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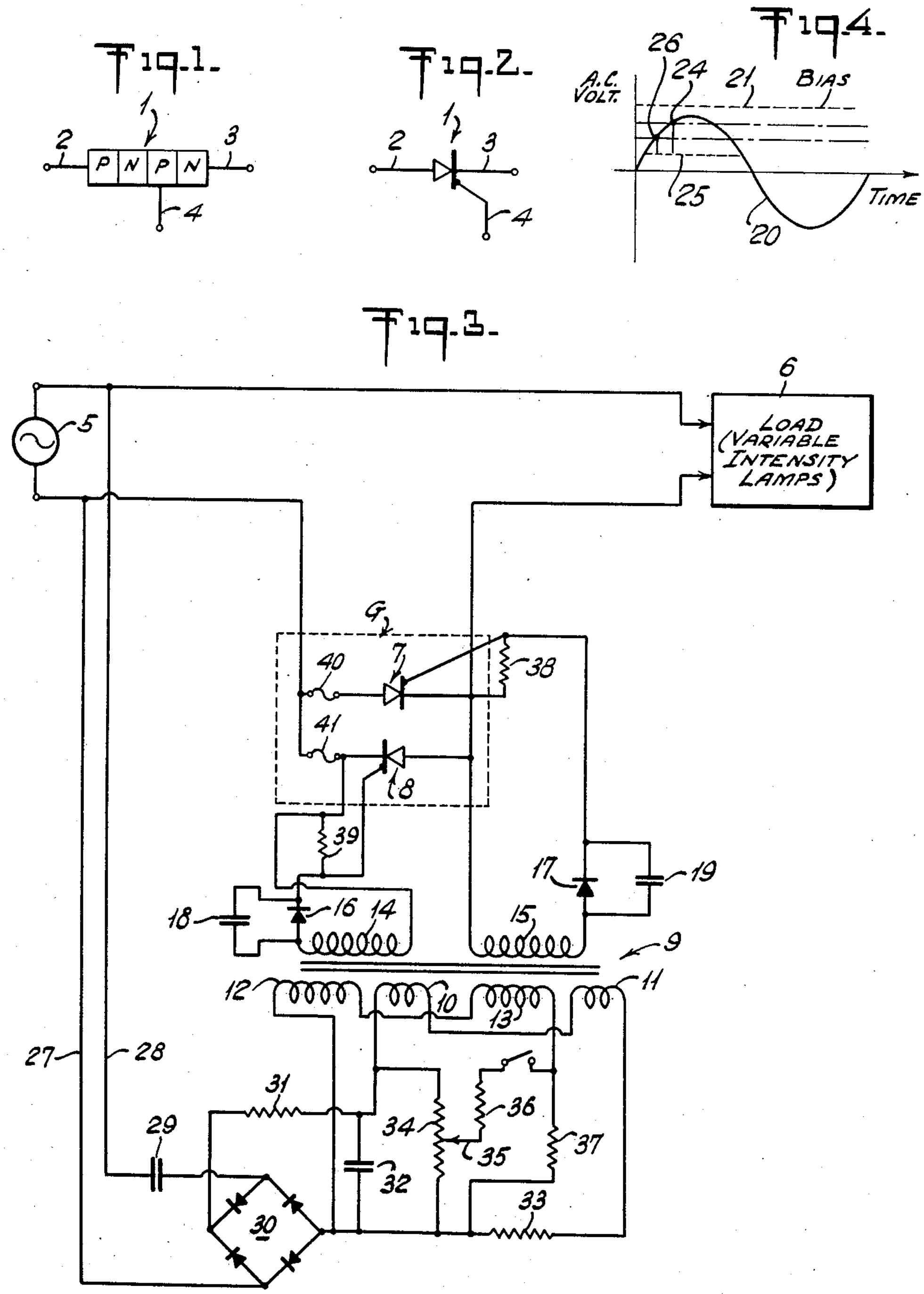

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THEATER LIGHTING CONTROL SYSTEM

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This invention relates to theater lighting control systems, and more particularly to a unique power and dimmer control for such systems.

Theater lighting control systems are now well known. There are commonly two types of control circuits, one utilizing the thyratron with grid control for regulating light intensity and the other utilizing saturable core reactors or magnetic amplifiers for controlling the quantity of current applied to the lighting circuits.

In the typical control circuits, the load or lighting circuit is connected to the source of power, usually alternating current, through the control element. In the thyratron circuit the power source may be coupled to the cathode and the lighting circuits to the anode. The grid circuit is utilized to control the flow of power through the tube. Conventionally, power control is achieved by applying an alternating voltage to the grid circuit, and by suitably phasing the grid voltage with the anode voltage, a desired power output is obtained. Since theater lighting circuits consume power usually in the order of hundreds of kilowatts and occasionally megawatts, it is apparent that the thyratrons required are bulky and inefficient. Moreover, as a result of the high current passing through the thyratrons, considerable heat is generated. Dissipation of this heat requires additional equipment which adds to the bulk and cost of the system. These are but a few disadvantages of the thyratron control system.

In the saturable reactor or magnetic amplifier control circuit, the load and power source are usually in series with the output winding of the inductor. The amplifier is usually equipped with two primary windings; one for providing a biasing current to increase the reactance sufficiently so as to prevent the flow of current through the secondary, and the other a control winding to counteract the effect of the biasing current and permit the secondary to conduct current.

The magnetic amplifier is generally preferred to the thyratron because of its high efficiency, stability, reliability and flexibility. It is also capable of handling large amounts of power; however, with increase in power capabilities the weight and size of the core becomes undesirably large.

Another disadvantage suffered by the magnetic amplifier is the non-linear variations of light intensity with increasing and decreasing voltages across the secondary. This is probably a result of losses in the core, particularly hysteresis, whereby the magnetization curve is asymmetrical for rising and decreasing voltages. This lack of linearity makes it difficult for the operator to predict the amount of dial rotation for a desired light intensity.

Accordingly, it is a primary object of this invention to provide a lighting control system which possesses all of the advantages of the magnetic amplifier and which is only a small fraction of the size and weight of a magnetic amplifier performing comparable functions.

It is a further object of this invention to provide a miniaturized control circuit comprising a solid state switching element controlled by a magnetic amplifier of greatly reduced proportions.

It is still a further object of this invention to provide a control circuit which has an approximately linear characteristic for increasing and decreasing light intensity.

In accordance with an aspect of the invention there is provided a lighting control circuit for selectively and continuously variably controlling the application of alternating current to variable intensity lamps. The circuit comprises a pair of normally blocked unidirectional gates, each having input, output and control electrodes. The input and output electrodes of one gate are connected to the opposite electrodes of the other gate and both gates are serially connected in a line connecting the lamps to the alternating current. The gates are of a type capable of being opened by the application of current of given amplitude and direction to the control electrodes. Current is applied to the control electrodes from a variable current source capable of producing current of sufficient amplitude to open the gates.

The control circuit is characterized by its miniature proportions and its ability to control large amounts of power. These features are partly a result of a newly-developed gated silicon rectifier and a unique control circuit for the rectifier. Since the gating function is performed by a gating switching element which is either "open" or "closed," there is relatively little loss of power in the element. Further, it is a characteristic of the gated silicon rectifier to be rendered conducting by a relatively small amplitude of current. This also improves the efficiency of the overall circuit.

Another important feature of the invention which derives from the use of a gating element requiring only relatively small amplitudes of current for operation is that the current source need only be large enough to produce the required current. Since the required current is small, the current source may be correspondingly small.

One of the most significant advantages of this invention resides in its simplicity. The invention actually comprises relatively few "building blocks" of miniature proportions for power control applications. For example, the apparatus represented schematically in Fig. 3 excluding the load, may weigh less than one pound per kilowatt of controlled power. In lighting control systems employing magnetic amplifiers, the functionally equivalent apparatus weighs approximately 100 times more than apparatus constructed in accordance with this invention. Furthermore, the apparatus represented in Fig. 3 may be made to occupy less than 27 cubic inches whereas a functionally comparable magnetic amplifier occupies approximately 1500 cubic inches.

The above-mentioned and other features and objects of this invention and the manner of attaining them will become more apparent and the invention itself will be best understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawing, wherein;

Fig. 1 is a diagrammatic illustration of a gated rectifier;

Fig. 2 is the electrical symbol for the rectifier shown in Fig. 1;

Fig. 3 is a schematic diagram of a preferred lighting control circuit; and,

Fig. 4 is a voltage curve showing the relationship between the line voltage and the bias voltage induced by current flowing in a winding of a magnetic amplifier.

My invention makes use of a recently introduced gated silicon rectifier, illustrated in Figs. 1 and 2, which comprises three p-n junctions, or four zones of p-n-p-n conductivities or vice versa. The rectifier shown generally at **1** comprises an input electrode or emitter electrode **2**, an output or collector electrode **3**, connected respectively to the opposite ends of the silicon body and a gate or control electrode **4** connected to the intermediate p or n zone. The electrical symbol for this rectifier is shown in Fig. 2.

The operating characteristics of gated silicon rectifiers are such that the rectifier may be rendered conductive solely by the application of sufficiently large potential across the emitter and collector electrodes **2** and **3** or by the combined effect of an emitter-collector potential which, in itself, is insufficient to cause conduction, and of a current of sufficient amplitude applied to the gate electrode **4**. The current applied to the electrode **4** must be in the forward conducting direction. The symbol shown in Fig. 2 is used in the circuit diagram of Fig. 3.

Referring now to Fig. 3, there is illustrated a control circuit according to my invention for selectively and variably controlling the application of alternating current, shown symbolically at **5**, to a load **6** comprising variable intensity lamps generally found in theaters.

The control circuit comprises generally a full-wave gate G enclosed by dash lines, which normally is closed to prevent the flow of power to the load. In the preferred embodiment, the full-wave gate comprises a pair of the gated rectifiers described in connection with Figs. 1 and 2. For Fig. 3, these rectifiers are shown at **7** and **8**. The input and output electrodes of one rectifier, e.g. **7**, are connected to opposite electrodes of rectifier **8** and both rectifiers are serially connected in a line joining the alternating current source **5** to the load **6**.

The gating function of the rectifiers is controlled by a selectively variable current source which preferably comprises a magnetic amplifier shown generally at **9**..

The magnetic amplifier comprises a pair of bias windings **10, 11**, control windings **12, 13** and output windings **14, 15**. The windings are preferably wound on the same core so that changes in flux produced by changes in the current flowing through one winding induces voltages in all of the other windings.

The output windings **14, 15**, are connected respectively in the gate-output electrode circuits of rectifiers **8** and **7**. Feed-back diodes **16** and **17** are serially connected in the circuits of the windings **14** and **15** respectively. The diodes **16** and **17** are conventional in magnetic amplifier circuits for providing rectifier feed-back currents for efficient operation. Capacitors **18** and **19** are connected across the diodes **16** and **17** and serve an important function which will be explained later.

The biasing current through the windings **10** and **11** is selected so that the induced voltage across the windings **14** and **15** produces a current in the reverse direction, thereby blocking the respective rectifiers **7, 8** and effectively opening the feed circuit to the load. In Fig. 4 the alternating current voltage is shown by the wave form **20** and the direct current biasing potential is shown in dotted line at **21**. As indicated by Fig. 4, the normal biasing potential maintains the rectifiers at cut-off so that the line to the load is effectively open.

The control windings **12, 13** are wound so as to counteract the effect of the biasing current through the windings **10** and **11**. By gradually increasing the flow of current through the control windings **12** and **13**, the resultant biasing potential is gradually decreased as shown in Fig. 4, at **22** and **23**. Although in Fig. 4 the biasing potential is shown at discrete levels, in practice the variation is gradual.

When the biasing potential is reduced to the level shown at **22**, the rectifier **7** is conducting at point **24**. Once the gated rectifier is opened or conducting, the voltage across it drops rapidly to a level **25** which represents the voltage drop across the diode. The rectifier continues to conduct current until the applied voltage drops below the level **25**. Thus, by increasing the current through the control windings to a still great extent to counteract the effect of the biasing current so that the resultant biasing potential is at a level **23**, the rectifier may be conducting at an earlier time in the cycle; for example, at point **26**. As can be readily appreciated, the time can be shortened considerably by producing a sharp current pulse at the inception of the voltage cycle. This is an advantage peculiar to this invention. The light intensity is a function, of course, of the amount of power applied to the lamps. Since the amplitude is varying constantly (A.-C.), the intensity of the lamps is varied by application of power to the load over varying periods of the cycle. Thus, application of the power at point **26**, Fig. 4, will increase the intensity of the lamps as compared to the application of power at point **24**.

The current applied to the bias and control windings is derived from the alternating current line over conductors **27, 28**. A capacitor **29** is provided for filtering and dropping the potential to a suitable value. The alternating current is rectified in the bridge **30** and applied to the several windings as follows: A resistor **31** and capacitor **32** serve to filter the voltage. The voltage across capacitor **32** is applied across the bias windings **10** and **11** and the resistor **33**; the resistor **33** being selected to provide a suitable time lag so as to prevent damage from a surge of current. The voltage across resistor **34** (coupled across the capacitor **32**) provides the voltage for the control windings **12** and **13**. An adjustable contact **35** taps off a desired voltage which is applied across the control windings after a suitable drop across resistor **36**. The resistor **34** may be called a fader or dimming resistor since variation of the tap **35** selectively varies the amount of current through the control windings. A further resistor **37** is provided across the control windings in order to limit the current through the windings.

Thus, gradual variation of light intensity is accomplished simply by moving the tap **35** from one end of the resistor **34** to the other end.

It is apparent that when the adjustable contact **35** is at the upper end of the resistor **34**, the control windings are coupled across the resistor **34** and maximum voltage is applied to the control windings. This voltage is reduced by moving the tap towards the lower end of the resistor **34**.

The capacitors **18** and **19** connected across the feedback diodes **16** and **17** respectively, provide an important function in linearizing the light intensity during variation of the voltage across the control windings. Apparently the capacitive reactance provided by the capacitors compensates the inductive reactance supplied by the windings of the magnetic amplifier. Since the dimensions of the magnetic amplifier core required by this invention are reduced to only a minor fraction of the cores heretofore required in magnetic amplifier control circuits, the hysteresis losses are correspondingly reduced and the magnetization curve is more linear. Of course, the valve of the capacitors **18** and **19** depends on the values of the other components in the circuit.

Resistors **38, 39**, are provided across the control-output electrodes of rectifiers **7, 8** respectively to limit the current in the electrode circuit. Fuses **40, 41** may also be provided to protect the rectifiers against damage from a surge in the line current.

Although the invention has been described in connection with lighting circuits, it is to be understood that the invention could also be utilized in motor control circuits. Further, by providing a plurality of magnetic amplifiers in combination with gated rectifiers, three-phase control may be obtained.

While the foregoing description sets forth the principles of the invention in connection with specific circuits, it is to be clearly understood that this description is made only by way of example and not as a limitation of the scope of the invention as set forth in the objects thereof and in the accompanying claims.

What is claimed is:

1. A control circuit for selectively and variably controlling variable intensity electric lights energized with alternating current, which control circuit comprises a

pair of controlled solid-state rectifier devices each of which consists of a plurality of alternately p- and n-type regions and having means for controlling the conductivity of the device connected to an intermediate region thereof, said pair of devices having their opposite terminal regions connected together, means for connecting said pair of devices in series with a source of energizing current and at least one lamp to be controlled, magnetic amplifier means for developing voltages of variable amplitude with respect to the amplitude of said source voltage, means for controlling the amplitude of voltages developed by said amplifier means, and means for applying said developed currents to the conductivity controlling means of said rectifier devices, whereby the conductivity of said devices may be varied and, hence, the amount of power delivered to the lamps may be controlled.

2. A control circuit for selectively and variably controlling variable intensity electric lights energized with alternating current, which control circuit comprises a pair of controlled solid-state rectifier devices each of which consists of a plurality of alternately p- and n-type regions and having means for controlling the conductivity of the device connected to an intermediate region thereof, said pair of devices having their opposite terminal regions connected together, means for connecting said pair of devices in series with a source of energizing current and at least one lamp to be controlled, magnetic amplifier means for developing voltages of variable amplitude with respect to the amplitude of said source voltage, said magnetic amplifier means comprising bias and control windings and a pair of output windings, means for applying currents of predetermined magnitude to said bias windings, means for applying currents of variable magnitude to said control windings, and circuit means for impressing on the conductivity controlling means of said rectifier devices the variable voltages developed in said output windings, whereby the conductivity of said rectifier devices is controlled in accordance with the amplitude of current applied to said control winding and, hence, the amount of power delivered to said lamps is controlled.

3. A control circuit for selectively and variably controlling variable intensity electric lights energized with alternating current, which circuit comprises a pair of solid-state rectifier devices each of which consists of a plurality of alternately p- and n-type regions and an electrode connected to an intermediate region thereof for controlling the conductivity of the device, and the terminal regions of each device being of opposite type, said pair of devices having the terminal regions of one connected to the opposite type terminal regions of the other, and circuit means for connecting said pair of devices in series with a source of alternating current and at least one variable intensity lamp, said devices having the characteristic of being normally non-conductive when the voltage of alternating polarity of the source is applied across said terminal regions and of becoming conductive of source current when source voltage of given instantaneous amplitude and polarity is applied to the terminal regions and control voltage of certain polarity and amplitude in relation to the instantaneous amplitude and polarity of the source voltage is impressed on the control electrode of the device, which control circuit further comprises magnetic amplifier means for developing voltages of variable amplitude with respect to the amplitude of said source voltage, said magnetic amplifier means comprising bias and control windings and a pair of output windings, means for applying currents of predetermined magnitude to said bias windings, means for applying currents of variable magnitude to said control windings, and circuit means for impressing on the control electrode of said rectifier devices the variable voltages developed in said output windings, whereby the conductivity of said rectifier devices is controlled in accordance with the amplitude of current applied to said control winding and, hence, the amount of power delivered to said lamps is controlled.

4. A control circuit according to claim 3 and which further comprises means for rectifying the currents applied to said bias and control windings, and rectifier means in said circuit means for rectifying the voltages applied to the control electrodes of said devices.

5. A control circuit according to claim 3 in which the circuit means for impressing voltages on the control electrode of each device comprises resistive means and rectifying means connected in series with the output winding associated with the device, and connections for impressing between said control electrode and a terminal region of the device the voltage across said resistive means.

6. A control circuit according to claim 5 and which further comprises capacitative means connected in shunt to said rectifying means in said circuit means.

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