled. Generally, the use of a second order model of synchronous generator for simulation is inadequate for transient study as units of microseconds are crucial to the performance of the machine. Hence, there is a need to analyze exclusively the model of synchronous machine in the power system. This paper demonstrates the simulation of the transient response of synchronous machine connected to an infinite bus using Matlab Simulink.

There are three main categories of stability analysis. There is namely steady state stability, transient state stability and dynamics stability. Transient state stability will be focused in this paper which refers to as capability of a power system to maintain synchronism when subjected to a severe and sudden disturbance. This disturbance in the network connections is brought about by faults and by sudden large increment of loads.

Currently Matlab/ Simulink is a widely used simulation tool for dynamic systems. A wide range of components will be involved for modeling large dynamic systems, for example, power system, including prime movers, generators, transformers, power electronic converters. Matlab/ Simulink is an effective tool for such applications [2]. The objective of the control strategy is to generate and deliver power in an interconnected system as economically and reliably as possible while maintaining the voltage and frequency within permissible limits.

The aim of this paper is to produce a program that can closely simulate the operation of the synchronous machine using a range of transfer functions in order to determine the transient response for any synchronous machine.

II. METHODOLOGY

The overall system of synchronous machine consist of speed governor control, automatic voltage regulator (AVR) control, effects of using different types of prime mover (turbine), Proportional Integral Derivative (PID) control for excitation system and Direct-quadrature axis theorem.

A. Simulation model specifications

There are some assumptions made prior to the design of the simulation model:

(i) A single turbine is used and will produce a constant torque with a constant speed maintained during steady state operation (at synchronous speed).
(ii) The output terminals of the generator are connected to infinite bus that has constant load.
(iii) Only the basic and linear models of the power system components (i.e. turbines, feedback sensors, exciter,

governor etc) will be used except for the model of synchronous generator.

(iv) The time constants of the synchronous machine used in this paper are assumed to be the optimum time constants extracted based on the values given in Walton [3].

(v) The investigations beyond fourth order model are outside the scope for this paper.

B. Determination of Synchronous Machine Parameters

There are several types of testing and analytical methods been used to obtain better models of synchronous machine [4]:

(i) Enhance sudden short-circuit tests,

(ii) Stator decrement test

(iii) Frequency-response tests which consist of Standstill frequency response (SSFR) and Open-circuit frequency response (OCFR).

It is well known that the techniques for extracting the parameters from the sudden short circuit test are only suitable for second order models. Frequency response tests have now become accepted as an alternative to sudden short circuit tests for the determination of the parameters for higher order of synchronous machines for transient studies [5]. Thus, the optimum time constants for fourth order synchronous machine were extracted from SSFR tests.

All the values involved were in per unit. The range of values of gain and time constants were typically values gathered from papers, articles and books [3-7] and the chosen values are the values adjusted in order to produce the better response. The optimum time constants which indicate the values in the rotor circuits are extracted from the result produced by Walton [3]. With all the four rotor branches being considered, they represent a fourth order model of the synchronous generator.

III. SIMULATION MODEL DESIGN

Since the conventional simulation model of the machine is a second order model, there is a need to explicitly redefine it. As shown in Fig.1 is the fourth order model that will be used in the simulation.

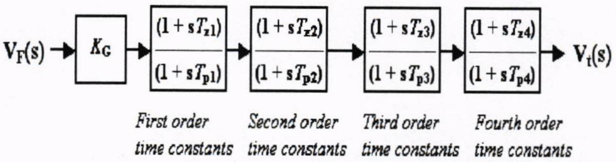

Fig. 1: Fourth order model synchronous machine block diagram

A. Automatic Generation Control (AGC)

The primary objectives of automatic generation control (AGC) are to regulate frequency to the specified nominal value and to maintain the interchange power between control areas at the scheduled values by adjusting the output of the selected generators. This function is commonly referred to as load-frequency control (LFC) [4].

In order to reduce the frequency deviation to zero, rest action has been provided. The rest action can be achieved by introducing an integral controller to act on the load reference setting to change the speed set point. The integral controller increases the system type by 1 which forces the final frequency deviation to zero. The integral controller K_I has been adjusted to obtain satisfactory transient response. The equivalent block diagram of AGC shown in Fig. 2,

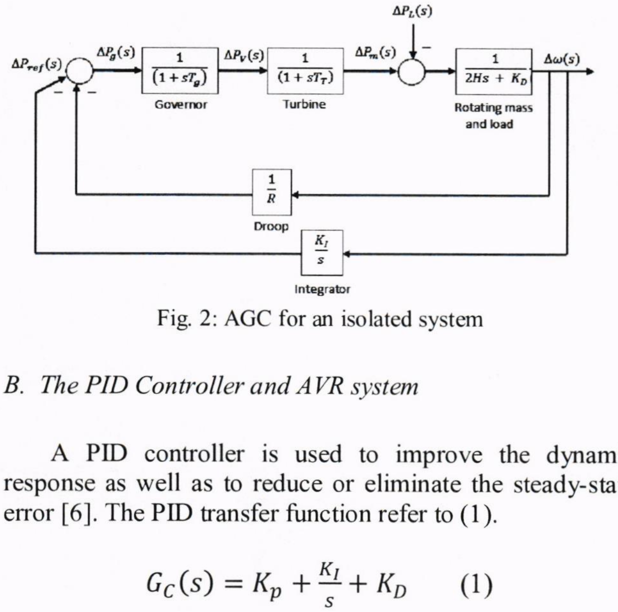

Fig. 2: AGC for an isolated system

B. The PID Controller and AVR system

A PID controller is used to improve the dynamic response as well as to reduce or eliminate the steady-state error [6]. The PID transfer function refer to (1).

$$G_C(s) = K_p + \frac{K_I}{s} + K_D \qquad (1)$$

The proportional gain, K_p is set to 3 and proportional integral K_I and proportional derivative K_D are adjusted until a step response with a minimum overshoot and a small settling time is obtained. A PID controller is added in the forward path of the AVR system. Most automatic voltage regulators (AVR) are only designed to operate over a limited range of input voltage [1]. Therefore, the proposed

AVR system block diagram for simulating a fourth order model of synchronous generator with the rest of the appropriate excitation system components is shown in Fig. 3.

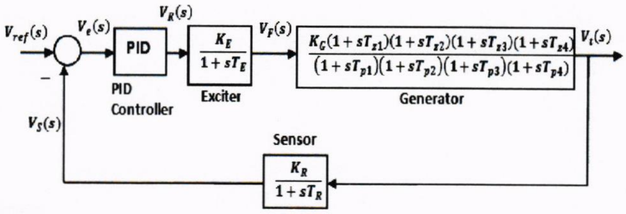

Fig. 3: Block diagram of the proposed AVR system with PID controller

A model of steam turbine is used in this paper. With the use of an integrator, it can restore the speed or frequency to its apparent value by monitoring the average error over a period of time to correct the offset. Due to the weak coupling relationship between the AVR and AGC, the voltage and frequency are regulated separately. The study of coupling effects of the linearized AVR and AGC can be found in Kundur [4] and Anderson [8] which discussed that small change in the electrical power ΔP_e is the product of the synchronizing power coefficient P_s which is known as K_1 in this paper and the change in the power angle $\Delta\delta$.

C. *Coupling Constant Parameters*

Since there is weak coupling between LFC and AVR system, the frequency and voltage were controlled separately. K_2, K_3, K_4 and K_5 called as coupling constants. For a stable system, K_1, K_2, K_4 and K_6 were positive but K_5 was negative. All these constants are briefly described.

K_1: power synchronizing coefficient (P_s)

K_2: change in electrical power for a small change in the stator emf

K_5: change in the terminal voltage for a small change in rotor angle at constant stator emf

K_6: change in terminal voltage for a small change in the stator emf at constant rotor angle

If small effect of voltage upon real power is included, the linearized equation (2) will obtain.

$$\Delta P_e = P_s\Delta\delta + K_2E' \quad (2)$$

When including small effect of rotor angle upon the generator terminal voltage is given by (3).

$$\Delta V_t = K_5\Delta\delta + K_6E' \quad (3)$$

The stator emf may express in (4) when modifying the generator field transfer function to include the effect of rotor angle.

$$E' = \frac{K_G}{1+T_G}\left(V_f - K_4\Delta\delta\right) \quad (4)$$

Including in the AGC system of Figure 2 and the AVR system of Figure 3, a linearized model for the combined LFC and AVR system is obtained. Then, the overall simulation block diagram of a fourth order model of synchronous machine can be constructed.

IV. SIMULATION RESULTS AND DISCUSSION

The results of the simulation are correctly reflected on the plots. The variations of integral controller on AGC system K_I, K_E and Kp, Ki, Kd on the PID controller were made to deduce how each variable affect the transient response of the synchronous machine. The output that have been observed are frequency deviation and terminal voltage. Since Matlab Simulink are limited for the axis setting, the x-axis was indicates as time in seconds and the y-axis indicates as the output measured in per unit respectively. The ideal response of output is to keep the deviation (oscillation) as close to zero as possible at the minimum period of time.

A. *Normal condition*

Under normal condition,, the K_p, Ki and K_d were set to 3, 0.7 and 0.2 respectively. Fig. 4 and Fig. 5 indicate the frequency deviation step response and terminal voltage step response respectively.

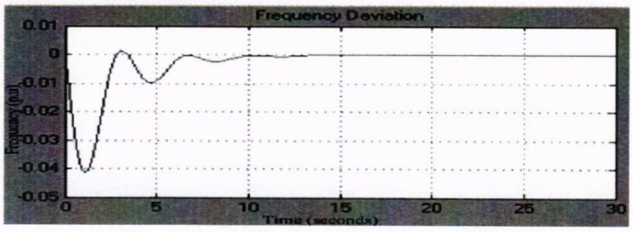

Fig. 4: Frequency deviation step response

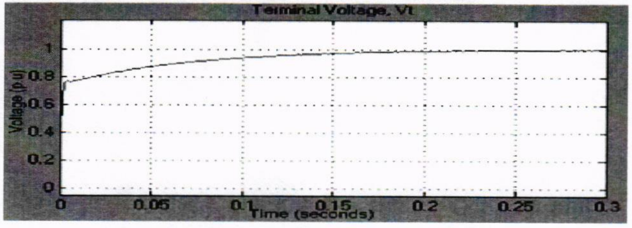

Fig. 5: Terminal voltage step response, Vt

In Fig. 4, the steady-state frequency deviation obtained is zero and the frequency oscillates for a period of 13 before settling down to zero deviation. There is an overshoot error occurring at 3.5 seconds and the frequency returns to its nominal value in approximately 13 seconds. This overshoot error has to be minimized by adjusting the values of the PID controllers and K_I. From Fig. 5 shows that it's able to restore the terminal voltage back to the nominal step input value of 1 at about 0.2 seconds.

B. Changed parameters value of the PID controller

The variations of parameters involved in PID controller consist of proportional Kp, integral Ki, and derivative Kd. By setting the proportional gain Kp to 1 and keeping the rest of variables at their initial values, terminal response as Fig. 6 is obtained.

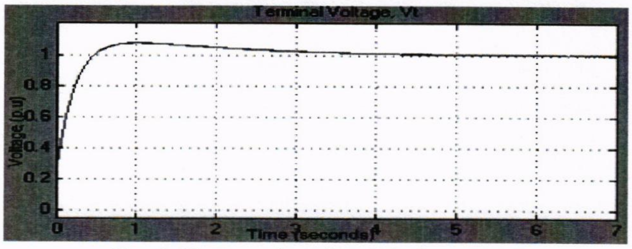

Fig. 6: Change value of K_p only from 3 to 1

There is an overshoot from 0.5 seconds and settling down to 1p.u voltage after 6 seconds in Fig. 6. In the case of excessive proportional gain K_p is applied shown in Fig. 7 and Fig. 8 shows the voltage response when K_p is set too low.

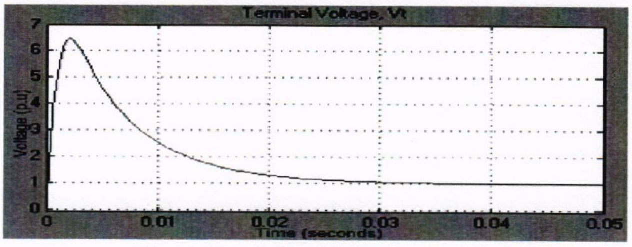

Fig. 7: Terminal voltage when K_p= 30

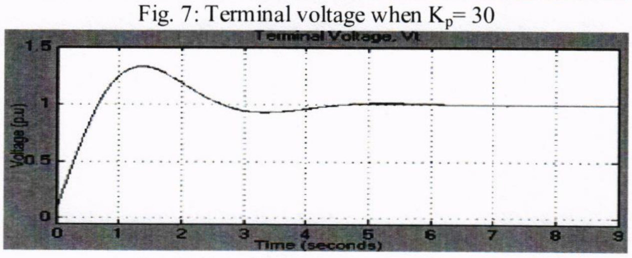

Fig. 8: Terminal voltage when K_p= 0.3

The Fig. 7 results in a 'spike' response in the output voltage during the transient state when K_p is set too high (Kp=30). In contrast, if Kp is set too low (Kp=0.3), the resultant response may oscillate and become unstable shown in Fig. 8. Both effects are undesirable. Thus, improper setting of Kp leads to the additional increase or decrease in excitation controlled by the voltage regulator.

The variations of another two parameter of PID controller, integral constant, Ki and derivative constant, K_d shown in Fig. 9 and Fig. 10.

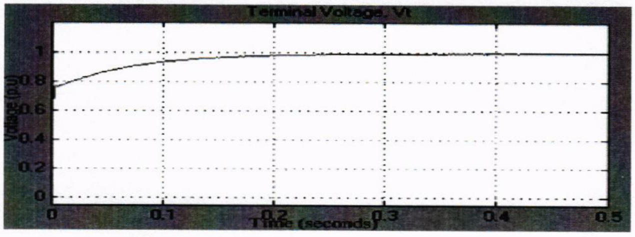

Fig. 9: Terminal voltage when Ki is 0.2

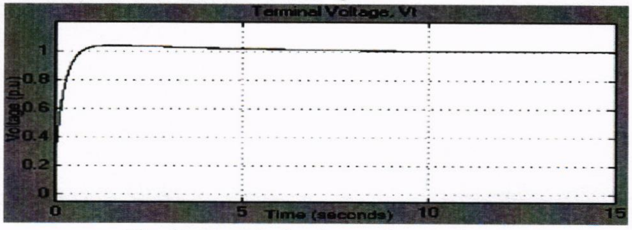

Fig. 10: Terminal voltage when K_d is 0.7

By decreasing Ki from 0.7 to 0.2 in Fig. 9, the response of the machine is slower compared to Fig. 5. The time taken for the terminal voltage to reach the value of 1p.u is now 0.5 seconds. In Fig. 10, K_d is increased from 0.2 to 0.7 causes the time for terminal voltage to reach 1p.u has increased to 13 seconds.

C. Change constant value in the AGC

Fig. 11 below shows that the value of K_I is obviously too high and causes the first positive peak of frequency is higher and small constant oscillation was identified.

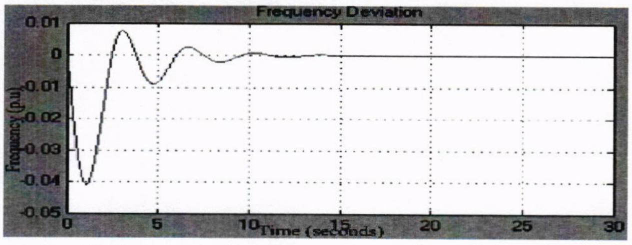

Fig. 11: Frequency deviation response when value of K_I has changed from 5.2 to 7.5

Changes in the excitation gain K_E were also conducted to analysis the output with a set of values for the various controller gains. By having the results of lower order model simulation, comparisons were made and the changes between different order models were almost undetectable due to the connection to an infinite bus. In order to get a stable system, the various controller gains must be adjusted simultaneously to satisfy the output response of the system.

V. CONCLUSION

The simulation of the transient response of synchronous machine has been successful implemented. The simulation of the transient response in this paper is able to generate the responses of the first, second, third and fourth order of synchronous machine correctly. Various adjusting can be made in order to obtain a better output response. The only restriction is that the small changes in response are not reflected clearly due to the strong grid between the machine and the infinite bus. The work presented in this paper is considered a small part in power system control. Future works will extend the use of higher order turbine model instead of using first order turbine model. The other proposed solution is to connect the output terminal to an actual load virtually by a mean of connecting an additional feedback of current at the terminal output. In this way the changes in the transient response of the machine can be reflected.

REFERENCES

[1] G.N. Patchett, "Automatic Voltage regulators and Stabilizers," Third edition, Pitman Publishing, 1970.

[2] Z. Chen, F. Blaabjerg, F.Iov, "A Study of Synchronous Machine Model Implementations in Matlab/Simulink Simulations for Renewable Energy Systems," Aalborg University, Denmark.

[3] Allan Walton, "A Systematic Method for the Determination of the Parameters of Synchronous Machines from the Results of Frequency Response Tests" IEEE Transaction on Energy Conversion, Vol. 15, No. 2, June 2000.

[4] P. Kundur, "Power System Stability and Control," McGraw-Hill Inc., 1994.

[5] Allan Walton, "The Extraction of Parameters for Synchronous Machines from the Results of Frequency Response Tests" James Cook University of North Queensland, Australia, 2000.

[6] Hadi Saadat, Power System Analysis, Second Edition, McGraw Hill, 2004

[7] Tin Win Mon, Myo Myint Aung, "Simulation of Synchronous Machine in Stability Study for Power System," International Journal of Electrical Systems Science and Engineering, 2008.

[8] P.M. Anderson, A.A. Fouad, "Power System Control and Satbility," Second Edition, IEEE Press, John Wiley & Sons Inc., 3003.