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Comparison of Numerical Method applied to Excitation System Model for Power System Stability Study

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Abstract: **A Synchronous generator is provided with two automatic feedback controllers for regulation of terminal voltage and frequency. Regulation of voltage is faster than that of frequency. Thus voltage regulation has a greater bearing on the system stability than frequency regulation. The excitation field current is controlled so as to regulate the terminal voltage of the machine. Majority of the excitation systems in service use the IEEE Type-1 excitation, and hence considered for this study. In this paper the system equations are simulated using Code::Blocks version 10.05 results plotted using Gnuplot. The study considers the case with no Transient Gain Reduction (TGR) and with Excitation System Stabilizer (ESS) blocks. Different numerical techniques are used for study. The results show that either TGR or ESS is necessary to improve the response which tends to be oscillatory and takes longer to settle.**

Index Terms — **Excitation system, ESS, TGR, Code::Blocks version 10.05 and Gnuplot, numerical techniques**

I. Introduction

The objective of the excitation system is to control the field current of synchronous machine. The field current is controlled so as to regulate the terminal voltage of the machine. As the field circuit time constant is high, fast control of field current requires field forcing. Thus exciter should have a high ceiling voltage which enables it to operate transiently with voltage levels that are three to four times the normal. The performance requirements of the excitation system are determined by considerations of the synchronous generator as well as the power system [3].

II. Literature review

There are three distinct types of excitation systems based on the power source for exciter [1].

(i) DC Excitation System (DC) which utilize a DC generator with commutator.

(ii) AC Excitation System (AC) which uses alternators and either stationary or rotating rectifiers to produce the direct current needed.

(iii) Static Excitation System (ST) in which the power is supplied through transformers and rectifiers.

Elements of an excitation system is shown in fig.1.It consists of the following blocks,

- *Exciter*: This provides the dc power to the synchronous machine field winding, constituting the power stage of excitation system.
- *Regulator*: It processes and amplifies the input signals to a level and form appropriate for control of the exciter, this includes both regulating and excitation system stabilizing function.
- *Terminal voltage transducer and load compensator*: This senses terminal voltage, rectifies and filters it to dc quantity, and compares it with a reference which represents desired terminal voltage.
- *Power system stabilizer*: It provides an additional input signal to the regulator to damp power system oscillations.
- *Limiters and protective circuits*: These include a wide array of control and protective functions which ensure that the capability limits of the exciter and the synchronous generator are not exceeded

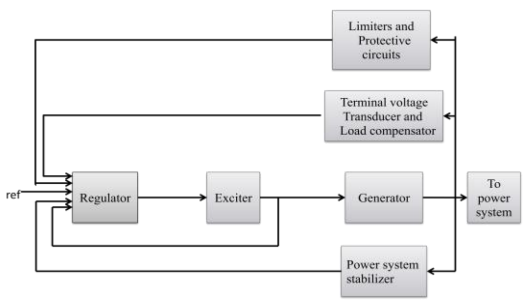

Figure 1.Elements of excitation system

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III. Methodology

The IEEE Type-1 excitation system [2] defined represents a majority of the excitation systems in service and is widely used. It essentially represents rotating exciters but with modifications can also represent static exciters. This is shown in fig.2.

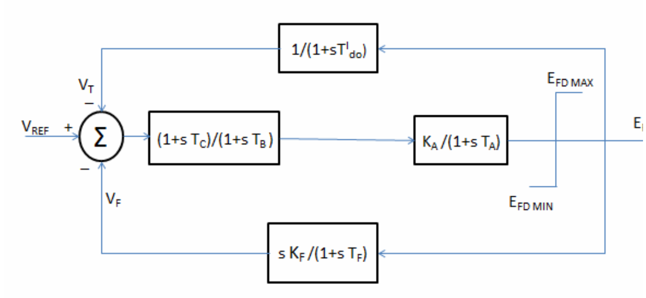

Figure 2.IEEE Type 1 excitation system

Excitation System Stabilizer (ESS) is used for increasing the stable region of operation of the excitation system and permit higher regulatory gains. The feedback transfer function or ESS is shown in fig.3 below.

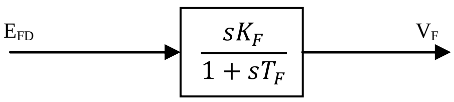

Figure 3.Excitation System Stabilizer (ESS)

ESS can be realized by a transformer (ideal) whose secondary is connected to a high impedance shown in fig. The turns ratio of the transformer and the time constant (L/R) of the impedance determine KF and TF according to the relations.

$$T_F = \frac{L}{R}$$

$$K_F = \frac{nL}{R}$$

The time constant is usually taken as 1sec.Instead of feedback compensation for ESS, a series connected lead/lag can also be used as shown in fig.4 below.

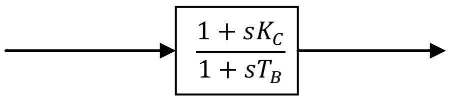

Figure 4.Transient Gain Reduction (TGR)

Here T_C is usually less than T_B. This means of stabilization is termed as Transient Gain Reduction (TGR). The objective of TGR is to reduce the transient gain or gain at higher frequencies, thereby minimizing the negative contribution of the regulator to system damping. A typical value of the transient gain reduction factor (T_B/T_C) is 10.

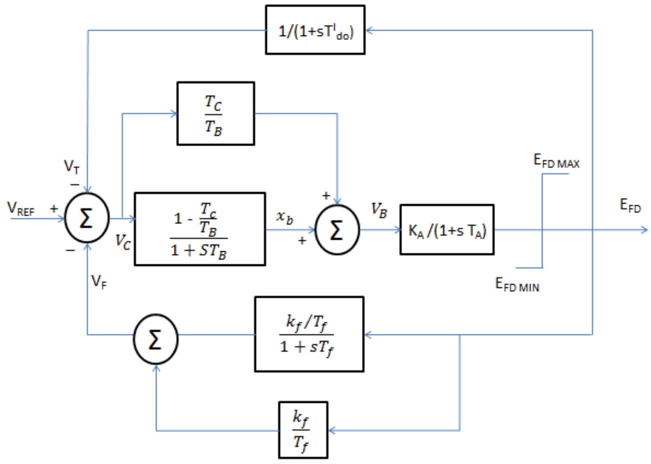

Figure 5.Block diagram indicating state variables

The system equations can be obtained from the block diagram representation given in fig.5 which is equivalent to that shown in Fig.2. These are as follows

$$\frac{dV_A}{dt} = \frac{1}{T_A}(-V_A + k_a + V_B) \qquad (1)$$

$$V_B = X_B + \frac{T_C}{T_B} * V_T \qquad (2)$$

$$V_1 = V_{ref} - V_f - V_t \qquad (3)$$

$$\frac{dX_B}{dt} = \frac{1}{T_B}\left(-X_B + \left(1 - \frac{T_C}{T_B}\right) V_1\right) \qquad (4)$$

Initial conditions are

$$V_{A(0)} = E_{fd(0)} = 1 \qquad (5)$$

$$X_B = \frac{V_{A(0)}}{k_a}\left(1 - \frac{T_C}{T_B}\right) \qquad (6)$$

$$T_C = 1s, V_{ref} = 1pu$$

IV. Results

The system equations are simulated using Code::Blocks is a free C++ IDE built to meet the most demanding needs of its users. It is designed to be very extensible and fully configurablewhere in twonumerical techniques such as forward Euler's and 4th order Runge-Kutta technique are utilized and the same are plotted using Gnuplot. Gnuplot is a free, command-driven, interactive, function and data plotting program

B. DC Excitation System

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Euler method

$$\frac{dE_{fd}}{dt} = \{V_R - (K_E + S\,E\,(E_{fd}))*\ E_{fd}\} * \frac{1}{T_E} \quad (7)$$

$$\frac{dE_{fd}}{dt} = f(E_{fd(n)},\ t_n) = \frac{E_{fd(n+1)} - E_{fd(n)}}{h} \quad (8)$$

$$E_{fd(n+1)} = Kh + E_{fd(n)} \quad (9)$$

T_E =1.15, K_E = -0.3022,
SE (E_{fd})=$Ae^{BE}{}_{fd}$
$S\,E\,(E\,fd\,) = 0.014 * e^{(1.55*E_{fd})}$

$$E_{fd(n+1)} = \left[\frac{1}{1.15} - \{1 - (-0.3022 + 0.014 * e^{(1.55*E_{fd(n)})}) * E_{fd(n)}\}\right] h + E_{fd(n)} \quad (10)$$

Results

Case(i) For h=0.5

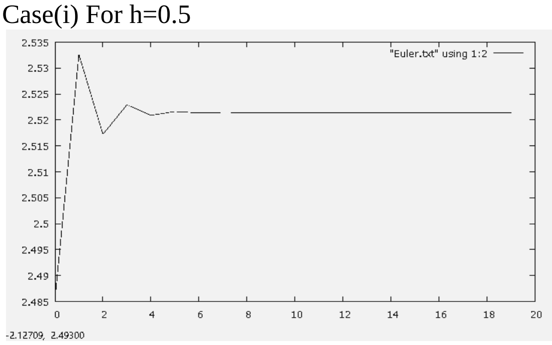

Figure 6. For h=0.5

Case (ii) For h=0.65

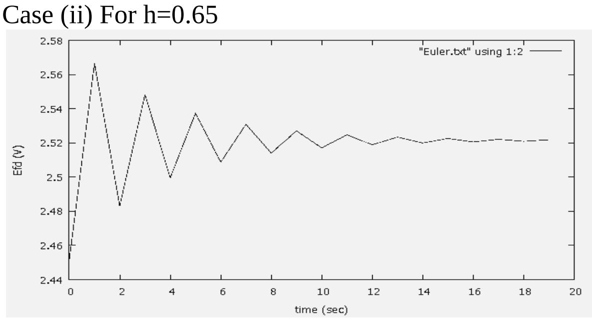

Figure 7. For h=0.65

4th order Runge-Kutta method

The system equation is given by

$$E_{fd(n+1)} = E_{fd(n)} + \frac{h}{6} * (K_1 + 2K_2 + 2K_3 + K4) \quad (11)$$

Where

$$k_1 = (0.869 - ((-.2628 + 0.0122 * e^{1.55*Efd(n)} * E_{fd(n)}))$$

$$k_2 = \left(\left(0.869 - \left(\left(-.2628 + 0.0122 * \left(e^{1.55*\left(Efd1+\left(\frac{h}{2}\right)*k1\right)}\right)\right) * \left(Efd1 + \left(\frac{h}{2}\right) * k1\right)\right)\right)\right)$$

$$k3 = \left(\left(0.869 - \left(\left(-.2628 + 0.0122 * \left(e^{1.55*\left(Efd1+\left(\frac{h}{2}\right)*k2\right)}\right)\right) * \left(Efd1 + \left(\frac{h}{2}\right) * k2\right)\right)\right)\right)$$

$$k4 = \left(0.869 - \left((-.2628 + 0.0122 * \left(e^{1.55*(Efd1+h)}\right) * Efd1)\right)\right)$$

Results

Case(i) For h=0.5

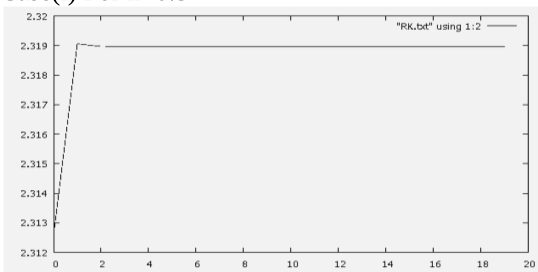

Figure 8.For h=0.5

Case (ii) For h=0.65

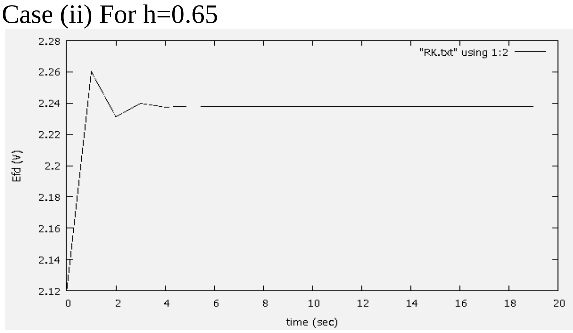

Figure 9.For h=0.65

C. Static Excitation system

Modeling of static excitation system

$$\frac{dVa}{dt} = \frac{1}{Ta}[-Va + Ka * VB] \quad (12)$$

$$V_B = X_B + \frac{T_C}{T_B} * V_1 \quad (13)$$

$$V_I = V_{ref} - V_f - V_T \quad (14)$$

$$\frac{dX_B}{dt} = \frac{1}{T_B}\left[-X_B + \left(1 - \frac{T_C}{T_B}\right) * V_1\right] \quad (15)$$

The initial conditions are

$$Va(0) = E_{fd}(0) = 1.0$$

$$X_{B(0)} = \frac{V_{a(0)}}{Ka}\left[1 - \frac{Tc}{TB}\right]$$

Tc=1 sec, T_B=10 sec, Vref=1 pu,Ka=400,Ta=0.025 sec

Forward Euler's method

$$E_{fd(n+1)} = [40 * (-E_{fd(n)} + 0.244) * h] + E_{fd(n)} \quad (16)$$

Results

Case (i) For h=0.03

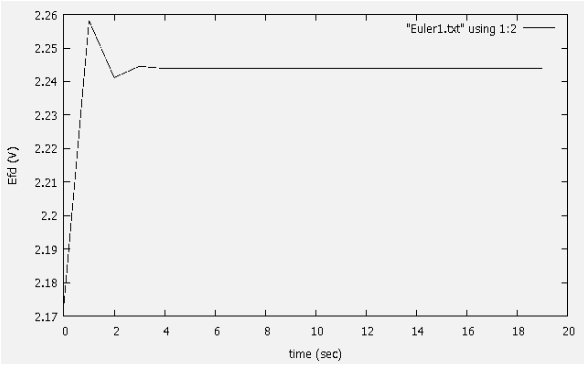

Figure 10.For h=0.03

Case(ii) For h=0.045

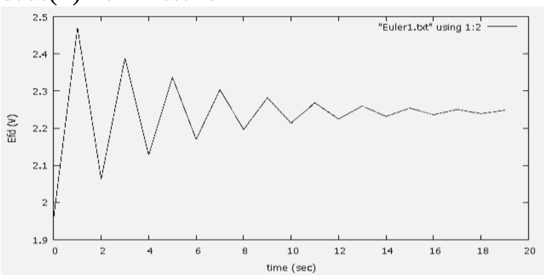

Figure 11. for h=0.045

Applying 4th order R-K method

$$E_{fd(n+1)} = E_{fd(n)} + \left[\left(\frac{h}{6}\right)(k_1 + 2*k_2 + 2*k_3 + k_4)\right] \quad (17)$$

Where

$$k1 = (40*(-Efd + 2.244)*h) + Efd$$

$$k_2 = \left(40*\left(-\left(E_{fd(n)} + \left(\frac{h}{2}\right)*k1\right) + 2.244\right)*h\right) + \left(E_{fd(n)} + \left(\frac{h}{2}\right)*k1\right)$$

$$k_3 = \left(40*\left(-\left(E_{fd(n)} + \left(\frac{h}{2}\right)*k2\right) + 2.244\right)*h\right) + \left(E_{fd(n)} + \left(\frac{h}{2}\right)*k2\right)$$

$$k_4 = \left(40*\left(-\left(E_{fd(n)} + h*k1\right) + 2.244\right)*h\right) + \left(E_{fd(n)} + h*k1\right)$$

Results of 4th order R-K method

Case (i) For h=0.1

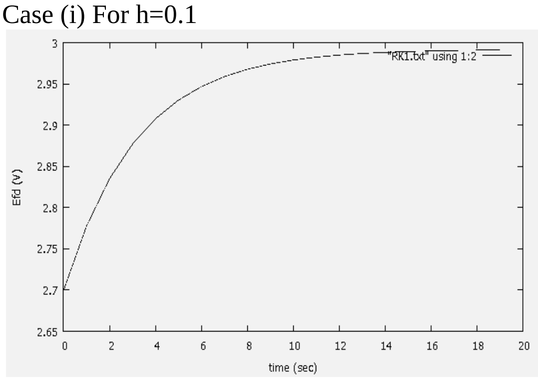

Figure 12. Case (i) For h=0.1

Case (ii) For h=0.15

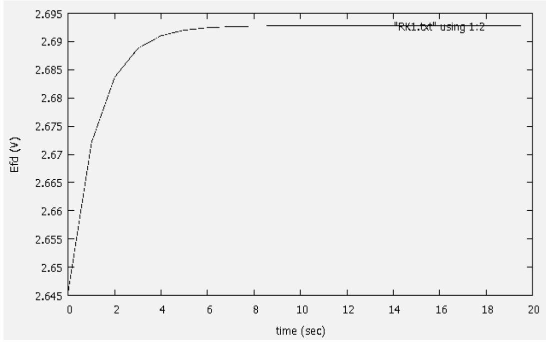

Figure 13.For h=0.15

Case (iii) For h=0.16

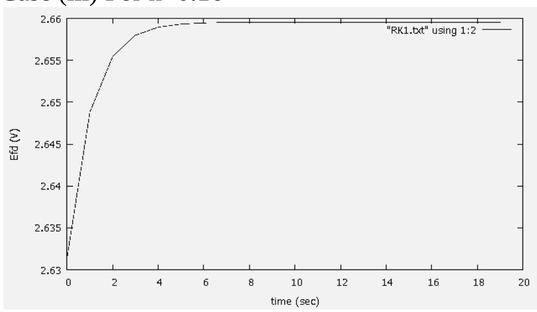

Figure 14. For h=0.16

CONCLUSIONS

The results of variation of EFD with time for considering the case with no TGR and with ESS is simulated and verified. The results show that RK 4th order technique is more numerically stable compared to forward Eulers technique.

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