

## Excitation Parameters for Stable Operation of SCECO-Central Power System

A. AL-OHALY\*, Z. EL-RAZAZ\* and S. AL-SOHAIBANI\*\*

*\*Electrical Engineering Dept., College of Engineering,  
King Saud University, and*

*\*\*Technical Studies Dept., SCECO (Central)  
Riyadh, Saudi Arabia*

**ABSTRACT.** A parametric variation analysis was carried out for two types of excitation systems used in SCECO-Central, namely the BBC and GE excitation systems. The effects of exciter, regulator stabilising circuit, saturation parameters, time constants and their important role in power system transient stability are discussed. Parameter ranges were suggested for proper system operation.

### 1. Introduction

Intelligent planning requires consideration of all technical and economical aspects for major equipments. The cost of the auxiliaries on one hand and their technical and operational capabilities on other hand, should be compared. For this purpose it is necessary to take into account the possibilities of automatic control and regulation to improve at low cost the operational reliability and stability of the system<sup>[1]</sup>.

Since 1968 the proper tuning of the generator controllers has attracted considerable attention as an available method to correct instability in the power system by reducing the gains of a certain generator controllers<sup>[2]</sup>. Most of the applications of this method were used to maximize the steady state stability of a multi-machine power system. In this paper, the improvement of transient stability by excitation parameters tuning is discussed through study case for Riyadh power system of which the simplified single line diagram is shown in Fig. 1. A fully detailed description and modelling for Riyadh power system is given in Ref. [1] including system planning and operation methodologies applied in SCECO (Central). This paper also emphasizes

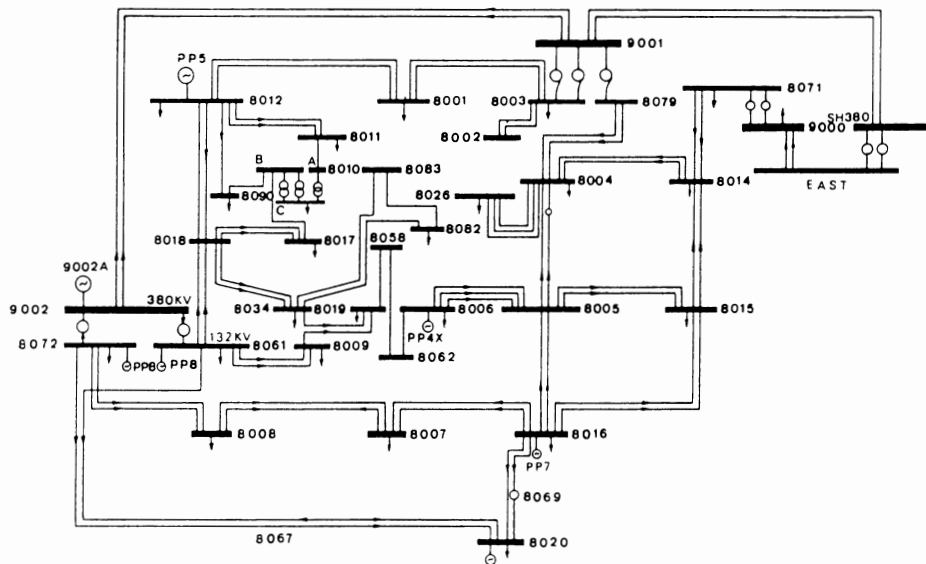


FIG. 1986 Riyadh electrical system.

the importances of using the actual generator controllers data in transient stability analysis since a misleading conclusion may be drawn by relying on a typical data.

## 2. Models and Analysis

### 2.1 Synchronous Machine Model

The generator model adopted in this study is a six order model ( $\omega, \delta, I_{fd}, \lambda_D, \lambda_{Q1}, \lambda_{Q2}$ ). It has a field winding and a single amortisseur circuit in the  $d$ -axis and two amortisseur circuits in the  $q$ -axis<sup>[1]</sup>.

### 2.2 Automatic Voltage Regulator (AVR) and Exciter Models

Mainly there are two excitation types used in SCECO (Central) generating plants. Static type is implemented in GE and Hitachi machines at PP7 & PP4X, respectively. Rotating rectifier type is used in BBC machines at PP5, PP8A, PP8B and 9002A power plants.

### 2.3 Static Excitation Model

The potential source excitation system is implemented in GE and Hitachi machines in PP7 and PP4X power plants. This system has physical characteristics similar to those of IEEE type ST1 Excitation system. So, the same block diagram and transfer function are used as shown in Fig. 2. The nominal values for the system parameters  $T_R, T_A, T_F, K_A$  and  $K_F$  are given in Table 1.

### 2.4 BBC Excitation Model

It consists of two main components, stator and rotor. The rotor comprises an AC armature and a diode-carrier (rectifier). Both components are bolted together be-

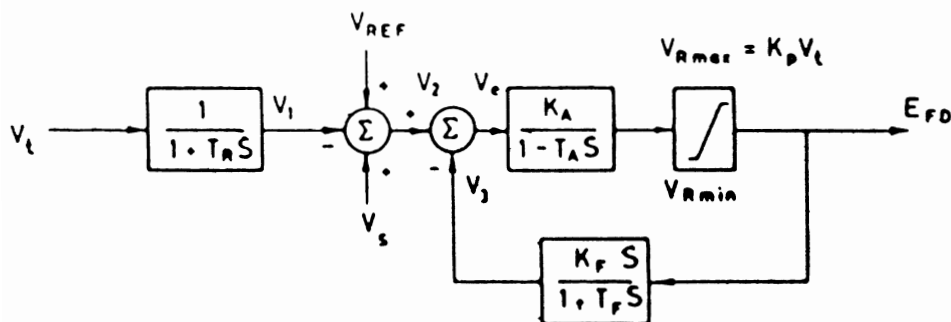


FIG. 2. Block diagram of GE excitation system.

TABLE 1. Excitation systems parameters.

| Static system GE                                                                                         | Rotating rectifier system BBC                                                                                                                                                                                                                    |
|----------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $T_R = 0.015 \text{ sec.}, T_A = 0.5 \text{ sec.}$<br>$T_F = 2.5 \text{ sec.}, K_A = 25,$<br>$K_F = 0.5$ | $K = 290, K_C = 2, K_E = 1, T_1 = 0.01 \text{ sec.},$<br>$T_2 = 0.022 \text{ sec.}, T_3 = 10 \text{ sec.}, T_4 = 0.7 \text{ sec.},$<br>$T_5 = 0.3 \text{ sec.}, T_6 = 0.03 \text{ sec.}, T_E = 1 \text{ sec.}$<br>$A_{ex} = 0.009, B_{ex} = 1.1$ |

fore fitting on the generator shaft. Power for the voltage regulator is provided by three-phase voltage transformers connected to the generator terminals. The stabilizing signal is fed back from the regulator output since the excitation voltage is not accessible for that. The actual excitation system has been modelled and Fig. 3 shows the block diagram of the system. The nominal values of the gains and the time constants are given in Table 1. Some of these values are taken from Reference [3] and others are suggested by the authors. This is because actual values are not available even in SCECO-C. The saturation of this exciter is represented by an exponential model derived to fit the actual saturation curve at the exciter ceiling voltage and at 75% of ceiling. The saturation function is defined as

$$S_E = A_{ex} e^{B_{ex} E_{fd}}$$

which gives the approximate saturation for any  $E_{fd}$ . The nominal values of the parameters are given in Table 1.

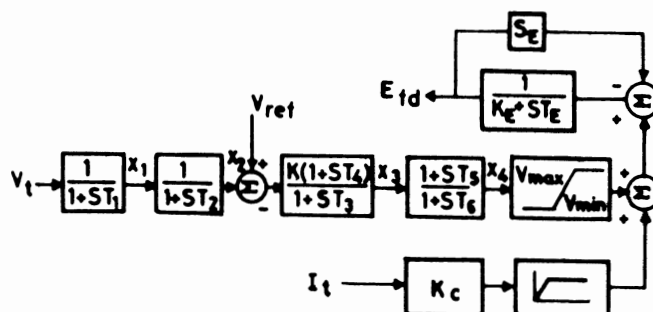


FIG. 3. Block diagram of BBC excitation system.

## 2.5 Parametric Variation Analysis

Two cases have been examined. In one case three phase fault was applied at S/S 8016 near PP7 and it is cleared in 300 msec. The same fault with the same clearing time was applied in the second case but at S/S 8061 near PP8A. These two cases have been repeated with changing voltage regulator parameters. The parameters are changed one at a time keeping the other parameters at their base values. The parameters of the machine near the fault location are changed only.

### 2.5.1 Effect of exciter parameters $K_E$ & $T_E$

Particular parameters of excitation systems, such as the gain  $K_E$  and the time constant  $T_E$  have the largest effects on the generator performance during transient conditions. Different values of  $T_E$  and  $K_E$  have been tested to demonstrate their effects on the generator performance. Figure 4 shows the effect of  $T_E$  on the ceiling voltage and its rate of rise. As  $T_E$  decreases, a high rate of rise and a high ceiling voltage is produced. Theoretically, the optimum value of  $T_E$  is zero, but this cannot be achieved in practice due to physical limitations. On the other hand, as  $K_E$  decreases the gain  $1 / K_E$  will increase, which will raise the ceiling voltage and its rate of rise as shown in Fig. 5. An increase in the ceiling voltage will increase the maximum power transfer capability. This is comparable to the effect of decreasing the generator reactance. It is recommended that the value of  $K_E$  to be equal or greater than 0.5

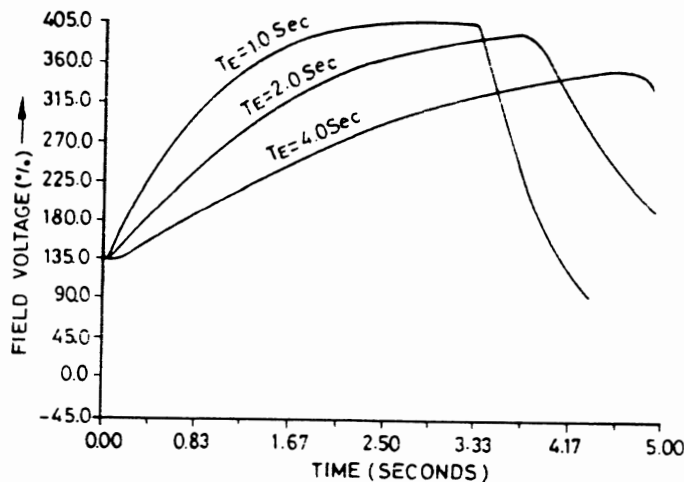
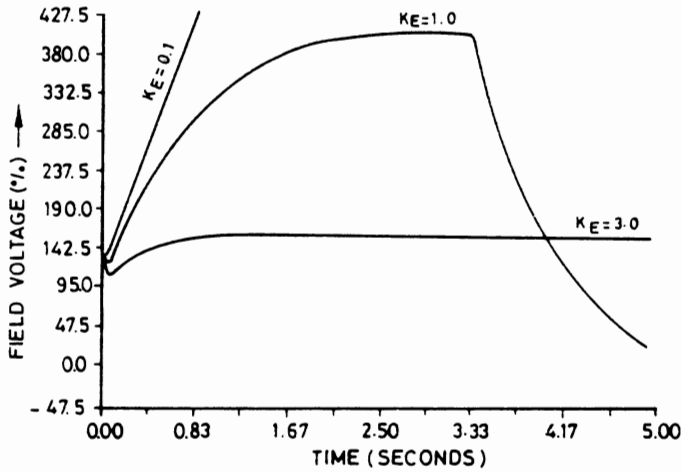


FIG. 4. The influence of  $T_E$  on the field voltage.

### 2.5.2 Effect of voltage regulator time constants $T_3$ , $T_4$ , $T_5$ & $T_6$

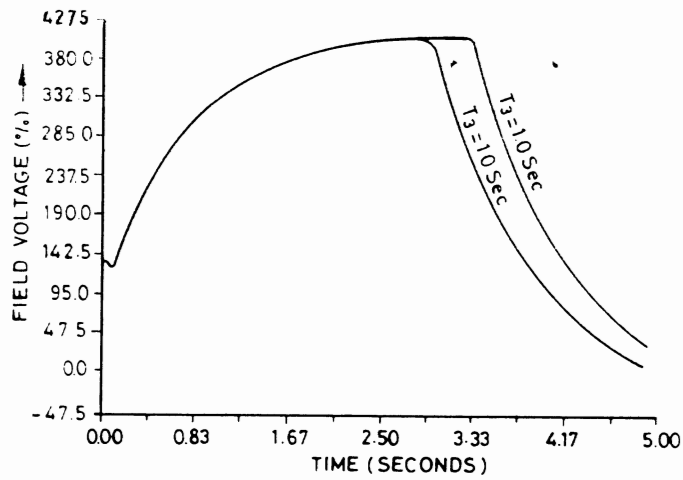
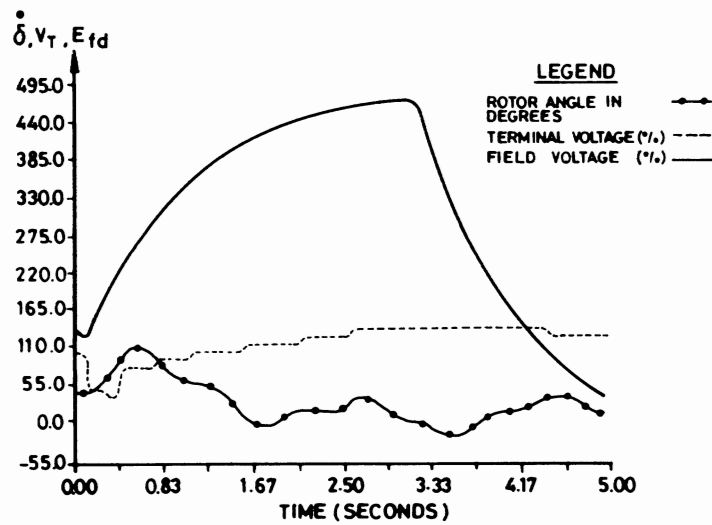
The voltage regulator time constants  $T_3$ ,  $T_4$ ,  $T_5$  and  $T_6$  can be adjusted during power plant commissioning<sup>[3]</sup>. These time constants correspond to those of the amplifier and the stabilizing signal. Different values for each time constant have

FIG. 5. The influence of  $K_E$  on the field voltage.

been tested to determine their effect on the field voltage. The results show that  $T_3$ ,  $T_4$  and  $T_5$  affect only the rate of reduction of the exciter voltage and they do not affect the value of the ceiling voltage. Figure 6 shows that as  $T_3$  increases the ceiling voltage will drop faster. This also occurs when  $T_4$  and/or  $T_5$  increased. The fast decrease in the exciter voltage gives better damping of the large oscillation. The recommended values for these time constants are  $T_3 = 10$  sec.,  $T_4 = 0.5$  sec. and  $T_5 = 0.3$  sec. It may be anticipated that  $T_3$  and  $T_6$  should have similar effect. On the other hand,  $T_3$  and  $T_6$  have different base values ( $T_3 = 10$ ,  $T_6 = 0.03$  sec), so their effects are not similar since their ranges have hardware constraints.

### 2.5.3 Effect of saturation parameters $A_{ex}$ and $B_{ex}$

The coefficients  $A_{ex}$  and  $B_{ex}$  are computed from saturation data where  $S_E$  and  $E_{fd}$  are specified at two points. Due to the lack of data, it is not possible to calculate the nominal values of  $A_{ex}$  and  $B_{ex}$  for this exciter. Various values of  $A_{ex}$  and  $B_{ex}$  are tested.  $A_{ex}$  and  $B_{ex}$  have a significant effect particularly on the ceiling voltage of the exciter, which has a noticeable effect on the transient stability<sup>[4]</sup>. With fixed  $B_{ex}$ , the effect of  $A_{ex}$  is tested. Figure 7 shows that when  $A_{ex}$  is zero, *i.e.*, neglecting saturation the field ceiling is about 470% of the nominal value. This high field voltage gives a high rate of rise of excitation which effectively improves the transient stability. As  $A_{ex}$  increases, the magnitude of maximum field voltage and its rate of rise are decreased. Also it is noted that as  $A_{ex}$  increases, the maximum field voltage can be sustained for longer time which is not desirable for transient stability because it reduces the damping. Similar effects occur when  $B_{ex}$  is increased with fixed  $A_{ex}$ . From the above analysis the recommended ranges for these parameters are:  $0.005 \leq A_{ex} \leq 0.1$  and  $1.0 \leq B_{ex} \leq 2.0$ .

FIG. 6. The influence of  $T_3$  on the field voltage.FIG. 7. Saturation parameter effect at PP8A ( $A_{ex} = 0.0$ ).

#### 2.5.4 Effect of stabilizing circuit parameters $K_F$ & $T_F$

Different values of  $K_F$  and  $T_F$  were tested. The values  $K_F = 0.5$  and  $T_F = 2.5$  are proposed by the manufacturer and the system response is shown in Fig. 8. The results show that when  $K_F$  increases, the rate of change of  $E_{fd}$  has decreased and the field

voltage will be saturated quickly at lower levels mainly due to large error ( $V_{ref} - V_T$ ). This is reflected in the generator terminal voltage which remains at 95% of the rated value even when the field voltage remains constants at its highest value for a long time. This drop in the terminal voltage affects the torque angle and decreases the damping in the system. Consequently, the stability margin is reduced. On the other hand, if  $K_F$  is very small ( $K_F = 0.1$ ), the controller is very sluggish and cannot quickly respond to the change in the generator terminal voltage. Increasing  $T_F$ , which results in delaying the feedback signal, will have the same effect as decreasing the stabilizing signal gain. Also decreasing the time constant to a small value is not physically possible. The appropriate range of  $T_F$  is from 1 to 3 sec. For transient stability, the appropriate range of  $K_F$  is  $0.1 \leq K_F \leq 0.5$ .

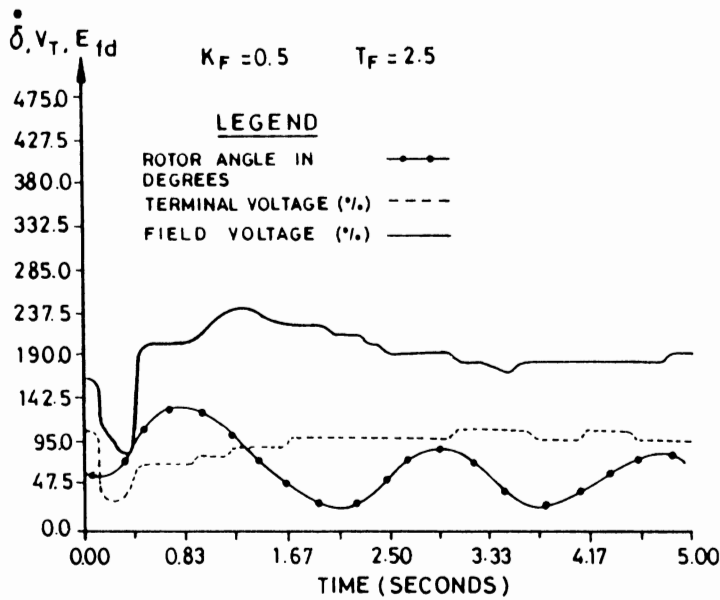


FIG. 8. Static excitation parameters effect in PP7.

As a closing remark, time constants are limited by hardware constraints. Also the gains ( $K_E$ ,  $K_F$ ) are operationally constrained. Some parameters such as  $A_{ex}$  and  $B_{ex}$  are not controlled since their effects are embedded in the exciter characteristics. The obtained ranges even for those uncontrolled parameters are useful in design stage specially in case of replacing some hardware components. The emphasize of using actual models with tuning parameters for the excitation system to reach meaningful results has been stressed recently in Reference [5].

### 3. Conclusion

The influence of the excitation system parameters on system stability has been demonstrated through a parametric variation procedure. It has been demonstrated that an actual improvement in the system behaviour can be achieved by proper tuning for the controllers parameters. This is true provided that the models used represent the actual system equipments. Consequently, parameters ranges have been suggested in order to improve the dynamics of SCECO-Central system.

### Acknowledgement

The authors wish to thank Saudi Consolidated Electric Company in the Central Region (SCECO-Central) for the system data made available to them.

### References

- [1] **Al-Sohaibani, S.**, *Transient Stability Study for Riyadh Electric Power System in SCECO-Central*, Master Thesis, KSU, Riyadh, S.A., March (1988).
- [2] **Vournas, C.D., Papadiaz, B.C.**, Power system stabilization via parameter optimization application to hellenic interconnected system, *IEEE Trans.*, **PWRS-2**(3) August (1987).
- [3] **Merz & McLellan Engineering Consultants**, *Design and Specification of 380 kV Transmission System Survey Report*, September (1987).
- [4] **Venikov, V.**, *Transient Processes in Electric Power System*, Mir Publishers, Moscow, First Edition (1977).
- [5] **Bhatt, N.B., DeGroff, A.G., Heyeck, M., Ridenbaugh, S.L., Schult, R.P.**, Benefits of excitation control system testing at AEP's rockport plant, *IEEE Trans. on Energy Conversion*, **6**(1) March (1991).

## ضبط عوامل الإثارة لتشغيل المستقر لنظام القوى الكهربائية للشركة السعودية الموحدة للكهرباء بالمنطقة الوسطى

عبد الحميد العوهلي\* و زغلول الرزاز\* و صالح السحياني\*\*

\* قسم الهندسة الكهربائية ، كلية الهندسة ، جامعة الملك سعود ؛

و\*\* قسم الدراسات الفنية ، الشركة السعودية الموحدة للكهرباء بالمنطقة الوسطى ،

الرياض - المملكة العربية السعودية

المستخلص . استخدمت طريقة تحليلية لمعرفة تأثير عوامل أنظمة الإثارة على أداء نظام القوى الكهربائي للشركة السعودية الموحدة للكهرباء بالمنطقة الوسطى . فقد تمت دراسة تأثير جهاز الإثارة ، دائرة الاستقرار ، عوامل التشبع ودورهم في الاستقرار اللحظية للنظام . ولقد تم اقتراح حدود لقيم هذه العوامل لكي يعمل النظام بصورة جيدة .