

Nov. 25, 1958

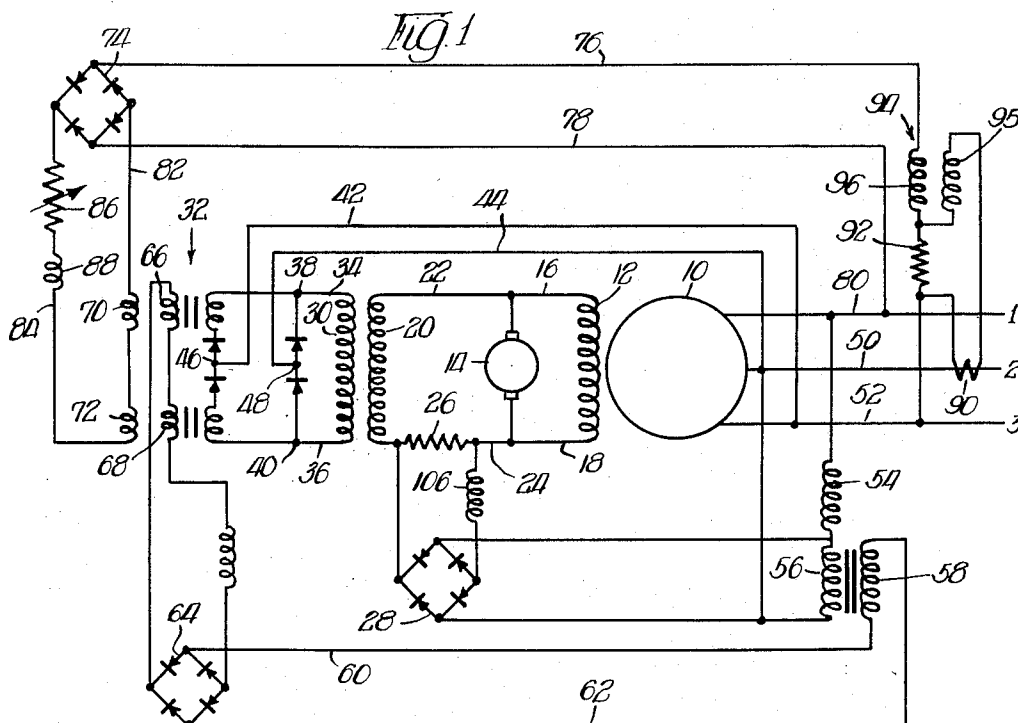
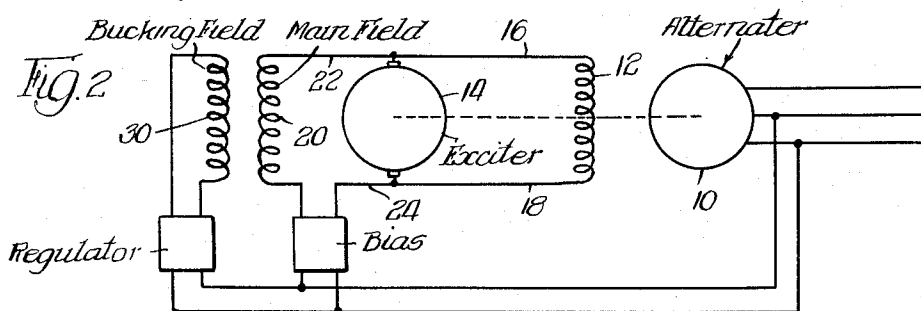
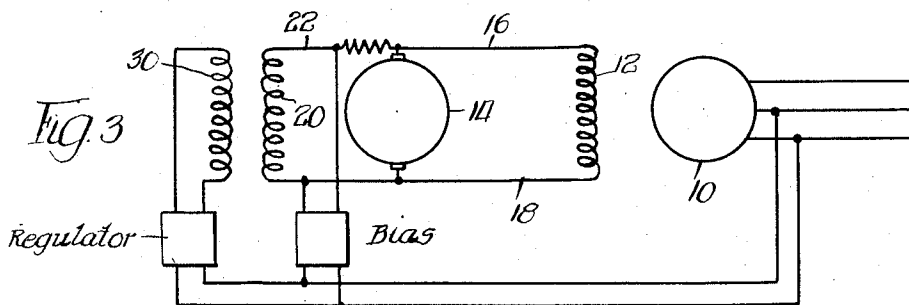
H. R. A. HANSEN ET AL

2,862,174

VOLTAGE REGULATOR FOR ALTERNATOR

Filed Oct. 11, 1954

2 Sheets-Sheet 1



INVENTORS
Hans Richard Osgar Hansen,
BY William J. Bradburn Jr.,
Wilkinson, Huxley,
Byron & Hume Attys

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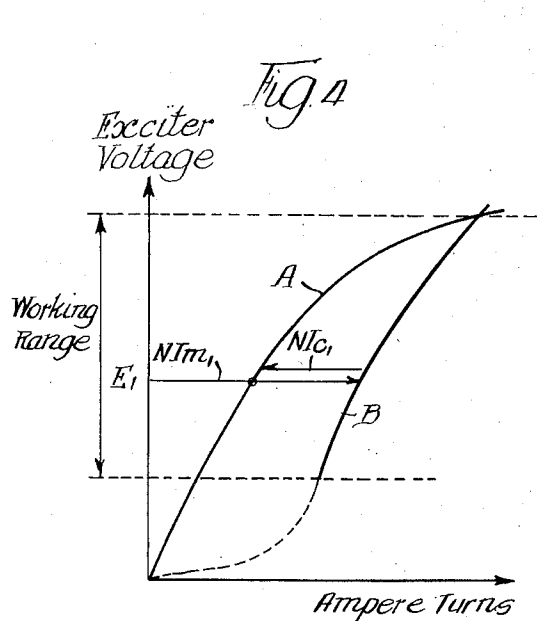
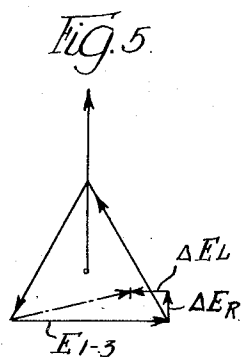
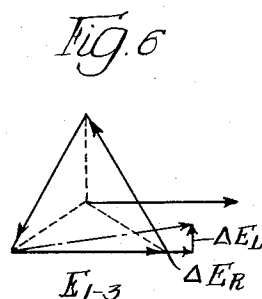
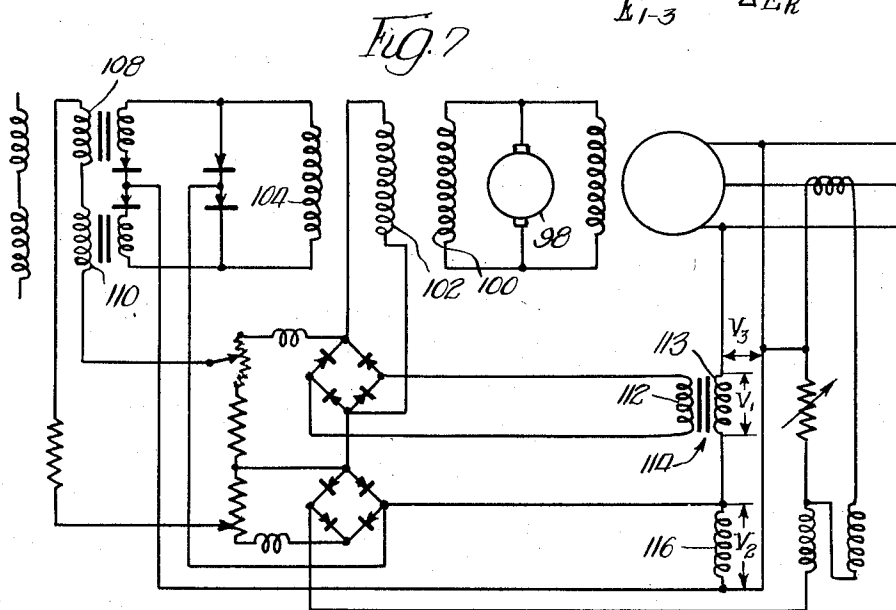
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VOLTAGE REGULATOR FOR ALTERNATOR

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2 Sheets-Sheet 2



INVENTORS.
Hans Richard Oregor Hansen,
BY William J. Bradburn, Jr.,
William H. Hufley,
Byron & Hume Attys

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VOLTAGE REGULATOR FOR ALTERNATOR

Hans Richard Ansgar Hansen, Cudahy, and William J. Bradburn, Jr., Milwaukee, Wis., assignors to The Louis Allis Co., Milwaukee, Wis., a corporation of Wisconsin

Application October 11, 1954, Serial No. 461,556

4 Claims. (Cl. 322—28)

This invention relates to regulating systems, and more particularly, to a voltage regulator system for an alternator incorporating a magnetic amplifier.

One of the primary objects of this invention is to provide a regulator of the character described having excellent regulation and response characteristics.

Another object of this invention is to provide a voltage regulator of the character described which utilizes the output of the alternator as the power supply voltage for the magnetic amplifier incorporated therein, as well as the source of voltage for a feed back control winding in said magnetic amplifier so that a change in the output will cause a cumulative effect in the regulation and response.

Still another object is to provide a voltage regulator which is low in cost and simple in both construction and operation, having no moving parts.

Yet another object is to provide a system of the character described in which provision may be made for speed drop compensation and also cross current compensation.

Further objects and advantages of this invention will become evident as the description proceeds and from an examination of the accompanying drawings which illustrate two embodiments of the invention and in which similar numerals refer to similar parts throughout the several views.

In the drawing:

Figure 1 is a circuit diagram illustrating one embodiment of the invention, some of the elements thereof being shown more or less diagrammatically.

Figure 2 is a diagrammatic representation of a portion of the circuit shown in Figure 1, showing the manner in which the exciter field is controlled with the bias voltage connected in series with the self-excitation voltage.

Figure 3 is a diagrammatic representation of a portion of an alternative form of circuit showing the manner in which the bias voltage can be connected in parallel with the self-excitation voltage.

Figure 4 is a graphical representation of the main field ampere turns plotted as a function of the exciter voltage and also of the exciter voltage as a function of the total field ampere turns.

Figure 5 is a vector diagram illustrating the operation of the compensation for a pure resistive load.

Figure 6 is a vector diagram illustrating the operation of the compensation for a pure inductive load.

Figure 7 is a more or less diagrammatic representation of a modified form of circuit illustrating another embodiment of the invention.

Referring now to Figures 1 and 2, a regulating system is shown therein for the alternator 10, having an excitation coil 12. The exciter voltage supply is obtained from the direct current generator 14, the output of which is connected across the coil 12 by the lines 16 and 18. The output of the exciter 14 is likewise connected to the main field winding 20 of the exciter through the lines 22 and 24, the resistor 26 being disposed in the line 24. A substantially constant bias voltage obtained from the full

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wave rectifier unit 28 is applied across the resistor 26, in adding relation to the voltage obtained from the exciter 14.

The exciter is also provided with a control field winding 30, the ampere turns of which oppose the main field ampere turns. The control field is connected to the output of a suitable regulator such as a magnetic amplifier (indicated generally by the numeral 32) by the lines 34 and 36, connected in turn to the output terminals 38 and 40 of the magnetic amplifier. The power supply voltage for the magnetic amplifier is obtained through the lines 42 and 44 which are connected respectively to the input terminals 46 and 48 of the magnetic amplifier. The opposite ends of the lines 42 and 44 are connected to the output lines 50 and 52 of the alternator.

The input to the full wave rectifier 28 can be from any suitable relatively constant voltage source, which is here shown as a series connected reactor 54 and transformer 56. The reactor 54 may be a conventional air gap reactor and the transformer 56 may be a gapless highly saturated transformer over which the voltage is fairly constant. A separate winding 58 on the saturated transformer is utilized for the reference voltage supply for the magnetic amplifier 32. The output of the winding 58 is connected through the lines 60 and 62 to the full wave rectifier 64, the output of which is in turn connected to the control windings 66 and 68 of the magnetic amplifier 32.

In order to minimize the effect of leakage fluxes from the bias winding, the two windings on the transformer 56 are preferably placed on separate legs. The reference voltage thus obtained from the winding 58 will vary only a slight amount with variations in the alternator voltage. The reference voltage will, however, vary with variations in the frequency of the output of the alternator.

As previously stated, the main field 20 of the exciter 14 is supplied with the sum of the exciter voltage and a bias voltage. The control field winding, being supplied by the magnetic amplifier and being a bucking winding, produces a remarkable feature in this regulating system in that the effect of a change in the power supply voltage to the magnetic amplifier will add to the effect of the changes in the feedback current and therefore will improve the regulation and the response. The magnetic amplifier is controlled by the two control windings 66 and 68 previously mentioned, having a source of constant current in the form of rectifier 64 connected thereto, and the two feedback windings 70 and 72 connected to the output terminals of the rectifier 74. The input terminals of the rectifier 74 are connected through the lines 76 and 78 to the output lines 52 and 54, respectively, of the alternator 10. The output side of the rectifier 74 is connected through the lines 82 and 84 to the windings 76 and 78, the line 84 also having a variable resistance 86 and a choke 88 in series therewith. The feedback control windings 70 and 72 have a polarity such that an increase in feedback control current will increase the current in the control field winding, and at the same time are opposite in polarity to the reference windings.

Curve A in Figure 4 shows the excitation curve for the exciter, the exciter voltage being plotted as a function of the resultant field ampere turns. Curve B is the main field ampere turns plotted as a function of the exciter voltage, this ampere turns being the result of the sum of the bias voltage and the exciter voltage in the exciter main field. Thus, if under certain steady conditions the exciter voltage is E_e , the ampere turns in the exciter main field must be NI_{m1} and the current in the control field winding must be NI_{c1} , as shown in Figure 4.

In operation, if the alternator voltage drops because of a change in load, the feedback current will also decrease, which will cause the current in the control field

winding to, in turn, decrease. The exciter voltage, because of this decrease of the voltage in the control field winding, will then increase until the alternator voltage is restored, since the control field winding is a bucking winding. As shown in Figure 4, the slope of line B at any given voltage point, with respect to the ampere turn ordinate, must always be greater than the slope of line A, in the working range of the regulator. Line B, of course, does not have to be a straight line. A voltage rise at the alternator terminals will have the opposite effect on the magnetic amplifier and the exciter, so that the exciter voltage will therefore decrease until the alternator voltage is restored. Although the restoration is substantially complete, a small error is induced because the gain of the magnetic amplifier is not infinity.

As previously mentioned and as best shown in Figures 2 and 3, the bias voltage can be connected either in series with the exciter to provide the voltage supply for the main field 20 of the exciter, or it may be connected in parallel, as shown in Figure 2 and 3, respectively. Likewise, it may be applied to a separate winding, as shown in Figure 7, and as discussed below.

If the speed drop for the prime mover is not negligible, a drop in speed caused by increasing load will cause a drop in frequency and this drop will cause the voltage across the saturable reactor to drop. Because the saturable reactor voltage is used for reference voltage, the speed drop therefore will cause a drop in the alternator voltage. If this drop is undesirable, a speed drop compensation can be added to the circuit. Likewise, if two or more alternators are connected in parallel the reactive as well as the active load must be properly distributed between the alternators. The active load distribution is determined by the speed drop characteristic for the drivers only. The reactive load distribution must be taken care of by a suitable cross current compensating device in the voltage regulators so that if an alternator has a tendency to carry too much reactive current, the regulator will decrease the excitation current. The portion of the regulator which creates the necessary signal to accomplish this is conventionally called the cross current compensation.

In the regulator shown in Figure 1, the speed drop compensation is combined with the cross current compensation. The compensating device consists of a current transformer 90 connected to a resistor 92 and an air gap reactor 94 with a primary winding 95 and a secondary winding 96. The primary of the current transformer is the output line 50 of the alternator 10. The voltage over the resistor 92 is used for cross current compensation and the voltage over a secondary winding 96 on the reactor 94 is used for speed drop compensation. The compensating voltages are fed into the voltage supply for the feedback windings 70 and 72, the voltage supply for those windings being obtained from the two alternator phases in which the compensating current transformer is not placed, namely, lines 52 and 80.

The operation of the compensation circuit is illustrated in the vector diagram shown in Figure 5 for a pure resistive load and in the vector diagram shown in Figure 6 for a pure induction load. ΔE_L is the voltage over the reactor winding and ΔE_R is the voltage over the resistor. The total feedback voltage is the sum of E_{1-3} , ΔE_L and ΔE_R . As shown in the diagram, with a pure resistive load the cross current compensation voltage ΔE_R has practically no effect on the total feedback voltage. The speed drop compensation signal ΔE_L , however, will subtract from the line voltage signal E_{1-3} and thus compensate for the previously mentioned drop in reference voltage due to a drop in speed. The reactor is preferably provided with taps for a proper setting.

The vector diagram shown in Figure 6 illustrates that with an inductive load when the speed drop is zero, the signal ΔE_L from the speed drop compensation has practically no effect on the feedback voltage E_{1-3} . Under

these circumstances, however, the cross current signal ΔE_R adds to the terminal voltage signal and, as required by proper cross current compensation, tends to decrease the excitation.

Referring now to Figure 7, a modified form of regulating system is shown therein more or less schematically without the stabilizing circuit. The exciter 98 in this case is provided with three field windings, namely, a self-excitation winding 100, a bias winding 102 and a bucking winding 104. This eliminates the resistor 26 shown in Figure 1 and the choke 106 shown in Figure 1, since the winding itself acts as a choke.

Likewise, an electrical comparison is used in this instance for control of the magnetic amplifier, the control windings 108 and 110 being utilized for this purpose. The bias and reference voltages are taken from the secondary winding 112 of the saturated transformer 114. This eliminates one set of rectifiers and also maintains a more constant voltage.

The feedback voltage and the power supply for the magnetic amplifier in this case are taken from the unsaturated reactor 116 which provides better regulation because of the nonlinearity of the voltage. The voltage V_3 applied across the windings 113 and 116 will produce a voltage V_1 in the winding 113 and V_2 in the winding 116. Voltage V_2 will therefore equal $V_3 - V_1$. Since V_1 will tend to level off upon saturation to a substantially constant value, subsequent changes in V_3 will be reflected primarily in V_2 .

As a matter of fact, in normal operation the reactor 114 is saturated while the reactor 116 is unsaturated and the voltage applied to the magnetic amplifier will be the voltage V_2 across the reactor 116. Since the reactor 114 is saturated, the voltage V_1 is practically constant so that any change ΔV_3 in the output voltage V_3 is reflected entirely in V_2 or in other words: $V_2 = V_3 - \Delta V_3$. Thus, if for a given value of V_3 , the ratio of V_3 to V_2 is equal to 2 then a 10 percent change in V_3 will cause a 20 percent change in V_2 so that immediately the output voltage of the magnetic amplifier is reduced 20 percent when V_3 changes 10 percent. The response and gain of the system are greatly improved as a result of this modification and a better regulator results.

In the drawing and specification, there has been set forth several preferred embodiments of the invention, and although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation. Changes in form and in the proportion of parts, as well as the substitution of equivalents, are contemplated, as circumstances may suggest or render expedient, without departing from the spirit or scope of this invention as further defined in the following claims.

We claim:

1. Controlling apparatus for an alternating current generator having an exciter comprising: an armature, a self excited field winding for said armature, a separate field winding for said armature, a control field winding for said armature, an excitation coil for said generator, means for connecting the output voltage of said armature to said self excited field winding and to said excitation coil, a saturated transformer having a primary and a secondary winding, an unsaturated reactor, the primary winding of said saturated transformer and said unsaturated reactor being connected in series across the output of said generator, a first rectifying means connected to the secondary winding of said saturated transformer, means for applying the output of said first rectifying means to said separate field winding so that the ampere turns of said separate field and said self excited field are in adding relation, a second rectifying means connected to said unsaturated reactor, regulating means powered by the difference between the outputs of said first rectifying means and said second rectifying means, and regulator means supplied by the voltage across the unsaturated reactor, the output of said regulator means varying

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directly with the output of said generator and being connected to said control field winding in opposing relation to the inputs to said self excited field winding and separate field winding.

2. Controlling apparatus for an alternating current generator having an exciter comprising: an armature, a self excited field winding for said armature, a separate field winding for said armature, a control field winding for said armature, an excitation coil for said generator, means for connecting the output voltage of said armature to said self excited field winding and to said excitation coil, a saturated transformer having a primary and a secondary winding, an unsaturated reactor, the primary winding of said saturated transformer and said unsaturated reactor being connected in series across the output of said generator, rectifying means connected to the secondary winding of said saturated transformer, means for applying the output of said rectifying means to said separate field winding so that the ampere turns of said separate field and said self excited field are in adding relation, a second rectifying means connected to said unsaturated reactor, a magnetic amplifier having its input connected across said unsaturated reactor and its output connected to said control field winding in opposing relation to the inputs to said self excited field winding and said separate field winding, and at least one control winding in said magnetic amplifier connected so as to have the difference between the outputs of said first named rectifying means and said second rectifying means applied thereto.

3. In a controlling apparatus for an alternating current generator having an exciter, the combination of a saturated transformer having a primary and a secondary winding, an unsaturated reactor, the primary winding of said saturated transformer and said unsaturated reactor

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being connected in series across the output of said generator, rectifying means connected to the secondary winding of said saturated transformer, a second rectifying means connected to said unsaturated reactor, regulating means powered by the difference between the outputs of first said rectifying means and second said rectifying means, and regulator means for said exciter supplied by the voltage across the unsaturated reactor, the output of said regulator means varying directly with the output of said generator.

4. In a controlling apparatus for an alternating current generator having an exciter, the combination of a saturated transformer having a primary and a secondary winding, an unsaturated reactor, the primary winding of said saturated transformer and said unsaturated reactor being connected in series across the output of said generator, rectifying means connected to the secondary winding of said saturated transformer, a second rectifying means connected to said unsaturated reactor, a magnetic amplifier having its input connected across said unsaturated reactor and at least one control winding in said magnetic amplifier connected so as to have the difference between the outputs of said first named rectifying means and said second rectifying means applied thereto.

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