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Impact of Reactive Power Generation and Absorption on Voltage Regulation. A case study in an Industrial Power System

Nisarga T L, Raghavendra M, Rithika A M, Tilak S, M Naveen Kumar
UG Student
Department of Electrical and Electronics Engineering
SJB Institute of Technology, Bengaluru, India

Abstract - The excitation system maintains generator voltage and control reactive power flow. Older excitation system is provided with slip rings and brushless dc generator mounted on synchronous machine. Modern excitation system consists of a generator and they are brushless. Change in reactive power mainly affects the voltage magnitude. The generator reactive power is controlled using generator excitation control system called Automatic Voltage Regulator (AVR). With increase in reactive power, there is drop in voltage magnitude of generator. Potential transformers sense the variation in voltage magnitude, which is rectified and compared to set input reference. The field exciter and its terminal voltage is controlled by amplified signal. As a result, current of generator filed is increased, which further results in increase in generator EMF. Hence reactive power is increased to new stable value, raising the terminal voltage to desired value. This paper presents the different modelling of AVR using MATLAB and its associated toolbox for varying power system parameters.

Keywords: Reactive Power, Voltage Control, Automatic Voltage Regulator, Simulink

I. INTRODUCTION

For an electric power system, to keep constant the nominal voltage level and to control reactive power supply to or received from power system is an important factor of power quality, grid security and grid reliability. Theoretically, the instantaneous amount of reactive power in a power system depends upon the voltage level, the instantaneous amount of active power in a power grid depends upon frequency of the system. These powers should be kept in stable at the steady-state condition of the power system. If available voltage value changes, the efficiency of the equipment connected to the power system will be significantly affected and their life expectation drops [1-2]. The transmission line losses depend upon the amount of active and reactive powers. Also, a reactive power interested in widely on output voltages of the synchronous generators connected to a power system. For this reason, to reduce the real transmission losses needs to keep reactive power equilibrium required to control a voltage value of a power system. At present, an AVR system is basically applied to synchronous generators included by a power system to resolve the problem [3-4]. Various control techniques like linear or nonlinear can be used to provide AVR control [5-6]. An increase in a reactive power load of generator is accompanied by a drop in terminal voltage magnitude. By using a potential transformer, a voltage magnitude is sensed on single reference dc point signal. The exciter terminal voltage is increased as the field is controlled by this amplified error signal. Thus, generator current also increase which results in increase of generator EMF.

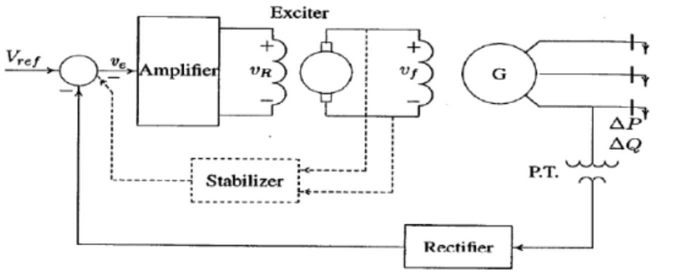

Figure 1: A simple AVR model

Hence a simple AVR model block diagram is showed in figure 1,
new equilibrium of increased reactive power is achieved which raised the terminal voltage to desired value [7-8]. This paper presents a study of actual AVR model, AVR model with stabilizer and AVR model with conventional controller. The simulation and comparison of these three AVR model is carried out in this article.

II. TRANSFER FUNCTION MODEL OF AVR

1. Amplifier Model:

The transfer function for Amplifier model is given,

$$\frac{V_R(S)}{V_e(S)} = \frac{K_A}{1+\tau_A S} \quad ---(1)$$

Where KA is the gain and TA is the time constant.

2. Exciter Model:

The terminal voltage and field voltage relationship of exciter model is nonlinear because of saturation effect of magnetic circuit. Many exciter models are reported in IEEE publication

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with various degree of experience[9-10]. A modern exciter system model is a linearized model, where the effect due to saturation and other nonlinearities are ignored.

The transfer function of modern exciter system is represented as,

$$\frac{V_F(S)}{V_R(S)} = \frac{K_E}{1+\tau_E S} \quad \text{---(2)}$$

Where KE is the gain and TE is the time constant of exciter model.

3. Generator Model:

The generated emf of synchronous machine is a function of its curve and termination voltage depends upon the load. The transfer function shows the relationship between terminal voltage to its field voltage and can be represented as,

$$\frac{V_t(S)}{V_F(S)} = \frac{K_G}{1+\tau_G S} \quad \text{---(3)}$$

Where KG is the gain and TG is the time constant of generator model.

4. Sensor Model:

The potential transformer senses the terminal voltage, which is then rectified through a bridge rectifier. A simple first order transfer function of a sensor model can be represented as,

$$\frac{V_S(S)}{V_t(S)} = \frac{K_R}{1+\tau_R S} \quad \text{---(4)}$$

Where KR is the gain and TR is the time constant of generator model

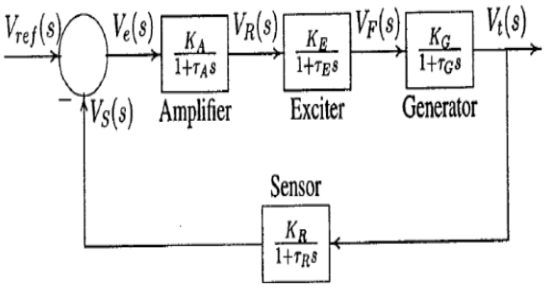

Figure 2: Block diagram of simplified AVR system

The above figure 2 shows open loop transfer function of a simplified AVR system[11-12] can be given as,

$$KG(S)H(S) = \frac{K_A}{1+\tau_A S} * \frac{K_E}{1+\tau_E S} * \frac{K_G}{1+\tau_G S} * \frac{K_R}{1+\tau_R S}$$

And the closed loop transfer function relating the terminal voltage with reference voltage is given by,

$$\frac{V_t(s)}{V_{ref}(s)} = \frac{K_A K_E K_G K_R (1+\tau_R S)}{(1+\tau_A S)(1+\tau_E S)(1+\tau_G S)(1+\tau_R S)} \quad \text{---(5)}$$

III. EXCITATION SYSTEM STABILIZER – RATE FEEDBACK:

It is seen that system without stabilizer remains in the unstable state. We can increase the relative stability by introducing a controller which will add a zero to the AVR open – loop transfer function. The better way to do this is to add rate feedback to the SScontrol system as shown in figure 3. By proper adjustment of Kf and Tf, a satisfactory response can be obtained.

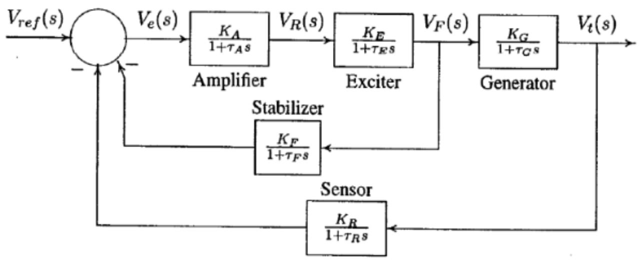

Figure 3: Block diagram of stabilizer with rate feedback

IV.EXCITATION SYSTEM– PID CONTROLLER:

It is one of the most common controllers which is used in most of the process plants. The PID controller is used to improve the dynamic response as well as to reduce or eliminate the steady state error. The derivative controller adds a finite zero to the open loop plant transfer function and improves the transient response. The below the figure 4 shows integral controller adds a pole at origin and increases the system type by one and reduces the steady – state error due to a step function to zero. The PID controller transfer function is,

$$G_C(s) = K_p + \frac{K_I}{s} + K_D s \quad \text{---(6)}$$

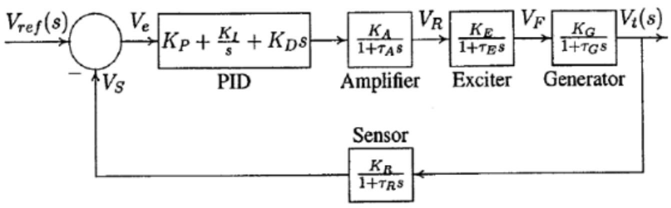

Figure 4: Block diagram of stabilizer with PID Controller.

V.MODEL PARAMETER OF AVR

	Transfer Function	Used Parameter Values
PID Controller	$K_p + \frac{K_i}{s} + K_D$	K_p, K_i, K_d = optimum value
Stabilizer – Rate Feedback	$\frac{K_R}{1 + T_R s}$	$K_R = 2$, $T_R = 0.4$
Amplifier	$\frac{K_a}{1 + T_a s}$	$K_a = 10$, Ta = 0.1
Exciter	$\frac{K_e}{1 + T_e s}$	$K_e = 1$, $T_e = 0.4$
Generator	$\frac{K_g}{1 + T_g s}$	$K_g = 0.1$, $T_g = 1$
Sensor	$\frac{K_s}{1 + T_s s}$	$K_s = 1$, $T_s = 0.5$

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VI.CONTROL OF VOLTAGE AND REACTIVE POWER

The approximate relationship between the magnitude of the voltage difference of two nodes in a network and the flow of power,

$$\Delta V \approx \Delta V_p = \frac{RP + XQ}{V} \qquad \text{---(7)}$$

Also, it was shown that the transmission angle d is proportional to

$$\delta \propto \Delta V_q = \frac{XP \quad RQ}{V} \qquad \text{---(8)}$$

VII. SIMULATION AND RESULT

In this article the simulation of three different AVR is executed, the AVR basic model, AVR model with stabilizer and AVR model with PID controller. The simulation shows that the AVR model with PID controller performs better in terms of peak overshoot and settling time. The simulation model and its simulation result is shown below[13-14],

SIMULATION 1:

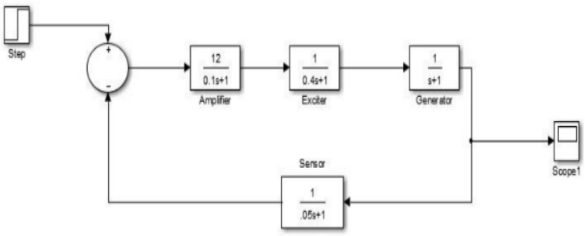

Figure 5: Simulation Model of Basic AVR

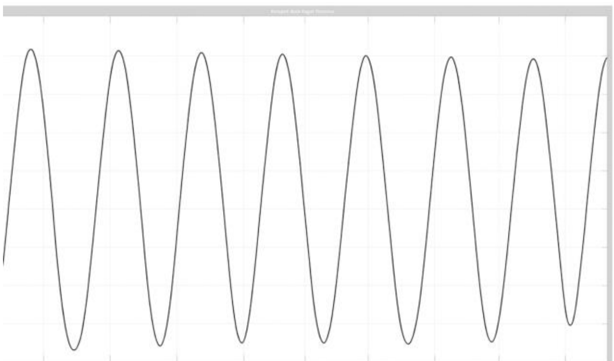

Figure 6: Simulation Result of Basic AVR

SIMULATION 2:

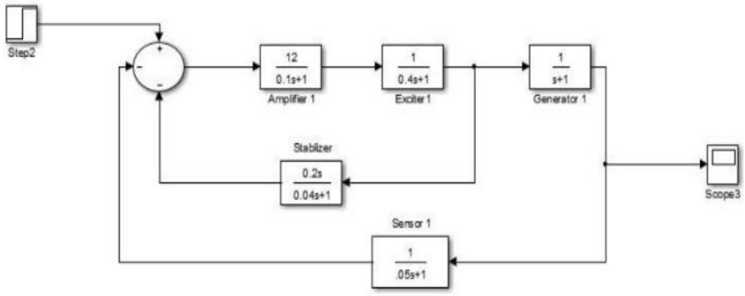

Figure 7: Simulation Model of AVR with Stabilizer

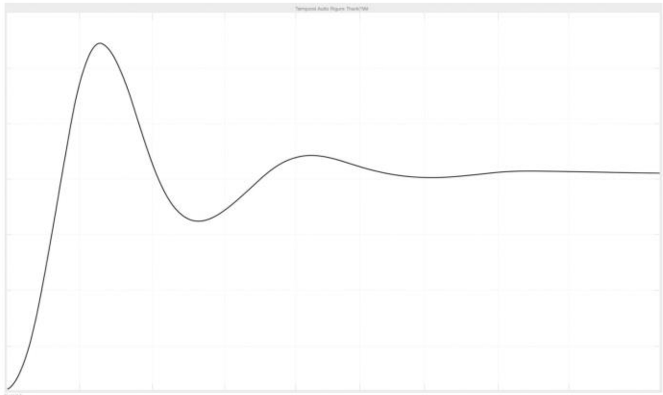

Figure 8: Simulation Result of AVR with Stabilizer

SIMULATION 3:

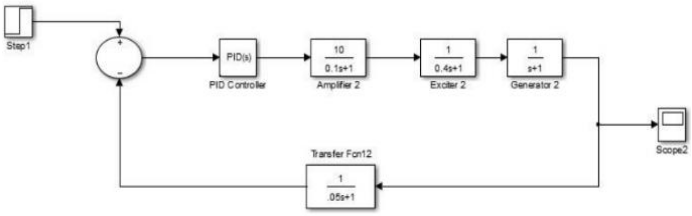

Figure 9: Simulation Model of AVR with PID Controller

Figure 10: Simulation Result of AVR with PID Controller

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VII. CONCLUSION

This study shows how important Automatic Voltage Regulators (AVRs) are in keeping a power system's voltage stable and in managing reactive power effectively. By comparing the basic AVR model, the AVR with a stabilizer, and the AVR combined with a PID controller, we can clearly see how each control method affects system behaviour. The basic AVR model, as seen in the simulation Figure 6, struggles to control oscillations and takes longer to settle, which means it is not very effective during sudden disturbances. When a stabilizer is added as shown in figure 7, the response improves because the stabilizer introduces an extra zero into the system, helping it settle faster and reducing the oscillations, as shown in Figure 8.

Among all the models tested, the AVR with the PID controller gives the best overall performance. The simulation in Figure 9 and 10 shows that the PID controller drastically reduces overshoot and helps the system stabilize much quicker. This matches the theoretical behaviour of a PID controller, where the proportional part speeds up the response, the integral part removes steady-state error, and the derivative part improves the handling of sudden changes. As discussed in the report, the PID-based AVR clearly performs better than the AVR with just a stabilizer, especially when looking at settling time and overall stability.

From the results, it is evident that using a PID controller greatly enhances the performance of an AVR system. Better voltage regulation and smoother reactive power control make it a stronger choice for real-world applications. The study also suggests that the AVR system can be improved even further by applying modern optimization methods such as AI-based tuning, adaptive techniques, or other advanced control strategies. These approaches could help build more efficient, reliable, and intelligent voltage-regulating systems for future power networks.

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