Dynamic Stability Improvement in Multi Machine Power System by Using AVR

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Abstract: Automatic voltage regulator (AVR) is a controller based on synchronous generator for controlling voltage in generators' terminals. AVR can generally change the system dynamic performance and the effect of AVR on dynamic stability has been seldom investigated. In this regard, effect of AVR on dynamic stability is investigated in this paper. IEEE 14 bus test system is considered as case study to show effectiveness of the proposed method.
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1. Introduction

Power system stability is an important issue in power systems and improving power system stability have been widely investigated and reviewed [1-20]. One the most important factors which affects on stability are AVRs. The generator excitation system consists of an exciter and an automatic voltage regulator (AVR) and is necessary to supply the generator with DC field current. The power rating of the exciter is usually in the range 0.2–0.8% of the generator's megawatt rating. In the case of a large generator this power is quite high, in the range of several megawatts. The voltage rating of the exciter will not normally exceed 1000 V as any higher voltage would require additional insulation of the field winding. Generally exciters can be classified as either rotating or static. Figure 1 shows some typical systems. In the rotating exciters of Figure 1-a–c, the excitation current is supplied either by a DC generator or by an AC generator with rectifiers. As DC generators usually have relatively low power ratings, they are cascaded to obtain the necessary output, Figure 1-a. Because of commutation problems with DC generators this type of exciter cannot be used for large generators which require large excitation currents. As the number of cascaded DC generators increases, the dynamic properties of the exciter deteriorate, resulting in an increase in the equivalent time constant. Nowadays DC generators have been almost entirely replaced by alternators, which are simpler and more reliable. This change to alternators has been possible because of advances in power electronics which allow cheap, high power rectifiers to be used in conjunction with the AC exciter. The exciter shown in Figure 1-b is a reluctance machine (inductor generator) operating at about 500–600 Hz so that the rectified current requires little smoothing. With this exciter both windings (AC and DC) are on the stator side. One disadvantage of this system is that slip rings are required to feed the rectified excitation current to the rotating field winding of the main generator. A further disadvantage is that the exciter itself tends to be quite large. This is a direct result of the way in which the sinusoidal flux changes, necessary to induce the alternating emf in the armature, are produced solely by the changes in reluctance due to the rotation of the salient rotor teeth. The exciter shown in Figure 1-c has neither commutator nor slip rings. The principal excitation source is an inside-out synchronous machine with the field winding on the stator and armature winding on the rotor. The induced current is rectified by diodes, which are also mounted on the rotor, and fed directly to the excitation winding of the main generator. One limitation of this type of exciter is that the current supplied to the main generator can only be controlled indirectly via field control of the exciter. This tends to introduce a time constant of about 0.5 to 1 s into the exciter control system. One solution to this problem is to use rotating thyristors, rather than diodes, and control the exciter output via the firing angle of the thyristors. Unfortunately, controlling the firing angle of a rotating thyristor is not easy and the reliability of such systems tends to be compromised by stray fields causing unscheduled thyristor firing. Some alternative exciter systems using static thyristor converters are shown in Figure 1-d–f. In these exciters the thyristor rectifiers are controlled directly by a voltage regulator. The main difference between the systems is in the type of supply used. Figure 1-d shows an exciter supplied by an additional auxiliary service transformer. Figure 1-e shows an alternative, and simpler, solution in which the exciter is fed from the generator output via a transformer. However, should a short circuit occur, particularly one close to the generator terminals, the decrease in the generator terminal voltage will result in a possible loss of excitation. With careful design the exciter can operate when the short circuit is further away from the generator terminals, for example at the high-voltage terminals of the step-up transformer. More flexibility can be obtained by modifying the supply to the rectifier as shown in the exciter design of Figure 1-f. In this system the generator does not lose excitation because its supply voltage is augmented, or compounded, by a component derived from the generator load current. The main disadvantage of all static exciters is the necessity of using slip rings to feed current to the rotor of the main generator. This is offset to a large extent by the rapid speed with which they can react to control signals. As the cost of high-power rectifiers decreases, and reliability increases, static exciters are becoming the main source of excitation for high-power generators [21].

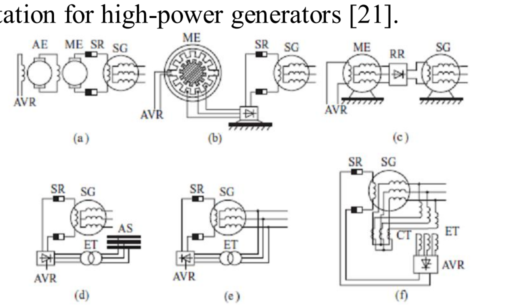

Figure 1: Typical exciter systems: (a) cascaded DC generators; (b) reluctance machine with rectifier; (c) inside-out synchronous generator with rotating rectifier; (d) controlled rectifier fed from the auxiliary supply; (e) controlled rectifier fed from the generator terminals; (f) controlled rectifier fed by the generator's voltage and current [21]

2. Automatic Voltage Regulators

The AVR regulates the generator terminal voltage by controlling the amount of current supplied to the generator field winding by the exciter. The general block diagram of the AVR subsystem is shown in Figure 2. The measuring element senses the current, power, terminal voltage and frequency of the generator. The measured generator terminal voltage Vg is compensated for the load current Ig and compared with the desired reference voltage Vref to produce the voltage error ΔV. This error is then amplified and used to alter the exciter output, and consequently the generator field current, so that the voltage error is eliminated. This represents a typical closed-loop control system. The regulation process is stabilized using a negative feedback loop taken directly from either the amplifier or the exciter. The AVR subsystem also includes a number of limiters whose function is to protect the AVR, exciter and generator from excessive voltages and currents. They do this by maintaining the AVR signals between preset limits. Thus the amplifier is protected against excessively high input signals, the exciter and the generator against too high a field current, and the generator against too high armature current and too high power angle. The last three limiters have built-in time delays to reflect the thermal time constant associated with the temperature rise in the winding. A power system stabilizer (PSS) is sometimes added to the AVR subsystem to help damp power swings in the system. PSS is typically a differentiating element with phase shifting corrective elements. Its input signals may be proportional to rotor speed, generator output frequency or the electrical real power output of the generator. The AVR parameters have to be chosen in such a way that an appropriate quality of voltage regulation is maintained. For small disturbances, that quality can be assessed by observing the dynamic voltage response of a generator to a step change in the reference value [21].

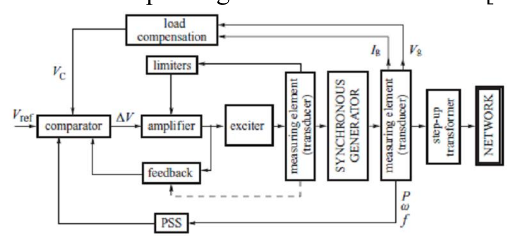

Figure 2: Block diagram of the excitation and AVR system [21]

3. System under Study

In this paper IEEE 14 bus test system is considered to evaluate the proposed method. The system data are completely given in IEEE standards. The excitation and AVR system parameters are changed to show effect of them on stability. Figure 3 shows the test system and its data are given in [22].

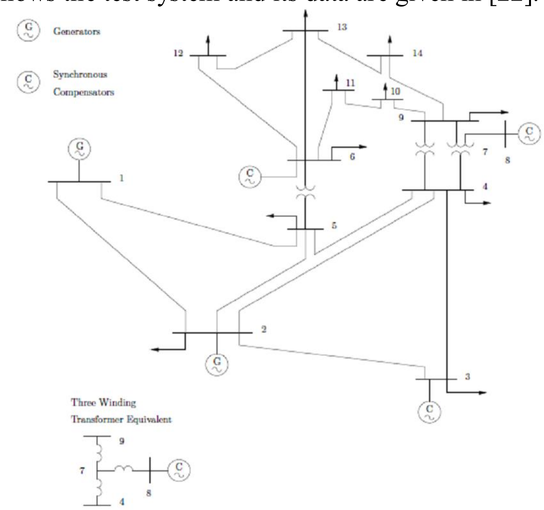

Figure 3: IEEE 14 bus test system [22]

3.1. AVR model

The AVR model is depicted in Figure 4 and described by the following equations and its parameters are defined in Table 1 [22].

$$\begin{aligned}
\dot{v}_m &= (V - v_m)/T_r \\
\dot{v}_{r1} &= (K_a(v_{\mathrm{ref}} - v_m - v_{r2} - \frac{K_f}{T_f}v_f) - vr1)/T \\
v_r &= \begin{cases} v_{r1} & \text{if } v_{r\,\min} \le v_{r1} \le v_{r\,\max}, \\ v_{r\,\max} & \text{if } v_{r1} > v_{r\,\max}, \\ v_{r\,\min} & \text{if } v_{r1} < v_{r\,\min}. \end{cases} \qquad (1) \\
\dot{v}_{r2} &= -(\frac{K_f}{T_f}v_f + v_{r2})/T_f \\
\dot{v}_f &= -(v_f(1 + S_e(v_f)) - v_r)/T_e
\end{aligned}$$

Table 1: Exciter system data

Variable	Description
$V_{r\,\max}$	Maximum regulator voltage
$V_{r\,\min}$	Minimum regulator voltage
K_a	Amplifier gain
T_a	Amplifier time constant
K_f	Stabilizer gain
T_f	Stabilizer time constant
T_e	Field circuit time constant
T_r	Measurement time constant
A_e	1st ceiling coefficient
B_e	2nd ceiling coefficient

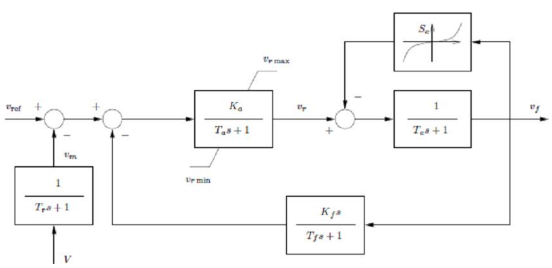

Figure 4: excitation model [22]

4. Simulation results

The following cases are considered for simulation, where the case 1 is the nominal condition.

Table 2: excitation system parameters for several conditions

	Ka	Ta
Case 1	40	0.02
Case 2	20	0.02
Case 3	100	0.04

The simulation results for the proposed system are depicted in Figures 5-14. The simulation results show the effect of AVR parameters on stability of power system. It is clearly seen that the system stability is a function of AVR parameters. The system oscillation depends to AVR tuning and with changing AVR parameters the oscillations are changed. The effect of AVR parameters on stability denotes the importance of AVR sitting in power systems. An optimal and good tuned AVR can improve power system stability, while a non-tuned AVR can greatly affect on stability and would lead to instability.

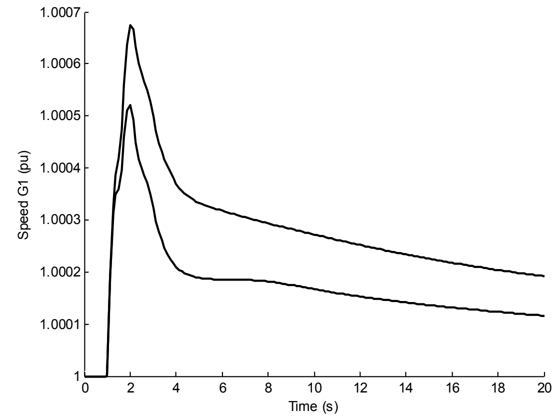

Figure 5: Speed G_1 (solid: case 1; dashed: case 2)

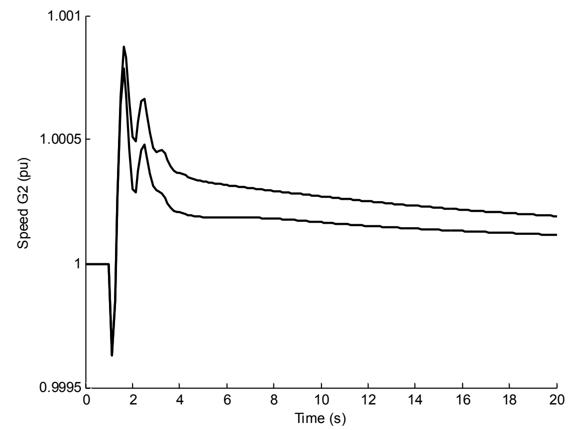

Figure 6: Speed G_2 (solid: case 1; dashed: case 2)

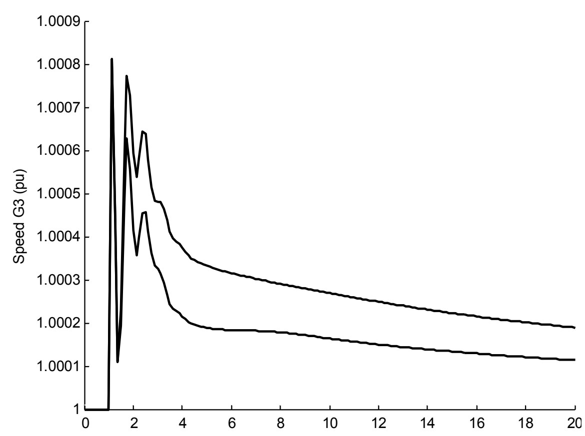

Figure 7: Speed G_3 (solid: case 1; dashed: case 2)

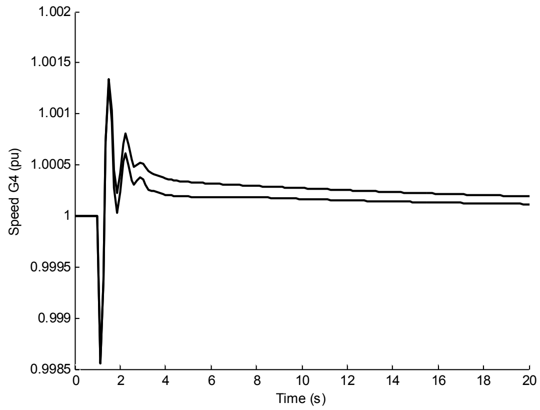

Figure 8: Speed G_4 (solid: case 1; dashed: case 2)

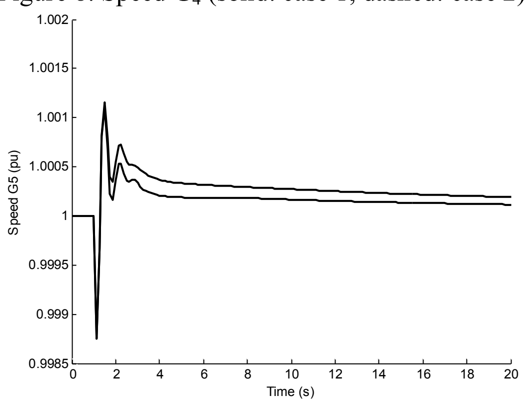

Figure 9: Speed G_5 (solid: case 1; dashed: case 2)

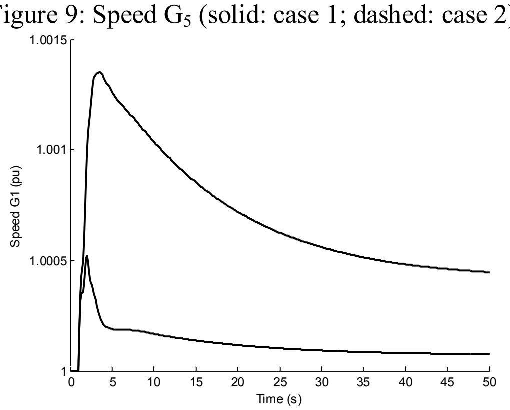

Figure 10: Speed G_1 (solid: case 1; dashed: case 3)

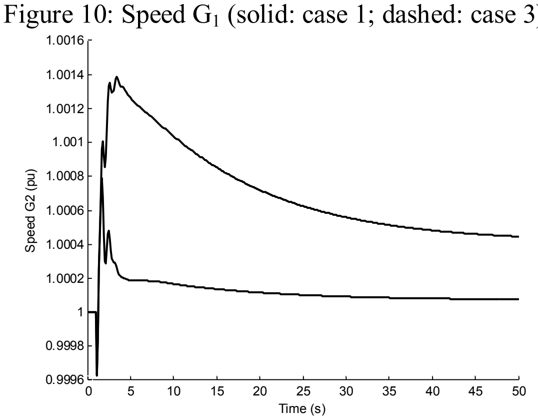

Figure 11: Speed G_2 (solid: case 1; dashed: case 3)

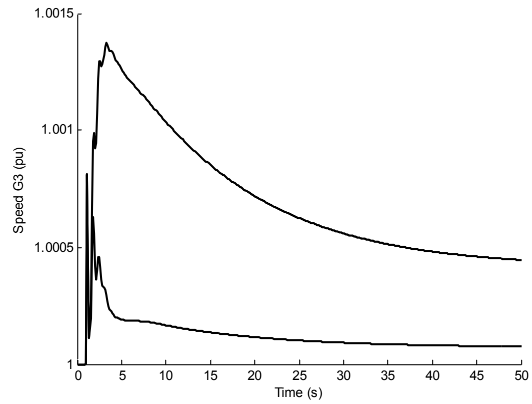

Figure 12: Speed G_3 (solid: case 1; dashed: case 3)

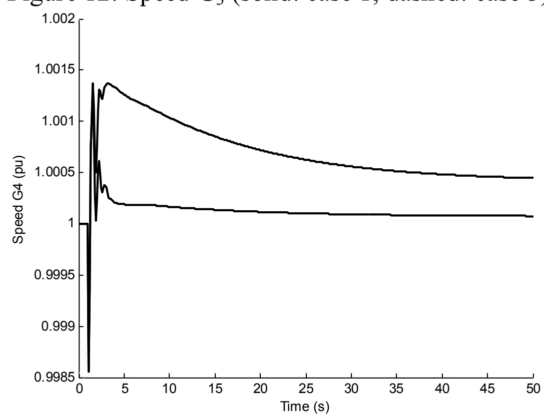

Figure 13: Speed G_4 (solid: case 1; dashed: case 3)

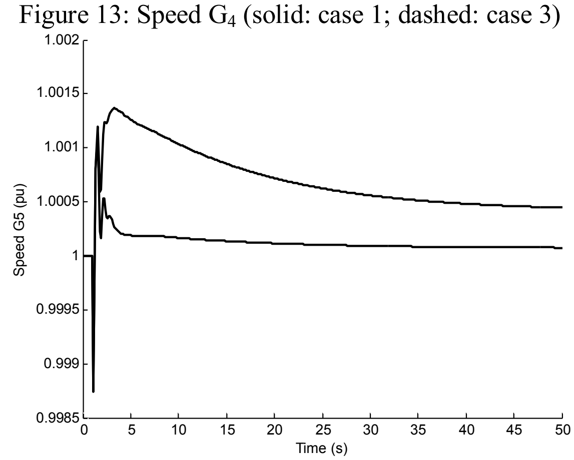

Figure 14: Speed G_4 (solid: case 1; dashed: case 3)

5. Conclusion

Effect of AVR and excitation system on stability and oscillations was investigated in this paper. A typical power system equipped with AVR on all generators was chosen as case study and effect of AVR parameters was investigated on test system. The simulation results showed the great effect of AVR parameters on power system stability. The power system stability is associated with AVR good sitting and non-tuned AVR may lead to instability.

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