March 19, 1963 W. M. HALLIDY 3,082,370

GENERATING SYSTEM REGULATION

Filed Oct. 30, 1957 2 Sheets-Sheet 1

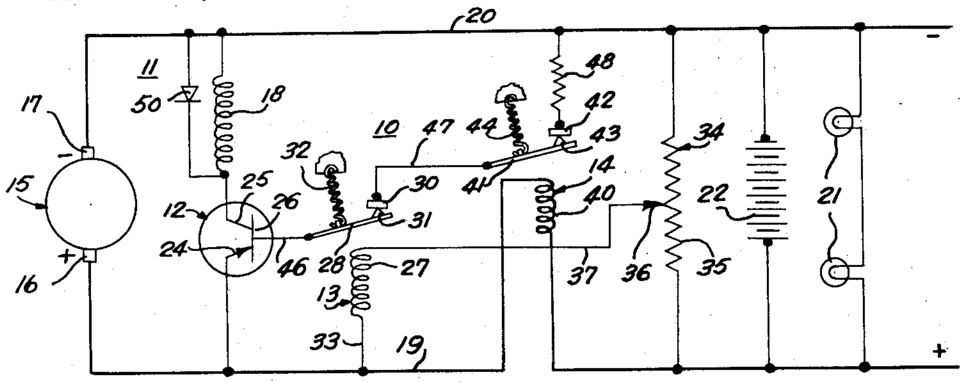

FIG. 1

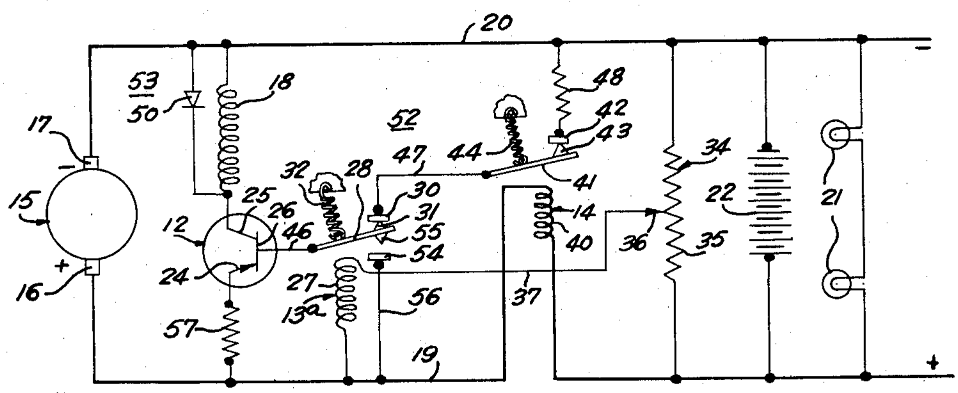

FIG. 2

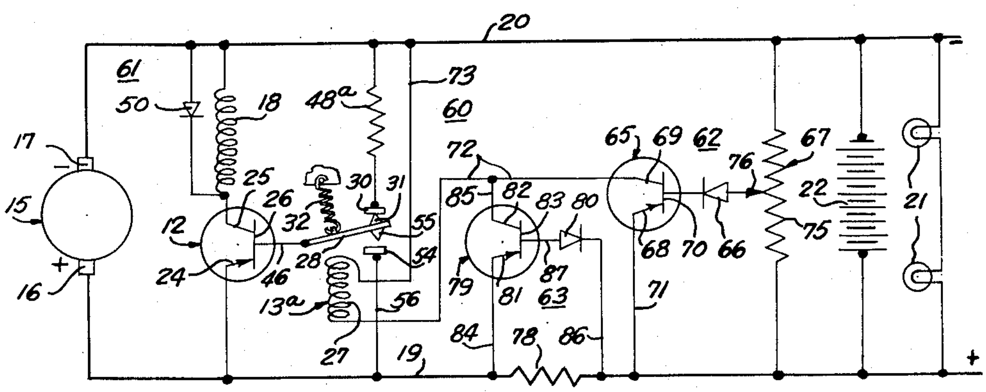

FIG. 3

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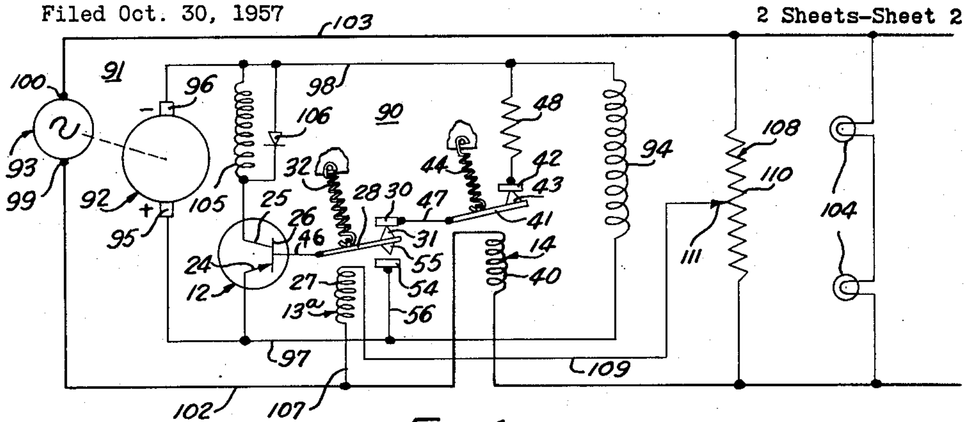

FIG. 4

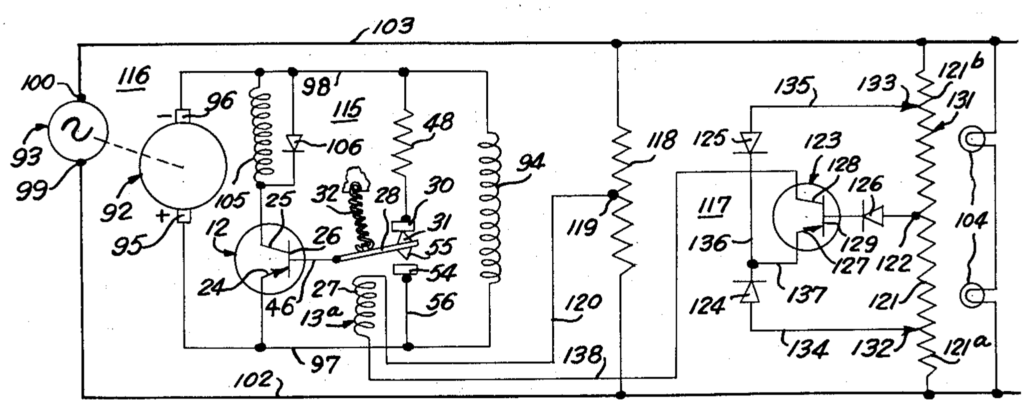

FIG. 5

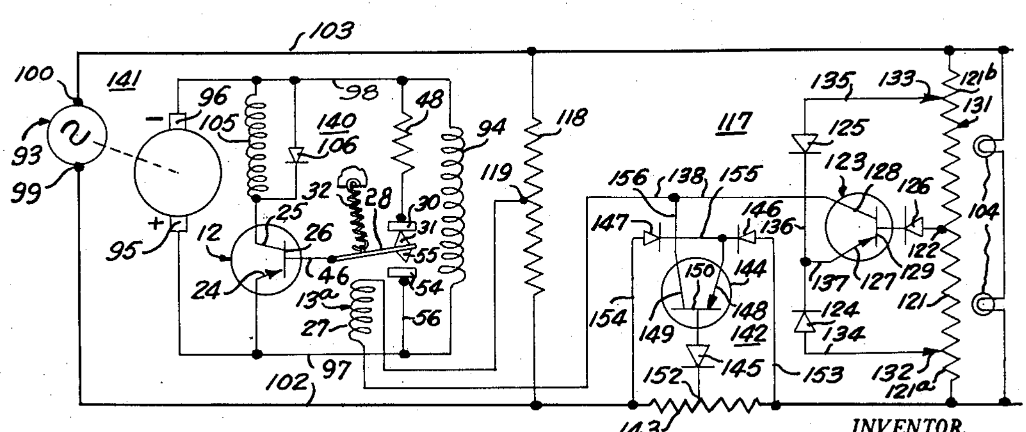

FIG. 6

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GENERATING SYSTEM REGULATION

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2 Claims. (Cl. 322—25)

This invention relates to voltage and current regulaing apparatus and to electrical generating systems embodying such regulating apparatus .

An object of the invention is to provide transistorized regulating apparatus for controlling voltage and current values and a novel generating system employing such transistorized regulating apparatus.

Another object is to provide a novel regulating apparatus and generating system employing transistor means in combination with a low-cost electromagnetic relay means, such that the transistor means provides a desirable long-life form of variable impedance and such that the contacts of the relay means handle only the input signal to the transistor means and will accordingly have a long contact life.

A further object is to provide such a combination transistor-and-relay form of regulating apparatus for application to a current supply means and in which the energizing coil means of the relay means is connected with the current supply means through voltage and/or current sensing means.

Still another object is to provide such a combination transistor-and-relay form of regulating apparatus for application to a current supply means and in which the sensing means comprises other transistor means for controlling or amplifying the coil current being supplied to the relay means.

Yet another object is to provide apparatus of the character above mentioned in which the current supply means comprises generator means whose field excitation is controlled by a transistor means in response to an input signal supplied to the latter through the contacts of the relay means.

It is also an object of this invention to provide novel sensing means for use with an alternating current supply means and comprising an amplifying transistor means connected with the current supply means through a pair of rectifiers and a center-tapped resistor, such that the output signal of the sensing means will always be a low-voltage direct current signal.

Additionally this invention provides novel regulating means for application to an alternating current generating system, in which the field excitation of the generator means is controlled by a first transistor means in response to an input signal supplied to the latter through the contacts of a relay means, and in which the coil current of the relay means is supplied thereto by a sensing means comprising an amplifying transistor means connected with the alternating current system through a pair of rectifiers and a center-tapped resistor.

Other objects and advantages of this invention will be apparent in the following detailed description and in the accompanying drawings forming a part of this specification and in which

FIGS. 1, 2 and 3 are wiring diagrams showing direct current generating systems embodying the voltage and current regulating means of the present invention; and

FIGS. 4, 5 and 6 are wiring diagrams showing alternating current generating systems embodying the regulating means of this invention.

As representing one of the preferred embodiments of the present invention, FIG. 1 shows regulating means **10** applied to a direct current generating system **11** and comprising in general a power transistor **12**, a voltage relay **13**, and a load limiter or current relay **14**.

The generating system **11** includes a direct current generator **15** having positive and negative output or load terminals **16** and **17** and a shunt field winding **18**. The system **11** also includes an external load circuit comprising load conductors **19** and **20** connected to the load terminals **16** and **17** respectively for supplying current to external load devices such as lamps **21** and a storage battery **22**.

The transistor **12** is a conventional form of transistor having emitter and collector electrodes **24** and **25** and a base electrode **26**. The transistor **12** is located in the field circuit of the generator **15** with its emitter and collector electrodes **24** and **25** as output electrodes and connected in series circuit with the field winding **18**. The transistor **12** can be either a PNP or an NPN transistor depending upon the polarity of the circuit connections employed but, as here shown, is a PNP transistor having its emitter electrode **24** connected with the positive load terminal **16** of the generator **15** through the load conductor **19**. The voltage relay **13** is of a conventional form comprising an energizing magnet coil **27** mounted on a suitable frame (not shown), and a movable armature **28** which is responsive to the energization of the magnet coil. The voltage relay **13** also comprises a pair of stationary and movable contacts **30** and **31**, of which the movable contact **31** is carried by the armature **28** and is biased toward engagement with the stationary contact **30** by a tension spring **32** connected with the armature.

The magnet coil **27** of the voltage relay **13** is connected across the output terminals **16** and **17** of the generator **15** through the load conductors **19** and **20**, so as to be responsive to variations in the output voltage of the generator. For this purpose, one end of the magnet coil **27** is connected with the load conductor **19** by a conductor **33** and the other end of this coil is connected to the load conductor **20** through a resistance device or voltage divider **34** which is preferably of the potentiometer type. The resistance device **34** comprises a resistor **35** connected across the load terminals **19** and **20** and a shiftable contact **36** movable along the resistor **35** and having such other end of the magnet coil **27** connected therewith by the conductor **37**.

The load limiter or current relay **14** is of a conventional form comprising an energizing magnet coil **40** mounted on a suitable magnet frame (not shown) and a movable armature **41** which is responsive to the energization of the magnet coil **40**. The current relay **14** also comprises cooperating stationary and movable contacts **42** and **43**, of which the latter contact is carried by the armature **41** and is biased toward engagement with the stationary contact **42** by a tension spring **44** connected to the armature. The energizing coil **40** of the current relay **14** is a series coil located in the load conductor **19**, such that the energization of this coil will be responsive to changes in the current values of the load current being delivered by the generator **15**.

The regulating apparatus **10** also comprises a signal or control circuit means through which a signal or control potential is supplied to the base **26** of the transistor **12** and is controlled by the cooperating contacts of the voltage and current relays **13** and **14**. This control circuit means is here shown as comprising a conductor **46** connecting the voltage relay armature **28** with the base **26** of the transistor **12**, a conductor **47** connecting the armature **41** of the current relay **14** with the stationary contact **30** of the voltage relay, and a resistor **48** connected between the stationary contact **42** of the current relay and the load conductor **20**.

The voltage and current relays **13** and **14** are of the vibratory type and, from the construction and circuit connections above described for the regulating means **10**, it will be seen that the voltage relay will be responsive to variations in the output voltage of the generator **15** and the current relay **14** will be responsive to variations in the load current being delivered by the generator. It will be seen further that the signal current, being supplied to the base **26** of the transistor **12** through the above-mentioned control circuit, passes through the voltage and current relay contacts **30**, **31** and **42**, **43**. Consequently, whenever either pair of these contacts is open in response to an increase occurring in the voltage or current value of the generator output, the control circuit will be opened to interrupt the supply of signal current to the base of the transistor.

The transistor **12** will accordingly serve as a variable impedance in the field circuit of the generator **15** and will also function as a true switching device inasmuch as the circuit to the transistor base **26** is either open or closed depending upon the condition of the contacts of the voltage and current relays **13** and **14**. When the voltage and current values of the output of the generator **15** are low, both pairs of regulator contacts will be closed by the influence of the springs **32** and **44** whereupon signal current will be supplied to the transistor base **26** causing the transistor to conduct. Thereupon a full value of field energizing current will flow through the emitter and collector electrodes **24** and **25** and through the field winding **18** of the field circuit. In response to a resulting build-up of the voltage and current values of the generator output, one or both of the pairs of contacts **30**, **31** and **42**, **43** of the voltage and current relays **13** and **14** will be opened to thereby interrupt the signal current supply to the transistor base **26**, whereupon the transistor will be in a non-conducting or off condition and the energizing current flowing through the field winding **18** will be of a minimum or zero value.

The resistor **48** of the above-mentioned control circuit is selected of a suitable resistance value such that when the transistor **12** is in an on or conducting condition, the current flow through the emitter and collector electrodes thereof will be limited to a safe value for the transistor but will still provide full excitation for the field winding **18**.

The regulating means **10** preferably also includes a suitable diode **50** connected in a shunt relation to the field winding **18** for protecting the transistor **12** by dissipating the induced potential or so-called inductive "kick" of the field winding.

FIG. 2 of the drawings shows transistorized regulating means **52**, similar to the regulating means **10** above described and applied to a direct current generating system **53** which is similar to the above-described generating system **11**. The components of the regulating means **52** and of the generating system **53**, which correspond with components of the regulating means **10** and of the generating system **11**, have been designated by the same reference characters.

The voltage relay **13***a* of the modified regulating means **52** differs from the above-described voltage relay **13** in that it is a double-contact type of voltage relay having a second pair of cooperating contacts **54** and **55**, of which the contact **54** is a stationary contact spaced from the stationary contact **30** and the contact **55** is a movable contact carried by the armature **28**. The stationary contact **54** is connected with the load conductor **19** by a conductor **56**. The resistance value of the resistor **56** can be varied to suit the circuit requirements of the regulating means **52** and, if desired, can be omitted.

The second pair of contacts **54** and **55** of the voltage relay **13***a*, when closed, serves to apply a signal bias to the transistor base **26** or to substantially short-circuit the emitter and base electrodes, such that the transistor **12** will be completely cut off. Thus, whenever the output voltage of the generator **15** rises above a predetermined value to cause such closing of the second pair of contacts **54** and **55**, the transistor **12** will be in a completely off condition causing a sudden and complete collapse of the field flux. Although opening of the voltage relay contacts **30** and **31** will convert the transistor **12** to an off condition by opening the signal circuit to the transistor base **26**, a flow of leakage current may still take place through the emitter and collector electrodes of the transistor, whereas the closing of the second pair of contacts **54** and **55** will insure the transistor being converted to the off condition to effectively deenergize the field winding **18** and quickly correct any abnormal voltage condition of the load circuit. The portion of the field circuit which connects the emitter **24** of the transistor **12** with the load conductor **19** is here shown as having a resistor **57** of suitable value therein although, if desired, this resistor can be omitted.

FIG. 3 of the drawings shows another form of transistorized regulating means **60** applied to a direct current generating system **61** which is substantially the same as the above-described generating systems **11** and **53**. The regulating means **60** employs the same power transistor **12** and voltage relay **13***a* as are used in the regulating means **52** of FIG. 2. The other components of the regulating means **60** and of the generating system **61** which correspond with those above described, are designated by the same reference characters.

The regulating means of FIG. 3 differs from the above-described regulating means **10** and **52** of FIGS. 1 and 2, in that the stationary contact **30** of the voltage regulator **13***a* is connected directly with the load conductor **20** through a resistor **48***a*, and in that the magnet coil **27** of the voltage relay **13***a* is connected with the output terminals of the generator **15** through transistorized voltage and current sensing devices **62** and **63**.

The voltage sensing devices **62** comprise a transistor **65**, a diode **66**, and a resistance device **67** which is preferably of the potentiometer type. The transistor **65** is used as a signal amplifying transistor and is of a conventional form having emitter, collector and base electrodes **68**, **69** and **70**. The emitter electrode **68** is connected with the load conductor **19** by the conductor **71** and the collector electrode **69** is connected with one end of the voltage relay magnet coil **27** through the conductor **72**. The other end of the magnet coil **27** is connected with the load conductor **20** by a conductor **73**.

The resistance device **67** comprises a resistor **75** connected across the load conductor **19** and **20**, and a shiftable contact **76** movable along the resistor **75** and connected with the base **70** of the transistor **65** through the diode **66**.

The diode **66** is of the well known Zener type and is one having a relatively low breakdown voltage such that the voltage sensing device **62** will be responsive to relatively low-value voltage fluctuations in the load output of the generator **15**. Thus when voltage increases above a predetermined value occur in the generator output, the diode **66** will become conductive and will apply voltage signals to the base **70** of the transistor **65**, resulting in this transistor becoming conductive and supplying an amplified control current to the magnet coil **27** of the voltage relay **13***a* for the functioning of the latter in the manner already explained above in connection with the regulating means **10** and **52** of FIGS. 1 and 2.

The current sensing device **63** comprises a series resistor **78** in the load conductor **19**, a transistor **79**, and a diode **80**. The transistor **79** is of a conventional form comprising emitter and collector electrodes **81** and **82** and a base electrode **83**. The emitter electrode **81** is connected with the load conductor **19** on one side, in this case the generator side, of the series resistor **78** by a conductor **84**, and the collector electrode **82** is connected with one end of the voltage regulator coil **27** through a portion of the conductor **72** and a circuit connection **85**.

The diode **80** can be of a conventional form and preferably has a low breakdown voltage so as to render the current sensing device **63** responsive to current fluctuations in the output of the generator **15** which exceed a predetermined permissible load current by only relatively small values. The diode **80** is connected to the base **83** of the transistor **79** by a conductor **87** and to the load conductor **19** at a point on the other or load side of a series resistor **78** by a conductor **86**.

Thus the diode **80** is connected in a shunt relation to the series resistor **78** and, when the IR drop across the series resistor exceeds the breakdown voltage of this diode, a current signal will be applied to the base **83** and the transistor **79** will then conduct. The transistor **79** functions as an amplifying transistor and responds to the current signal applied to the base **83** thereof by supplying a relatively larger coil-energizing current to the voltage relay coil **27**.

From the circuit connections and functioning of the voltage and current sensing devices **62** and **63** as above described, it will be seen that the transistors **65** and **79** will function as switching transistors as well as amplifying transistors. Thus, when the voltage and current values of the generator output are relatively low, these transistors will be in an off condition and the voltage relay coil **27** will be substantially deenergized, but when either of the voltage and current values of the generator output exceeds a predetermined value, the transistor of the corresponding sensing devices will become conductive and will supply amplified energizing current to the voltage relay coil **27**.

In the regulating apparatus **60**, the transistors **12**, **65** and **79** can be conveniently referred to as the first, second and third transistors respectively. The transistors **65** and **79** can be PNP or NPN transistors, depending upon the polarity of the circuit connections employed, and as here used are of the PNP type.

FIG. 4 of the drawings shows transistorized regulating means **90** applied to an alternating current generating system **91** which includes an exciter generator **92**. The regulating means **90** comprises the same components as the regulating means **52** of FIG. 2, namely a power transistor **12**, a voltage regulator **13***a* and a load limiter or current relay **14**, but they are differently located, as will be explained presently.

The alternating current generating system **91** includes an alternator **93** having a field winding **94** to which the positive and negative output terminals **95** and **96** of the exciter generator **92** are connected by conductors **97** and **98**. The alternator **93** has output terminals **99** and **100** to which a pair of load conductors **102** and **103** are connected respectively for supplying current to an external load such as to lamps **104**. The exciter generator **92** includes a conventional shunt field winding **105** on which the regulating means **90** is effective in substantially the same manner as has been described above in connection with the control action of the regulating means **10** and **52** on the field winding **18** of the direct current generator **15**.

In the application of the regulating means **90** to the alternating current generating system **91**, the magnet coil **27** of the voltage relay **13***a* has one end thereof connected with the load conductor **102** by a conductor **107** and its other end connected to the alternator **93** through a potentiometer-type of resistance device **108** and a conductor **109**. The resistance device **108** comprises a resistor **110** connected across the load conductor **102** and **103**, and a movable contact **111** shiftable along the resistor **110** and having such other end of the voltage relay coil **27** connected therewith by the conductor **109**. The series magnet coil **40** of the current relay **14** is located in the load conductor **102** of this alternating current generating system.

From the construction and the circuit connections just above described for the regulating means **90** and the alternating current generating system **91** of FIG. 4, it will be seen that the regulating means will be directly responsive to voltage and current fluctuations in the alternating current output of the system **91** such that the transistor **12** will control the excitation of the field winding **105** of the exciter **92**, with the result that the output of the exciter will correspondingly vary the excitation of the field winding **94** of the alternator **93** and produce a controlled effect on the voltage and current values of the alternator output being supplied to the load circuit.

The regulating means **90** preferably includes a diode **106** in shunt relation to the exciter field **105** for protecting the transistor **12** against the inductive effects of the field winding in the manner already explained above for the diode **50** of FIG. 1.

FIG. 5 of the drawings shows transistorized regulating means **115** which, in certain respects, is similar to the above-described regulating means **90** and which is applied to an alternating current generating system of substantially the same form as the above-described alternating current generating system **91** of FIG. 4. The components of the regulating means **115** and of the generating system **116**, which correspond with those of the regulating means **90** and generating system **91**, have been designated by the same reference characters. The regulating means **115** of FIG. 5 differs from the regulating means **90** in that the load limiter or current relay **14** has been omitted, and in the use of a different form of voltage sensing device **117**.

The voltage sensing device **117** includes a first center-tapped resistor **118** connected across the load conductors **102** and **103** and having a center tap **119** to which one end of the voltage relay magnet coil **27** is connected by a conductor **120**. The voltage sensing device **117** also includes a second center tapped resistor **121** connected across the load conductors **102** and **103** and having a center tap **122**. Additionally the voltage sensing device **117** comprises a transistor **123**, a pair of diodes used as rectifiers **124** and **125**, and a diode **126** of the Zener type and having a low breakdown voltage.

The transistor **123** is of a conventional form having emitter and collector electrodes **127** and **128** and a base electrode **129**. The transistor **123** functions as both a switching transistor and an amplifying transistor. The base **129** of the transistor is connected with the center tap **122** of the resistance device **121** through the diode **126**. The center tapped resistor **121** forms a part of a variable resistance device **131** which also includes adjustable contacts **132** and **133** shiftable along end portions or resistance sections **121***a* and **121***b* of the resistor **121**.

The diodes **124** and **125** are half-wave rectifiers which are connected respectively with the contacts **132** and **133** by conductors **134** and **135** and are also connected with each other by a junction conductor **136**. The emitter electrode **127** of the transistor **123** is connected with the rectifiers **124** and **125** at a point therebetween by a conductor **137**. The collector electrode **128** of the transistor **123** is connected with the other end of the voltage relay coil **27** through a conductor **138**.

From the construction and circuit connections of the voltage sensing device **117** as above described, it will be seen that the voltage relay **13***a* will be responsive to relatively low-value voltage fluctuations occurring in the output of the alternator **93** and that the voltage sensing means itself will be subjected to only relatively low voltage values by reason of the use of the center-tapped resistors 118 and 121 for connecting this sensing means in circuit with the alternator. It will also be seen that, by reason of the use of the pair of rectifiers 124 and 125, the alternating current signals supplied to the sensing device 117 by the load conductors 102 and 103 will be rectified with respect to both half-wave portions of the alternating current output, such that the energizing current supplied to the voltage relay coil 27 by the sensing means will be a full-wave rectified D.C. current.

Moreover, it will be seen that by use of the adjustable contacts 132 and 133 of the resistance device 131 as the circuit connections to the pair of rectifiers 124 and 125, the voltage of the rectified current being supplied to the voltage relay coil 27 can be maintained at a suitably low value which will be a safe value for the transistor 123 and will permit the latter to be of a small and inexpensive size. Additionally it will be seen that by using as the diode 126 a conventional diode having a low breakdown voltage, the transistor 123 will be responsive to low voltage fluctuations in the output of the alternator 93 and will be switched to an on or conducting condition in response to signals of a relatively low voltage value. It will be seen further that the voltage relay coil 27 will be energized only when the transistor 123 is in its on condition and that when this transistor is switched to its off condition, the voltage relay coil will be substantially deenergized.

The transistors 12 and 123 of the regulating means 115 can be conveniently referred to as the first and second transistors.

FIG. 6 of the drawings shows transistorized regulating means 140 which is generally similar to the regulating means 115 of FIG. 5 and is applied to an alternating current generating system 141 which is substantially the same as the above-described alternating current generating system 116 of FIG. 5. The regulating means 140 differs from the above-described regulating means 115 in that it employs a novel current sensing device 142 in addition to the voltage sensing device 117.

The current sensing device 142 comprises a series resistor 143 located in the load conductor 102 and a third transistor 144 which is used as both a switching transistor and an amplifying transistor. The current sensing device 142 also comprises a diode 145 of a low breakdown voltage and a pair of diodes operating as half-wave rectifiers 146 and 147.

The transistor 144 is of a conventional form having emitter and collector electrodes 148 and 149 and a base electrode 150. The series resistor 143 is a center tapped resistor having a center tap 152 to which the base 150 of the transistor 144 is connected through the diode 145. The rectifiers 146 and 147 are connected with the load conductor 102 on opposite sides of the series resistor 143 by conductors 153 and 154. The emitter electrode 148 of the transistor 144 is connected with the rectifiers 146 and 147 at a point therebetween by being connected to a junction conductor 155 extending between the rectifiers. The collector electrode 149 of the transistor 144 is connected with the same end of the voltage relay coil 27 as the voltage sensing means 117, through a portion of the common conductor 138 and through a circuit connection 156.

From the construction and circuit connection above described for the current sensing device 142, it will be seen that this device will supplement and cooperate with the voltage sensing device 117 for energizing the voltage relay coil 27 in accordance with current and voltage variations in the output of the alternator 93. It will also be seen that the current sensing device 142 will be responsive to current variations of a relatively low value occurring in the load circuit inasmuch as the diode 145 has a relatively low breakdown voltage and will become conductive to apply a current signal to the base 150 of the transistor 144 whenever the current variation in the load circuit exceeds a predetermined value represented by a predetermined increase in the IR drop across the series resistor 143.

Thus whenever the diode 145 becomes conductive and supplies a current signal to the base 150, the transistor 144 will be switched to a conducting or on condition during which it will cause current to be supplied to the voltage relay coil 27 and, by reason of the use of the pair of half-wave rectifiers 146 and 147, the energizing current thus supplied to the voltage relay coil will be a continuous rectified D.C. current resulting from the rectification of both half-waves of the alternating current of the load circuit. By reason of the switching action of the transistor 144, the current supplied to the voltage relay coil will be of a maximum value when a current signal is supplied to the base 150 through the diode 145 and will be of a zero value when the transistor is in its off condition. By reason of the amplifying use of the transistor 144, the current thus supplied to the voltage relay coil 27 while the transistor is in its on condition will be an amplified current.

From the accompanying drawings and the foregoing detailed description it will now be readily understood that this invention provides a novel and highly effective form of regulating means for application to a current supply means and which utilizes the desirable long-life characteristics of a transistor means and the desirable low-cost characteristic of voltage and current relays of the electromagnetic type. It will also be understood that the invention provides novel electrical generating systems employing such a combination transistor-and-relay type of regulating means. Additionally it will be seen that this invention achieves the important advantage from such a combination type of regulating means that the power transistor controlling the variable energization of a magnet coil of the current supply means will have a long life and will need to be of a load rating handling only the energizing current of such coil rather than the load current of the load circuit, and also the advantage that this transistor will function as a true switching transistor having an on or off condition depending upon whether control or signal current is being supplied to the base thereof by the voltage and current relays. It will be seen furthermore that another important advantage is realized in that the contacts of the low-cost voltage and current relays will need to handle only the signal current being supplied to the base of the power transistor, with the result that the relay contacts will not be subjected to any destructive amount of sparking and will consequently have a long life and will remain in an efficient operating condition.

Although the novel regulating means of this invention and the novel generating systems embodying the same have been illustrated and described herein to a somewhat detailed extent, it will be understood that the invention is not to be regarded as being limited correspondingly in scope but includes all changes and modifications coming within the terms of the claims hereof.

Having described my invention, I claim:

1. An electric generating system comprising, a generator having load terminals and a field winding, a field circuit for said field winding, a load circuit connected with said load terminals, a relay comprising a magnet coil and vibratory contact means responsive to the energization of said magnet coil, energizing circuit means for said magnet coil, a first transistor having main electrodes in said field circuit and a first control electrode connected to be energized through said vibratory contact means, a second transistor having main electrodes in said energizing circuit means and a second control electrode, a third transistor having main electrodes in said energizing circuit means and a control electrode, and means connected to the control electrodes of said second and third transistors to control energization thereof in depedence upon voltage across and current in said load circuit.

2. An electric generating system comprising, a generator having load terminals and a field winding, a field circuit for said field winding, a load circuit connected with said load terminals, a relay comprising a magnet

coil and contacts responsive to energization of the relay coil, a first transistor having main electrodes in said field circuit and a control electrode connected to be energized under the control of said contacts, second and third transistors each having main electrodes and a control electrode, the main electrodes of each of said second and third transistors being connected to said relay coil to control energization of said relay coil, a pair of voltage responsive breakdown devices connected to the control electrodes of said second and third transistors, and means connected to apply voltages to said breakdown devices dependent respectively upon current in and voltage across said load circuit.

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