4

Automatic Voltage Regulation

4.1 MODERN PRACTICE

Most modern synchronous generators are furnished with a self-contained voltage regulation system, in that it does not require a power supply from an external switchboard. The complete system consists of:-

- Circuits to measure the current and voltage of the generator stator windings.
- A voltage error sensing circuit to compare the terminal voltage at the generator with a set or reference value.
- A power amplifier to amplify the error signal and to provide sufficient power to energise the field winding of the exciter.
- An auxiliary AC generator, called the exciter, to further amplify the signal power to a sufficient level to energise the field winding of the main generator.

Figure 4.1 shows the control system as a block diagram, and scaled into a per unit form that is suitable for computer studies and analysis.

4.1.1 Measurement Circuits

The terminal voltage of the main generator is measured by the use of a voltage transformer connected across two of the stator lines, e.g. L1 and L2. The signal is then rectified and smoothed in the automatic voltage regulator (AVR), by a circuit that incurs a small time constant T_{r1}.

Most modern generators are required to operate in parallel with other generators on the same busbars, which requires them to share the reactive power in proportion to their individual ratings. This sharing process is determined by using a proportional feedback signal. This signal is derived from a circuit that creates the reactive power component from the sinusoidal terminal voltage and sinusoidal current of the main generator stator winding. The voltage is the same as that taken above from the voltage transformer connected to lines L1 and L2. A current transformer is connected in the third line L3. The voltage and current signals are fed into a multiplier that creates a DC signal equivalent to the reactive power. The unsmoothed signal also contains sinusoidal components, which are subsequently smoothed out by a suitable filter. The smoothing circuit incurs a small time constant T_{r2}, of similar magnitude to T_{r1}.

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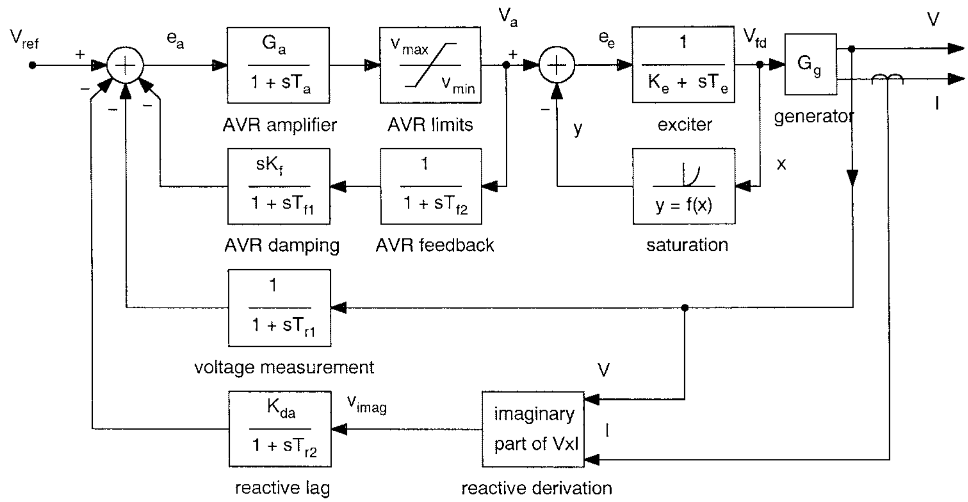

Figure 4.1 Control system for the automatic voltage regulation of a synchronous generator.

The proportional gain of the reactive power is called the 'droop' constant K_{da} in Figure 4.1 and is usually set on the range of 3 to 6% of the rated MVA of the generator.

4.1.2 Error Sensing Circuit

The reference voltage V_{ref} for the AVR is usually taken from the moving brush of a potentiometer that is driven by a small servomotor inside the AVR controller. The servomotor receives 'raise' and 'lower' signals from control switches mounted locally on the AVR controller, remotely at the main generator switchgear or at a control room.

The terminal voltage signal V is compared with the reference signal V_{ref}. In addition the reactive droop signal is deducted from V_{ref} so that the terminal voltage falls slightly with an increase in reactive loading on the generator.

The automatic voltage regulation is stabilised by the use of derivative feedback. The source of the feedback is the output of the power amplifier. The output from the derivative, or damping, circuit is deducted from the reference voltage at the summing junction. The damping is mainly determined by the factor K_f. The two time constants T_{f1} and T_{f2} result from the components in the feedback measurement and smoothing circuits.

4.1.3 Power Amplifier

The power amplifier raises the signal level from a few volts and few milliamps to tens of volts and tens of amps that are required by the field winding of the exciter. The amplification is shown as the gain G_a that is typically in the range 200 to 500 per unit (see example below).

The design of the AVR system is such that, without the droop being enabled, the regulation of the terminal voltage of the generator should be approximately 0.5%. This occurs when the generator is loaded from zero to full-load at rated power factor. In order to achieve this low level of regulation the gain G_a needs to be high.

The power amplifier has a practical lower limit of zero and an upper limit of typically 10.0 per unit. The upper limit should be high enough to ensure that the full output of the exciter can be obtained during field forcing of the main generator, e.g. during short circuits that are at or near to the generator.

4.1.3.1 Worked example

Find the value of the gain G_a for an AVR fitted to a generator that has a synchronous reactance of 2.0 pu. Assume the full-load has a power factor of 0.8 lagging and a terminal voltage V of 0.995 pu i.e. (0.5% regulation)

Step 1. Find the equivalent series impedance Z that can represent the load. The full volt-ampere load on the generator is S,

$$S = P + jQ \quad \text{pu} \quad \text{MVA}$$

When the terminal voltage is $V < 1.0$, the load impedance Z is,

$$Z = R + jX = \frac{VV^*}{S^*}$$

Where $*$ denotes a conjugate quantity.

Hence

$$Z = \frac{0.995^2}{0.8 - j0.6} = 0.792 + j0.594 \quad \text{pu}$$

Step 2. Find the emf in the generator

The emf feeds a series circuit consisting of the load plus the synchronous reactance X_s. It can be shown that the emf E is,

$$E = \frac{V}{Z^2}\left[(Z^2 + X.X_s) + jR.X_s\right]$$

Hence

$$|E| = \frac{V}{Z^2}\sqrt{(Z^2 + X.X_s)^2 + (R.X_s)^2} \tag{4.1}$$

Now

$$\begin{aligned} Z^2 &= R^2 + X^2 = 0.9801 \text{ pu} \\ |E| &= \frac{0.995}{0.9801}\sqrt{(0.9801 + (0.594)(2.0))^2 \times ((0.792)(2.0))^2} \\ &= 2.7259 \end{aligned}$$

Hence the gain G_g of the generator in its full-load steady state is,

$$G_g = \frac{|V|}{|E|} = \frac{0.995}{2.7259} = 0.365 \text{ pu} \tag{4.2}$$

Step 3. Derive the steady state conditions of the AVR for no load and full-load on the generator.

Step 3a) No load

From Figure 4.1 it can be seen that at no load $V = 1.0$. Assuming that the exciter is not saturated,

$$e_e = V_{fd} = V = 1.0, \quad \text{since at no load } G_g = 1.0$$

Let

$$V_o = V \text{ at no load}$$

Hence,

$$e_a = \frac{e_e}{G_a} \text{ and } V_{\text{ref}} = e_a + V_o$$

And so,

$$V_o = G_a(V_{\text{ref}} - V_o) \tag{4.3}$$

Step 3b) Full-load

From Figure 4.1 it can be seen that at full-load, $V = 0.995$, $V_{fd} = 2.7259$ from equation (4.1) and therefore $G_g = 0.365$.

Again assume that the exciter is not saturated and so,

$$e_e = V_{fd} = |E| = 2.7259 \text{ pu}$$

Let

$$V_1 = V \text{ at full-load}$$

Hence,

$$e_a = \frac{e_e}{G_a} \text{ and } V_{\text{ref}} = e_a + V_1$$

And so,

$$V_1 = G_a\ G_g(V_{\text{ref}} - V_1) \tag{4.4}$$

Step 4. Find V_{ref} and G_a

There are two equations, equations (4.3) and (4.4), containing two unknowns V_{ref} and G_a. Divide (4.4) by V_1 and rearrange to give,

$$G_a\left(G_g\frac{V_{\text{ref}}}{V_1} - G_g\right) = 1.0 \tag{4.5}$$

In (4.3) the voltage $V_o = 1.0$, and so,

$$G_a(V_{\text{ref}} - 1.0) = 1.0 \tag{4.6}$$

Equate the bracketed terms in (4.5) and (4.6)

$$G_g \frac{V_{\mathrm{ref}}}{V_1} - G_g = V_{\mathrm{ref}} - 1.0$$

Hence,

$$V_{\mathrm{ref}} = \frac{(G_g - 1.0)V_1}{G_g - V_1} \tag{4.7}$$

Inserting the data gives $V_{\mathrm{ref}} = 1.002897$ pu

Substitute V_{ref} into (4.6) to find G_a,

$$G_a = \frac{G_g - V_1}{G_g(V_1 - 1.0)} \tag{4.8}$$

Inserting the data gives $G_a = 345.205$ pu, which is of the correct order for an AVR.

The solution to the example can be found by using equations (4.1), (4.2) and (4.8) V_{ref} can be found from (4.7).

4.1.3.2 Variation of G_a with X_s

If the above sequence is repeated for different values of synchronous reactance then appropriate values of the AVR gain G_a can be found, as shown in Table 4.1.

In practice the value of G_a may be higher than those given in Table 4.1, in which case a regulation better than 0.5% would be obtained. In general the higher the value of G_a that is used, the

Table 4.1. AVR gain G_a as a function of the synchronous reactance X_s

Synchronous reactance X_s (pu)	Generator gain G_g (pu)	AVR gain G_a (pu)
1.5	0.442	250.0
1.6	0.424	268.9
1.7	0.408	287.8
1.8	0.393	306.9
1.9	0.378	326.0
2.0	0.365	345.2
2.1	0.353	364.4
2.2	0.341	383.7
2.3	0.330	403.1
2.4	0.320	422.5
2.5	0.310	442.0
2.6	0.301	461.5
2.7	0.292	481.0
2.8	0.284	500.5
2.9	0.276	520.1
3.0	0.269	539.7

more damping feedback will be required. Hence the values of K_f and T_{f2} will tend towards their higher values, see Table 4.3.

4.1.4 Main Exciter

The exciter (sometimes called the main exciter) is a synchronous generator that has its stator and rotor windings inverted. Its field winding is fixed in the stator, and the rotor carries the armature or AC windings. In addition the rotor carries the semiconductor bridge rectifier that converts the armature voltages to a two-wire DC voltage system. The AC voltages and currents in the armature are often alternating at a higher frequency than those in the main generator, e.g. 400 Hz. The higher frequency improves the speed of response of the exciter. The DC power circuit is coupled to the field of the main generator by the use of insulated conductors that pass coaxially inside the rotor of the exciter and the rotor of the main generator. This eliminates the use of slip rings, which were traditionally used before shaft mounted rectifiers were developed. A slight disadvantage of this technique is that the derivative feedback cannot be taken from the output of the exciter. However, with modern electronic devices used throughout the AVR, this can be regarded as an insignificant disadvantage.

The time constant T_e of the exciter is mainly related to its field winding.

The saturation block in Figure 4.1 accounts for the magnetic saturation of the iron core of the exciter, and it is important to represent this because the expected range of the performance of the exciter is wide. Its terminal voltage may have a value of typically 3.0 per unit when the generator is fully loaded. This may increase to about 6.5 per unit when the generator needs to maintain a full short circuit at or near to its terminals. The maximum excitation voltage is called the 'ceiling voltage' of the exciter.

4.1.4.1 Pilot exciter

The AVR system requires a source of power for its amplifier, its reference voltage and other electronic circuits that may be involved e.g. alarms. There are several methods of obtaining this necessary power,

- An external power supply.
- Self-excitation.
- Pilot exciter.

An external supply could be an uninterrupted power supply (UPS) that is dedicated to the generator. Although this is feasible it is not a method that is used, the main reason being that it departs from the requirement of self-containment. The equipment involved would require external cables and switchgear, both of which add a factor of unreliability to the scheme.

The self-excitation method relies upon the residual magnetism in the iron core of the main generator that remains in the core after the generator is shut down. When the generator is started again and run up to speed a small emf is generated by the residual magnetism. A special circuit detects the residual emf at the main terminals and amplifies it to a predetermined level. This amplified voltage is rendered insensitive to a wide range of emf values and has sufficient power to feed all the auxiliary requirements of the AVR. The advantage of this method is its low cost compared with using a pilot exciter. Its main disadvantage is an inferior performance when a short circuit occurs at or near the main generator. The detected emf, or terminal voltage, when the generator is connected to the busbars, falls to near zero when the short circuit exists. The AVR may loose its supply during this period or perform in an unpredictable manner. The excitation of the generator may collapse, which is not desirable.

The pilot exciter method is highly reliable and has a fully predictable performance. A small alternator is mounted on the same shaft, and often within the same frame, as the main exciter. It receives its excitation from a shaft mounted permanent magnet rotor system. Hence its level of excitation is constant and dependable. The AC output from the pilot exciter is rectified and smoothed by components within the AVR cubicle. It can be seen that this method is completely independent of the conditions existing in the main generator. This is the method usually specified in the oil industry.

4.2 IEEE STANDARD AVR MODELS

In order to standardise the modelling of AVR systems for computer analysis the IEEE, see Reference 1, has derived a set of block diagrams for the purpose. The model described above is called the Type 2 and is the most frequently used. If a slip-ring connected main exciter is used then a Type 1 is appropriate.

In Figure 4.1 the block representing the generator shows a function G_g. This function is a complicated combination of the dynamic variables and time constants within the generator equations. However, in the steady state the numerical value of G_g as a gain term varies from 1.0 at no-load where V is equal to V_{fd}, to typically 0.365 at full-load and rated power factor. This variation G_g needs to be taken into account when the value of the AVR gain G_a is established to give an overall voltage regulation of 0.5% and zero reactive drop.

The saturation function for the main exciter is approximated by a simple exponential function of the form, $y = Ae^{Bx}$, where x is the output voltage V_{fd} of the exciter and y is the error e_e leaving the summing junction.

The constant A is usually a small number typically in the range 0.07 and 0.1 per unit so that when the generator is at or near no load the exciter is either not saturated or is only just beginning to become saturated. The constant B takes account of the extent of saturation that occurs as the exciter field voltage is increased. It has a typical value in the range of 0.4 to 0.6 per unit.

Figures 4.2 and 4.3 show the open-circuit curves for a wider range of values for A and B in order to show more clearly the effect that they have on the shape of the curve.

The two constants A and B can be found from data given by the manufacturer for the exciter open-circuit voltage V_{fd} and the excitation voltage (or current) V_a. The data are usually given in graphical form as actual quantities, i.e. volts and amps. These should first be converted into their equivalent per unit form by dividing by their values that correspond to the no-load condition of the main generator. When this conversion is made unit output voltage of the exciter produces unit terminal voltage at the main generator.

Since there are two unknown constants their solution will require two equations. Hence any two pairs of data points can be used from the open-circuit voltage curve of the exciter. Using the notation in Figure 4.2 or 4.3 let these pairs of points be,

$$V_{a1} \text{ with } V_{fd1} \text{ and } V_{a2} \text{ with } V_{fd2}$$

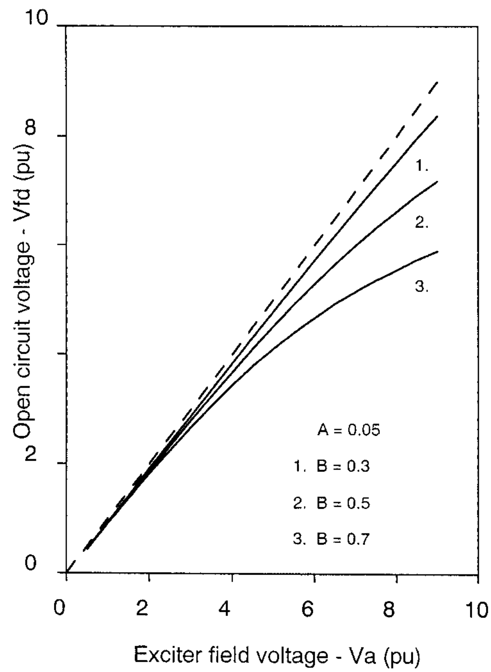

Figure 4.2 Open circuit voltage versus exciter field voltage. The graph shows the effect on the saturation curvature caused by changing the constant B over a wide range with the constant A fixed at 0.05.

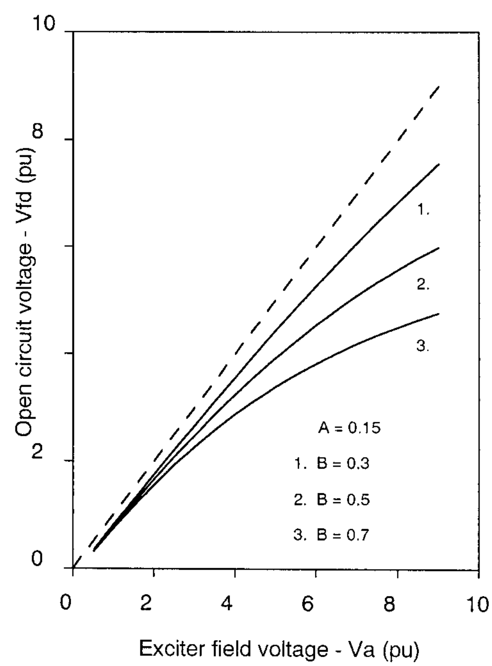

Figure 4.3 Open circuit voltage versus exciter field voltage. The graph shows the effect on the saturation curvature caused by changing the constant B over a wide range with the constant A fixed at 0.15.

The output signals from the saturation block are therefore,

$$V_{a1} - V_{fd1} = Ae^{BVfd1} \tag{4.9}$$

And

$$V_{a2} - V_{fd2} = Ae^{BVfd2} \tag{4.10}$$

Taking natural logarithms of both sides of equations (4.9) and (4.10) gives,

$$\log_e(V_{a1} - V_{fd1}) = \log_e A + BV_{fd1}$$

And

$$\log_e(V_{a2} - V_{fd2}) = \log_e A + BV_{fd2}$$

Eliminating $\log_e$ A by subtraction gives

$$B = \frac{\log_e(V_{a1} - V_{fd1}) - \log_e(V_{a2} - V_{fd2})}{V_{fd1} - V_{fd2}}$$

$$B = \frac{\log_e\left(\dfrac{V_{a1} - V_{fd1}}{V_{a2} - V_{fd2}}\right)}{V_{fd1} - V_{fd2}} \tag{4.11}$$

And therefore from (4.9) and (4.10)

$$A = \frac{V_{a1} - V_{fd1}}{e^{BVfd1}} \quad \text{or} \quad \frac{V_{a2} - V_{fd2}}{e^{BVfd2}} \tag{4.12}$$

It has become the custom to choose the two pairs of data at the 100% and 75% excitation levels of the exciter. The purpose being to suit computer simulation programs that require these specific data points.

The 100% pairs are those at the ceiling output voltage of the exciter whilst the 75% pair are at 75% of the ceiling output voltage. The saturation level can be described by dividing the difference in V_a that is needed above that required on the linear non-saturated line, by the non-saturated value of V_a. Hence at V_{fd100} the value of V_a is V_{a100S} from the saturated curve and V_{a100U} from the straight line. Similarly at the reduced output voltage V_{fd75} the two values of V_a are V_{a75S} and V_{a75U}. The two saturation levels S_{E100} and S_{E75} are given by,

$$S_{E100} = \frac{V_{a100S} - V_{a100U}}{V_{a100U}} \qquad \text{per unit}$$

And

$$S_{E75} = \frac{V_{a75S} - V_{a75U}}{V_{a75U}} \qquad \text{per unit}$$

From the data for the exciter V_{fd100} and V_{a100S} should be available together with V_{a75S}. The manufacturer may also provide S_{E100} and S_{E75}. V_{fd75} is easily calculated from V_{fd100}.

4.2.1 Worked Example

An exciter has an open-circuit curve which has the following two pairs of data points.

$$V_{a1} = 2.0 \quad V_{fd1} = 1.853$$
$$V_{a2} = 4.0 \quad V_{fd2} = 3.693$$

Find the constants A and B in the exponential function that describes the saturation characteristic of the exciter,

$$\frac{V_{a1} - V_{fd1}}{V_{a2} - V_{fd2}} = \frac{2.0 - 1.853}{4.0 - 3.693} = \frac{0.1470}{0.3070} = 0.478827$$
$$V_{fd1} - V_{fd2} = 1.853 - 3.693 = -1.840$$
$$B = \frac{\log_e 0.478827}{-1.840} = 0.400226$$
$$A = \frac{V_{a1} - V_{fd1}}{e^{BVfd1}} = \frac{0.1470}{e^{0.741618}} = 0.070022$$

4.2.2 Worked Example

Repeat the example of 4.2.1 but assume the data are less accurate due to visual rounding errors in V_{fd}. Assume the data are,

$$V_{a1} = 2.0 \qquad V_{fd1} = 1.85 \text{ instead of } 1.853$$
$$V_{a2} = 4.0 \qquad V_{fd2} = 3.70 \text{ instead of } 3.693$$
$$\frac{V_{a1} - V_{fd1}}{V_{a2} - V_{fd2}} = \frac{2.0 - 1.85}{4.0 - 3.70} = \frac{0.15}{0.30} = 0.5$$
$$V_{fd1} - V_{fd2} = 1.85 - 3.70 = -1.85$$
$$B = \frac{\log_e 0.5}{-1.85} = 0.374674$$
$$A = \frac{V_{a1} - V_{fd1}}{e^{BVfd1}} = \frac{0.15}{e^{0.6931}} = 0.075$$

or

$$A = \frac{V_{a2} - V_{fd2}}{e^{BVfd2}} = \frac{0.15}{e^{0.6931}} = 0.075$$

Hence an average error in V_{fd} of 0.176% causes an error in B of 6.38% and an error in A of 7.11%. It is therefore important to carefully extract the data from the open-circuit curves to at least the third decimal place.

4.2.3 Determining of Saturation Constants

Saturation data for exciters and main generators can be described in an approximate manner by an exponential function of the form,

$$S = Ae^{BVfd}$$

In order to find A and B it is necessary to be given two values of S. In practice these two values are usually called S_{E75} and S_{E100}, which will be discussed at the conclusion of this subsection. The following procedure is applicable to both exciters and main generators and shows how any two values of S can be used, and why S_{E75} and S_{E100} are preferred.

Figure 4.4 shows the open-circuit curve for an exciter in actual volts and amps. Figure 4.5 shows the same curve converted into its per-unit form. Three points are chosen on the linear characteristic that has been extrapolated over the range excitation voltage. Call these V_{fd1}, V_{fd2} and V_{fd3}. Their corresponding excitation voltages are called V_{a12}, V_{a22} and V_{a32} for a non-saturating exciter. At each V_{fd} point a horizontal line is drawn to intercept the saturated or actual characteristic, and call these V_{a11}, V_{a21} and V_{a31} respectively.

Define three saturation functions as,

$$S_1 = \frac{V_{a11} - V_{a12}}{V_{a12}} \tag{4.13}$$

$$S_2 = \frac{V_{a21} - V_{a22}}{V_{a22}} \tag{4.14}$$

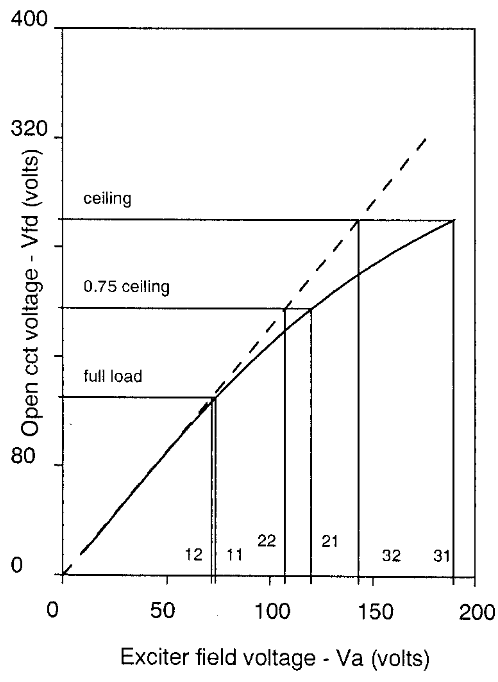

Figure 4.4 Open-circuit voltage in volts versus exciter field voltage in volts. For use in determining the SE75 and SE100 parameters of the exciter.

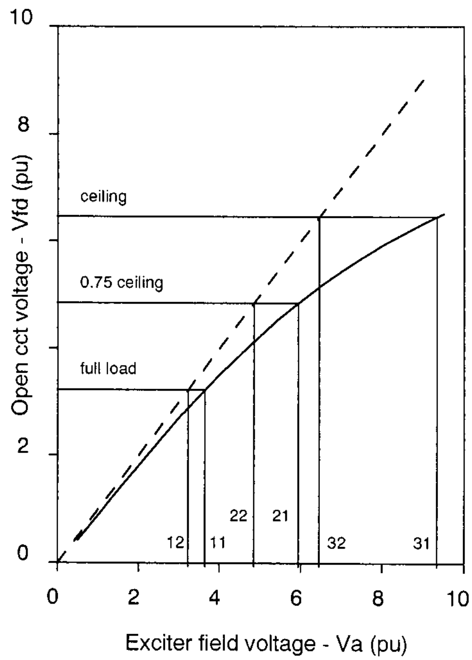

Figure 4.5 Open-circuit voltage in per unit versus exciter field voltage in per unit. For use in determining the SE75 and SE100 parameters of the exciter.

$$S_3 = \frac{V_{a31} - V_{a32}}{V_{a32}} \tag{4.15}$$

Use V_{fd1} as the reference output voltage and convert V_{fd3} into a per unit factor of V_{fd1}, denoted as $V_{fd3\text{pu}}$.

$$V_{fd3\text{pu}} = \frac{V_{fd3}}{V_{fd1}} \tag{4.16}$$

By simple proportions,

$$V_{a32} = V_{a12}.V_{fd3\text{pu}} \tag{4.17}$$

Choose a factor $u > 1$, such that,

$$u = \frac{V_{a32}}{V_{a22}} = \frac{V_{a12}.V_{fd3\text{pu}}}{V_{a22}} \tag{4.18}$$

Therefore,

$$V_{a22} = \frac{V_{a12}.V_{fd3\text{pu}}}{u} \tag{4.19}$$

Substitute (4.19) into (4.14), and (4.17) into (4.15),

$$S_2 = \left(\frac{V_{a21} - V_{a22}}{V_{a12}V_{fd3\text{pu}}}\right)u = Ae^{BVfd2} \tag{4.20}$$

And,

$$S_3 = \left(\frac{V_{a31} - V_{a32}}{V_{a12}V_{fd3\text{pu}}}\right)u = Ae^{BVfd3} \tag{4.21}$$

Divide (4.21) by (4.20)

$$\frac{S_3}{S_2} = e^{B(Vfd3 - Vfd2)}$$

From which,

$$B = \frac{\log_e\left(\dfrac{S_3}{S_2}\right)}{V_{fd3} - V_{fd2}} \tag{4.22}$$

Also,

$$\frac{S_3}{S_2} = \frac{(V_{a31} - V_{a32})}{(V_{a21} - V_{a22})u}$$

Since

$$u = \frac{V_{fd3}}{V_{fd2}} \quad \text{by proportion from (4.18)}$$

$$S_3 = A\ e^{Bu\ Vfd2}$$

$$S_2 = A\ e^{B\ Vfd2}$$

Hence,

$$\log_e S_3 = \log_e A + uBV_{fd2} \tag{4.23}$$

And,

$$\log_e S_2 = \log_e A + BV_{fd2} \tag{4.24}$$

Multiply (4.24) by u, and subtract from (4.23),

$$\begin{aligned}\log_e S_3 - u\log_e S_2 &= \log_e A - u\log_e A\\ &= (1-u)\log_e A\end{aligned}$$

Therefore,

$$A^{1-u} = \frac{S_3}{S_2{}^u}$$

Hence,

$$A = \frac{S_3{}^{1/(1-u)}}{S_2{}^{u/(1-u)}}$$

Returning to (4.22) and substituting u,

$$V_{fd3} - V_{fd2} = \left(\frac{u-1}{u}\right) V_{fd3}$$

And so,

$$B = \frac{1}{V_{fd3}} \left(\frac{u}{u-1}\right) \log_e \left(\frac{S_3}{S_2}\right)$$

If u is chosen as a quotient of integer numbers, one greater than the other, such that the result is greater than unity, then the quotient is,

$$u = \frac{m+1}{m}$$

From which,

$$\frac{1}{1-u} = -m, \quad \frac{u}{1-u} = -m-1, \quad \text{and} \quad \frac{u}{u-1} = m+1$$

Therefore,

$$A = \frac{{S_2}^{m+1}}{{S_3}^{m}}$$

And

$$B = \frac{1}{V_{fd3}} (m+1) \log_e \left(\frac{S_3}{S_2}\right)$$

Table 4.2 shows the various coefficients and subscripts of S_2 and S_3 for different choices of m.

For an exciter the customary choices of S_2 and S_3 are S_{E75} and S_{E100} because the excursions of V_a and V_{fd} above their full-load values are large. However, such excursions in a main generator are smaller and the data given covers a smaller range of values. In this situation a larger value of m is more suitable, e.g. $m = 4$ or 5, which requires S_2 to be S_{E80} or S_{E83}.

Since computer programs usually require per unit data, the calculation of S_2, S_3, A and B should be carried out after the open-circuit data has been converted into per unit values.

Table 4.2. Saturation function S_2 and S_3 as functions of integer m

m	u	$m+1$	S_2	S_3
1	2.0	2	SE50	SE100
2	1.5	3	SE67	SE100
3	1.333	4	SE75	SE100
4	1.25	5	SE80	SE100
5	1.20	6	SE83	SE100

Table 4.3. Typical data for AVR control systems

Parameter	Low	Values Typical	High
G_a	250	500	1500
T_a	0.01	0.04	0.1
K_f	0.02	0.06	0.1
T_{f1}	0.1	0.4	0.6
T_{f2}	0.3	1.5	2.5
$V_{\max}$	5.0	15.0	20.0
$V_{\min}$	0.0	0.0	0.0
K_e	1.0	1.0	1.0
T_e	0.05	0.4	1.2
S_{E75}	0.45	0.75	0.96
S_{E100}	0.80	0.90	0.96
A	0.07	0.08	0.1
B	0.4	0.5	0.6
G_g	0.3	0.35	0.4
T_{r1}	0.01	0.02	0.03
T_{r2}	0.01	0.02	0.03
K_{da}	0.03	0.04	0.06

4.2.4 Typical Parameter Values for AVR Systems

Table 4.3 shows typical per unit values for the gains, limits and time constants used in the automatic voltage regulation systems for generators having ratings up to 50 MW.

REFERENCE

1. *Computer representation of excitation systems*. IEEE Transactions, PAS 87, No.6, June 1968.