

Oct. 22, 1957

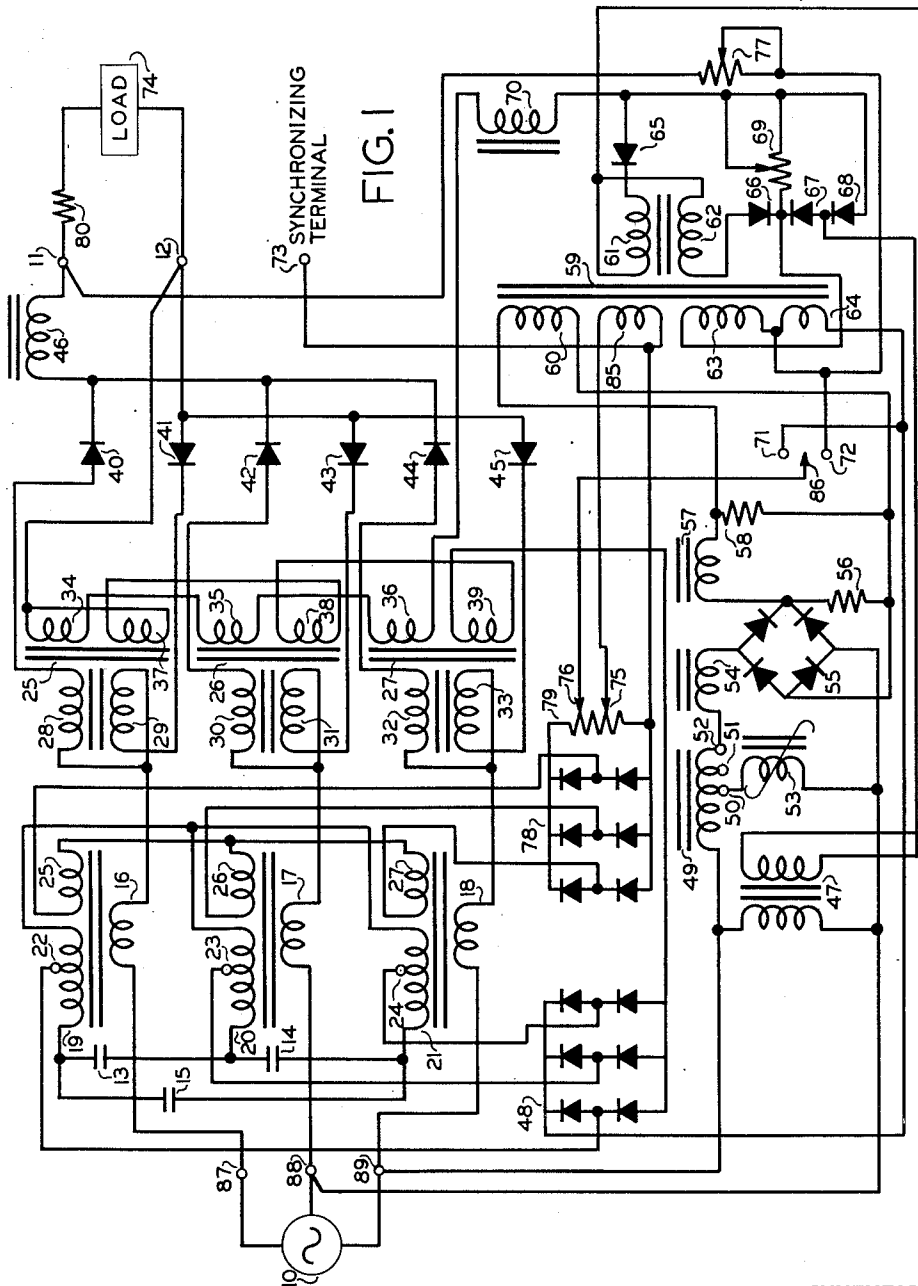
H. M. HUGE

2,810,876

REGULATED RECTIFIER

Filed July 30, 1953

2 Sheets-Sheet 1



INVENTOR.

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BY

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2 Sheets-Sheet 2

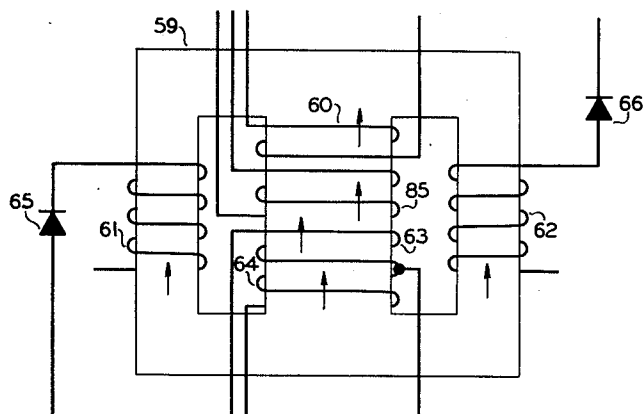


FIG. 2

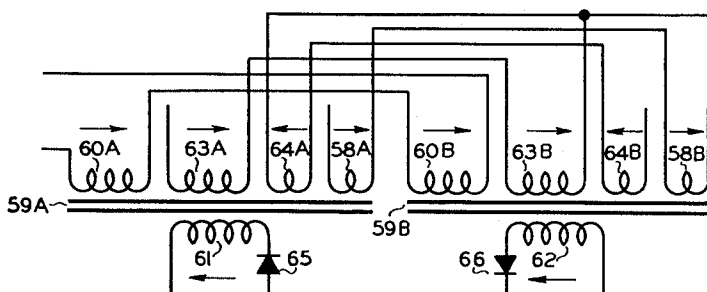


FIG. 3

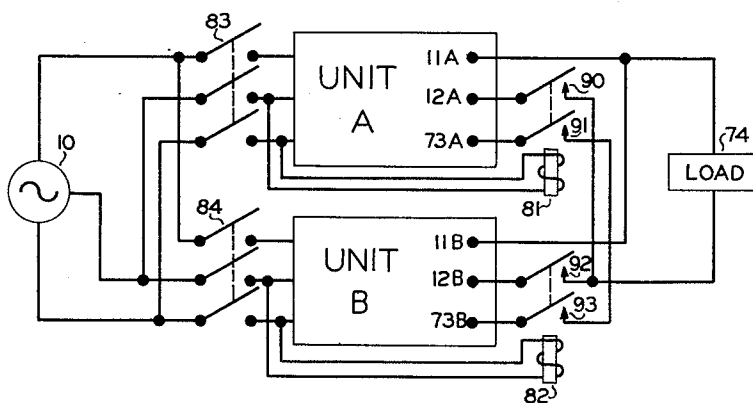


FIG. 4

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REGULATED RECTIFIER

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Application July 30, 1953, Serial No. 371,269

15 Claims. (Cl. 321—19)

This invention deals with a regulated rectifying system, and especially with a system in which a small source of regulated voltage serves as a standard for controlling the output of a larger system. This invention is an improvement over the arrangement shown in my U. S. patent application Serial No. 780,408, filed October 17, 1947, now Patent No. 2,653,293, which is a regulated rectifying system employing a source of standard voltage to control the output voltage of a relatively large rectifying system.

An object of my invention is to provide a regulated rectifying system in which the rectified output voltage is substantially independent of the alternating current voltage, the input frequency, the load current, and the ambient temperature.

A further object of my invention is to limit the maximum output current of a regulated rectifying system and to reduce the output of the standard voltage source when the current limit is reached.

Another object of my invention is to synchronize the operation of two or more regulated rectifiers operating in parallel to make them share the load in proportion to their ratings.

Another object of my invention is to increase the output voltage of a regulated rectifier with increasing load current in order to supply constant voltage to a load supplied from the regulated rectifier through a series resistance.

My present invention employs a different type of standard voltage source which is not sensitive to changes in line frequency, and which has several other advantages which will be pointed out more particularly in the specification.

When a regulated system has its output voltage controlled by comparison with a standard voltage, the point at which the standardizing circuit is connected is the point at which the voltage will be regulated. Sometimes the load is located a distance away from the source of regulated power, and a considerable voltage drop may occur between the source and the load.

In prior devices, this resulted in a dropping voltage characteristic at the load, which could be compensated by extending a set of potential leads, used for the voltage comparison circuit, to the load. By this means, the voltage at the load could be regulated to the required degree of accuracy, but the installation was considerably complicated by the extra potential leads, and by the necessity for protection in the potential circuit, particularly protection against the possibility of the power source becoming disconnected from the potential leads.

By means of my present invention, these difficulties can be overcome and the voltage drop between the source of power and the load can be compensated without extending the standard voltage circuit to the load. Instead, the standard voltage source of my invention can be made with a voltage characteristic rising with increasing load current, this characteristic being adjustable to match the voltage drop between the power source and the load.

Another feature of my invention is the positive synchronization of two or more regulated rectifiers operating in parallel across a common load. When two or more regulated rectifiers or other direct current power supply units having constant direct current output voltage operate in parallel with each other, the fact that each unit maintains a nearly constant voltage up to its full rating tends to cause an unequal division of load current between the several power supply units. If one of the units has a slightly higher regulated output voltage than another, even though the difference in voltage is very small, the unit having the higher output voltage may deliver its full load current before the lower unit delivers any current at all. My present invention overcomes this disadvantage, and makes it possible to operate two or more constant voltage rectifier units in parallel with each other and to synchronize their operation so that each unit carries its proportionate share of the load current. I accomplish this by means of a synchronizing circuit extending from one to the other of the regulated rectifier units and effecting the standard voltage source of each unit in such a way as to increase or decrease its voltage just enough to produce the proper division of load current between the two or more rectifier units.

The synchronizing circuit is energized by an auxiliary rectifier in each power supply unit. The auxiliary rectifier produces an output voltage substantially proportional to the output current of the power supply unit. By balancing the voltage of the auxiliary rectifier in one unit against that in another unit by means of the synchronizing circuit, I am able to regulate the output current of each power unit to produce the required division of load current as will be pointed out in more detail in the following specification.

Other objects of my invention will become apparent by referring to the following specification and claims taken in conjunction with the accompanying drawings, in which:

Figure 1 shows the circuit diagram of a voltage regulated rectifying system made according to my invention and capable of supplying a constant output voltage which is substantially unaffected by input voltage or frequency and by ambient temperature. The system shown in Figure 1 is equipped to be synchronized with another similar system operated in parallel with it. It also includes means for limiting the maximum output current of the rectifying unit, and for compensating for resistance existing between the load terminals of the unit and the load;

Figure 2 is a detailed drawing of one of the three-legged reactors which is shown symbolically in Figure 1;

Figure 3 shows an alternative arrangement for the saturating reactors shown in Figure 1, employing two separate saturating cores in place of a single three-legged reactor; and

Figure 4 is a circuit diagram showing how two of the regulated rectifying units such as shown in Figure 1 can be operated in parallel, taking advantage of the synchronizing feature shown in Figure 1.

Referring more particularly to Figure 1, there is shown a regulated rectifying arrangement having alternating current input terminals 87, 88 and 89 energized from the three-phase alternating current source 10, and having direct current load terminals 11 and 12 to which a load 74 is connected through a series resistance 80. The power circuit which extends from the alternating current input terminals to the direct current load terminals includes rectifier elements, impedance windings which control the flow of current through the rectifier elements, and series transformer windings which are used in the control circuit. Thus the power circuit extends from the input terminals 87, 88 and 89 through the series transformer

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windings 16, 17 and 18 and through the impedance windings 28, 29, 30, 31, 32 and 33. These impedance windings are located on the three-legged magnetic core structures 25, 26 and 27 indicated symbolically by the T-shaped figures on the diagram. Each magnetic core structure has impedance windings located on its two outer core members and also has saturating windings located on its central core member. Thus on the three-legged core structure 26, impedance windings 28 and 29 are on the two outer core members and saturating windings 34 and 37 are on the central core member.

Each of the impedance windings is connected in series with a half wave rectifier element, thus impedance winding 28 is in series with rectifier element 40, impedance winding 29 is in series with rectifier element 41, winding 30 in series with rectifier 42, winding 31 in series with rectifier 43, winding 32 in series with rectifier 44 and winding 33 in series with rectifier 45. Together, these six rectifier elements constitute a full wave three-phase rectifier bridge supplying direct current to the load terminals 11 and 12. Filter choke 46 connected between the rectifiers and positive output terminal 11 serves to filter the output current, but this choke may be omitted where the load does not require the elimination of the small amount of ripple present in the three-phase full wave rectified output.

The impedance of windings 28-33 inclusive, and consequently the current supplied to terminals 11 and 12 is primarily controlled by the current flowing through saturating windings 34, 35 and 36. The current through these windings is determined by balancing a standard voltage appearing across resistor 69 against the voltage across load terminals 11 and 12.

The standard voltage source in Figure 1 is of the type shown and described in my U. S. patent application entitled "Voltage and Current Regulator," which is being filed concurrently with this present application. The voltage source comprises the three-legged magnetic core structure 59 shown symbolically by the T-shaped figure and having impedance windings 61 and 62 on its two outer core members and saturating winding means comprising windings 60, 63, 64 and 85 on its central core member.

The symbolic representation of the three-legged core structure used in Figure 1 can be more clearly understood by reference to Figure 2 in which the three-legged core 59 is diagrammatically represented, with the impedance windings 61 and 62 on the two outer core members, and saturating windings 60, 63, 64 and 85 on the central core member. Each of the impedance windings is connected in series with a half wave rectifier element, element 65 being in series with winding 61 and element 66 being in series with winding 62. These rectifier elements together with elements 67 and 68 comprise a full wave rectifier bridge energized from transformer 47 under the control of impedance windings 61 and 62.

The three-legged core structure 59 is magnetized by a substantially constant biasing current flowing through a winding 60. The arrows shown in Figure 2 indicate the directions of the direct current fluxes produced by the various windings on core 59. Current through winding 60 premagnetizes the core structure with the flux flowing upward in the central core member and downward in the two outer core members. With the core thus premagnetized, the impedance of windings 61 and 62 is very low for all values of current up to the value of current which substantially cancels the magnetization produced by winding 60. When this value of current is reached, the impedance of the winding becomes very high, substantially limiting the rectified current to a value determined by the premagnetization produced by winding 60. Rectifiers 65 and 66 conduct on alternate half cycles of alternating current, so that each half cycle is limited in the same way, and the resultant rectified current supplied to resistance

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element 69 is very accurately limited to a value determined by the premagnetization of core 59.

The voltage balancing circuit extends from resistance element 69 to direct current load terminals 11 and 12 through filter choke 70, saturating winding 34, 35 and 36, adjusting resistor 77, and saturating winding 63.

The current through saturating winding 63 increases the premagnetization of core 59 with increasing load current drawn from across resistor 69 at a rate sufficiently great to cause the voltage across resistor 69 to increase as the load current drawn from it increases, the amount of increase being just sufficient to compensate for the voltage drop through winding 63, resistor 77, filter choke 70, and saturating windings 34, 35 and 36. Because of this characteristic, I am able to maintain a substantially constant voltage across load terminals 11 and 12 even when considerable values of saturating current are drawn from the standard voltage source through the saturating windings 34, 35 and 36. Furthermore, in case the circuit conditions are such that a reversal of current through windings 34, 35 and 36 is required, the current reversing through winding 63 reduces the premagnetization of core 59 at exactly the rate required to maintain constant voltage across terminals 11 and 12.

The output voltage characteristic of the circuit just described is almost completely independent of input voltage and input frequency, but by proper control of the energizing circuit connected to winding 60, I am able to compensate for minor variations which may occur as the result of changes in input voltage and input frequency.

The regulated biasing current for winding 60 is obtained from rectifier 55 which is energized from source 10 through substantially linear inductances 49 and 54. The saturable inductance 53 is also energized from source 10 through at least a portion of inductance 49; as shown in Figure 1, it is connected to tap 50, with the optional connections being shown as taps 51 and 52, tap 52 being the end of the winding of inductance 49. Because of the saturation of its core, the voltage across inductance 53 changes very little over a wide range of magnetizing current. The slight variation in voltage across inductance 53 which may occur with increasing magnetizing current (increasing input voltage) can be neutralized by proper location of the taps 50 and 51. When the core material used for saturable inductance 53 is such that the change in voltage across inductance 53 is negligible over the normal operating range, tap 52 may be used for connection with inductance 53.

Inductance 54 acts as a current limiting impedance in the circuit of rectifier 55, so that even though the resistance of the direct current circuit connected to rectifier 55, and comprising filter inductance 57, and winding 60, may change due to changes in temperature, a substantially constant current can be maintained through this circuit. Furthermore, since the output voltage developed across saturable inductance 53 increases linearly with increasing frequency, and the impedance of linear inductance 54 likewise increases linearly with increasing frequency, the current through rectifier 55 may be maintained substantially constant with variable frequency input as well as with variable voltage input from source 10.

A filter circuit comprising inductance 57, and resistors 56 and 58 is connected between rectifier 55 and biasing winding 60. This filter circuit prevents ripple voltage from winding 60 from being fed back into rectifier 55 where it could adversely influence the regulating properties of the circuit. Resistors 56 and 58 are preferably proportioned so that the direct current passed by them is a small fraction of the output of rectifier 55, so they do not prevent the maintenance of constant current through winding 60 when its resistance changes due to changing temperature. Capacitors may be used in place of resistors 56 and 58, but the power handled by this circuit is generally small and resistors are more economical.

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As previously mentioned, the regulating circuit can be made to have a characteristic which will compensate for minor effects of the variation of source 10 on the regulating properties of the impedance windings on core 59. With saturable inductance 53 connected to tap 50 on inductance 49, the current supplied to rectifier 55 can be caused to decrease as the voltage of source 10 increases, because of the effect of the voltage produced between taps 50 and 52 on inductance 49. Since the voltage across saturable inductance 53 is nearly constant with variations in the voltage of source 10, the voltage drop occurring through the entire winding of inductance 49 becomes more than sufficient to compensate for the variation in the voltage of source 10, because the voltage in the portion of the winding terminated at tap 50 is sufficient to compensate for practically all of the voltage variation in source 10. Under these conditions, the voltage and current supplied to rectifier 55 diminish as the voltage of source 10 increases. This characteristic can be used to compensate for the effect of changing input voltage on the reference source unit having magnetic core 59. I am therefore able to maintain a substantially constant voltage across terminals 11 and 12, even though the performance of the saturating reactor having core 59 may not closely approach the ideal performance previously described.

The series transformer having primary windings 16, 17 and 18 are loaded with capacitors 13, 14 and 15 connected across secondary windings 19, 20 and 21. With these capacitors connected across the secondary windings, the series transformers become substantially linear impedance elements in series with the power circuit which extends from the input terminals to the load terminals and includes the regulating reactors and the rectifiers. As a result, the voltage developed across the series transformers increases substantially in direct proportion to the current drawn from load terminals 11 and 12. Rectifier 48 connected to taps 22, 23 and 24 of secondary windings 19, 20 and 21 has an output voltage which therefore increases as the load current increases. The direct current terminals of rectifier 48 are connected across the direct current load terminals 11 and 12 in a circuit which extends through windings 37, 38 and 39 on cores 25, 26 and 27 and also through winding 64 on core 59.

The purpose of rectifier 48 is to limit the maximum output current which can be drawn from load terminals 11 and 12 to a value which is within the safe operating limits of the rectifying unit. As long as the load current is below a predetermined maximum value, the voltage developed by rectifier 48 is less than the voltage across terminals 11 and 12 and the circuit extending through windings 37, 38, 39 and 64 passes substantially no current, as the current is blocked by the reverse resistance of rectifier 48. However, when the load current exceeds this predetermined maximum, the voltage developed by rectifier 48 exceeds the voltage across load terminals 11 and 12 and the rectifier delivers current through the windings just mentioned. The current flowing through windings 37, 38 and 39 is in a direction which demagnetizes the cores 25, 26 and 27, thereby causing the impedance of windings 28—33 to be increased in order to limit the load current.

At the same time, the current which rectifier 48 passes through winding 64 on core 59 opposes the magnetization produced by winding 60 and reduces the flow of current supplied to resistance element 69, thereby reducing the standard voltage. By this means, I am able to reduce the standard voltage at the same time that the impedance of windings 28—33 is increased so that the action of the standard voltage source does not oppose the demagnetizing action of the current delivered by rectifier 48 through windings 37, 38 and 39. In some cases the result of reducing the standard voltage when the circuit is overloaded will be sufficient to limit the load current and the windings 37, 38 and 39 can be omitted entirely,

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because the load voltage will be reduced at the same time the standard voltage is reduced.

Rectifier 78 is also energized from the series transformers having primary windings 16, 17 and 18. The rectifier 78 is energized from secondary windings 25, 26 and 27, and it likewise develops across resistor 79 an output voltage which increases in proportion to the load current. This voltage is used both for synchronizing with other rectifiers, and for the compensation for the voltage drop across resistance 80 between the load terminals 11 and 12 and the load 74.

I obtain the synchronizing feature by connecting one terminal of resistor 79 to a separate terminal 73 designated as a synchronizing terminal. In the circuit shown, terminal 73 is connected to the negative end of resistor 79. The required portion of the voltage across resistor 79 is obtained from slider 76 which is connected to the positive load terminals 11 through the circuit which includes resistance element 77 and, optionally, winding 64 on core 59. This circuit is intended to be used as a balancing arrangement when two or more rectifier units of this type are operated in parallel across a common load.

When the synchronizing terminal 73 is connected to a similar synchronizing terminal in another regulated rectifier, as shown in Figure 4, the voltage developed between terminal 11 and terminal 73 in the one rectifier is balanced against the voltage developed between terminal 11 and terminal 73 in the other rectifier. Because this voltage consists primarily of the voltage developed by rectifier 78 in each machine, the voltages balanced against each other are proportional to the load currents delivered by the several regulated rectifier units. For example, if the rectifier unit as shown in Figure 1 is delivering more than its share of load current, the voltage developed across resistor 79 in Figure 1 will be greater than the voltage against which it is balanced, and a current will flow from slider 76 through the circuit consisting of resistor 77 and, optionally, winding 64. The flow of current from rectifier 78 through resistor 77 causes an additional voltage drop through resistor 77, and since resistor 77 is common to both the synchronizing circuit and the voltage balancing circuit which extends from resistor 69 to load terminals 11 and 12, the additional voltage across resistor 77 will appear in the voltage balancing circuit, and will modify the output voltage of the regulated rectifier unit. In this case, the additional voltage drop through resistor 77 will reduce the voltage across load terminals 11 and 12, by reducing the saturating current through windings 34, 35 and 36. The optional use of winding 64 is controlled by contacting member 86 which may be connected either to terminal 71 or to terminal 72.

When contacting member 86 is connected to terminal 71, the output current from rectifier 78 will flow through winding 64 as well as through resistor 77. The direction of current flow through winding 64 is such that the effect on the regulation is the same as the effect of the voltage drop through resistor 77. In other words, when the rectifier, as shown in Figure 1, is delivering more than its share of load current, so that current from rectifier 78 flows out through tap 76 and through winding 64, the magnetization of core 59 is reduced, reducing the voltage across resistor 69 and thereby reducing the output voltage appearing across load terminals 11 and 12. This has the effect of reducing the output voltage and consequently the output current of any rectifier which is delivering more than its share of load current. Conversely, the flow of current in the reverse direction through this circuit will increase the output voltage of any rectifier which is delivering less than its share of load current.

Although the circuit as shown makes use of both resistor 77 and winding 64, resistor 77 may be omitted

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when winding 64 is used, and winding 64 may be omitted from this circuit when resistor 77 is used.

The slider 75 on resistor 79 energizes winding 85 on core 59. The magnetizing effect of winding 85 is preferably small compared to the effect of winding 60, and is used to adjust the output voltage across terminals 11 and 12 in order to compensate for the voltage drop through resistor 80. As indicated in Figure 2, the flow of current through winding 85 magnetizes the core 59 in the same direction as the flow of current through winding 60. Because the voltage supplied to rectifier 78 and resistor 79 increases directly in proportion to the load current, the standard voltage across resistor 69 which is determined by the magnetization of core 59 increases linearly as the load current increases. By the proper adjustment of slider 75 on resistor 79, this increase in voltage can be made to exactly compensate for the voltage drop through resistor 80, so that the load 74 receives a constant voltage from load terminals 11 and 12 over the full range of load current. This is an extremely useful characteristic, as it permits regulation inside the regulated rectifying unit to compensate for voltage drop in a resistance outside the unit which may be located a considerable distance away, as the load 74 may be located a considerable distance from the regulated rectifying unit. Furthermore, simply by adjusting tap 75 to the desired point, I am able to compensate for changes in the resistance 80, and, if desired, the tap 75 can be moved to the lower end of resistor 79 to completely eliminate compensation of this type, as for example, when the resistance 80 is negligible.

The inductance 70 connected in series in the voltage balancing circuit between resistor 69 and load terminals 11 and 12, is used to limit the flow of alternating current through this circuit. In general, some ripple voltage may appear across load terminals 11 and 12, and I prefer to keep this ripple voltage from causing an appreciable current flow back through the control circuit to resistor 69 where it could be impressed on the rectifier elements 65, 66, 67 and 68 to change their output voltage.

As previously mentioned, Figure 2 is a diagrammatic drawing of the three-legged core structure 59 indicated symbolically in Figure 1. The arrows on Figure 2 indicate the relative directions of the normal magnetizing forces produced by the various windings. Thus, the current through winding 60 produces a magnetizing force in the upward direction in the central core member to premagnetize the core 59. The direct current flowing through windings 61 and 62 opposes the premagnetization of winding 60. In general, the demagnetizing effect of the current through windings 61 and 62 will be substantially equal to the premagnetizing effect of the current through the windings 60, 85, 63 and 64 because the windings 61 and 62 have a very low impedance as long as the core 59 is saturated, and their impedance becomes very high as soon as the core 59 is demagnetized to the point where the flux through the core changes rapidly for small changes in magnetizing current. As previously mentioned, the premagnetizing effect of the current through winding 60 is aided by the magnetizing effect of the current through compounding winding 63, and by the effect of the variable current through winding 85 which in Figure 1 is used to increase the output voltage of the rectifying unit as the load current increases. The current through winding 64 as indicated on Figure 2, is used to reduce the magnetization of core 59 and thereby reduce the output voltage of the rectifying unit.

Figure 3 shows how the three-legged core structure of Figure 2 can be replaced by two separate magnetic cores. Winding 61 is shown on core 59A in Figure 3 and winding 62 is shown on core 59B. However, because the two flux paths in Figure 3 are separated from each other, the

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windings 60, 63, 64 and 85 are also divided, each winding being divided into two parts, each part being identified by the letter A or B according to whether it is on core 59A or core 59B. Thus, windings 60A and 60B are in series with each other, windings 63A and 63B are in series with each other, windings 64A and 64B are connected in series, and windings 85A and 85B are connected in series, so that the magnetization of each of the two flux paths in Figure 3 is substantially the same as the magnetization of each of the two flux paths in Figure 2.

It will be apparent that the division of the three-legged core into two separate cores as is done in Figure 3 with the core 59 can be applied equally well to the cores 25, 26 and 27 in Figure 1.

Figure 4 shows a circuit arrangement for operating two regulated rectifying units such as the one shown in Figure 1 in parallel with each other, making use of the synchronizing connection in order to maintain accurate division of load between the two units. The two regulated rectifying units in Figure 4 are designated as unit A and unit B, unit A being energized from source 10 through a switch 83 and unit B being energized from source 10 through a switch 84. The direct current load terminals 11 and 12 of unit A are designated as terminals 11A and 12A and the direct current load terminals of unit B are designated as 11B and 12B. The load connections from the two units are paralleled across the load 74.

When switch 83 is closed, putting unit A in operation, relay 81 operates closing contacts 90 and 91. When switch 84 is closed putting unit B in operation, relay 82 operates closing contacts 92 and 93. When both units are in operation, therefore, the synchronizing terminals 73A and 73B are connected together through the relay contacts 91 and 93. Therefore, if the voltage developed by rectifier 78 across the portion of resistor 79 terminated at slider 76 is greater in one unit than it is in the other unit, a circulating current will flow through the synchronizing circuit as previously described, increasing the output current of one unit and decreasing that of the other unit. It is not necessary that both units be of the same rating, it is only necessary that the voltage developed in the synchronizing circuit at full load be the same in units which are to be synchronized. In this way, the current will be divided between the units in operation in proportion to their full load current ratings.

Relay contacts 90 and 92 which open one lead of the direct current circuit to each rectifying unit can be used to prevent possible reverse current flow through a rectifying unit which is not in operation. When contacts 90 and 92 are omitted, the voltage of the unit which is in operation will be impressed across the unit which is not in operation whenever the units are operated singly. In addition, the load 74 may include a battery floated across the line, and the voltage of the battery would then be impressed across either unit during all the time it was de-energized if it were not for the relay contacts 90 and 92. At the same time, it must be noted that the flow of reverse current through a rectifying unit such as shown in Figure 1 is blocked by the reverse resistance of the rectifying elements, and when the value of reverse current which the rectifiers will pass in the de-energized condition is not objectionable, the contacts 90 and 92 may be omitted.

Although Figure 4 shows only two units operating in parallel, additional units operating in parallel across load 74 can be operated in the same manner without difficulty.

Although I have described my invention with a certain degree of particularity as applied to a polyphase rectifying system, it is understood that this disclosure has been made only by way of example and that single-phase rectifying systems and other changes in the details of construction and the combination and arrangement of parts may be resorted to without departing from the spirit and the scope of the invention as hereinafter claimed.

I claim as my invention:

1. A regulating arrangement having alternating current input terminals and direct current load terminals and comprising in combination, first rectifying means, first magnetic core means having first impedance winding means and first saturating winding means thereon, a first circuit extending from the input terminals to the load terminals and including said first impedance winding means and said first rectifying means in series, second rectifying means, second magnetic core means having second impedance winding means and second saturating winding means thereon, a resistance element, a second circuit extending from said input terminals to said resistance element and including said second rectifying means in series with said second impedance winding means, a third circuit extending from said resistance element to said load terminals and including at least a portion of each of said first and second saturating winding means, to control the impedance of the first impedance winding means in response to the difference between the voltage across said resistance element and the voltage across the load terminals, and means for supplying a substantially constant direct current to at least a portion of said second saturating winding means to regulate the voltage across said resistance element.

2. A regulating arrangement having alternating current input terminals and direct current load terminals and comprising in combination, first rectifying means, first magnetic core means having first impedance winding means and first saturating winding means thereon, a first circuit extending from the input terminals to the load terminals and including said first impedance winding means and said first rectifying means in series, second rectifying means, second magnetic core means having second impedance winding means and second saturating winding means thereon, a resistance element, a second circuit extending from said input terminals to said resistance element and including said second rectifying means in series with said second impedance winding means, a third circuit extending from said resistance element to said load terminals and including at least a portion of each of said first and second saturating winding means to control the impedance of the first impedance winding means in response to the difference between the voltage across said resistance element and the voltage across the load terminals, third rectifying means connected to at least a portion of said second saturating winding means, first and second substantially linear inductances, a saturable inductance, a fourth circuit extending from said input terminals to said saturable inductance and including at least a portion of the first linear inductance, and a fifth circuit extending from said input terminals to said third rectifying means and including the first and second linear inductances in series.

3. A regulating arrangement having alternating current input terminals and direct current load terminals and comprising in combination, first rectifying means, first magnetic core means having first impedance winding means and first saturating winding means thereon, a first circuit extending from the input terminals to the load terminals and including said first impedance winding means and said first rectifying means in series, second rectifying means, second magnetic core means having second impedance winding means and second saturating winding means thereon, a resistance element, a second circuit extending from said input terminals to said resistance element and including said second rectifying means in series with said second impedance winding means, a third circuit extending from said resistance element to said load terminals and including at least a portion of each of said first and second saturating winding means to control the impedance of the first impedance winding means in response to the difference between the voltage across said resistance element and the voltage across the load terminals, and means for impressing on a portion of said second saturating wind-

ing means an additional direct current substantially proportional to the load current drawn from said load terminals.

4. A regulating arrangement having alternating current input terminals and direct current load terminals and comprising in combination, first rectifying means, first magnetic core means having first impedance winding means and first saturating winding means thereon, series transformer means, the first rectifying means and the first terminals to the load terminals and including the series transformer means, the first rectifying means and the first impedance winding means in series, second rectifying means, second magnetic core means having second impedance winding means and second saturating winding means, a resistance element, a second circuit extending from said input terminals to said resistance element and including said rectifying means in series with said second impedance winding means, a third circuit extending from said resistance element to said load terminals and including at least a portion of each of said first and second saturating winding means, means for supplying a substantially constant direct current to said second saturating winding means, third rectifying means energized from said series transformer means, and a fourth circuit extending from the third rectifying means to the load terminals through a portion of said second saturating winding means and carrying current when the voltage of the third rectifying means exceeds the voltage across the load terminals, thereby reducing the voltage across said resistance element when the load current exceeds a predetermined value.

5. A regulating arrangement having alternating current input terminals and direct current load terminals and comprising in combination, first rectifying means, first magnetic core means having first impedance winding means and first saturating winding means thereon, series transformer means, a first circuit extending from the input terminals to the load terminals and including the series transformer means, the first rectifying means and first impedance winding means in series, second rectifying means, second magnetic core means having second impedance winding means and second saturating winding means, a resistance element, a second circuit extending from said input terminals to said resistance element and including said second rectifying means in series with said second impedance winding means, a third circuit extending from said resistance element to said load terminals and including at least a portion of each of said first and second saturating winding means, means for supplying a substantially constant direct current to said second saturating winding means, third rectifying means energized from said series transformer means, and supplying additional current to said second saturating winding means to thereby modify the voltage across said resistance element in proportion to the amount of load drawn from said load terminals.

6. A regulating arrangement having alternating current input terminals and direct current load terminals and comprising in combination, first rectifying means, first magnetic core means having first impedance winding means and first saturating winding means thereon, series transformer means, a first circuit extending from the input terminals to the load terminals and including the series transformer means, the first rectifying means and the first impedance winding means in series, second rectifying means, second magnetic core means having second impedance winding means and second saturating winding means, a resistance element, a second circuit extending from said input terminals to said resistance element and including said second rectifying means in series with said second impedance winding means, a third circuit extending from said resistance element to said load terminals and including at least a portion of each of said first and second saturating winding means, means for supplying a substantially constant direct current to said second saturating winding means, third rectifying means energized from said series transformer means, a second resistance element energized from the third rectifying means,

and a fourth circuit extending from one of said load terminals through at least a portion of said second resistance element and at least a portion of said second saturating winding means, to a synchronizing terminal adapted to be connected to a similar terminal on another similar regulating arrangement having its load terminals connected in parallel with said load terminals, whereby current flowing through said fourth circuit will act to synchronize the output currents of the regulating arrangements.

7. A regulating arrangement having alternating current input terminals and direct current load terminals and comprising in combination, first rectifying means, first magnetic core means having first impedance winding means and first saturating winding means thereon, series transformer means, a first circuit extending from the input terminals to the load terminals and including the series transformer means, the first rectifying means and the first impedance winding means in series, second rectifying means, second magnetic core means having second impedance winding means and second saturating winding means, a resistance element, a second circuit extending from said input terminals to said resistance element and including said second rectifying means in series with said second impedance winding means, a third circuit extending from said resistance element to said load terminals and including at least a portion of each of said first and second saturating winding means, means for supplying a substantially constant direct current to said second saturating winding means, third rectifying means energized from said series transformer means, a second resistance element energized from the third rectifying means, and a fourth circuit extending from one of said load terminals through a third resistance element common to said third and fourth circuits and through at least a portion of said second resistance element to a synchronizing terminal adapted to be connected to a similar terminal on another similar regulating arrangement having its load terminals connected in parallel with said load terminals, whereby current flowing through said fourth circuit will act to synchronize the output currents of the regulating arrangements.

8. A regulating arrangement having alternating current input terminals and direct current load terminals and comprising in combination, first rectifying means, first magnetic core means having first impedance winding means and first saturating winding means thereon, a first circuit extending from the input terminals to the load terminals and including said first impedance winding means and said first rectifying means in series, second rectifying means, second magnetic core means having second impedance winding means and second saturating winding means thereon, a resistance element, a second circuit extending from said input terminals to said resistance element and including said second rectifying means in series with said second impedance winding means, a third circuit extending from said resistance element to said load terminals and including at least a portion of each of said first and second saturating winding means, to control the impedance of the first impedance winding means in response to the difference between the voltage across said resistance element and the voltage across the load terminals, and means for applying a substantially constant bias to said second magnetic core means.

9. A regulating arrangement having alternating current input terminals and direct current load terminals and comprising in combination, first rectifying means, first magnetic core means having first impedance winding means and first saturating winding means thereon, a first circuit extending from the input terminals to the load terminals and including said first impedance winding means and said first rectifying means in series, second rectifying means, second magnetic core means having second impedance winding means and second saturating winding means thereon, a resistance element, a second circuit extending

from said input terminals to said resistance element and including said second rectifying means in series with said second impedance winding means, a third circuit extending from said resistance element to said load terminals and including at least a portion of each of said first and second saturating winding means, to control the impedance of the first impedance winding means in response to the difference between the voltage across said resistance element and the voltage across the load terminals, means for applying to said second magnetic core means a substantially constant bias and means for applying thereto an additional bias in proportion to the current through said first circuit.

10. A regulating arrangement having alternating current input terminals and direct current load terminals and comprising in combination, first rectifying means, first magnetic core means having first impedance winding means and first saturating winding means thereon, a first circuit extending from the input terminals to the load terminals and including said first impedance winding means and said first rectifying means in series, second rectifying means, second magnetic core means having second impedance winding means and second saturating winding means thereon, a resistance element, a second circuit extending from said input terminals to said resistance element and including said second rectifying means in series with said second impedance winding means, a third circuit extending from said resistance element to said load terminals and including at least a portion of each of said first and second saturating winding means, to control the impedance of the first impedance winding means in response to the difference between the voltage across said resistance element and the voltage across the load terminals, means for applying to said second magnetic core means a substantially constant bias, and means for applying thereto an opposing bias whenever the current through said first circuit exceeds a predetermined value.

11. A regulating arrangement having alternating current input terminals and direct current load terminals and comprising in combination, first saturable reactor means having impedance winding means and saturating winding means, first rectifying means connected in series with said impedance winding means between the input terminals and the load terminals, second saturable reactor means having impedance winding means and saturating winding means, a resistor, second rectifying means connected in series with the last-named impedance winding means between the input terminals and the resistor, means for balancing the voltage across said resistor against the voltage across the load terminals through the saturating winding means on both the first and second saturable reactors, and means for applying a substantially constant bias to the second saturable reactor.

12. A regulating arrangement having alternating current input terminals and direct current load terminals and comprising in combination, first saturable reactor means having impedance winding means and saturating winding means, first rectifying means connected in series with said impedance winding means between the input terminals and the load terminals, second saturable reactor means having impedance winding means and saturating winding means, a resistor, second rectifying means connected in series with the last-named impedance winding means between the input terminals and the resistor, means for balancing the voltage across said resistor against the voltage across the load terminals through the saturating winding means on both the first and second saturable reactors, means for applying a substantially constant bias to the second saturable reactor, and means for reducing said bias whenever the current through the first rectifying means exceeds a predetermined value.

13. A regulating arrangement having alternating current input terminals and direct current load terminals and comprising in combination first saturable reactor means having impedance winding means and saturating winding

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means, first rectifying means connected in series with said impedance winding means between the input terminals and the load terminals, second saturable reactor means having impedance winding means and saturating winding means, a resistor, second rectifying means connected in series with the last-named impedance winding means between the input terminals and the resistor, means for balancing the voltage across said resistor against the voltage across the load terminals through the saturating winding means on both the first and second saturable reactors, means for applying a substantially constant bias to the second saturable reactor and means for applying an additional bias in proportion to the current drawn from said load terminals.

14. Means for synchronizing a plurality of regulated rectifying arrangements operating in parallel, each of said arrangements comprising saturable reactor means having impedance winding means connected in series with rectifying means between alternating current input terminals and direct current load terminals and having saturating winding means energized according to the difference between the voltage across the load terminals and a standard voltage, said synchronizing means comprising means in each rectifying arrangement for producing a control voltage proportional to load current, means for balancing the control voltages in the several rectifying arrangements against each other, and means in each rectifying arrangement for changing its standard voltage according to the unbalance of the control voltages.

15. Means for synchronizing a plurality of regulated rectifying arrangements operating in parallel, each of said arrangements comprising first saturable reactor means having first impedance winding means connected in series with first rectifying means between alternating current

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input terminals and direct current load terminals and having saturating winding means energized according to the difference between the voltage across the load terminals and a standard voltage obtained from second rectifying means connected in series with second impedance winding means on a second saturable reactor, said standard voltage being controlled by the application of a substantially constant bias to said second saturable reactor, said synchronizing means comprising means in each rectifying arrangement for producing a control voltage proportional to load current, means for balancing the control voltages in the plurality of rectifying arrangements against each other, and means in each rectifying arrangement for applying to said second saturable reactor an additional bias derived from the unbalance of the control voltage.

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