

SPECIFICATION

Voltage regulator

5 BACKGROUND OF THE INVENTION

This invention relates to voltage regulators for generators and, more particularly, to a voltage regulator for an AC generator that provides power to at least two different loads at different voltages.

10 Voltage regulation of the output power of AC generators is usually effected by controlling the magnitude of the field current to the exciter winding of the generator. If the load on the generator increases, causing a drop in a selected voltage, that condition is detected and the field current is increased, causing the output voltage to return to the selected voltage. Similarly, if the load on the generator is reduced, causing the voltage to increase above the selected voltage, the magnitude of the field current is reduced, thereby decreasing the output voltage.

If a single AC generator is to provide power to at least two loads at different voltage levels, it becomes necessary to decide which voltage should control the field current. If one voltage suddenly decreases significantly and the field current is increased to drive the decreasing voltage back within its selected range, the voltage to the other load(s) may become undesirably excessive.

30 Many voltage regulators employ a summing-type control system wherein signals representative of the individual voltages or other control variables are summed to provide a field current representing the average of the individual variables. This type of control system makes independent compensation of the individual voltages difficult and provides a mixed error signal, making effective verification testing difficult.

In accordance with the present invention, the above drawbacks are overcome by a voltage regulator that provides a field current which is selected from only one input control variable at a time. The invention provides a voltage regulator for providing a field current to a generator supplying power to at least a first and a second load at different voltages. The voltage regulator comprises means for concurrently detecting the voltages across the first and second loads respectively, means for determining if the voltage across the first load is within a given voltage range, means for generating a field current representative of the voltage across the second load, and means for providing the field current to the generator when the determining means detects that the voltage across the first load is within the given voltage range. Preferably at least one of the loads is an AC load and at least one is a DC load. The invention is hereinafter illustrated, by way of example only, with reference to the drawings of which:

60 *Figure 1* is a diagram showing the generator in schematic form and the voltage regulator in accordance with the present invention in block diagram form;

Figure 2 is a diagram showing the selection of the field current as a function of AC voltage; and

Figure 3 is a detailed block diagram of the voltage regulator of *Figure 1*.

Referring to *Figure 1*, a generator 10, schematically shown to include main windings 12, provides power at a rated AC voltage to load 14. Windings 12 are tapped at a suitable level to provide power at an AC voltage less than rated to rectifier 16. Rectifier 16 provides a DC voltage to load 18.

Voltage regulator 20 receives voltages representing the control variables including a voltage indicative of the rated AC voltage applied to load 14, a voltage indicative of the DC voltage applied to load 18, and a signal from current transformer 22 representative of the current to load 14. As will be explained in detail below, voltage regulator 20 provides a field current responsive to either the voltage across load 14, the DC voltage across load 18, or the current flow from windings 12 as a function of the magnitude of the AC voltage applied to load 14. The voltage output from generator 10 is proportional to the magnitude of the field current from regulator 20.

The generator 10 and the voltage regulator 20 are contemplated for use in an aircraft wherein the rated AC voltage is intended to be regulated at 115 volts, 400 Hz, and the DC voltage is intended to be regulated to 27.6 volts. Also, the per unit current is not to exceed 3.3 per unit (1.0 per unit current is rated), and the constant power hyperbola (2.2 per unit power) intersects the rated voltage at 2.2 per unit current. The following discussion will be directed primarily to an aircraft system with the above-noted voltage ranges and per unit current limits. However, it is appreciated that other DC voltages, AC voltages and per unit current values could be selected for use with a generator for providing output power at different voltages and currents.

Referring to *Figure 2*, and assuming that the per unit current is less than 2.0, the field current, I_F , provided to exciter winding 24 of generator 10 is dependent upon the value of the AC voltage across load 14. Specifically, if the voltage applied to load 14 lies between 0 and 112 volts, the field current I_F provided to the exciter winding 24 is at a maximum. If the AC voltage across load 14 is within a range between 113 volts and 117 volts, that is, a mid-range voltage of 115 volts $\pm$ 2 volts, the field current selected and applied to exciter winding 24 is responsive to the magnitude of the DC voltage across load 18. However, if the voltage across load 14 is within a tolerance range between 112 volts and 113 volts, the field current selected applied to exciter winding 24 is responsive to the AC voltage or the DC voltage, whichever requires the higher field current. If the AC voltage across load 14 is within a tolerance range between 117 volts and 118 volts, the field current selected and applied to exciter winding 24 is responsive to either the DC voltage or the AC voltage, whichever requires the lower field current. If the AC voltage exceeds 118 volts, the field current from regulator 20 to exciter winding 24 is zero.

In the event that the per unit current is greater than 2.0, the selected field current may be responsible to the per unit current, or the AC voltage as a function

of the per unit current, as will be explained in greater detail below.

Referring to Figure 3, the voltage regulator 20 includes the inputs from rectifier 16, the three-phase input from generator 10 and the three-phase current from transformers 22, and provides an output to exciter winding 24.

The DC voltage from rectifier 16 is applied to a summer 26 through a voltage divider 28. A reference voltage from source 30 is also applied to summer 26. The reference voltage from source 30 represents the selected DC reference voltage as 27.6 volts. The output from summer 26 is an error signal representing the difference, in magnitude and sign, between the voltage from rectifier 16 and the source 30. The output is applied to an active gain and compensation circuit 32 where steady state and transient response characteristics are controlled.

The signal from the active gain and compensation circuit 32 is applied to DC control transfer function 34 which has an output characteristic similar to that shown in the figure. Specifically, the output voltage from the DC control transfer function 34 is at a maximum selected level +V from 0 volts to 27.3 volts, the reference voltage minus a maximum selected tolerance in which the DC voltage is permitted to vary ($27.6 - 0.3 = 27.3$). The magnitude of the output voltage from the DC control transfer function 34 decreases as a function of an increase in the input representative of the voltage from rectifier 16. The output from DC control transfer function 34 is 0 at the reference voltage. The output of DC control transfer function 34 is applied to the higher input is output circuit 36.

The three-phase AC voltage from generator 10 is applied to a three-phase half-wave rectifier bridge 38 to provide a DC voltage representative of the voltage across load 14. The output from the three-phase half-wave rectifier bridge 38 is applied to a high-phase takeover circuit 40 and a voltage divider 42. The high-phase takeover circuit 40 is arranged so that no phase can exceed a predetermined limit below the minimum over voltage steady state trip level even when the other phases are zero. The high-phase takeover circuit 40 responds to average RMS phase voltage during normal balanced load operation. The output from voltage divider 42 is applied to summer 44 where it is compared to an AC reference voltage (115 volts) from reference source 46. The reference source 46 provides a signal representing the rated voltage. The output from summer 44 is an error voltage which represents the difference, in magnitude and sign, between the voltage from voltage divider 42 and the AC reference voltage from source 46. The output from summer 44 is applied to the active gain and compensation circuit 48 where steady state and transient response characteristics are controlled. The output from active gain and compensation circuit 48 is applied to summers 50 and 52.

A bias AC reference voltage from source 54 is applied to summer 50 at a negative input terminal and to summer 52 at a positive input terminal. The magnitude of the bias AC is the amount in which the AC is permitted to vary from its reference (i.e. 115

volts ± 2 volts) thereby defining a voltage range. The output from summer 50 is the signal representing the AC voltage across load 14 reduced by the amount established by reference 54 and is applied to lower limit AC control transfer function 56. The output from summer 52 is the signal representing the AC voltage across load 14 increased by the amount established by reference 54, and is applied to upper limit AC control transfer function 58. The output characteristics of the upper limit AC control transfer function 58 are shown graphically in Figure 3. As shown, the output is at the preselected level +V when the representative input from summer 52 increases from 0 volts to 117 volts. The output of the transfer function 58 decreases linearly to 0 as the representative input voltage increases to 118 volts.

The output characteristics of the lower limit AC control transfer function 56 are shown in the figure. Specifically, the output voltage from lower limit AC control transfer function 56 is at the preselected level +V when the input representative voltage across the AC load increases from 0 volts to 112 volts. The output of the transfer function 56 decreases linearly as the voltage increases beyond 112 volts. The output of the transfer function 56 is 0 when the AC voltage input is at its lower limit (113 volts). The output from transfer function 56 is applied to higher input is output circuit 36 where it is compared to the output from DC control transfer function 34.

Higher input is output circuit 36 compares the magnitude of the voltage from DC control transfer function 34 to the magnitude of the voltage from lower limit control transfer function 56 and provides an output signal to lowest input is output circuit 60 equal to the higher one of the two input signals. The high input signal will be that signal which is closer proportionally to +V for its respective range. That is, if the DC voltage is closer proportionally to 27.3 than the AC voltage is to 112 volts, then the output from higher input is output circuit 36 will be responsive to the DC voltage.

The signal representing the current from transformers (with burden resistors) 22 is applied to a three-phase half wave rectifier bridge 62 to provide a voltage representative of the current to load 14. The output from the three-phase half wave rectifier bridge 62 is applied to a high-phase takeover circuit 62. The high-phase takeover circuit 64 senses the highest current in the three phases and applies it to summers 66 and 68.

A signal representing 3.3 per unit current from source 70 is applied to summer 66 where it is compared with the output from high-phase takeover circuit 64. The output from summer 66 is applied to the active gain and compensation circuit 72 for control of the steady state and transient response characteristics. The output from active gain and compensation circuit 72 is applied to the current control transfer function 74. The output characteristics of transfer function 74 are shown in the figure. Specifically, the output voltage from the current control transfer function 74 is at the selected level +V from 0 to 2.0 per unit current. The output of transfer function 74 decreases linearly from +V to 0 as the per unit current increases from 2.0 to a



16

maximum permitted per unit current as 3.3 per unit. The output from the current control transfer function 74 is applied to lowest input is output circuit 60. If the current sensed by transformers 22 increases past
5 twice the rated current, the output from current control transfer function 74 decreases. The purpose of the decreasing output will be explained below.

A signal representing 2.0 per unit current from source 76 is applied to summer 68 where it is
10 compared to the output from the high-phase takeover circuit 64. The output from the summer 68 represents the difference between the current from the high-phase takeover circuit 64 and the signal from source 76. The output from summer 68 is
15 applied to the V vs. I power override circuit 78 along with the AC voltage from 42. The output from the V vs. I override circuit 78 is applied to summer 44. The output characteristics of the V vs. I power override circuit 78 are shown in the figure. The output is zero
20 between 0 to 2.0 per unit current at 1.0 per unit voltage and increases linearly to 115 volts as the per unit current increases from 2.0 to 2.2 at 1.0 per unit rated voltage. Similarly, the output is zero between 0 to 3.1 per unit current at 0.0 per unit voltage and
25 increases linearly to 115 volts as per unit current increases from 3.1 to 3.3 at 0.0 per unit voltage. Therefore, it is apparent that the output is a function of the per unit current and falls within a band defined by 3.1 and 3.3 at 0 per unit voltage and 2.0 and 2.2 at
30 1.0 per unit voltage. Although various per unit current values can be selected, 2.0 per unit current corresponds to the guaranteed performance specifications of the system, 2.2 per unit current corresponds to the maximum protective torque
35 limit, 3.3 per unit current corresponds to the maximum permissible feeder current, and 3.1 corresponds to a selected value to define the fourth corner of the band. The output from the override circuit 78 provides a signal which increases as the
40 voltage and current approach a constant power hyperbola for the system at 2.2 per unit power equal to 115 volts.

The output from the power override circuit biases the signal representing the AC voltage across load
45 14 from voltage divider 42 downwardly, causing the outputs from the lower limit AC transfer function 46 and the upper limit AC control transfer function 58 to provide outputs modified by the current as described.

The outputs from the high input is output circuit 36, the upper limit AC control transfer function 58 and the current control transfer function 74 are applied to lowest input is output circuit 60. The output from the lowest input is output circuit 60 is
55 equal to the lowest input and is applied to output amplifier 80 through summer 82. The output of amplifier 80 is the field current which is applied to exciter field 24. The output from amplifier 80 is also applied to low pass filter 84 for providing an average
60 field current feedback to the negative terminal of summer 82 to ensure current stability over a wide range of thermal conditions.

The field current amplifier may be pulse width modulated and synchronized to the generator 10 in
65 any acceptable manner including synchronization to

the 1200 Hz ripple frequency. Alternatively, the field current amplifier can be synchronized to the generator 10 by use of a PMG.

70 CLAIMS

1. A voltage regulator for providing a field current to a generator supplying power to at least a first and a second load at different voltages, which
75 voltage regulator comprises means for concurrently detecting the voltages across the first and second loads respectively, means for determining if the voltage across the first load is within a given voltage range, means for generating a field current
80 representative of the voltage across the second load, and means for providing the field current to the generator when the determining means detects that the voltage across the first load is within the given voltage range.
- 85 2. A voltage regulator according to claim 1 wherein the given voltage range is from 113 volts to 117 volts.
3. A voltage regulator according to claim 1 or claim 2, wherein the determining means is also
90 capable of determining if the voltage across the first load is within a first tolerance voltage range that is below the given voltage range, and the voltage regulator further comprises means for generating a field current representative of the voltage across the
95 load requiring the highest field current, and means for providing that field current to the generator if the voltage across the first load is within the first tolerance voltage range.
4. A voltage regulator according to claim 3,
100 wherein the first tolerance voltage range is from 112 to 113 volts.
5. A voltage regulator according to any preceding claim; wherein the determining means is also capable of determining if the voltage across the
105 first load is within a second tolerance voltage range that is above the given voltage range, and the voltage regulator further comprises means for generating a field current representative of the voltage across the load requiring the lowest field
110 current, and means for providing that field current to the generator if the voltage across the first load is within the second tolerance voltage range.
6. A voltage regulator according to claim 5, wherein the second tolerance voltage range is from
115 117 to 118 volts.
7. A voltage regulator according to any preceding claim, further comprising means for preventing the provision of any field current to the generator when the voltage across the first load is
120 above a predetermined maximum value.
8. A voltage regulator according to any preceding claim, wherein at least one of the loads is an AC load and at least one of the loads is a DC load.
9. A generator for providing an AC voltage to a
125 first load and a DC voltage to a second load, having a voltage regulator comprising:
means for establishing a reference voltage for said DC voltage;
means for comparing said reference voltage to
130 said DC voltage to provide a first error signal;

16

maximum permitted per unit current as 3.3 per unit. The output from the current control transfer function 74 is applied to lowest input is output circuit 60. If the current sensed by transformers 22 increases past twice the rated current, the output from current control transfer function 74 decreases. The purpose of the decreasing output will be explained below.

A signal representing 2.0 per unit current from source 76 is applied to summer 68 where it is compared to the output from the high-phase takeover circuit 64. The output from the summer 68 represents the difference between the current from the high-phase takeover circuit 64 and the signal from source 76. The output from summer 68 is applied to the V vs. I power override circuit 78 along with the AC voltage from 42. The output from the V vs. I override circuit 78 is applied to summer 44. The output characteristics of the V vs. I power override circuit 78 are shown in the figure. The output is zero between 0 to 2.0 per unit current at 1.0 per unit voltage and increases linearly to 115 volts as the per unit current increases from 2.0 to 2.2 at 1.0 per unit rated voltage. Similarly, the output is zero between 0 to 3.1 per unit current at 0.0 per unit voltage and increases linearly to 115 volts as per unit current increases from 3.1 to 3.3 at 0.0 per unit voltage. Therefore, it is apparent that the output is a function of the per unit current and falls within a band defined by 3.1 and 3.3 at 0 per unit voltage and 2.0 and 2.2 at 1.0 per unit voltage. Although various per unit current values can be selected, 2.0 per unit current corresponds to the guaranteed performance specifications of the system, 2.2 per unit current corresponds to the maximum protective torque limit, 3.3 per unit current corresponds to the maximum permissible feeder current, and 3.1 corresponds to a selected value to define the fourth corner of the band. The output from the override circuit 78 provides a signal which increases as the voltage and current approach a constant power hyperbola for the system at 2.2 per unit power equal to 115 volts.

The output from the power override circuit biases the signal representing the AC voltage across load 14 from voltage divider 42 downwardly, causing the outputs from the lower limit AC transfer function 46 and the upper limit AC control transfer function 58 to provide outputs modified by the current as described.

The outputs from the high input is output circuit 36, the upper limit AC control transfer function 58 and the current control transfer function 74 are applied to lowest input is output circuit 60. The output from the lowest input is output circuit 60 is equal to the lowest input and is applied to output amplifier 80 through summer 82. The output of amplifier 80 is the field current which is applied to exciter field 24. The output from amplifier 80 is also applied to low pass filter 84 for providing an average field current feedback to the negative terminal of summer 82 to ensure current stability over a wide range of thermal conditions.

The field current amplifier may be pulse width modulated and synchronized to the generator 10 in any acceptable manner including synchronization to

the 1200 Hz ripple frequency. Alternatively, the field current amplifier can be synchronized to the generator 10 by use of a PMG.

70 CLAIMS

1. A voltage regulator for providing a field current to a generator supplying power to at least a first and a second load at different voltages, which voltage regulator comprises means for concurrently detecting the voltages across the first and second loads respectively, means for determining if the voltage across the first load is within a given voltage range, means for generating a field current representative of the voltage across the second load, and means for providing the field current to the generator when the determining means detects that the voltage across the first load is within the given voltage range.
2. A voltage regulator according to claim 1 wherein the given voltage range is from 113 volts to 117 volts.
3. A voltage regulator according to claim 1 or claim 2, wherein the determining means is also capable of determining if the voltage across the first load is within a first tolerance voltage range that is below the given voltage range, and the voltage regulator further comprises means for generating a field current representative of the voltage across the load requiring the highest field current, and means for providing that field current to the generator if the voltage across the first load is within the first tolerance voltage range.
4. A voltage regulator according to claim 3, wherein the first tolerance voltage range is from 112 to 113 volts.
5. A voltage regulator according to any preceding claim, wherein the determining means is also capable of determining if the voltage across the first load is within a second tolerance voltage range that is above the given voltage range, and the voltage regulator further comprises means for generating a field current representative of the voltage across the load requiring the lowest field current, and means for providing that field current to the generator if the voltage across the first load is within the second tolerance voltage range.
6. A voltage regulator according to claim 5, wherein the second tolerance voltage range is from 117 to 118 volts.
7. A voltage regulator according to any preceding claim, further comprising means for preventing the provision of any field current to the generator when the voltage across the first load is above a predetermined maximum value.
8. A voltage regulator according to any preceding claim, wherein at least one of the loads is an AC load and at least one of the loads is a DC load.
9. A generator for providing an AC voltage to a first load and a DC voltage to a second load, having a voltage regulator comprising:
 - means for establishing a reference voltage for said DC voltage;
 - means for comparing said reference voltage to said DC voltage to provide a first error signal;



- means responsive to said first error signal for providing an output at a selected level when said DC voltage is at least a preselected amount less than said DC reference voltage and for providing an
- 5 output less than said selected level as said DC voltage increases therefrom to said DC reference voltage;
- means for establishing a reference voltage for said AC voltage;
- 10 means for comparing said AC reference voltage with the AC voltage to said first load for providing a second error signal;
- means for establishing a lower and an upper limit for said AC voltage, thereby defining a range for said
- 15 AC voltage;
- means responsive to said second error signal for providing an output at said selected level when said AC voltage is less than said lower limit and for decreasing the output from said selected level as
- 20 said AC voltage increases beyond said lower limit;
- means for comparing said output representing the DC voltage with said output representing the AC voltage at said lower limit for providing an output equal to the higher of the two outputs;
- 25 means for providing an output at said selected level when said AC voltage is less than said upper limit and for decreasing the output when said AC voltage increases beyond said upper limit; and
- means for comparing said higher of the two
- 30 outputs to said output representing the AC voltage at said upper limit and for providing a generator field current equal to the lower of the two.
10. A generator according to claim 9, further comprising:
- 35 means for measuring the current applied to the first load;
- means for establishing a reference current;
- means for comparing said reference current with the current applied to said first load to provide a
- 40 third error signal;
- means responsive to said third error signal for providing an output at said selected level when said current is less than said reference current by at least a given amount and for providing an output less
- 45 than said selected level when said current increases therefrom to said reference current; and
- means for comparing the output representing the current with said field current and providing a field current to said generator equal to the lower.
- 50 11. A voltage regulator for providing field current to a generator supplying power to loads at different voltages, substantially as described herein with reference to the drawings.