Feb. 17, 1970 G. J. FISCHER 3,496,390

MULTI-JUNCTION CONTROLLABLE UNIT WITH BI-DIRECTIONAL CURRENT PATH FROM ANODE TO GATE TO RENDER SAID UNIT BI-DIRECTIONAL

Filed Dec. 9, 1965 6 Sheets-Sheet 1

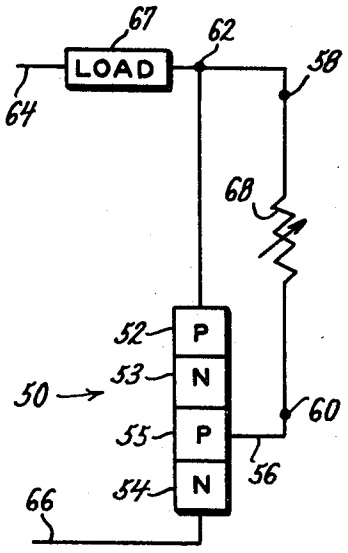


FIG. 1.

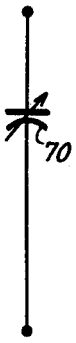


FIG. 2.



FIG. 3.



FIG. 4.



FIG. 5.

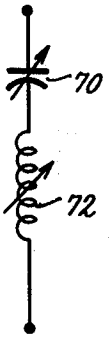


FIG. 6.



FIG. 7.



FIG. 8.

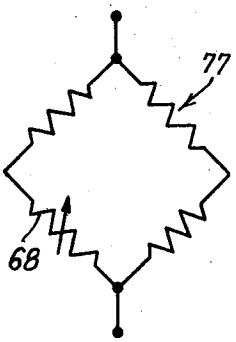


FIG. 9.

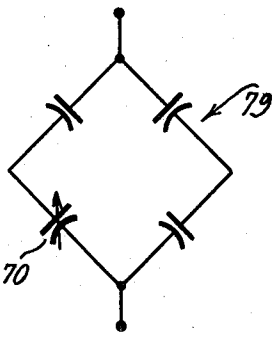


FIG. 10.

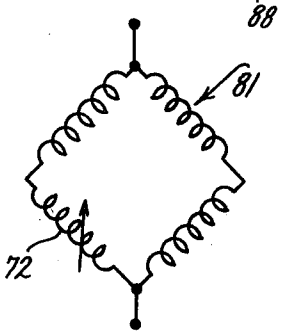


FIG. 11.

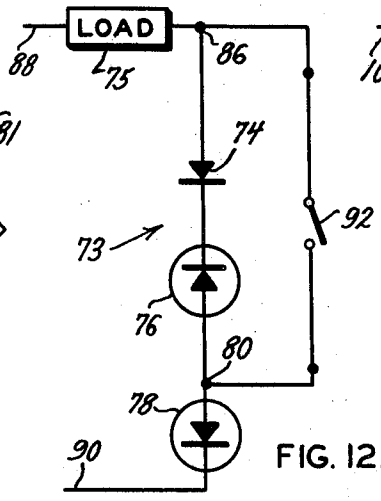


FIG. 12.

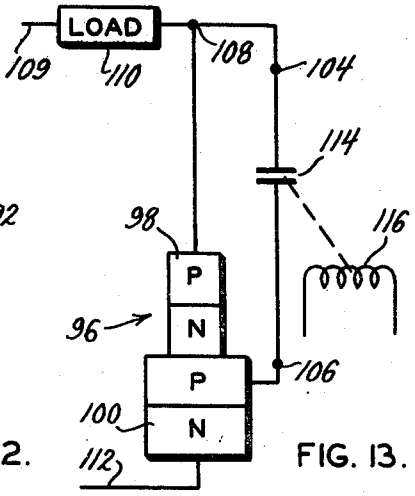


FIG. 13.

FIG. 14A.

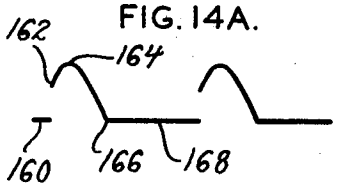


FIG. 14B.

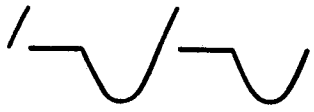


FIG. 14C.



FIG. 15A.



FIG. 15B.



FIG. 15C.



FIG. 16A.



FIG. 16B.

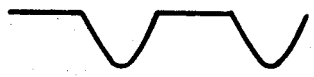


FIG. 16C.



FIG. 17A.



FIG. 17B.



FIG. 17C.

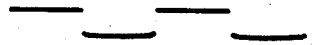


FIG. 18A.



FIG. 18B.



FIG. 18C.



FIG. 19A.



FIG. 19B.



FIG. 19C.

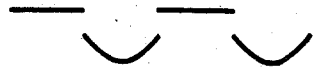


FIG. 20A.



FIG. 20B.



FIG. 20C.

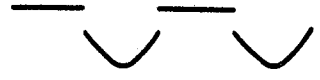


FIG. 21A.



FIG. 21B.



FIG. 21C

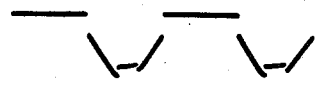
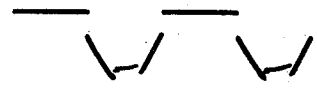


FIG. 22A.



FIG. 22B.

FIG. 22C.



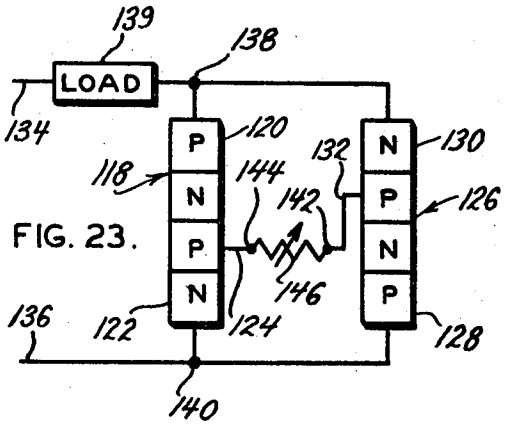


FIG. 23.

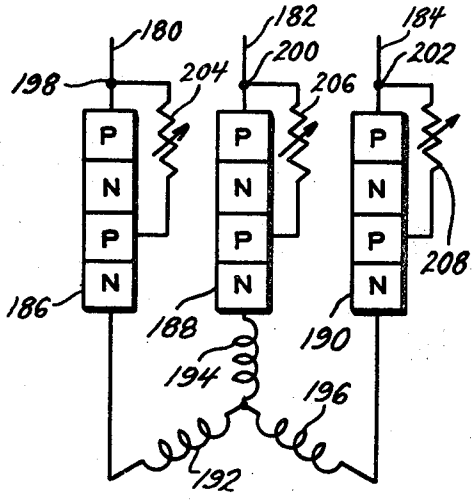


FIG. 32.

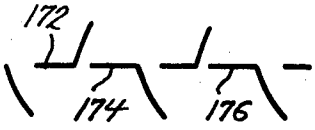


FIG. 24.



FIG. 27.

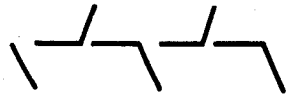


FIG. 25.

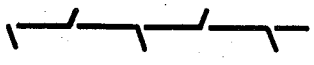


FIG. 28.

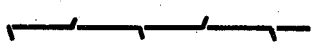


FIG. 30.

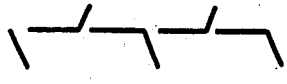


FIG. 26.



FIG. 29.



FIG. 31.

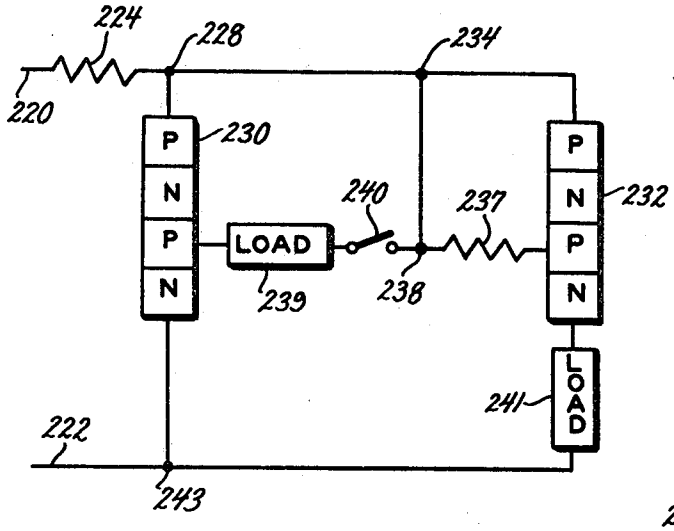


FIG. 33.

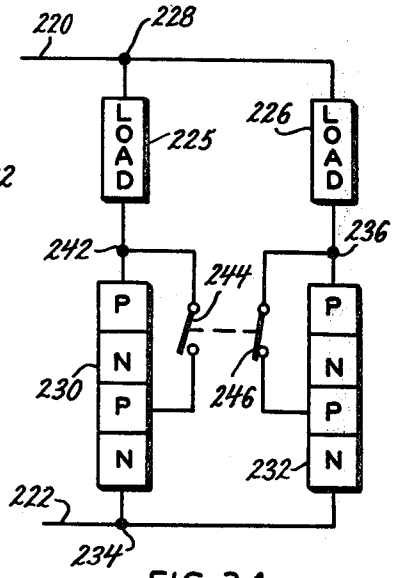


FIG. 34.

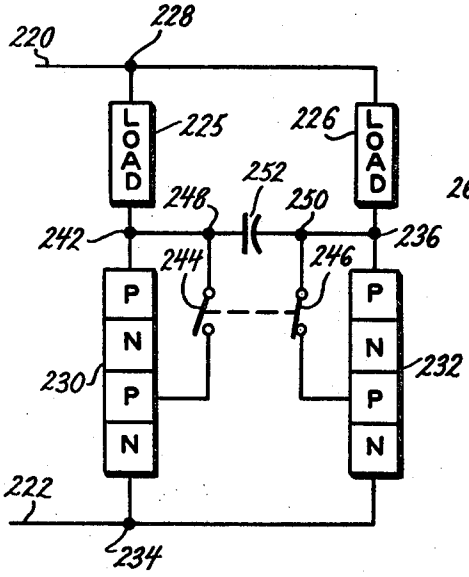


FIG. 35.

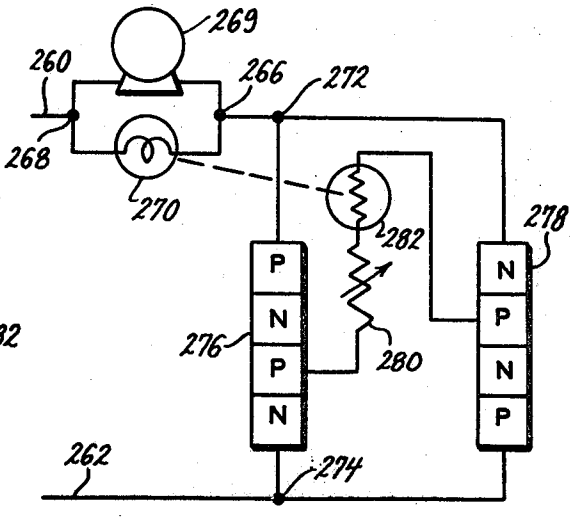


FIG. 36.

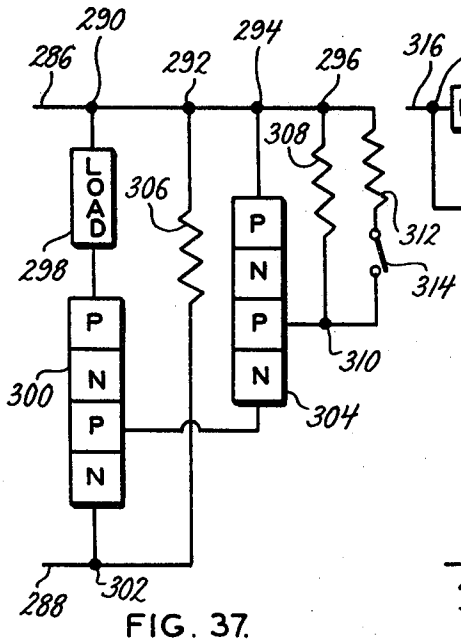


FIG. 37.

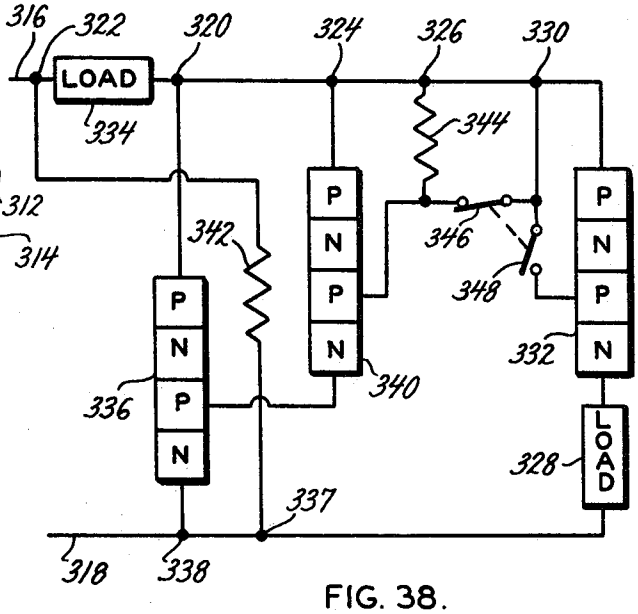


FIG. 38.

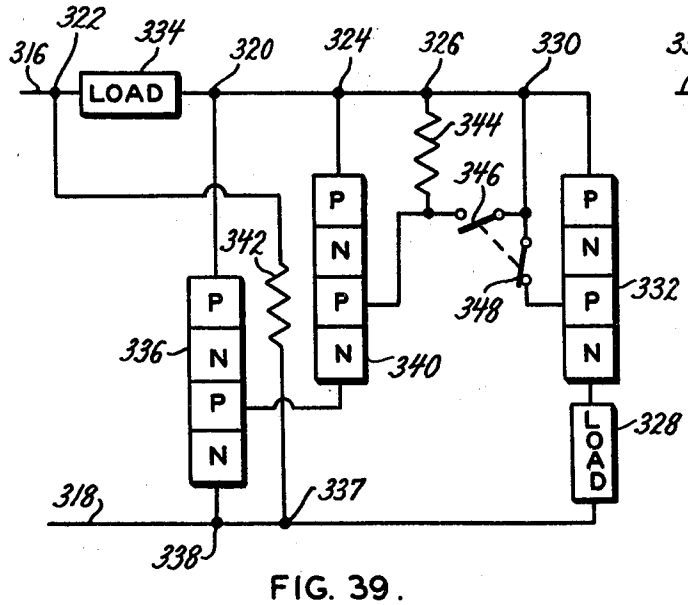


FIG. 39.

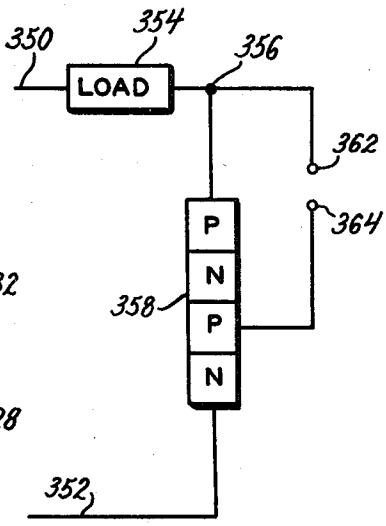


FIG. 40.

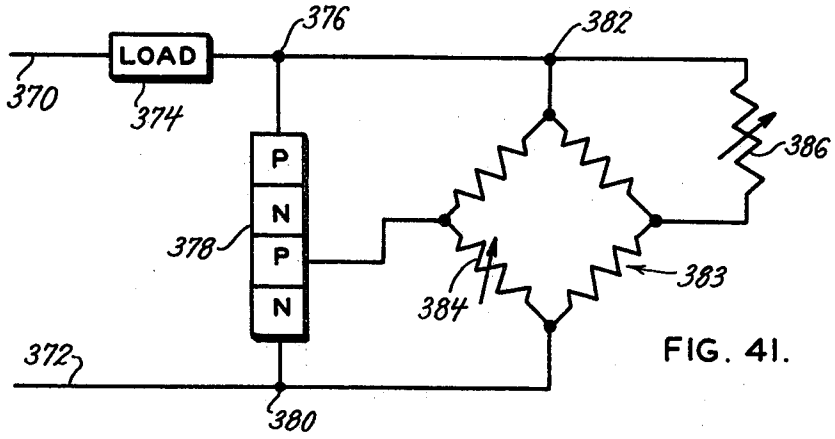


FIG. 41.

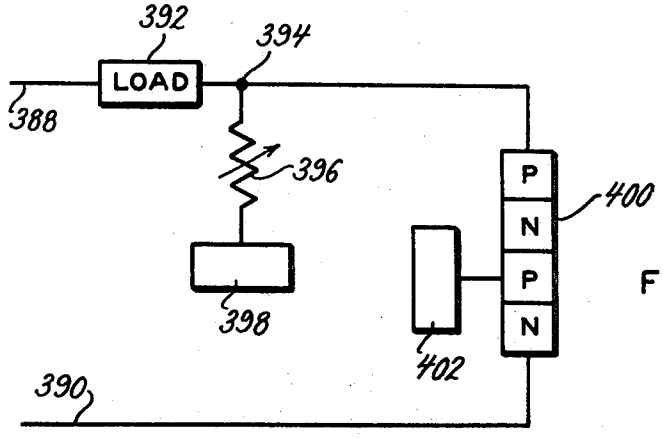


FIG. 42.

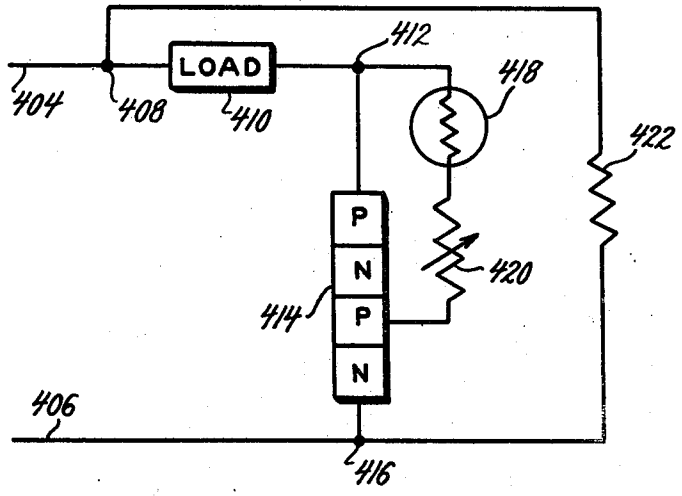


FIG. 43.

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Patented Feb. 17, 1970

3,496,390

MULTI-JUNCTION CONTROLLABLE UNIT WITH BI-DIRECTIONAL CURRENT PATH FROM ANODE TO GATE TO RENDER SAID UNIT BI-DIRECTIONAL

George J. Fischer, 2030 Lonedell, Arnold, Mo. 63010

Filed Dec. 9, 1965, Ser. No. 512,655
Int. Cl. H03k 3/26
U.S. Cl. 307—305 18 Claims

ABSTRACT OF THE DISCLOSURE

A controllable unit which has a p-n junction, an n-p junction, a second p-n junction, and a terminal intermediate said n-p junction and said second p-n junction has a bi-directional control circuit between the p-type layer of the first p-n junction and the said terminal; and that bi-directional control circuit is adapted to have an impedance low enough to enable said controllable unit to conduct current in both directions.

This invention relates to improvements in control systems. More particularly, this invention relates to improvements in devices which can control electric power.

It is, therefore, an object of the present invention to provide an improved device which can control electric power.

It is important to be able to apply electric power to a load, to control the value of that power, and to shut off that power. In recognition of that fact, control devices have been developed which could apply electric power to a load, could control the value of that power, and could shut off that power However, those control devices have had many components, and hence those control devices have been expensive and bulky. It would be desirable to provide a control device which could apply electric power to a load, could control the value of that power, and could shut off that power but which would have only a few components. The present invention provides such a control device; and it is, therefore, an object of the present invention to provide a control device which can apply electric power to a load, can control the value of that power, and can shut off that power and which has only a few components.

The control device provided by the present invention utilizes one or more controllable units and one or more control circuits for those controllable units; and each of those controllable units has a p-type layer, an n-type layer, a p-type layer, and an n-type layer which form a p-n junction, an n-p junction, and a p-n junction. One of the p-type layers serves as the anode of the controllable unit, the other p-type layer serves as an intermediate terminal for that unit, and one of the n-type layers serves as the cathode of that unit. The control circuit is connected between the anode and the intermediate terminal, and that control circuit will determine the amount of power which the control device can apply to a load. In the preferred embodiments of the present invention, the control circuits can enable the control devices to supply power to the loads over the full range from zero power to full power, and to do so in smooth, step-less fashion. It is, therefore, an object of the present invention to provide a control device that includes a controllable unit with a p-type layer, an n-type layer, a p-type layer, and an n-type layer which form a p-n junction, an n-p junction and a p-n junction, and that also includes a control circuit connected between the two p-type layers and that can supply power to a load over the full range from zero power to full power, and to do so in smooth step-less fashion.

Other and further objects and advantages of the present invention should become apparent from an examination of the drawing and accompanying description.

In the drawing and accompanying description several preferred embodiments of the present invention are shown and described but it is to be understood that the drawing and accompanying description are for the purpose of illustration only and do not limit the invention and that the invention will be defined by the appended claims.

In the drawing, FIG. 1 is a diagrammatic showing of one preferred embodiment of control device that is made in accordance with the principles and teachings of the present invention, and the control circuit of that control device is an adjustable resistor,

FIG. 2 is a diagrammatic showing of an adjustable capacitor which can be used as the control circuit of the control device of FIG. 1.

FIG. 3 is a diagrammatic showing of an adjustable inductor which can be used as the control circuit of the control device of FIG. 1,

FIG. 4 is a diagrammatic showing of a series-connected adjustable resistor and adjustable capacitor which can be used as the control circuit of the control device of FIG. 1,

FIG. 5 is a diagrammatic showing of a series-connected adjustable resistor and adjustable inductor which can be used as the control circuit of the control device of FIG. 1,

FIG. 6 is a diagrammatic showing of a series-connected adjustable capacitor and adjustable inductor which can be used as the control circuit of the control device of FIG. 1,

FIG. 7 is a diagrammatic showing of a series-connected adjustable resistor, adjustable capacitor and adjustable inductor which can be used as the control circuit of the control device of FIG. 1,

FIG. 8 is a diagrammatic showing of a series-connected switch and adjustable resistor which can be used as the control circuit of the control device of FIG. 1,

FIG. 9 is a diagrammatic showing of an adjustable resistance bridge which can be used as the control circuit of the control device of FIG. 1,

FIG. 10 is a diagrammatic showing of an adjustable capacitance bridge which can be used as the control circuit of the control device of FIG. 1,

FIG. 11 is a diagrammatic showing of an adjustable inductance bridge which can be used as the control circuit of the control device of FIG. 1,

FIG. 12 is a diagrammatic showing of another preferred embodiment of control device that is made in accordance with the principles and teachings of the present invention,

FIG. 13 is a diagrammatic showing of a further preferred embodiment of control device that is made in accordance with the principles and teachings of the present invention,

FIGS. 14A–14C are representations of oscillograms obtained with the control device of FIG. 1 when the load was a forty watt incandescent lamp and the ohmic value of the control circuit was one megohm,

FIGS. 15A–15C are representations of oscillograms obtained with the control device of FIG. 1 when the load was a forty watt incandescent lamp and the ohmic value of the control circuit was three hundred and thirty thousand ohms,

FIGS. 16A–16C are representations of oscillograms obtained with the control device of FIG. 1 when the load was a forty watt incandescent lamp and the ohmic value of the control circuit was ten thousand ohms,

FIGS. 17A–17C are representations of oscillograms

obtained with the control device of FIG. 1 when the load was a forty watt incandescent lamp and the ohmic value of the control circuit was five thousand ohms,

FIGS. 18A–18C are representations of oscillograms obtained with the control device of FIG. 1 when the load was a forty watt incandescent lamp and the ohmic value of the control circuit was one thousand ohms,

FIGS. 19A–19C are representations of oscillograms obtained with the control device of FIG. 1 when the load was a forty watt incandescent lamp and the ohmic value of the control circuit was one hundred and eighty ohms,

FIGS. 20A–20C are representations of oscillograms obtained with the control device of FIG. 1 when the load was a forty watt incandescent lamp and the ohmic value of the control circuit was one hundred ohms,

FIGS. 21A–21C are representations of oscillograms obtained with the control device of FIG. 1 when the load was a forty watt incandescent lamp and the ohmic value of the control circuit was fifty ohms,

FIGS. 22A–22C are representations of oscillograms obtained with the control device of FIG. 1 when the load was a forty watt incandescent lamp and the ohmic value of the control circuit was ten ohms,

FIG. 23 is a diagrammatic showing of a preferred embodiment of control device that is made in accordance with the principles and teachings of the present invention and that has two controllable units and one control circuit therefore,

FIGS. 24–31 are representations of oscillograms obtained with the control device of FIG. 23 when the load was a forty watt incandescent lamp and the ohmic value of the control circuit was six and six-tenths megohms, five and six-tenths megohms, three and three-tenths megohms, one and eight-tenths megohms, one megohm, five hundred and sixty thousand ohms, one hundred thousand ohms, and ten ohms, respectively.

FIG. 32 is a diagrammatic showing of a preferred embodiment of control device that is made in accordance with the principles and teachings of the present invention and that has three controllable units connected to form a three-phase bridge,

FIG. 33 is a diagrammatic showing of a control device that is made in accordance with the principles and teachings of the present invention and that can be used as a flip-flop circuit,

FIG. 34 is a diagrammatic showing of a further control device that is made in accordance with the principles and teachings of the present invention and that can be used as a flip-flop circuit,

FIG. 35 is a diagrammatic showing of a control device that is made in accordance with the principles and teachings of the present invention and that can be used as a D.C. flip-flop circuit,

FIG. 36 is a diagrammatic showing of a control device that is made in accordance with the principles and teachings of the present invention and that can be used as a speed control for an electric motor,

FIG. 37 is a diagrammatic showing of a control device that is made in accordance with the principles and teachings of the present invention and that can be used as a time delay circuit,

FIG. 38 is a diagrammatic showing of a control device that is made in accordance with the principles and teachings of the present invention and that can be used as a "slow to make" control circuit,

FIG. 39 is a diagrammatic showing of a control device that is made in accordance with the principles and teachings of the present invention and that can be used as a "slow to break" control circuit,

FIG. 40 is a diagrammatic showing of a control device that is made in accordance with the principles and teachings of the present invention and that can have a signal injected into the control circuit of the controllable unit thereof,

FIG. 41 is a diagrammatic showing of a control device that is made in accordance with the principles and teachings of the present invention and that has an adjustable bridge and an adjustable resistor in the control circuit of the controllable unit thereof,

FIG. 42 is a diagrammatic showing of a control device that is made in accordance with the principles and teachings of the present invention and that has sensing elements and an adjustable resistor in the control circuit of the controllable unit thereof, and

FIG. 43 is a diagrammatic showing of a control device that is made in accordance with the principles and teachings of the present invention and that has a condition-sensing element in the control circuit of the controllable unit thereof.

Referring to FIG. 1 in detail, the numeral **50** generally denotes a controllable unit which is made in accordance with the principles and teachings of the present invention; and that unit has four layers **52, 53, 55** and **54**. The layer **52** is a p-type layer, the layer **53** is an n-type layer, the layer **55** is a p-type layer, and the layer **54** is an n-type layer. The layer **52** serves as the anode for the unit **50**; and the layer **54** serves as the cathode for that unit. A terminal **56** is secured to the layer **55**; and that terminal serves as an intermediate terminal for the unit **50**. The layers **52, 53, 55** and **54** of the controllable unit **50** will preferably be made from silicon pellets in which p-type impurities and n-type impurities have been introduced. However, where desired, the layers **52, 53, 55** and **54**, of the unit **50** could be made from pellets of another material such as germanium.

A junction **62** connects one side of a load **67** to the anode **52** and to a terminal **58**; and the other side of that load is connected to one side of a suitable source of alternating current by a conductor **64**. A conductor **66** extends from the cathode **54** to the other side of that source of alternating current. As a result, the load **67** and the anode-cathode circuit of the controllable unit **50** are connected in series across the source of alternating current. The numeral **60** denotes a terminal which is connected to the intermediate terminal **56**; and an adjustable resistor **68** is shown connected between the terminals **58** and **60**. That adjustable resistor is the control circuit for the controllable unit **50**; and it constitutes a bi-directional path for current flowing from conductor **64** via load **67**, junction **62**, terminal **58**, adjustable resistor **68**, terminal **60**, intermediate terminal **56**, layer **55**, the p-n junction between the layers **55** and **54**, layer **54**, and conductor **66**, and for current flowing from conductor **66** via layer **54**, the n-p junction between layers **54** and **55**, layer **55**, intermediate terminal **56**, terminal **60**, adjustable resistor **68**, terminal **58**, junction **62**, load **67**, and conductor **64**.

If the adjustable resistor **68** has a high ohmic value, in the range of several megohms, the controllable unit **50** will be essentially non-conductive when the conductors **64** and **66** are connected to a suitable source of alternating current. The voltage supplied by that source of alternating current will divide across the load **67** and the unit **50**; and that voltage also will divide across that load, the adjustable resistor **68**, the layer **55**, the junction between the layers **55** and **54**, and the layer **54**. When the conductor **64** is positive relative to the conductor **66**, the p-n junction between the layers **55** and **54** will be biased in the forward direction, but the voltage drops across the load **67** and the adjustable resistor **68** will be so large that the voltage across the p-n junction will be too small to render that junction conductive. As a result, that junction and the overall controllable unit **50** will remain substantially non-conductive. When the conductor **66** is positive relative to the conductor **64**, the n-p junction between the layers **54** and **55** will be biased in the reverse direction; and, as a result, that junction and the overall controllable unit **50** will remain substantially non-conductive.

If the ohmic value of the adjustable resistor **68** is reduced to one megohm, the voltage drop across the load

67 will increase and the votage across the p-n junction between the layers 55 and 54 will increase; and if, during a half cycle of the alternating current in which the conductor 64 is positive relative to the conductor 66, the voltage across that p-n junction increases sufficiently to cause current to flow through that junction, that junction and the overall controllable unit 50 will become conductive and will remain conductive throughout the rest of that half cycle. During the next half cycle of the alternating current, the n-p junction between the layers 54 and 55 will be biased in the reverse direction; and that junction and the overall controllable unit 50 will be non-conductive throughout that half cycle.

Specifically, as shown by the numeral 160 in FIG. 14A, the voltage across the load 67 will be essentially zero at the start of a half cycle in which the conductor 64 is positive relative to the conductor 66, because the p-n junction between the layers 55 and 54 and the overall controllable unit 50 will essentially be non-conductive. However, as the voltage increases during that half cycle, the p-n junction between the layers 55 and 54 and the overall controllable unit 50 will become conductive; and thereupon, the voltage across the load 67 will immediately increase to the value indicated by the numeral 162 in FIG. 14A. That voltage will increase until the mid-point of that half cycle is reached, as indicated by the numeral 164 in FIG. 14A; and then that voltage will decrease to essentially zero at the end of that half cycle, as indicated by the numeral 166 in FIG. 14A. During the next half cycle of the alternating current, the n-p junction between the layers 54 and 55 will be biased in the reverse direction, and that junction and the overall controllable unit 50 will be non-conductive throughout that half cycle: and hence the voltage across the load 67 will be essentially zero, as indicated by the numeral 168 in FIG. 14A. During succeeding cycles of the alternating current, the voltage across the load 67 will have the waveform denoted by the numerals 160, 162, 164, 166 and 168 in FIG. 14A.

If the ohmic value of the adjustable resistor 68 is reduced to three hundred and thirty thousand ohms, the voltage drop across the load 67 and the voltage across the p-n junction between the layers 55 and 54 will be larger; and hence that junction and the overall controllable unit 50 will become conductive closer to the start of each half cycle of the alternating current in which the conductor 64 is positive relative to the conductor 66, as shown by FIG. 15A. During those half cycles in which the conductor 66 is positive relative to the conductor 64, the n-p junction between the layers 54 and 55 and the overall unit 50 will be non-conductive, as shown by FIG. 15A.

If the ohmic value of the adjustable resistor 68 is decreased to ten thousand ohms, the p-n junction between the layers 55 and 54 and the overall controllable unit 50 will be conductive throughout substantially all one hundred and eighty degrees of each half cycle of the alternating current wherein the conductor 64 is positive relative to the conductor 66, as shown by FIG. 16A. When the ohmic value of the adjustable resistor 68 is reduced to that extent, the sum of the voltage drop across the load 67 and of the voltage drop across that adjustable resistor will be small enough to make the voltage across the n-p junction between the layers 55 and 54 larger than the break-over voltage of that junction; and, thereupon, that junction and the overall controllable unit 50 will conduct current during these half cycles of the alternating current wherein the conductor 66 is positive relative to the conductor 64. The flow of that current will develop a voltage across the load 67 which will increase until the mid-point of that half cycle is reached and will then decrease to essentially zero at the end of that half cycle.

The voltage that is developed across the load 67, during those half cycles of the alternating current in which the conductor 66 is positive relative to the conductor 64, will be very small as shown by FIG. 16A; but that voltage can be increased by further decreasing the ohmic value of the adjustable resistor 68. Thus as shown by FIGS. 17A–22A the voltage across the load 67, during those half cycles of the alternating current in which the conductor 66 is positive relative to the conductor 64, can be increased by successively reducing the ohmic value of the adjustable resistor 68 to five thousand ohms, one thousand ohms, one hundred and eighty ohms, one hundred ohms, fifty ohms, and ten ohms. When the ohmic value of the adjustable resistor 68 is reduced to ten ohms, the voltage across the load 67, during those half cycles of the alternating current in which the conductor 66 is positive relative to the conductor 64, will be substantially as large as the voltage across that load during those half cycles of the alternating current wherein the conductor 64 is positive relative to the conductor 66. This means that the control device of FIG. 1 can be made to supply substantially full power to the load 67 by reducing the ohmic value of the control circuit of the controllable unit 50 of that control device.

If desired, the ohmic value of the adjustable resistor 68 can be increased above one megohm; and, where that is done, the voltage across the load 67 will be essentially zero for longer periods of time during those half cycles of the alternating current wherein the conductor 64 is positive relative to the conductor 66. In fact, the ohmic value of the adjustable resistor 68 can be increased to the point where only a very small voltage is developed across the load 67 during those half cycles of the alternating current wherein the conductor 64 is positive relative to the conductor 66; and, of course, the voltage across that load will be essentially zero during those half cycles of the alternating current in which the conductor 66 is positive relative to the conductor 64. It should thus be apparent that the control device of FIG. 1 makes it possible to vary the voltage and power supplied to the load 67 from essentially zero to essentially full value. While FIGS. 14A–22A represent nine different finite values of voltage that were developed across the load 67 by the control device of FIG. 1, an infinite number of different values of voltage can be developed across that load by that control device. Further, that control device can vary the voltage and power which it supplies to the load 67 in smooth, step-less fashion.

The control circuit for the controllable unit 50 of FIG. 1 can have different kinds and values of impedance therein. For example, a thermistor could be used in place of the adjustable resistor 68 of FIG. 1; and that thermistor could be of the type which experiences a decrease in resistance as the temperature thereof increases or could be of the type which experiences an increase in resistance as the temperature thereof increases. With a thermistor of the type that experiences a decrease in resistance as the temperature thereof increases, the controllable unit 50 will become conductive as the temperature in the area in which the thermistor is located increases. Subsequently, that unit will become non-conductive as the temperature in that area decreases. With thermistors that experience an increase in resistance as the temperature thereof increases, the controllable unit 50 will become conductive as the temperature in the area in which the thermistor is located decreases. Subsequently, that unit will become non-conductive as the temperature in that area increases.

Also, heat-sensitive paints or coatings could be substituted for the adjustable resistor 68 of FIG. 1. The ohmic values of the resistances of those paints or coatings should, close to one end of the anticipated temperature range, be large enough to keep the controllable unit 50 non-conductive and should, close to the other end of that temperature range, be small enough to render that controllable unit conductive. Moreover, a tapped impedance and a thermostat or contact-equipped thermometer could be substituted for the adjustable resistor 68. Where that was done, the overall ohmic resistance of

that tapped impedance should be great enough to keep the controllable unit **50** non-conductive, but the thermostat or the contact-equipped thermometer should "short" enough of that impedance to permit the controllable unit **50** to become conductive.

Light-sensitive elements of the photo-resistive type could be substituted for the adjustable resistor **68**; and, as those elements responded to the light falling thereon to decrease the resistance thereof, enough current would flow through those light-sensitive elements to render the controllable unit **50** conductive. When those light-sensitive elements subsequently experienced an increase in resistance, as the amount of light falling thereon decreased, those light-sensitive elements would render the controllable unit **50** non-conductive.

Further, if desired, a pressure-sensitive paint or coating, or a pressurestat associated with a tapped impedance, could be substituted for the adjustable resistor **68** of FIG. 1. The pressure-sensitive paint or coating could respond to the application of pressure to reduce the ohmic value of the control circuit between the junction **62** and the intermediate terminal **56** to the point where the controllable unit **50** became conductive. Subsequently, that pressure-sensitive point or coating could respond to the removal of that pressure to increase its ohmic resistance to the point where that controllable unit again became non-conductive. Where the adjustable resistor **68** of FIG. 1 was replaced by a pressurestat and an associated tapped impedance, the pressurestat could respond to a given change in pressure to "short" a sufficient portion of the tapped impedance to reduce the impedance of the control circuit between the junction **62** and the intermediate terminal **56** sufficiently to render the controllable unit **50** conductive. Subsequently, that pressurestat and tapped impedance could respond to the restoration of the pressure to its initial value to render the controllable unit **50** non-conductive again.

Additional, the adjustable resistor **68** of FIG. 1 could be replaced by a humidistat and a tapped impedance. Changes in humidity could cause that humidistat to "short" portions of that impedance and thereby render the controllable unit **50** conductive. Subsequent restoration of the humidity to its original level would cause the controllable unit **50** to again become non-conductive. Similarly, a combination of a pH meter and a tapped impedance could respond to a pre-determined change in the pH of a solution to selectively render the controllable unit **50** conductive. Also, the combination of a microphone and a tapped impedance could be made to respond to a pre-determined noise level to selectively render the controllable unit **50** conductive. Further a microphone and a frequency-sensitive circuit including a variable impedance could be made to selectively respond to a predetermined frequency to render the controllable unit **50** conductive. Similarly, a combination of a variable impedance and a sensor of any sort of radiation, whether that radiation includes X-rays, gamma rays, beta particles, neutrons, electrons, ultra violet light, infra-red rays, could be substituted for the adjustable resistor **68**. Actually, any component or combination of components which could respond to a pre-determined change of any kind to vary the effective value of the impedance between the junction **62** and the intermediate terminal **56** could be used to control the conductivity of the controllable unit **50**.

FIG. 2 shows an adjustable capacitor **70** which can be substituted for the adjustable resistor **68** of FIG. 1. That adjustable capacitor should have a sufficient range of capacitance to enable it to have an impedance which is great enough to keep the controllable unit **50** from becoming conductive and to have an impedance which is small enough to enable that controllable unit to become conductive.

FIG. 3 shows an adjustable inductor **72** which can be substituted for the adjustable resistor **68** of FIG. 1. That adjustable inductor should have a sufficient range of inductance to enable it to have an impedance which is great enough to keep the controllable unit **50** from becoming conductive and to have an impedance which is small enough to enable that controllable unit to become conductive.

As indicated by FIGS. 4–7, the control circuit between junction **62** and the intermediate terminal **56** of the controllable unit **50** need not be solely resistive, capacitive, or inductive in nature. Instead, that control circuit can be a composite of an adjustable resistor **68** and an adjustable capacitor **70**, as shown by FIG. 4, can be a composite of an adjustable resistor **68** and an adjustable inductor **72**, as shown by FIG. 5, can be a composite of an adjustable capacitor **70** and an adjustable inductor **72**, as shown by FIG. 6, or can be a composite of an adjustable resistor **68** and an adjustable capacitor **70** and an adjustable inductor **72**, as shown by FIG. 7. Where desired, any of the adjustable resistors **68**, adjustable capacitors **70** and adjustable inductors **70** in FIGS. 4–7 could be replaced by a fixed-value resistor, capacitor or inductor.

Where desired, the control circuit for the controllable unit **50** of FIG. 1 can be replaced by a switch **69** and an adjustable resistor **68**, as shown by FIG. 8. The setting of that adjustable resistor will be selected so the ohmic value of the control circuit, constituted by that adjustable resistor and the switch **69**, will be small enough to render the controllable unit **50** of FIG. 1 conductive whenever the switch **69** is closed. That controllable unit will, of course, become non-conductive whenever the switch **69** is re-opened. Appropriate adjustment of the setting of the adjustable resistor **68** will enable the control circuit of FIG. 8 to cause the controllable unit **50** of FIG. 1 to supply the desired value of voltage and power to the load **67**. The provision of the switch **69** enables the adjustable resistor **68** of FIG. 8 to have a much smaller range than the adjustable resistor **68** of FIG. 1; because the former adjustable resistor does not have to have sufficient resistance to render the controllable unit **50** non-conductive.

Where desired, the adjustable resistor **68** of FIG. 8 could be replaced by an adjustable capacitor or an adjustable inductor or a combination of adjustable impedances. Also, if desired, the adjustable resistor **68** of FIG. 8 could be replaced by a fixed resistor, a fixed capacitor, a fixed inductor, or a combination of fixed impedances. Where a fixed resistor, a fixed capacitor, a fixed inductor, or a combination of fixed impedances was used, the impedance of that resistor, capacitor, inductor, or combination of impedances would be small enough to enable the controllable unit **50** to become conductive whenever the switch **69** was closed.

If desired, the control circuit of FIG. 1 could be replaced by a resistance bridge **77**, as shown by FIG. 9. That resistance bridge includes an adjustable resistor **68** and three other resistors. If desired, one or more of those other three resistors could be made adjustable. The values of the various resistors of the resistance bridge **77** of FIG. 9 should be such that appropriate adjustment of the setting of the adjustable resistor **68** of that bridge could selectively cause the controllable unit **50** to become conductive or non-conductive.

A capacitive bridge **79**, shown in FIG. 10, or an inductive bridge **81**, shown in FIG. 11, also could be substituted for the control circuit of the control device of FIG. 1. The capacitive bridge **79** includes an adjustable capacitor **70** plus three other capacitors; and, if desired, one or more of those other three capacitors could be made adjustable. The inductive bridge **81** includes an adjustable inductor **72** plus three other inductors; and, if desired, one or more of those other three inductors could be made adjustable. The values of the various capacitors in the capacitive bridge **79** and the values of the various inductors in the inductive bridge **71** should be such that appropriate adjustment of the adjustable capacitor or

inductor could selectively cause the controllable unit **50** of FIG. 1 to become conductive or non-conductive.

The controllable unit **50** of FIG. 1 can be fabricated in different sizes to enable it to have different ratings. Also, that controllable unit can be fabricated in different ways. Preferably, that controllable unit will be fabricated in the manner in which the four-layered pellets used in silicon controlled rectifiers are fabricated; because the technology of the fabrication of such pellets is understood by several manufacturers. In fact, one of the said four-layered pellets can be used as the controllable unit **50** of FIG. 1.

Where desired, a controllable unit **73** can be fabricated from a diode **74**, a breakdown diode **76**, a breakdown diode **78**, and an intermediate terminal **80**, as shown by FIG. 12. A junction **86** connects the anode of the diode **74** to a load **75**, and the cathode of that diode is connected directly to the cathode of the breakdown diode **76**. The intermediate terminal **80** is connected directly to the anodes of the breakdown diodes **76** and **78**; and the cathode of the breakdown diode **78** is connected to a connector **90**. That conductor is connected to one side of a suitable source of alternating current; and a conductor **88** connects the other side of that source to the load **75**. The control circuit for the controllable unit **73** is connected between the junction **86** and the intermediate terminal **80**; and that control circuit is a single pole, single throw switch **92**.

That switch can be opened to provide a virtually infinite impedance between the junction **86** and the intermediate terminal **80**; and such an impedance will keep the control device of FIG. 12 non-conductive. Closing of the switch **92** will establish a virtually zero impedance between the junction **86** and the intermediate terminal **80**; and such an impedance will render the control device of FIG. 12 highly conductive. The values of the current flowing through the breakdown diode **78** will be greater than the values of the current flowing through the junction between the layers **55** and **54** in FIG. 1, because the switch **92** will "short" the series-connected diode **74** and breakdown diode **76**; but proper selection of the breakdown diode **78** will enable that breakdown diode to carry those values of current without injury. Because the size and capacity of the breakdown diode **78** can be greater than the sizes and capacities of diode **74** and of breakdown diode **76**, the controllable unit **73** of FIG. 12 can be more rugged than the controllable unit **50** of FIG. 1. However, the use of three diodes to constitute the controllable unit **73** of FIG. 12 makes the overall size and cost of that controllable unit very much larger than the size and cost of the controllable unit **50** of FIG. 1.

While a single pole, single throw switch **92** has been shown as the control circuit for the controllable unit **73** of the control device of FIG. 12, any of the control circuits of FIGS. 1–11 could be substituted for that switch. In fact, any component or combination of components which can respond to a predetermined change to sufficiently vary the impedance of the path from junction **86** to the intermediate terminal **80** could be substituted for the switch **92**.

FIG. 13 shows a controllable unit **96** which has the rugged and sturdy characteristics of the controllable unit **73** of FIG. 12 but which has the compactness of the controllable unit **50** of FIG. 1. The controllable unit **96** has a p-type layer **98** and an adjacent n-type layer which can be identical to the p-type layer **52** and the n-type layer **53** of the controllable unit **50** of FIG. 1. The controllable unit **96** has an n-type layer **100** and an adjacent p-type layer which are considerably larger in area than the n-type layer **54** and the p-type layer **55** of the controllable unit **50** of FIG. 1. The layer **98** serves as the anode and the layer **100** serves as the cathode. The larger areas of the n-type layer **100** and of the adjacent p-type layer of the controllable unit **96** enable that controllable unit to safely pass the large values of current which will flow through the junction between those layers when the path between junction **108** and the intermediate terminal **102** of that controllable unit is "shorted."

In FIG. 13, a conductor **109** connects one side of a load **110** to one side of a suitable source of alternating current, and the other side of that load is connected to the junction **108**. The other side of the source of alternating current is connected to the layer **100**. Normally-open relay contacts **114** serve as the control circuit which is connected between the junction **108** and the intermediate terminal **102** by terminals **104** and **106**. A relay coil **116** is provided to actuate the relay contacts **114**. As long as the relay contacts **114** are open, the controllable unit **96** will remain non-conductive; but when those relay contacts are closed, that controllable unit will become highly conductive. While the relay contacts **114** are shown as the control circuit for the controllable unit **96** in FIG. 13, any of the control circuits of FIGS. 1–12 could be substituted for those relay contacts. In fact, any component or combination of components which can respond to a predetermined change to sufficiently vary the impedance of the path from junction **108** to the intermediate terminal **102** could be substituted for the relay contacts **114**.

As pointed out hereinbefore, and as shown by FIGS. 14A–22A, the control device of FIG. 1 can provide voltage wave forms across the load **67** which vary when the ohmic value of the adjustable resistor **68** is changed. Similar wave forms can be provided across that load by progressively varying the effective impedance of any control circuit that is substituted for the adjustable resistor **68**. As a result, the control device of FIG. 1 can provide voltage wave forms across the load **60** which vary from essentially zero to the full wave sinusoid of FIG. 22A.

The control device of FIG. 1 also provides other voltage wave forms, as shown particularly by FIGS. 14B and 14C, 15B and 15C, 16B and 16C, 17B and 17C, 18B and 18C, 19B and 19C, 20B and 20C, 21B and 21C, and 22B and 22C. The wave forms shown by FIGS. 14B–22B were developed between the junction **62** and the conductor **66**, and thus were developed across the anode-cathode circuit of the controllable unit **50**. Those wave forms show that the average impedance of that controllable unit progressively decreases as the impedance of the control circuit for that controllable unit is decreased. The wave forms shown by FIGS. 14C–22C were taken between the intermediate terminal **56** and the conductor **66**, and thus were taken across the junction between the layers **55** and **54**. The wave forms shown in FIGS. 16C and 17C are essentially square waves; and hence the control device provided by the present invention can serve as a square wave generator whenever it has an appropriate impedance connected between the anode and the intermediate terminal of the controllable unit thereof.

FIGS. 19C and 20C show voltage wave forms that are generally V-shaped. Consequently, it should be apparent that the control device provided by the present invention can provide generally V-shaped wave forms whenever an appropriate impedance is connected between the anode and the intermediate terminal of the controllable unit thereof.

Referring to FIG. 23, the numeral **118** generally denotes a controllable unit which can be identical to the controllable unit **50** of FIG. 1. The numeral **126** denotes a second controllable unit that also can be identical to the controllable unit **50** of FIG. 1. The controllable unit **118** has a p-type layer **120** which constitutes the anode of that unit; and that anode is connected to one side of a suitable source of alternating current by a junction **138**, a load **139**, and a conductor **134**. The other side of that source of alternating current is connected to the layer **122**, which serves as the cathode of the controllable unit **118**, by a conductor **136** and a junction **140**. The controllable unit **126** has a p-type layer **128** that serves as the anode of that controllable unit; and that layer is

connected to the conductor **136** by the junction **140**. The controllable unit **126** has an n-type layer **130** which serves as the cathode of that unit, and that layer is connected to the conductor **134** by junction **138** and load **139**. The intermediate terminal **124** of the controllable unit **118** is connected to the intermediate terminal **132** of the controllable unit **126** by terminal **144**, an adjustable resistor **146**, and the terminal **142**. The adjustable resistor **146** serves as the control circuit for both of the controllable units **118** and **126**.

If the ohmic value of the adjustable resistor **146** is great enough, usually in the order of many megohms, insufficient current can flow from conductor **134** via load **139**, junction **138**, layer **130** of the controllable unit **126**, the junction between that layer and the adjacent p-type layer, the said p-type layer, intermediate terminal **132**, terminal **142**, adjustable resistor **146**, terminal **144**, intermediate terminal **124**, the lower p-type layer of the controllable unit **118**, the junction between that p-type layer and the n-type layer **122**, the layer **122**, and the junction **140** to the conductor **136** to render the controllable unit **118** conductive. Similarly, the ohmic value of that adjustable resistor can be great enough so insufficient current can flow from conductor **136** via junction **140**, the n-type layer **122** of the controllable unit **118**, the junction between that layer and the adjacent p-type layer, the said p-layer, the intermediate terminal **124**, terminal **144**, adjustable resistor **146**, terminal **142**, intermediate terminal **132**, the upper p-type layer of the controlable unit **126**, the junction between that layer and the n-type layer **130**, junction **138**, and load **139** to the conductor **134** to render the controllable unit **126** conductive. However, whenever the value of the adjustable resistor **146** is reduced sufficiently and the conductor **134** is positive relative to the conductor **136**, enough current will flow through the layer **130** and the adjacent p-type layer of the controllable unit **126** and through the lower p-type layer and the n-type layer **122** of the controllable unit **118** to render the latter controllable unit conductive throughout part of each cycle of the alternating current. Also, whenever the value of the adjustable resistor **146** is reduced sufficiently and the conductor **136** is positive relative to the conductor **134**, enough current will flow through the n-type layer **122** and the adjacent p-type layer of the controllable unit **118** and through the upper p-type layer and the n-type layer **130** of the controllable unit **126** to the conductor **134** to render the latter controllable unit conductive during another part of each cycle of the alternating current. The controllable unit **118** will be rendered conductive during part of each positive-going half cycle of the alternating current, whereas the controllable unit **126** will be rendered conductive during part of each negative-going half cycle of the alternating current. Thus, the controllable unit **126** will be conductive during the portions of the negative-going half cycle denoted by the numerals **172** and **176** in FIG. 24, whereas the controllable unit **118** will be conductive during the portion of the positive-going half cycle denoted by the numeral **174**.

The waveform of FIG. 24 was produced when the load **139** was a forty watt incandescent lamp and the ohmic value of the adjustable resistor **146** was six and six-tenths megohms. By decreasing the ohmic value of the adjustable resistor **146** to five and six-tenths megohms, the "on" times of the controllable units **118** and **126** can be increased, as shown by FIG. 25. Further, by progressively decreasing the ohmic value of the adjustable resistor **146** to three and three-tenths megohms, one and one-eighth megohms, one megohm, five hundred and sixty thousand ohms, one hundred thousand ohms, and ten ohms, the "on" times of the controllable units **118** and **126** can be increased, as shown by FIGS. 26–31. As the ohmic value of adjustable resistor **146** is made smaller and smaller, the "on" times of the controllable units **118** and **126** become longer and longer—approaching full cycle conduction. This means that the voltage developed across the load **139** can be very close to the voltage across the alternating current source, and substantially full power can be delivered to that load.

While the adjustable resistor **146** has been shown as the control circuit for the controllable units **118** and **126** of FIG. 23, any of the control circuits shown by FIGS. 2–13 can be substituted for that adjustable resistor. Furthermore, any component or combination of components which can respond to a predetermined change to vary the impedance thereof sufficiently to selectively render the controllable units **118** and **126** conductive and nonconductive can be used as the control circuit for those controllable units.

The initial cost of the control device of FIG. 23 can be greater than the initial cost of the control device of FIG. 1; because the former control device requires two controllable units whereas the latter control device requires just one controllable unit. However, the control device of FIG. 23 is very desirable in that the value of the current flowing through the n-type layer **130** and the adjacent p-type layer of controllable unit **126**, the adjustable resistor **146**, and the lower p-type layer and the layer **122** of the controllable unit **118**, and the value of the current flowing through the n-type layer **122** and the adjacent p-type layer of controllable unit **118**, the adjustable resistor **146**, and the upper p-type layer and the layer **130** of the controllable unit **126** can be far smaller than the value of the current flowing through the layers **55** and **54** and the adjustable resistor **68** of FIG. 1. For example, where the ohmic values of the adjustable resistor **146** of FIG. 23 and of the adjustable resistor **68** of FIG. 1 were ten ohms, the value of the current flowing through the former resistor was between one five hundredth and one thousandth of the value of the current flowing through the latter adjustable resistor. As a result, far less energy will be dissipated in the form of heat in the adjustable resistor **146** than will be dissipated in the adjustable resistor **68**. Also, far less energy will be dissipated in the form of heat in the junctions adjacent the n-type layers **122** and **130**, respectively, of the controllable units **118** and **126**.

The control device of FIG. 23 is additionally desirable because each of the controllable units **118** and **126** thereof is nonconductive for at least half of the time, and thus can cool down. In addition, that control device does not require the control circuit thereof to be capable of withstanding the very substantial voltages to which the control circuit of the control device of FIG. 1 is subjected. The overall result is that the impedance used in the control device of FIG. 23 can be smaller, can have a lower wattage rating, and will generate less heat than will the impedance usage in the control device of FIG. 1.

The control devices of FIGS. 1, 12 and 13 are very useful in controlling the voltage and power which a source of single phase alternating current can apply to a load; but it is frequently important to control the voltage and power which a source of polyphase alternating current can apply to a load. The control device shown by FIG. 32 can easily control the voltage and power which a source of three phase alternating current applies to a load. In FIG. 32, conductors **180**, **182** and **184** are connectable to a suitable source of three phase alternating current; and the conductor **180** is connected to the anode of a controllable unit **186** by a junction **198**, the conductor **182** is connected to the anode of a controllable unit **188** by a junction **200**, and the conductor **184** is connected to the anode of a controllable unit **190** by a junction **202**. The controllable units **186**, **188** and **190** can be identical to the controllable unit **50** of FIG. 1. The cathode of the controllable unit **186** is connected to the outer terminal of a phase **192** of a three phase load, the cathode of the controllable unit **188** is connected to the outer terminal of a phase **194** of that load, and the cathode of the controllable unit **190** is connected to the outer terminal of a phase **196** of that load. The inner terminals

of those phases of that load are connected together. An adjustable resistor **204** is connected between the junction **198** and the intermediate terminal of the controllable unit **186**, an adjustable resistor **206** is connected between the junction **200** and the intermediate terminal of the controllable unit **188**, and an adjustable resistor **208** is connected between the junction **202** and the intermediate terminal of the controllable unit **190**. The adjustable resistors **204**, **206** and **208** will preferably have the adjustable portions thereof "ganged" to permit simultaneous adjustment of the ohmic values of those adjustable resistors. Those adjustable resistors should be selected so the ohmic values thereof can be made small enough to render the controllable units **186**, **188** and **190** conductive.

When the conductors **180**, **182** and **184** are connected to a suitable source of three phase alternating current, and when the ohmic values of the adjustable resistors **204**, **206** and **208** are reduced to levels at which the controllable units **186**, **188** and **190** can become conductive, those controllable units will successively become conductive and will successively supply power to the various phases **192**, **194** and **196** of the load. The amount of power which will be supplied to the various phases of the load can be controlled by adjusting the settings of the adjustable resistors **204**, **206** and **208**.

The arrangement shown by FIG. 32 is very useful in controlling the amount of voltage and power which a source of three phase alternating current can apply to a load. However, that arrangement is merely representative; and other arrangements, which use the controllable units of the present invention, can be used to control the amount of voltage and power which a source of three phase alternating current can apply to a load. Further, other arrangements, which use the controllable units of the present invention, can be used to control the amount of voltage and power which sources of two phase and multi-phase alternating current can apply to a load.

Referring to FIG. 33, the numerals **220** and **222** denote conductors that can be connected to a suitable source of alternating current. A voltage-dropping resistor **224** has one side thereof connected to the conductor **220**; and the other side of that resistor is connected to the anode of a controllable unit **230** by a junction **228** and to the anode of a controllable unit **232** by junction **228** and a junction **234**. The controllable units **230** and **232** can be identical to the controllable unit **50** of FIG. 1. A junction **243** connects the cathode of the controllable unit **230** to the conductor **222**; and a load **241** and that junction connect the cathode of the controllable unit **232** to that conductor. A junction **238** and a resistor **237** connect the junction **234** to the intermediate terminal of the controllable unit **232**; and the junction **238**, a normally open, single pole, single throw switch **240**, and a load **239** can connect the junction **234** to the intermediate terminal of the controllable unit **230**. The load **241** should be the type of load which has a relatively high rated voltage and which is inoperable when the voltage applied thereto is substantially below that rated voltage; and the voltage-dropping resistor **224** should be a resistor which can have a voltage drop that can be added to the rated voltage of the load **241** to approximate the voltage supplied by the source of alternating current. The voltage-dropping resistor **224** must be a resistor that can safely withstand a substantial voltage overload. The load **239** should be a load that requires less than one volt to make it operable, and that can withstand much higher voltages. Also, the impedance value of the load **239** should be close to that of the resistor **237**.

When the switch **240** is open, the controllable unit **230** will be non-conductive, and hence the load **239** will be inoperable. However, the controllable unit **232** will be conductive—that controllable unit having a low impedance between the anode and the intermediate terminal thereof. Current will, whenever the conductor **220** is positive relative to the conductor **222**, flow from conductor **220** via resistor **224**, junctions **228** and **234**, controllable unit **232**, load **241**, and junction **243** to the conductor **222**. Conversely, current will, whenever the conductor **222** is positive relative to the conductor **220**, flow from conductor **222** via junction **243**, load **241**, controllable unit **232**, junctions **234** and **228**, and resistor **224** to the conductor **220**. As a result, substantially full voltage and substantially full power will be applied to the series-connected resistor **224** and load **241**. The voltage across that load will be close to the rated voltage of that load; and hence that load will operate. At this time, the load **241** will be operating, but the load **239** will be inoperable.

When the switch **240** is closed, the voltage across the load **239** will render that load operable; and the voltage across the lower p-n junction of the controllable unit **230** will render that junction, and hence the overall controllable unit **230**, conductive. The impedance of the controllable unit **230** will be quite small after that unit has been rendered conductive, and hence substantially all of the voltage from the source of alternating current will appear across the voltage-dropping resistor **224**. The controllable unit **230** is connected in parallel with the series-connected controllable unit **232** and load **241**; and the few volts developed across the controllable unit **230**, and also across the series-connected controllable unit **232** and load **241**, will be too small to permit the load **241** to be operated. Consequently, at this time the load **241** will be inoperable. The load **239** will be connected in parallel with the upper two junctions of the controllable unit **230**, and the combined impedances of those two junctions will be quite low when that controllable unit is conductive. However, because the load **239** is a load that requires less than a volt to make it operable, that load will continue to operate as long as the switch **240** is closed.

When the switch **240** is re-opened, the load **239** will become inoperable, and the load **241** will again become operable. This means that the closing and re-opening of the switch **240** will cause the control device of FIG. 33 to act as a flip-flop circuit.

If desired, a resistor could be connected between the junction **228** and the anode of the controllable unit **230**. The voltage drop which would appear across such a resistor when the controllable unit **230** became conductive, should not be great enough to render the load **241** operable; but should be great enough to enable the load **239** to require more than a volt to operate it. The use of such a resistor would increase the number and types of loads that could be used as the load **239**.

Referring to FIG. 34, the numerals **220** and **222** denote conductors which can be connected to a suitable source of alternating current. A junction **228** connects the upper terminals of loads **225** and **226** to the conductor **220**, and junctions **242** and **236** connect the lower terminals of those loads to the anodes of controllable units **230** and **232**. The cathodes of those controllable units are connected to the conductor **222** by a junction **234**. A normally-open switch **244** is connected between the intermediate terminal and the anode of the controllable unit **230** by the junction **242**; and a normally-closed switch **246** is connected between the intermediate terminal and the anode of the controllable unit **232** by the junction **236**. The switches **244** and **246** are "ganged" so that the switch **244** will be open whenever the switch **246** is closed and so the switch **246** will be open whenever the switch **244** is closed.

Whenever the switch **246** is closed, the controlable unit **232** will be conductive, and the load **226** will have substantially full power applied to it. The controllable unit **230** will be non-conductive at such time, because the switch **244** will be open. As a result, substantially no current will flow through the load **225**. However, when the switch **244** is closed and the switch **246** is opened, the controllable unit **230** will become conductive and the controllable unit **232** will become non-conductive. There-

upon, the load **225** will have substantially full voltage and substantially full power applied to it, and the load **226** wil have substantially no current flowing through it. The circuit of FIG. 34 thus selectively applies voltage and power to the load **226** or to the load **225**; and hence that circuit is usable as a flip-flop circuit. The control circuit of FIG. 34 is, in some respects more desirable than the control circuit of FIG. 33; because it has fewer components, because the loads **225** and **226** can have substantially full voltage applied to them, and because both of those loads can require voltages, close to their rated voltages, to make them operative.

FIG. 35 shows a flip-flop circuit which is very similar to the flip-flop circuit shown in FIG. 34, but the circuit of FIG. 35 is usable with direct current. When the switch **246** of FIG. 35 is a closed, current will flow from the positive conductor **220** via junction **228**, load **226**, junction **236**, controllable unit **232**, and junction **234** to the negative conductor **222**; and current will momentarily flow from conductor **220** via junction **228**, load **225**, junctions **242** and **248**, capacitor **252**, junctions **250** and **236**, controllable unit **232**, and junction **234** to the conductor **222**. The latter flow of current will charge the capacitor **252** with the left-hand terminal thereof positive and with the right-hand terminal thereof negative. The flow of current through the load **226** and the controllable unit **232** will make that load operative.

The controllable unit **232** will continue to cause current to flow through the load **226** until the switch **244** is closed and the switch **246** is opened. When the switch **246** is opened and the switch **244** is closed, the controllable unit **230** will become conductive; and, thereupon, the capacitor **252** will tend to force current to flow from the left-hand terminal thereof via junctions **248** and **242**, controllable unit **230**, junction **234**, controllable unit **232**, and junctions **236** and **250** to the right-hand terminal of that capacitor. At such time, the controllable unit **232** will become non-conductive. Current will then flow from conductor **220** via junction **228**, load **225**, junction **242**, controllable unit **230**, and junction **234** to the conductor **222**; and current will momentarily flow from conductor **220** via junction **228**, load **226**, junctions **236** and **250**, capacitor **252**, junctions **248** and **242**, controllable unit **230**, and junction **234** to the conductor **222**. The latter flow of current will discharge the capacitor **252** and then charge that capacitor with the right-hand terminal thereof positive and with the left-hand terminal thereof negative.

The controllable unit **230** will continue to conduct current, and apply substantially full voltage and substantially full power to the load **225**, until the switch **224** is re-opened and the switch **246** is re-closed. The reclosing of the switch **246** will render the controllable unit **232** conductive; and, thereupon, current will tend to flow from the right-hand terminal of the capacitor **252** via junctions **250** and **236**, controllable unit **232**, junction **234**, controllable unit **230**, and the junctions **242**, **248** to the left-hand terminal of that capacitor. Thereupon, the controllable unit **230** will become non-conductive.

The circuit of FIG. 35 can be used as a flip-flop circuit which is operable on direct current. That circuit will normally apply voltage and power to the load **226**, but will immediately respond to shifting of the switches **244** and **246** to halt any further application of voltage and power to that load and to apply voltage and power to the load **225**. When the switches **244** and **246** are subsequently restored to their normal positions, the circuit of FIG. 35 will halt any further application of voltage and power to the load **225** and will apply voltage and power to the load **226**.

Referring to FIG. 36, the numerals **260** and **262** denote conductors which can be connected to a suitable source of alternating current. A junction **268** connects the conductor **260** to one terminal of an A.C. motor **269** and to one terminal of a lamp **270**. A junction **266** and a junction **272** connect the other terminal of that motor and the other terminal of that lamp to the anode of a controllable unit **276** and to the cathode of a controllable unit **278**. A junction **274** connects the cathode of the controllable unit **276** and the anode of the controllable unit **278** to the conductor **262**, and thus to the other side of the source of alternating current. An adjustable resistor **280** and a photo-resistive cell **282** are connected in series between the intermediate terminals of the controllable units **276** and **278**. The light from the lamp **270** is directed toward the photo-resistive cell **282** and the intensity of that light will control the ohmic value of that photo-resistive cell. The adjustable resistor **280** will be set so that sum of its ohmic value and of the ohmic value of the photo-resistive cell **282** will, throughout the anticipated range of luminosity of the lamp **270**, render the controllable units **276** and **278** conductive.

When the conductor **260** is positive relative to the conductor **262**, current will flow via junction **268**, the parallel-connected motor **269** and lamp **270**, junctions **266** and **272**, controllable unit **276**, and junction **274** to the conductor **262**; and that flow of current will cause the rotor of that motor to rotate and will illuminate the lamp **270**. When the conductor **262** is positive relative to the conductor **260**, current will flow via junction **274**, the controllable unit **278**, junctions **272** and **266**, the parallel-connected motor **269** and lamp **270**, and junction **268** to the conductor **260**; and that flow of current will keep the rotor of the motor **269** rotating and will keep the lamp **270** illuminated.

The rotor of the motor **269** will rotate at a speed which is controlled by the setting of the adjustable resistor **280** and by the load on that motor. If that load increases and tends to slow down the rotor of that motor, the back E.M.F. of that motor will tend to decrease, with a consequent increase in the voltage across that motor. That increase in voltage will cause the lamp **270** to become brighter; and the resulting increase in light reaching the photo-resistive cell **282** will reduce the resistance of that cell. Thereupon, the controllable units **276** and **278** will conduct throughout longer portions of the half cycles of the alternating current, and will thereby increase the power and voltage supplied to the motor **269**. That increased power and voltage will cause the rotor of the motor to return to its normal speed; and, as that rotor returns to that speed, the E.M.F. of that motor will decrease and the voltage across the motor **269** and across the lamp **270** will decrease to its normal level. Thereupon, the resistance of the photo-resistive cell **282** will increase to its normal level; and the controllable units **276** and **278** will again conduct current throughout the desired portions of the half cycles of the alternating current.

If the load on the motor **269** of FIG. 36 were to decrease, the rotor of that motor would tend to speed up; and the consequent increase in back E.M.F. would decrease the voltage across that motor. The consequent decrease in voltage across the lamp **270** would reduce the luminosity of that lamp; and the resulting decrease in light falling on the photo-resistive cell **282** would cause the resistance of that cell to increase. That increased resistance would shorten the lengths of time during which the controllable units **276** and **278** were conductive during the half cycles of the alternating current; and the resulting reduction in the power supplied to the motor **269** would cause the rotor of that motor to slow down to the desired speed. As that rotor slowed down, the voltage across the motor **269** would increase to the desired value, and the luminosity of the lamp **270** would increase to the desired level. Thereupon, the resistance of the photo-resistive cell **282** would decrease to the desired level; and the controllable units **276** and **278** would again conduct current throughout the desired portions of the half cycles of the alternating current.

It should be noted that the control circuit shown by FIG. 36 provides a desirable compounding action. Specifically, as the lamp **270** brightens with increases in the

load on the motor **269**, and as the photo-resistive cell **282** causes the controllable units **276** and **278** to increase the voltage applied to the motor **269**, the lamp **270** will experience a further brightening. That further brightening will additionally decrease the ohmic value of the photo-resistive cell **282**, and will thereby cause the controllable units **276** and **278** to provide a further increase in the voltage applied to the motor **269**. Conversely, as the load on the motor **269** lightens and the luminosity of the lamp **270** decreases, the increased ohmic resistance of the photo-resistive cell **282** will cause the controllable units **276** and **278** to decrease the voltage supplied to the motor **269**. The lamp **270** will respond to that decreased voltage to become still less bright; and, thereupon, the ohmic value of the photo-resistive cell **282** will increase still further and will cause the controllable units **276** and **278** to additionally decrease the voltage supplied to the motor **269**. This compounding action is desirable because it enables the control circuit of FIG. 36 to provide exceedingly prompt corrections in the values of the voltage which the controllable units **276** and **278** apply to the motor **269**. Consequently, the control circuit of FIG. 36 is able to hold the voltage across the motor **269** substantially constant despite changes in the load applied to that motor; and this means that the motor **269** will operate substantially in the manner of a constant torque, variable speed motor. By proper adjustment of the ohmic value of the adjustable resistor **280**, the speed of the motor **269** can be varied over a wide range; but once the adjustable resistor **280** has been set to provide a desired speed for the motor **269**, the control circuit of FIG. **36** will automatically maintain that speed.

Referring to FIG. 37, the numerals **286** and **288** denote conductors which are connected to a suitable source of alternating current. Junctions **290** and **302** connect a load **298** and a controllable unit **300** in series across that source of alternating current. A controllable unit **304** has the cathode thereof connected to the intermediate terminal of the controllable unit **300**, and has the anode thereof connected to the anode of the controllable unit **300** by junctions **294**, **292** and **290** and by load **298**. The controllable unit **304** constitutes the control circuit for the controllable unit **300**. The controllable units **300** and **304** can be identical to the controllable unit **50** of FIG. 1.

A heater **306** is connected between the junctions **292** and **302**, and thus is connected across the source of alternating current. That heater is disposed adjacent the controllable unit **304**, and it will maintain the temperature of that controllable unit above ambient temperatures. A fixed resistor **308** is connected between the intermediate terminal and the anode of the controllable unit **304** by junctions **310**, **296** and **294**; and a series-connected resistor **312** and a single pole, single throw switch **314** are connected in parallel with the resistor **308** by the junctions **310** and **296**. The ohmic value of the resistor **308** is great enough to keep the controllable unit **304** non-conductive whenever the switch **314** is open and that controllable unit is at the temperature level which is normally established by the heat from the heater **306**. The ohmic value of the resistor **312** is quite small, and hence the controllable unit **304** will become highly conductive whenever the switch **314** is closed. As a matter of fact, the ohmic value of the resistor **312** is so small that whenever the switch **314** is closed the controllable unit **304** will be heated to a temperature above the temperature that is normally established for that controllable unit by the heater **306**.

When the switch **314** is open, the controllable unit **304** will be non-conductive, and will thus constitute a large impedance in the control circuit of the controllable unit **300**. The latter controllable unit will respond to that large impedance to remain non-conductive. However, when the switch **314** is closed, the controllable unit **304** will become conductive and will cause the controllable unit **300** to become conductive. The value of the current flowing through the controllable unit **304** will be high, while the switch **314** is closed; and hence the temperature of that controllable unit will rise above the temperature which the heater **306** normally establishes for that controllable unit. When the switch **314** is re-opened, the controllable unit **304** will, because of its higher-than-normal temperature, remain conductive for a short period of time, even though the ohmic value of the resistor **308** is great enough to keep that controllable unit non-conductive when the temperature of that controllable unit is at the level which is normally established by the heater **306**. The controllable unit **304** will remain conductive, and hence the controllable unit **300** will remain conductive, until the controllable unit **304** cools down and approaches the temperature which is normally established for that controllable unit by the heater **306**. As the temperature of the controllable unit **304** approaches that temperature level, the controllable unit **304** will again become non-conductive, and the controllable unit **300** also will again become non-conductive.

The closing and subsequent re-opening of the switch **314** caused the controllable element **300** to become conductive, and then to remain conductive for a predetermined length of time after the switch **314** was re-opened. Consequently, the control circuit of FIG. 37 can be used as a time-delay circuit. The amount of time delay provided between the re-opening of the switch **314** and the rendering of the controllable unit **300** non-conductive can be adjusted by appropriate selection of the value of the resistor **312** and by appropriate selection of the temperature which is normally established for the controllable unit **304** by the heater **306**.

Referring to FIG. 38, the numerals **316** and **318** denote conductors which can be connected to a suitable source of alternating current. Junctions **322**, **320** and **338** connect a load **334** and a controllable unit **336** across those conductors. A controllable unit **340** is connected between the intermediate terminal of the controllable unit **336** and the junction **320** by a junction **324**; and the former controllable unit constitutes the control circuit for the latter controllable unit. A heater **342** is connected between the junctions **322** and **338** by a junction **337**; and that heater is positioned close to the controllable unit **340** to maintain the temperature of that controllable unit above the ambient temperatures. A resistor **344** is connected between the intermediate terminal of the controllable unit **340** and the junction **324** by a junction **326**. A load **328** and a controllable unit **332** are connected in series between the junctions **326** and **337** by a junction **330**. The controllable units **336**, **340** and **332** can be identical to the controllable unit **50** of FIG. 1. A single pole, single throw switch **348** is connected between the junction **330** and the intermediate terminal of the controllable unit **332**; and a single pole, single throw switch **346** is connected between the junction **330** and the intermediate terminal of the controllable unit **340**. The switches **346** and **348** are "ganged" so the switch **346** will be closed whenever the switch **348** is open, and so the switch **346** will be open whenever the switch **348** is closed. Normally the switch **346** is closed and the switch **348** is open.

Whenever the switch **348** is open, the controllable unit **332** will be non-conductive; because the impedance of the control circuit for that controllable unit will be virtually infinite. Whenever the switch **346** is open, the controllable unit **340** will be non-conductive, because the resistor **344** will have such a large ohmic value that the controllable element **340** will be unable to become conductive. As long as the controllable unit **340** is non-conductive, the controllable unit **336** also will be non-conductive; because the former controllable unit will constitute a control circuit with an impedance that is too great to permit the latter controllable unit to be-

come conductive. However, whenever the controllable unit **340** becomes conductive, the controllable unit **336** will become conductive.

Because the switch **346** is normally closed and the switch **348** is normally open, the controllable units **340** and **336** will normally be conductive and the controllable unit **332** will normally be non-conductive. The controllable unit **340** will be heated by heat from the heater **342** and will also be heated by the current flowing through it. As a result, the temperature of that controllable unit will be higher than ambient temperatures.

Whenever it is desirable to render the controllable unit **332** conductive and to render the controllable units **340** and **336** non-conductive, the switches **346** and **348** will be shifted—the switch **346** being shifted to open position and the switch **348** being shifted to closed position. Because the controllable unit **340** is in a heated condition, due to the heat received from the heater **342** and also due to the heat generated by the current flowing through it, that controllable unit will not become non-conductive immediately—even though the ohmic value of the resistor **344** is large enough to keep that controllable unit from becoming conductive whenever that controllable unit is at ambient temperature. Not until the temperature of the controllable unit **340** decreases sufficiently to approach the ambient temperatures will that controllable unit become non-conductive. As long as the controllable unit **340** remains conductive, the controllable unit **336** also will remain conductive; and the latter controllable unit will effectively "short" the series-connected controllable unit **332** and load **328**. Consequently, even when the switch **346** has been opened and the switch **348** has been closed, the controllable unit **332** will not become conductive until after the temperature of the controllable unit **340** has decreased sufficiently to approach the ambient temperature. Once the temperature of the controllable unit **340** has approached the ambient temperature, that controllable unit and the controllable unit **336** will become non-conductive, and then the controllable unit **332** will immediately become conductive and will cause current to flow through the load **328**. The controllable units **340** and **336** will then remain non-conductive, and the controllable unit **332** will remain conductive, as long as the switch **348** is closed and the switch **346** is open. When the switch **348** is re-opened and the switch **346** is re-closed, the controllable unit **332** will immediately become non-conductive and the controllable units **340** and **336** will immediately become conductive.

In keeping the controllable unit **332** from becoming conductive as soon as the switches **346** and **348** are shifted from the positions shown by FIG. 38, and in permitting the controllable unit **332** to become conductive only after the controllable unit **340** has cooled, the control circuit of FIG. 38 constitutes a delay-to-make control circuit for the load **328**. The amount of time delay between the opening of switch **346** and the closing of switch **348** and the rendering of the controllable unit **332** conductive can be adjusted by changing the ohmic value of the resistor **344** and by adjusting the amount of heat which the heater **342** supplies to the controllable unit **340**.

The control circuit shown in FIG. 39 is substantially identical to the control circuit shown in FIG. 38—the only differences between the two circuits being that the switch **346** in FIG. 39 is normally open whereas the similarly-numbered switch in FIG. 38 is normally closed, and the switch **348** in FIG. 39 is normally closed whereas the similarly-numbered switch in FIG. 38 is normally open. The controllable unit **340** in FIG. 39 is normally non-conductive, because the resistor **344** has such a high impedance value that the lower p-n junction of that controllable unit **340** is normally non-conductive. Because the controllable unit **340** is normally non-conductive, the controllable unit **336** also is normally non-conductive. The controllable unit **332** will, however, normally be conductive because the switch **348** is normally closed.

When the switch **346** is closed and the switch **348** is opened, the controllable unit **332** will become non-conductive and the controllable unit **340** will become conductive. Thereupon, the controllable unit **336** also will become conductive. The consequent flow of current through the controllable unit **340** will heat that controllable unit; and, because that controllable unit also is heated by the heater **342**, the temperature of that controllable unit will be considerably above the ambient temperature. As a result, when the switch **346** is re-opened, the controllable unit **340** will continue to conduct current; and hence the controllable unit **336** also will continue to conduct current. Those controllable units will continue to conduct current until the temperature of the controllable unit **340** decreases sufficiently to approach the ambient temperature. As a result, the control circuit of FIG. 39 can be used as a slow-to-break circuit for the load **334**.

Referring to FIG. 40, the numerals **350** and **352** denote conductors which can be connected to a suitable source of alternating current. A load **354** has one terminal thereof connected to the conductor **350**, and the other terminal of that load is connected to the anode of a controllable unit **358** by a junction **356**. The cathode of that controllable unit is connected to the conductor **352**. The controllable unit **358** can be identical to the controllable unit **50** of FIG. 1.

A terminal **362** is connected to the anode of the controllable unit **358** by a junction **356**, and a terminal **364** is connected to the intermediate terminal of that controllable unit. The terminals **362** and **364** can be connected to any desired signal source which can constitute part of a bi-directional path between the junction **356** and the intermediate terminal of the controllable unit **358**. For example, the resistor of an R-C coupling network could be connected between the terminals **362** and **364**. Also, if desired, the secondary winding of a transformer, or one capacitor of a split-fed capacitor network, could be connected between the terminals **362** and **364**. Additionally, if desired, the output of a flip-flop circuit, a counter, or the like could be connected to the terminals **362** and **364**. Further, if desired, a storage battery could be selectively connected to or disconnected from the terminals **362** and **364** to cause the controllable unit **358** to vary the voltage and power supplied to the load **354**. In fact, many different kinds of pulse-forming or pulse-shaping circuits could be connected between the terminals **362** and **364**. Where, as in the case of a photo-voltaic cell or a storage battery, the signal source alternately aids and bucks the voltage developed across the lower p-n junction of the controllable unit **358**, the voltage waveform applied to the load **354** will not be a true sinusoid, but will have positive-going and negative-going portions of unequal amplitude. If desired, a fixed or adjustable impedance could be connected between the junction **356** and the terminal **362** or between the terminal **364** and the intermediate terminal of the controllable unit **358**. The value of that impedance would be selected to enable the sub-circuit connected between the terminals **362** and **364** to provide the desired conducting characteristics for the controllable unit **358**.

If desired, the signal-injection which is used in the control circuit of FIG. 40 could be used with the flip-flop circuit shown by FIG. 33. Specifically, the switch **240** of FIG. 33 could be replaced by a signal-injection sub-circuit which normally had an impedance great enough to keep the controllable unit **230** from being rendered conductive, but which could respond to the injection of a signal to make that controllable unit conductive. Where such a sub-circuit was used to replace the switch **240**, the flip-flop circuit of FIG. 33 could be actuated without any need of moving parts such as switches.

Referring to FIG. 41, the numerals **370** and **372** denote conductors which can be connected to a suitable

source of alternating current. The conductor **370** is connected to one terminal of a load **374**, and the other terminal of that load is connected to the anode of a controllable unit **378** by a junction **376**. The cathode of that controllable unit is connected to the conductor **372** by a junction **380**. That controllable unit can be identical to the controllable unit **50** in FIG. 1.

The numeral **383** denotes an adjustable resistance bridge which has an adjustable resistor **384** as one leg thereof; and one of the input terminals of that resistance bridge is connected to the junction **376** by a junction **382**, and the other input terminal of that resistance bridge is connected to the junction **380**. One of the output terminals of that resistance bridge is connected to the intermediate terminal of the controllable unit **378**, and the other output terminal of that resistance bridge is connected to the junction **382** by an adjustable resistor **386**. The ohmic values of the adjustable resistor **384** and of the other resistors of the resistance bridge **383**, and the ohmic value of the adjustable resistor **386** are selected to enable the controllable unit **378** to be rendered conductive. Adjustment of the setting of the adjustable resistor **384** will adjust the voltage drop across the output terminals of the resistance bridge **383**; and adjustment of the setting of the adjustable resistor **386** will control the voltage drop across the series-connected load **374**, adjustatble resistor **386**, adjustable resistance bridge **383**, and the lower p-n junction of the controllable unit **378**. Consequently, appropriate adjustments of the adjustable resistors **384** and **386** will determine the value of the voltage and power supplied to the load **374**.

If desired, the adjustable resistance bridge **383** could be supplanted by an adjustable inductance bridge or an adjustable capacitance bridge. Further, if desired, the legs of the bridge **383** could have any desired combination of resistance and inductance therein. Moreover, where desired, different kinds of resistances, capacitances, and inductances could be used in forming that bridge. Thus, one or more of the components of the bridge **383** could be a thermistor, a temperature sensitive paint or coating, a tapped impedance associated with a thermostat or contact-equipped thermometer, a photo-resistive cell, a pressure-sensitive paint or coating, a pressurestat associated with a tapped impedance, a humidistat associated with a tapped impedance, or the like. The bridge **383** of FIG. 41 is a true bridge whereas the bridges of FIGS. 9–11 are essentially resistors, capacitors and inductors, respectively, that are connected in series-parallel relation. Where desired, the bridge **383** or the bridges of FIGS. 9–11 could be arranged so each of the legs thereof was a series-parallel combination of resistors, inductors and capacitors.

Referring to FIG. 42, the numerals **388** and **390** denote conductors which can be connected to a suitable source of alternating current. A load **392** has one terminal thereof connected to the conductor **388**, and has the other terminal thereof connected to the anode of a controllable unit **400** by a junction **394**. The cathode of that controllable unit is connected to the conductor **390**. That controllable unit can be identical to the controllable unit **50** of FIG. 1.

A sensing element **402**, which can have the form of a relatively large metal plate, is connected to the intermediate terminal of the controllable unit **400**; and a similar sensing element **398** is connected to the junction **394** by an adjustable resistor **396**. The sensing elements **398** and **402** are spaced apart; and they can be used to sense the presence of an object or can require an object to bridge them. If desired, that object can be a human body; and, where the sensing elements **398** and **402** are large enough and are set close enough together, the movement of a person into close proximity to those sensing elements will render the controllable unit **400** conductive. Where it is desirable that a person actually touch the sensing elements **398** and **402** to render the controllable unit **400** conductive, those sensing elements can be made smaller in size and can be spaced further apart; and the operator will then have to touch those sensing elements to establish the required low resistance between the junction **394** and the intermediate terminal of the controllable unit **400**. Adjustment of the setting of the adjustable resistor **396** will determine the sensitivity of the control circuit of FIG. 42.

Referring to FIG. 43, the numerals **404** and **406** denote conductors which can be connected to a suitable source of alternating current. A junction **408** connects the conductor **404** to one terminal of a load **410**, and a junction **412** connects the other terminal of that load to the anode of a controllable unit **414**. The cathode of that controllable unit is connected to the conductor **406** by a junction **416**. A thermistor **418** and an adjustable resistor **420** are connected in series between the junction **412** and the intermediate terminal of the controllable unit **414**. That controllable unit can be identical to the controllable unit **50** of FIG. 1. A heating element **422** is connected between the junctions **408** and **416**. The sum of the minimum ohmic values of the thermistor **418** and of the adjustable resistor **420** should be small enough to render the controllable unit **414** conductive.

Where the thermistor **418** is the type of thermistor which experiences a decrease in ohmic value as the temperature thereof increases, the control circuit of FIG. 43 will constitute a slow-to-make circuit. Specifically, the room temperature ohmic value of the thermistor **418** will add to the ohmic value of the adjustable resistor **420** to make the total ohmic value between the junction **412** and the intermediate terminal of the controllable unit **414** too great to permit that controllable unit to become conductive. However, when the conductors **404** and **406** are suitably connected to the source of alternating current, current will flow from conductor **404** via junction **408**, heating element **422** and junction **416** to the conductor **406**; and that current will heat that heating element. That heating element will be disposed in heat-transferring relation to the thermistor **418**; and that thermistor will respond to heat from that heating element to experience a decrease in the ohmic value thereof. When that ohmic value falls to a predetermined level, the controllable unit **414** will become conductive. By selecting the proper rating for the heating element **422**, by providing the proper spacing between that heating element and the thermistor **418**, or by adjusting the value of the adjustable resistor **420**, the desired time delay between the connecting of the conductors **404** and **406** to the source of alternating current and the rendering of the controllable unit **414** conductive can be obtained.

The control circuit of FIG. 43 can be used as a circuit-interrupting device, where the thermistor **418** is the type of thermistor which experiences an increase in ohmic value as the temperature thereof increases. With such a thermistor, the adjustable resistor **420** will be set so the total ohmic value between the junction **412** and the intermediate terminal of the controllable unit **414**, at the temperature which is normally established by the heating element **422**, will be low enough to render the controllable unit **414** conductive. This means that when the conductors **404** and **406** are connected to the source of alternating current, and when the voltage across the controllable unit **414** is close to its intended value, the heat from the heating element **422** will maintain the temperature, and hence the ohmic value of the thermistor **418**, at a level which will permit the controllable unit **414** to be conductive. However, in the event the voltage applied to the conductors **404** and **406** were to increase to an undesired value, the heat generated by the heating element **422** would increase and the thermistor **418** would respond to the increased heat from that heating element to increase the ohmic value thereof. Prior to the time the increased voltage applied to the conductors could injure the load **410** or the controllable unit **414**, the heat from

the heating element **422** would have caused the thermistor **418** to increase its ohmic value to the point that the controllable unit **414** would become non-conductive.

It will be noted that the heating element **422** is connected between the junctions **408** and **416**; and hence the voltage across that heating element is substantially independent of the conductivity of the controllable unit **414**. This is desirable, because it will permit that heating element to continue to generate heat during those periods when the controllable unit **414** is rendered non-conductive. As a result, the heating element **422** will continue to keep the thermistor **418** heated, and will thus keep the controllable unit **414** non-conductive, as long as the unduly high voltage continues.

If desired, a thermostat could be substituted for the thermistor **418** of FIG. 43. Also, if desired, a temperature-sensitive paint or coating could be substituted for that thermistor.

FIGS. 14 A–C through 22 A–C show some of the voltage waveforms which can be obtained from the controllable unit **50** of FIG 1. To obtain a given voltage waveform, it is only necessary to adjust the value of the adjustable resistor **68**, or other impedance, connected between the terminals **58** and **60**. As the value of that impedance is adjusted, the voltage across the load, the voltage across the controllable unit **50**, and the voltage across the lower p-n junction of that controllable unit will vary. For example, when the adjustable resistor **68** was set to have a value of one megohm, the voltage across the load was approximately fifty eight volts, the voltage across the anode-cathode circuit of the controllable unit **50** was approximately ninety two volts, and the voltage across the lower p-n junction of that controllable unit was approximately seven tenths of a volt. When the ohmic value of that adjustable resistor was reduced to three hundred and thirty thousand ohms, the voltage across the load increased less than a volt, the voltage across the controllable unit **50** dropped to approximately seventy one volts, and the voltage across the the lower p-n junction of that controllable unit increased to about one and four tenths volts. When the ohmic value of the adjustable resistor **68** was reduced to one thousand ohms, the voltage across the load increased to approximately seventy volts, the voltage across the controllable unit **50** decreased to about forty eight volts, and the voltage across the lower p-n junction of that controllable unit increased to about three and six tenths volts. When the ohmic value of the adjustable resistor **68** was reduced to one hundred ohms, the voltage across the load increased to about ninety four volts, the voltage across the controllable unit **50** decreased to about twenty two volts, and the voltage across the lower p-n junction of that controllable unit increased to about five and eight tenths volts. When the ohmic value of the adjustable resistor **68** was reduced to ten ohms, the value of the voltage across the load increased to one hundred and eight volts, the voltage across the controllable unit **50** decreased to about eight volts, and the voltage across the lower p-n junction of that controllable unit increased to about six and one half volts. These various various voltages were measured when the line voltage was approximately one hundred and eighteen volts root means square. As a result, it should be apparent that proper selection of the value of the impedance connected to the intermediate terminal of the controllable unit **50** will permit a desirable range of voltages to be developed across the load **67**, across the controllable unit **50**, or across the lower p-n junction of that controllable unit.

In the various control circuits provided by the present invention, the loads can be wholly resistive in nature, can be wholly inductive in nature, can be wholly capacitive in nature, can be both resistive and inductive in nature, can be both resistive and capacitive in nature, can be both inductive and capacitive in nature, or can be resistive and inductive and capacitive in nature. Further, those loads can be power-consumng devices, can be control devices, or can be the control circuits of further controllable units. As a result, the control circuits provided by the present invention have widespread application and use.

Whereas the drawing and accompanying description have shown and described several preferred embodiments of the present invention it should be apparent to those skilled in the art that various changes may be made in the form of the invention without affecting the scope thereof.

What I claim is:

1. A control device that comprises:

(a) a controllable unit which has a p-n junction, an n-p junction, a second p-n junction, and an intermediate terminal between said n-p junction and said second p-n junction,

(b) the p-type layer of the first said p-n junction being connectable to one side of a source of bi-directional current to constitute the anode of said controllable unit,

(c) the n-type layer of said second p-n junction being connectable to the other side of said source of bi-directional current to constitute the cathode of said controllable unit,

(d) a control circuit connectable between said one side of said source of bi-directional current and said intermediate terminal to constitute a bi-directional path for current, and

(e) a load connectable in series with said controllable unit across said source of bi-directional current,

(f) said control circuit permitting bi-directional current to flow through it and having an impedance value low enough to enable all of said junctions of said controllable unit to permit current flow therethrough in both directions which is greater than the level of reverse leakage current flow and thereby enable said controllable unit to supply more than half-wave power and half-wave voltage to said load.

2. A control device that comprises:

(a) a controllable unit which has a p-n junction, an n-p junction, a second p-n junction, and an intermediate terminal between said n-p junction and said second p-n junction,

(b) the p-type layer of the first said p-n junction being connectable to one side of a source of bi-directional current to constitute the anode of said controllable unit,

(c) the n-type layer of said second p-n junction being connectable to the other side of said source of bi-directional current to constitute the cathode of said controllable unit,

(d) a control circuit connectable between said one side of said source of bi-directional current and said intermediate terminal to constitute a bi-directional path for current, and

(e) a load connectable in series with said controllable unit across said source of bi-directional current,

(f) said control circuit permitting bi-directional current to flow through it and having an impedance value low enough to enable all of said junctions of said controllable unit to permit current flow therethrough in both directions which is greater than the level of reverse leakage current flow and thereby enable said controllable unit to supply more than half wave power and half-wave voltage to said load,

(g) said control circuit including an impedance which has an impedance value less than the sum of the non-conductive impedance values of the first said p-n junction and of said n-p junction.

3. A control device as claimed in claim **1** wherein said control circuit includes a capacitance.

4. A control device as claimed in claim **1** wherein said control circuit includes an inductance.

5. A control device that comprises:
(a) a controllable unit which has a p-n junction, an n-p junction, a second p-n junction, and an intermediate terminal between said n-p junction and said second p-n junction.
(b) the p-type layer of the first said p-n junction being connectable to one side of a source of bi-directional current to constitute the anode of said controllable unit,
(c) the n-type layer of said second p-n junction being connectable to the other side of said source of bi-directional current to constitute the cathode of said controllable unit,
(d) a control circuit connectable between said one side of said source of bi-directional current and said intermediate terminal to constitute a bi-directional path for currrent, and
(e) a load connectable in series with said controllable unit across said source of bi-directional current,
(f) said control circuit permitting bi-directional current to flow through it and having an impedance value low enough to enable all of said junctions of said controllable unit to permit current flow therethrough in both directions which is greater than the level of reverse leakage current flow and thereby enable said controllable unit to supply more than half-wave power and half-wave voltage to said load,
(g) the impedance value of said control circuit selectively being greater than or less than the sum of the non-conductive impedance values of the first said p-n junction and of said n-p junction,
(h) whereby said control circuit can selectively render said controllable unit conductive.

6. A control device as claimed in claim 1 wherein said control circuit includes a switch.

7. A control device as claimed in claim 1 wherein said control circuit includes a bridge.

8. A control device as claimed in claim 1 wherein said control circuit includes sensing elements that are spaced apart and that can respond to the movement of an object into close proximity with them to render said controllable unit conductive.

9. A control device as claimed in claim 1 wherein said control circuit includes sensing elements that are spaced apart and that can coact with an object that bridges them to render said controllable unit conductive.

10. A control device that comprises:
(a) a controllable unit which has a p-n junction, an n-p junction, a second p-n junction, and an intermediate terminal between said n-p junction and said second p-n junction,
(b) the p-type layer of the first said p-n junction being connectable to one side of a source of bi-directional current to constitute the anode of said controllable unit,
(c) the n-type layer of said second p-n junction being connectable to the other side of said source of bi-directional current to constitute the cathode of said controllable unit, and
(d) a control circuit connectable between said one side of said source of bi-directional current and said intermediate terminal to constitute a bi-directional path for current, and
(e) a load connectable in series with said controllable unit across said source of bi-directional current,
(f) said control circuit permitting bi-directional current to flow through it and having an impedance value low enough to enable all of said junctions of said controllable unit to permit current flow therethrough in both directions which is greater than the level of reverse leakage current flow and thereby enable said controllable unit to supply more than half-wave power and half-wave voltage to said load,
(g) said second p-n junction having an area greater than the area of said n-p junction.

11. A control device that comprises:
(a) a controllable unit which has a p-n junction, an n-p junction, a second p-n junction, and an intermediate terminal between said n-p junction and said second p-n junction,
(b) the p-type layer of the first said p-n junction being connectable to one side of a source of bi-directional current to constitute the anode of said controllable unit,
(c) the n-type layer of said second p-n junction being connectable to the other side of said source of bi-directional current to constitute the cathode of said controllable unit,
(d) a control circuit connectable between said one side of said source of bi-directional current and said intermediate terminal to constitute a bi-directional path for current, and
(e) a load connectable in series with said controllable unit across said source of bi-directional current,
(f) said control circuit permitting bi-directional current to flow through it and having an impedance value low enough to enable all of said junctions of said controllable unit to permit current flow therethrough in both directions which is greater than the level of reverse leakage current flow and thereby enable said controllable unit to supply more than half-wave power and half-wave voltage to said load,
(g) said control circuit having an impedance value that causes said controllable unit to apply substantially full voltage and substantially full power to said load.

12. A control device that comprises:
(a) a controllable unit which has a p-n junction, an n-p junction, a second p-n junction, and an intermediate terminal between said n-p junction and said second p-n junction,
(b) the p-type layer of the first said p-n junction being connectable to one side of a source of bi-directional current to constitute the anode of said controllable unit;
(c) the n-type layer of said second p-n junction being connectable to the other side of said source of bi-directional current to constitute the cathode of said controllable unit,
(d) a control circuit connectable between said one side of said source of bi-directional current and said intermediate terminal to constitute a bi-directional path for current, and
(e) a load connectable in series with said controllable unit across said source of bi-directional current,
(f) said control circuit permitting bi-directional current to flow through it and having an impedance value low enough to enable all of said junctions of said controllable unit to permit current flow therethrough in both directions which is greater than the level of reverse leakage current flow and thereby enable said controllable unit to supply more than half-wave power and half-wave voltage to said load,
(g) said control circuit having an impedance value that causes substantially square wave forms to be developed across said control circuit.

13. A control device that comprises:
(a) a controllable unit which has a p-n junction, an n-p junction, a second p-n junction, and an intermediate terminal between said n-p junction and said second p-n junction,
(b) the p-type layer of the first said p-n junction being connectable to one side of a source of alternating current to constitute the anode of said controllable unit,
(c) the n-type layer of said second p-n junction being connectable to the other side of said source of alternating current to constitute the cathode of said controllable unit, and
(d) a control circuit connectable between said one

side of said source of alternating current and said intermediate terminal,

(e) said control circuit providing a bi-directional path for current flowing through said second p-n junction and causing said controllable unit to permit bi-directional current flow which is greater than the level of reverse leakage current flow through all of said junctions thereof.

14. A control device that comprises:

(a) a controllable unit which has a p-n junction, an n-p junction, a second p-n junction, and an intermediate terminal between said n-p junction and said second p-n junction,

(b) the p-type layer of the first said p-n junction being connectable to one side of a source of alternating current to constitute the anode of said controllable unit.

(c) the n-type layer of said second p-n junction being connectable to the other side of said source of alternating current to constitute the cathode of said controllable unit, and

(d) a control circuit connectable between said one side of said source of alternating current and said intermediate terminal,

(e) said control circuit providing a bi-directional path for current flowing through said second p-n junction,

(f) said control circuit having an impedance that is small enough to permit the forward voltage drop across said second p-n junction to be great enough to render said second p-n junction conductive and thereby render said controllable unit conductive, and said control circuit having an impedance that is small enough to permit the inverse voltage drop across said second p-n junction to be great enough to render said second p-n junction conductive and thereby render said controllable unit conductive with a current flow that is greater than the level of reverse leakage current flow.

15. A control device that comprises

(a) a plurality of controllable units,

(b) each of said controllable units having a p-n junction, an n-p junction, a second p-n junction, and an intermediate terminal between said n-p junction and said second p-n junction,

(c) each of said controllable units having the p-type layer of the first said p-n junction thereof connectable to one lead of a plural phase alternating current source to constitute the anode of said controllable unit,

(d) each of said controllable units having the n-type layer of said second p-n junction thereof connectable to a plural phase alternating current load to constitute the cathode of said controllable unit, and

(e) each of said controllable units having a control circuit connectable between the anode and the intermediate terminal thereof to constitute a bi-directional path for current,

(f) each of said control circuits permitting bi-directional current to flow through it and having an impedance value low enough to enable all of said junctions of the controllable unit to which it is connected to permit current to flow through said controllable unit in both directions which is greater than the level of reverse leakage current flow and thereby enable said controllable unit to supply more than half-wave power and half-wave voltage to said load,

(g) said controllable units being incorporated into the phases of a plural phase circuit to enable said plural phase circuit to supply alternating current to said plural phase alternating current load.

16. A control device that comprises:

(a) a controllable unit which has a p-n junction, an n-p junction, a second p-n junction, and an intermediate terminal between said n-p junction and said second p-n junction,

(b) the p-type layer of the first said p-n junction of said controllable unit being connectable to one side of a source of bi-directional current to constitute the anode of said controllable unit,

(c) the n-type layer of said second p-n junction of said controllable unit being connectable to the other side of said source of bi-directional current to constitute the cathode of said controllable unit,

(d) a load connected in series with said controllable unit across said source of bi-directional current,

(e) a control circuit for said controllable unit connected to constitute a bi-directional path for current,

(f) a second controllable unit which has a p-n junction, an n-p junction, a second p-n junction, and an intermediate terminal between said n-p junction and said second p-n junction,

(g) the p-type layer of the first said p-n junction of said second controllable unit being connectable to said one side of said source of bi-directional current to constitute the anode of said second controllable unit,

(h) the n-type layer of said second p-n junction of said second controllable unit being connectable to said other side of said source of bi-directional current to constitute the cathode of said second controllable unit, and

(i) a second control circuit for said second controllable unit connected to constitute a bi-directional path for current,

(j) said control circuit permitting bi-directional current to flow through it and having an impedance value low enough to enable all of said junctions of said second controllable unit to permit current flow therethrough which is greater than the level of reverse leakage current flow.

(k) said second controllable unit essentially "shorting" the series-connected load and the first said controllable unit whenever said second controllable unit becomes conductive,

(l) whereby said control device can be used as a flip-flop circuit.

17. A control device as claimed in claim 16 wherein said second control circuit includes a second load.

18. A control device that comprises:

(a) a controllable unit which has a p-n junction, an n-p junction, a second p-n junction, and an intermediate terminal between said n-p junction and said second p-n junction,

(b) the p-type layer of the first said p-n junction being connectable to one side of a source of bi-directional current to constitute the anode of said controllable unit,

(c) the n-type layer of said second p-n junction being connectable to the other side of said source of bi-directional current to constitute the cathode of said controllable unit,

(d) a control circuit connectable between said one side of said source of bi-directional current and said intermediate terminal to constitute a bi-directional path for current, and

(e) a load connectable in series with said controllable unit across said source of bi-directional current,

(f) said control circuit permitting bi-directional current to flow through it and having an impedance value low enough to enable all of said junctions of said controllable unit to permit current flow therethrough in both directions which is greater than the level of reverse leakage current flow and thereby enable said controllable unit to supply more than half-wave power and half-wave voltage to said load.

(g) said control circuit including terminals to which a signal-injecting sub-circuit can be connected.

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