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Excitation Parameters for Stable Operation of SCECO-Central Power System

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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[1].

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[2]. 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

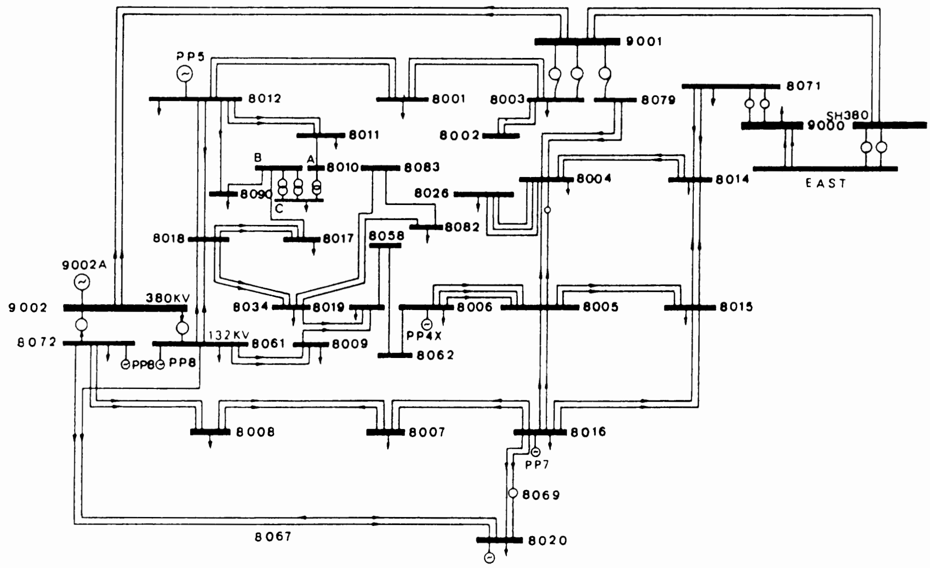

FIG. 1986 Riyadh electrical system.

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 (ω, δ, I_{fd}, λ_D, λ_{Q1}, λ_{Q2}). It has a field winding and a single amortisseur circuit in the d-axis and two amortisseur circuits in the q-axis[1].

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 sytem 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-

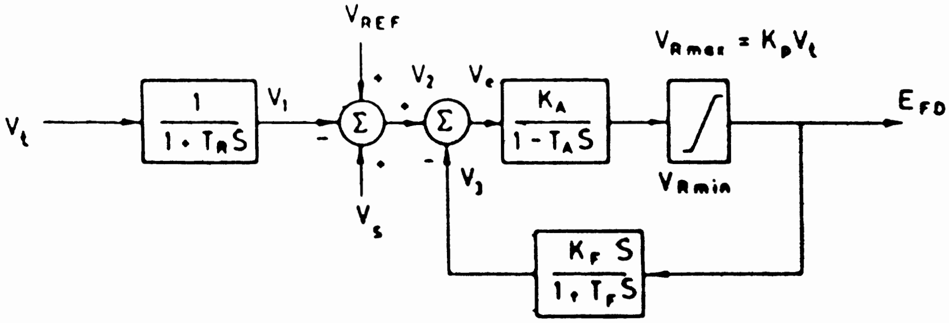

FIG. 2. Block diagram of GE excitation system.

TABLE 1. Excitation systems parameters.

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

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.

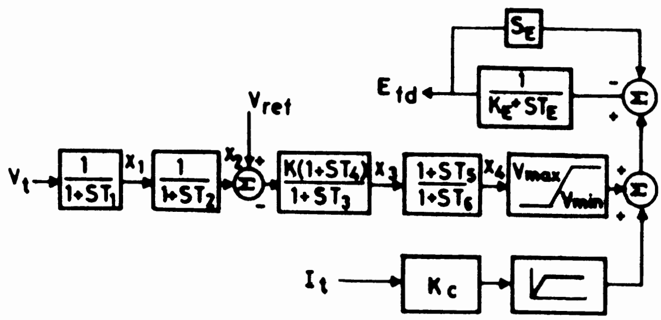

FIG. 3. Block diagram of BBC excitation system.

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 appied 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

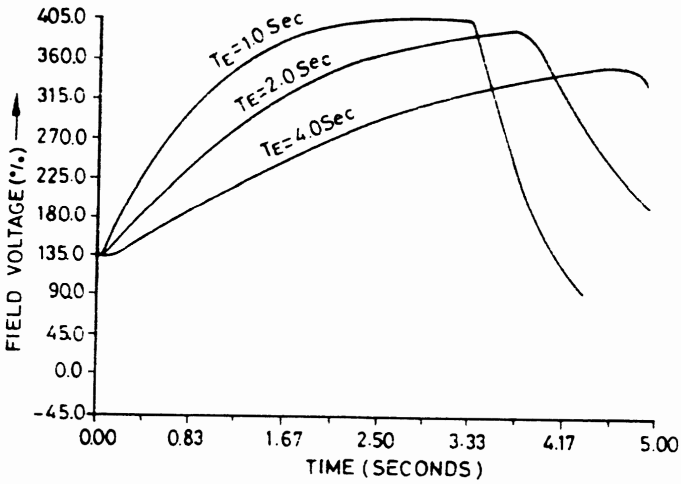

FIG. 4. The influence of T_E on the field voltage.

2.5.2 Effect of voltage regulator time costants 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[3]. These time constants correspond to those of the amplifier and the stabilizing signal. Different values for each time constant have

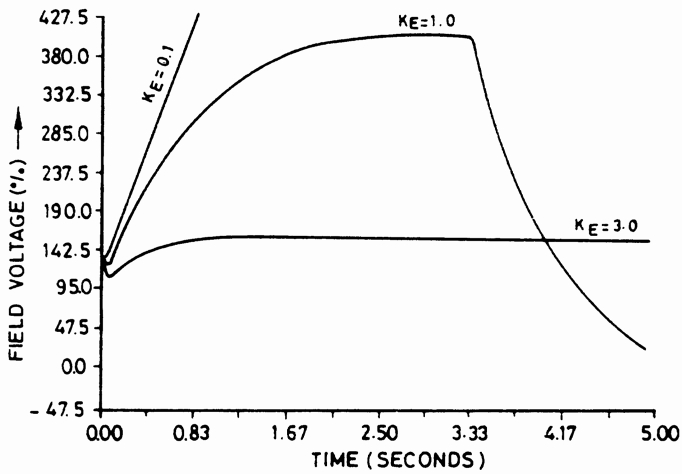

FIG. 5. The influence of K_E on the field voltage.

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[4]. 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 $1.0 \leq B_{ex}$ 2.0.

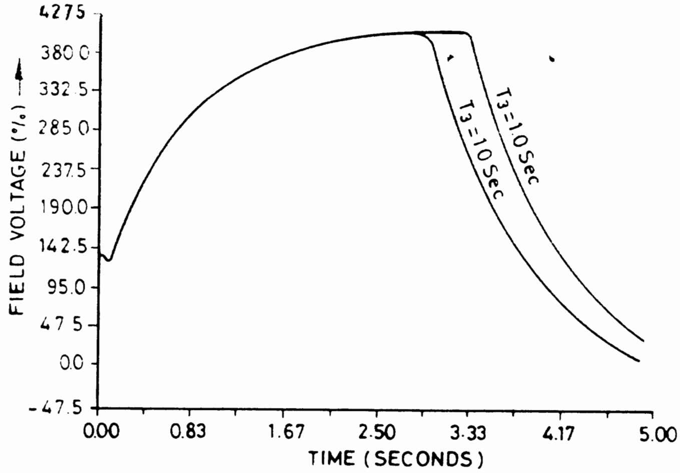

FIG. 6. The influence of T_3 on the field voltage.

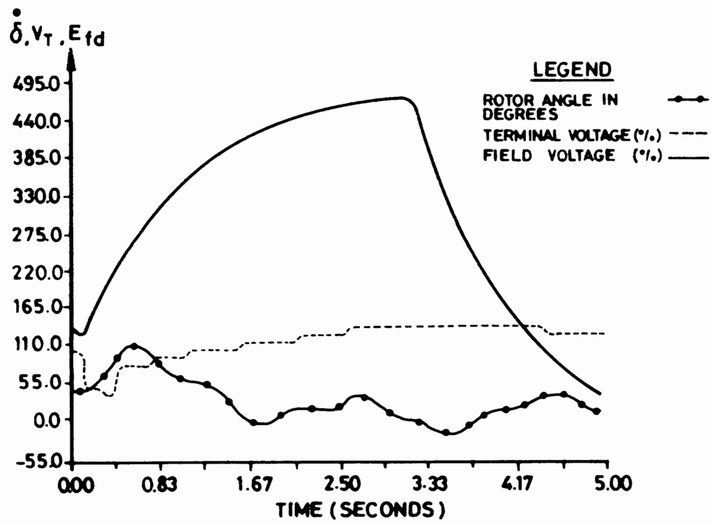

FIG. 7. Saturation parameter effect at PP8A (A_{ex} = 0.0).

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 $0.1 \leq K_F \leq 0.5$.

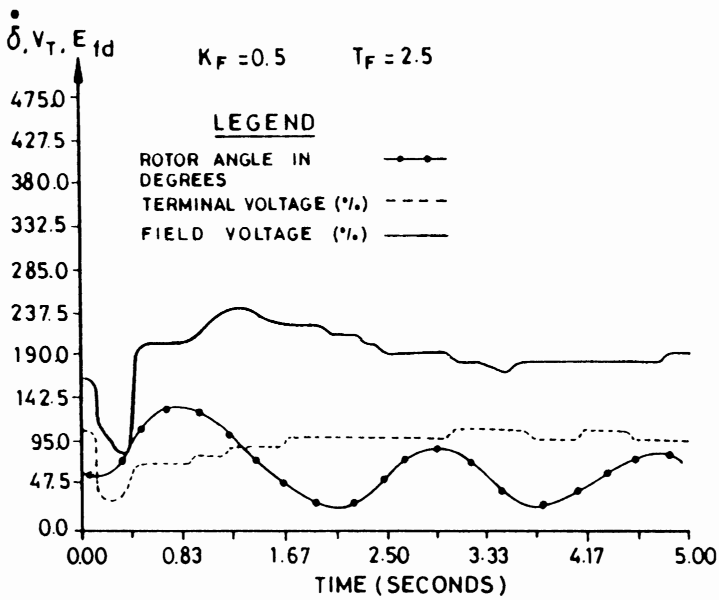

FIG. 8. Static excitation parameters effect in PP7.

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

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ضبـــط عوامـــل الإثـــارة للتشغيـــل المستقـر لنظـــام القـــوى الكهربائيـــة للشركة السعوديـــة الموحـــدة للكهربـــاء بالمنطقـــة الوســـطى

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

الريـــــاض - 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 الاستقرارية اللحظية للنظام . ولقد تم اقتراح حدود لقيم هذه العوامل لكي يعمل النظام بصورة جيدة .