

Nov. 27, 1945.

H. H. SEIFERT ET AL

2,390,005

RECTIFIER SYSTEM

Filed Jan. 21, 1943

4 Sheets-Sheet 2

FIG. 2.

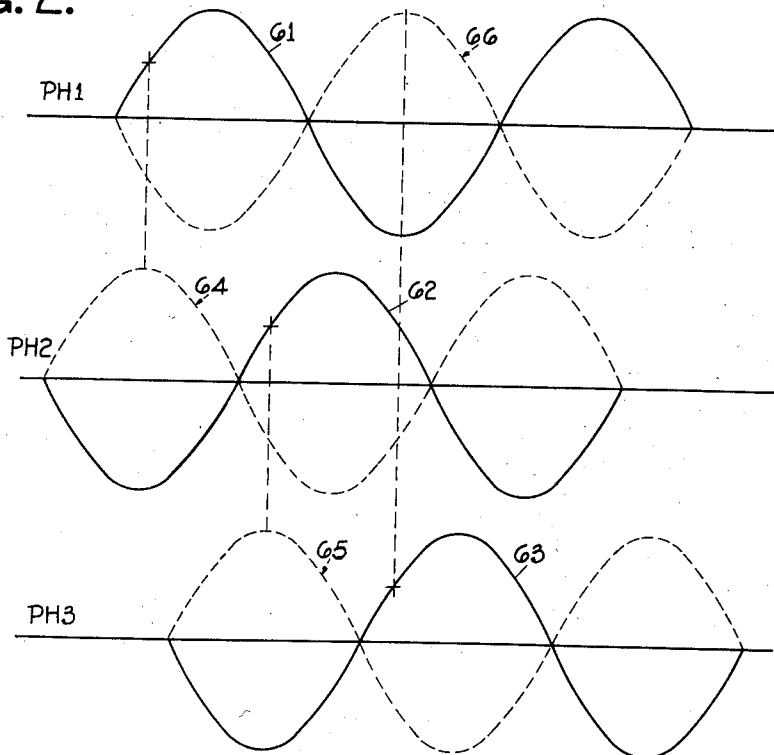


FIG. 6A.

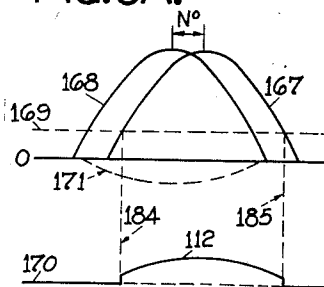


FIG. 6B.

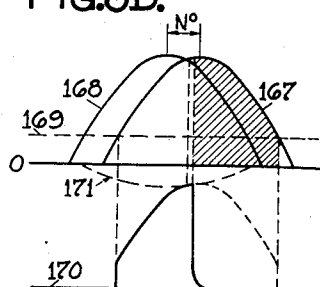


FIG. 6C.

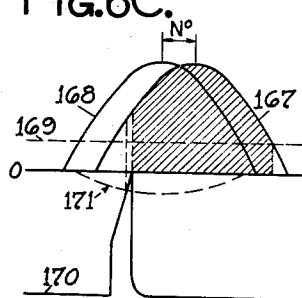
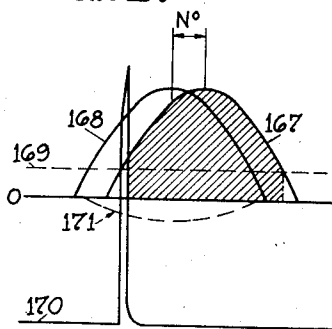


FIG. 6D.



Inventors
H.H. Seifert and W.W. Seifert
By *Neil H. Alston,*
THEIR Attorney

Nov. 27, 1945.

H. H. SEIFERT, ET AL

2,390,005

RECTIFIER SYSTEM

Filed Jan. 21, 1943

4 Sheets-Sheet 3

FIG. 4.

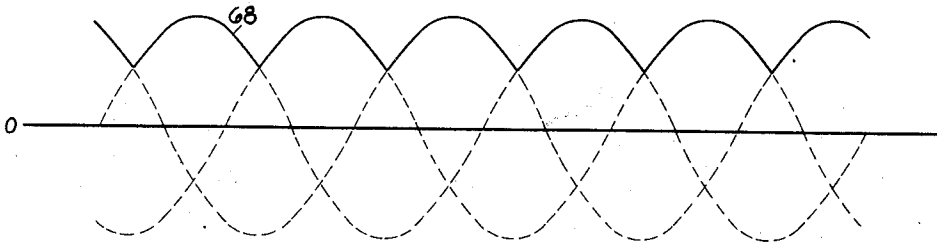


FIG. 5.

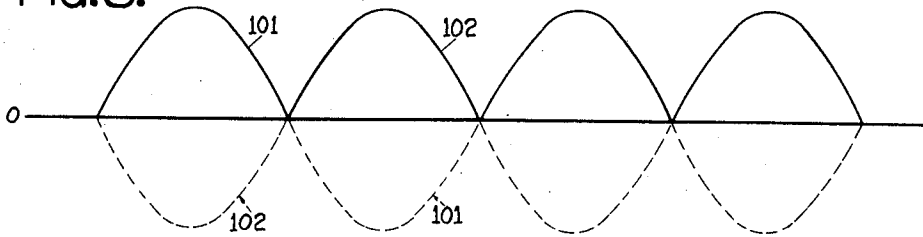


FIG. 3A.

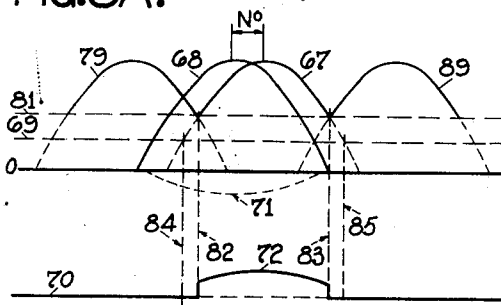


FIG. 3B.

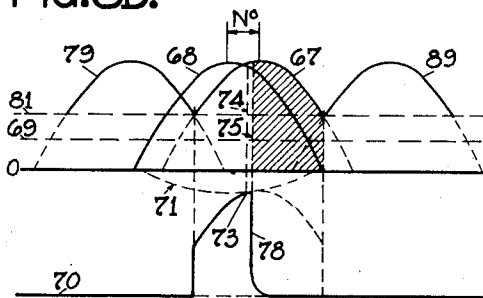
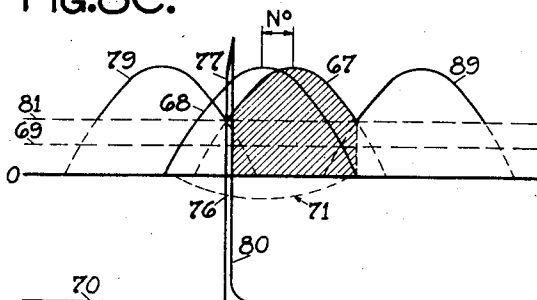


FIG. 3C.



Inventors

H.H. Seifert and W.W. Seifert

Neil H. Preston,

THEIR Attorney

Nov. 27, 1945.

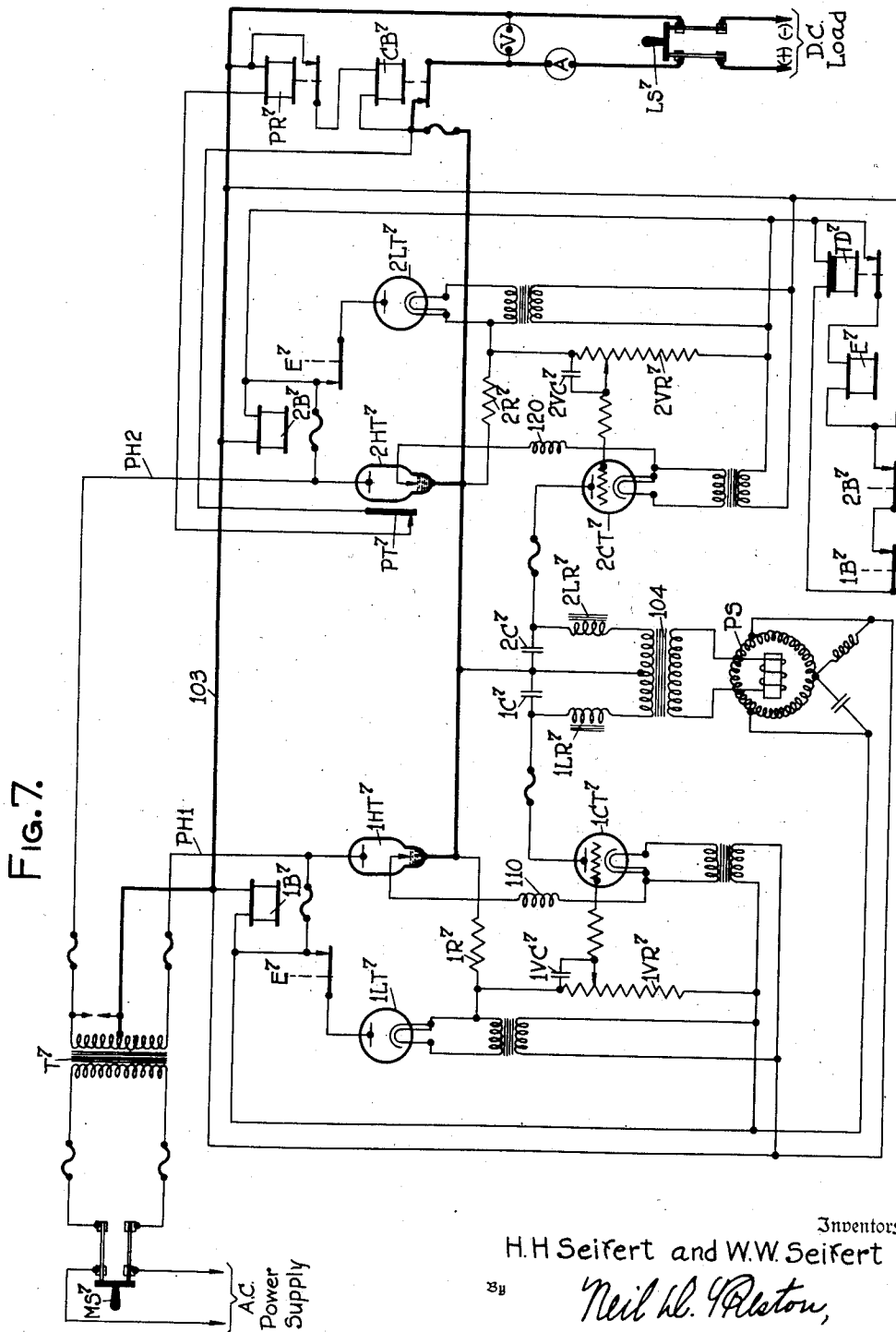
H. H. SEIFERT ET AL

2,390,005

RECTIFIER SYSTEM

Filed Jan. 21, 1943

4 Sheets-Sheet 4



Inventors

H.H Seifert and W.W. Seifert

Neil H. Preston,

THEIR Attorney

UNITED STATES PATENT OFFICE

2,390,005

RECTIFIER SYSTEM

Harry H. Seifert and William W. Seifert,
Troy, N. Y.

Application January 21, 1943, Serial No. 473,082

20 Claims. (Cl. 175-363)

This invention relates to alternating current rectifier systems, and more particularly to such systems that use gas or mercury vapor content electric discharge tubes.

One type of mercury vapor discharge tube is a heated cathode mercury vapor tube which is particularly adaptable for rectifying relatively small continuous currents; while another form of mercury vapor discharge tube is of the type incorporating an emersion-ignitor element or starting electrode that acts upon the flow of a starting pulse of current to form a minute arc between the starting electrode and a pool of mercury to thereby initiate an electric discharge from the anode to the cathode of such tube, and this type of tube is especially adaptable for rectifying relatively large intermittent currents. The heated cathode type mercury vapor tube above mentioned is commonly known in the art as a "phanotron" tube; while the mercury vapor tube employing an emersion-ignitor element is commonly known in the art as an "ignitron" tube.

One of the objects of the present invention is to provide an organization of circuits for controlling a phanotron tube and an ignitron tube in a rectifier combination so that the phanotron tube will supply the normal relatively low continuous load currents, while the ignitron tube will be automatically cut-in to supply the load current when the load rises above a predetermined value too great for the phanotron. Such a rectifier system is particularly desirable for the situations in practice where there is a relatively low normal current to be continuously supplied, and the heavy load currents occur only intermittently and for relatively short intervals. This is because the heated cathode type mercury vapor tubes have a fairly long life, but the mercury vapor tubes with the ignitor elements have a relatively short life when used continuously. It will be readily seen that such conditions occur in practice in connection with the operation of cranes, car retarders, interlocking systems for railroads and various other similar applications, and therefore provide a large field of usefulness for the rectifier system of the present invention.

In the operation of those devices or systems where the heavy loads occur intermittently, there is a tendency in the usual rectifier system for the voltage to drop or decrease upon the sudden application of the heavy load requirements. But the present invention proposes to organize a rectifier system for the provision of both high and low currents in a way to give a voltage regulation of the over-compounded type, that is, where the

voltage will actually rise under the heavy load conditions.

In the past, it has been usually necessary to provide motor-generator sets in order to obtain an over-compounded direct current supply, but a motor-generator set which will supply a relatively heavy load has a very poor efficiency at low loads, while the system of the present invention has a very high operating efficiency under both high and low load conditions. A further disadvantage of the motor-generator set is the high starting current involved when placing such a set across an alternating current line circuit extending to a distant source of supply, as the heavy starting current tends to cause a severe voltage drop across such line circuit thereby interfering with the various other devices also supplied with power from that line circuit. It is of course appreciated that, a system employing electric discharge devices of the type contemplated by the present invention, requires practically the same current under starting conditions as is required after the system has been placed across the line circuit and is running idle.

It will be seen from the above discussion that one object of the present invention is to provide a rectifier organization which will provide over-compounded voltage regulation and still maintain high operating efficiency at both low and high load levels as well as being initially connectable to a line circuit with a minimum of disturbance to such line circuit.

A further object of the present invention is to provide a rectifier system of the type briefly described above which is adaptable for use in rectifying three-phase alternating currents.

It is believed that further objects and purposes of the present invention will be best understood by considering the organization and operation of the embodiments of the present invention as disclosed in the accompanying drawings.

Fig. 1 of the accompanying drawings shows one embodiment of the present invention for rectifying three-phase alternating currents.

Fig. 2 illustrates graphically the three-phase principal potentials being rectified by the system of Fig. 1 together with the advancement of such potentials by suitable transformers for purposes later described;

Figs. 3A, 3B and 3C illustrate graphically one possible theory of operation of the apparatus associated with one phase of alternating current in Fig. 1 and particularly showing the relationship of that phase to the other phases of the three-phase alternating current supply;

Fig. 4 illustrates graphically the rectified three-phase potentials supplied by the rectifier system of Fig. 1 to a direct current load;

Fig. 5 illustrates graphically the rectified single phase principal potentials supplied by the rectifier system of Fig. 7 to a direct current load;

Figs. 6A, 6B, 6C and 6D illustrate graphically one possible theory of operation of the apparatus disclosed in Fig. 7 associated with one phase of alternating current for one positive half-cycle then being rectified by that portion of the apparatus; and

Fig. 7 shows a simplified form of the present invention which is particularly adapted for use in connection with the double-wave rectification of the single-phase alternating current.

With reference to the drawings, it will be seen that a source of alternating current power supply may be connected or disconnected by a main switch MS from the primary windings of a three-phase delta connected transformer T through suitable fused connections including fuses 4, 5 and 6. The secondary windings of this three-phase transformer T are arranged in a so-called zigzag Y connection of the well known conventional type. This zigzag Y connection of the secondary windings is used to reduce the saturating effect of a rectifier load on the cores of the several transformers employed, which saturating effect is present in a transformer when a rectifier is connected across its secondary windings while drawing a substantial direct current load. The saturation of the core structure of a transformer tends to reduce the efficiency of such transformer, while the provision of the zigzag connections maintains the efficiency of the transformers at a relatively high level. However, it is sufficient for an understanding of the present invention to know that three-phase alternating currents are provided from the secondary windings of this transformer which have been designated as phase one, two and three by the reference characters PH1, PH2 and PH3 respectively associated with the wires leading from the secondary windings. The common connection to the Y is designated C. There are suitable discharge resistors connected across portions of the secondary windings to allow any excess voltages across such coils to be discharged, and this is especially desirable in case sudden surges occur on the line circuit, and also in case of the sudden removal of a heavy direct current load from the rectifier system. These discharge resistors or devices may be of any suitable type, such as those commonly known as the "thyrite" type.

Associated with each of the three different phases of alternating current is a group of electric discharge tubes and other devices as will be presently described. Some of these devices have been given the same letter reference characters to indicate their similar functions but these letters have the distinctive preceding numerals 1, 2 and 3 associated therewith as the case may be to show the particular phase of alternating current with which such devices are associated. Other devices have been given distinctive numeral reference characters, the first digits of which have been assigned 1, 2 or 3 in accordance with which phase such devices are used. Still other devices have been given quite different reference characters because such devices are used in common with the complete organization rather than specifically in connection with any particular phase of alternating current.

Each mercury vapor tube of the heated cath-

ode type, commonly known as "phanotron," has been designated LT with a suitable preceding numeral to designate the phase with which it is associated. Each tube has a heater element which supplies the heat for the cathode to render it active, and the proper activity is set up only after the heating element has been supplied with energy for a predetermined period of time. Thus, the system is so organized by the use of a slow-acting timing device TD and its repeater relay E that the potential is not applied to the anodes of these tubes until the heating elements have been supplied with energy for the proper time. Although these low load LT tubes may have various operating characteristics and may supply different maximum load currents in accordance with their design, it will be assumed for the purpose of the discussion that these tubes will supply currents up to say six amperes average.

For supplying the high currents, suitable mercury vapor tubes 1HT, 2HT and 3HT are provided (having preceding numerals corresponding to the phase with which they are respectively associated) and these tubes have emersion-ignitor elements or starting electrodes 16, 26 and 36 which are controlled by their respective control tubes 1CT, 2CT and 3CT. It is to be understood in connection with this heavy duty tube HT, that the starting electrode is emersed in a pool of mercury forming a part of the cathode of such tube and functions only to initiate the discharge between the anode of this tube and its cathode, and this is effected by passing a relatively high but short starting pulse through the emersion-ignitor element and the mercury pool. Such a starting pulse may be in the order of forty amperes but its duration may be but a few micro-seconds, it being understood that the quantity of current and the time involved is of course a matter of design for the particular tube employed. These tubes are so characterized that there must be a certain minimum potential applied to the anode in order to initiate a discharge through the tube even though a starting pulse has been passed through the ignitor element. Also, once a discharge has been initiated from the anode through this tube, such discharge or transfer of energy continues in spite of the cessation of the starting pulse, until the potential on the anode of this tube has been reduced to substantially zero or its polarity is reversed.

The control tubes 1CT, 2CT and 3CT, are of the mercury vapor type with heated cathodes and grid controls, commonly known as "thyatron" tubes. These tubes are characterized by the fact that no discharge from the anode to the cathode occurs while the grid is maintained negative with at least a predetermined bias, but if the negative bias on the grid is reduced to the critical value for the particular potential then on the plate or anode of this tube, then a discharge is initiated which continues in spite of the then existing bias on the grid, until the potential on the plate or anode is reduced to substantially zero or its polarity is reversed.

The control tubes CT for the several phases have their heating elements supplied with energy from the secondary windings of transformers 11, 21 and 31 for the respective phases of alternating current, it being noted that the primary winding of each such transformer is supplied with energy from the particular phase with which it is associated. Similarly, transformers 12, 22 and 32 have their primary windings connected to the respective phases of alternating current, while their

secondary windings supply energy for the heater elements of the low load tubes LT associated with the corresponding phases.

Transformers 13, 23 and 33 have their secondary windings connected through limiting resistors 1LR, 2LR and 3LR respectively to supply charging energy for their respective condensers 1C, 2C and 3C. The charge from each of these condensers is used to provide the starting pulse for the associated ignitor elements 10, 20 and 30 for the high capacity tubes HT. It should be understood that the starting pulse for each phase is controlled by its associated control tube CT and the circuit for the associated ignitor element includes an air core reactor and a fuse. These air core reactors for the several phases have been designated 10, 20 and 30; while the fuses have been designated 19, 29 and 39. The primary winding of each of these transformers 13, 23 and 33 is supplied with energy from the phase of the transformer T which is immediately following (considering vectorial rotation) the particular phase of the transformer with which its control and rectifying tubes CT, LT and HT are associated for reasons which will be explained in detail hereinafter.

The control tubes CT, as above mentioned, are of the grid controlled type and their respective grids have a negative bias supplied by reason of the potential drop across portions of variable resistors 1VR, 2VR and 3VR. Each of these variable resistors is connected across the buses 50 and C in such a relation with an associated resistor R that is included in series with the low capacity tube LT, that the potential drop across such resistor R (when load current flows through it) is subtracted from the bias provided by the associated variable resistor VR. This is to provide automatic variation of the bias on the grid for each control tube in accordance with the load supplied by the associated low capacity tube LT. Each resistor VR has associated therewith a condenser VC for smoothing out the bias voltage for their respective tubes CT. These condensers are designated 1VC, 2VC and 3VC.

The main phase wires PH1, PH2 and PH3 have included fuses 17, 27 and 37 respectively. These fuses are more particularly for protecting the heavy capacity tubes HT. These phase wires also include fuses 18, 28 and 38 in the circuit in such a way that only the currents for the low capacity tubes flow through such fuses. But with the arrangement provided in accordance with the present invention the main fuses 17, 27 and 37 are so associated with the fuses 18, 28 and 38 that relays 1B, 2B and 3B for the several phases serve to check the supply of energy through the fuses for their respective phases by providing that the closure of the main switch MS will not result in the application of energy to the anodes of the low capacity tubes LT if one or more of such fuses is burned out. These relays obviously will also check the supply of energy from the transformer T.

With reference to Fig. 1, it will be seen that relays 1B, 2B and 3B are provided with contacts 15, 25 and 35 respectively included in an energizing circuit for a slow-acting device TD. Under normal conditions, the closure of the main switch MS results in the application of energy from the three phases to the respective checking relays B so that energy is immediately applied to the timing device TD which begins to measure off a suitable time at least greater than the predetermined time required for properly heating

the cathodes of the tubes LT and CT. This timing device TD may be of any suitable type, such as a slow pick-up relay, a thermal relay, or the like, which acts to measure off the required time.

As disclosed, the timing device TD is shown as a slow pick-up relay having a front contact 51 which energizes the relay E. This relay E has contacts 14, 24 and 34 for applying the potential to the anodes of the respective low capacity tubes LT and to the primaries of the transformers 13, 23 and 33.

A protective device PT is associated with the high capacity tubes HT in such a way that if a protracted over-load occurs, this thermal responsive device will open its contact and deenergize the protective relay PR which in turn will open its contact 52 and deenergize the circuit breaker relay CB. The opening of front contact 53 of the circuit breaker CB will of course remove the load on the direct current circuit the same as if the load switch LS were open. This protective device PT has been shown associated with the tube 3HT, but it is of course appreciated that a similar device may be associated with each of the other tubes 1HT and 2HT and included in series in the circuit for the relay PR, if desired.

A direct current load fuse 54 is included in the direct current bus 50 in series with the load switch LS. A volt-meter V and an ampere-meter A are properly connected in the circuit to determine the out-put of the rectifier system.

It is believed that the further features of the invention as disclosed in Fig. 1 will be best understood by considering the operation of the system. In this connection, it should be appreciated that the operation of the system can be measured and varied as desired, but inasmuch as the detail electrical theory pertaining to the electric discharge devices is somewhat conjectural, such theory is discussed merely to that extent which will show how the system may be adjusted to obtain various results desired in the practice of the invention.

Also, specific types of electron tubes have been described for the sake of definiteness in the disclosure, but it should be understood that other tubes adapted for similar purposes might be used within the scope of the invention.

Operation of Fig. 1.—The various devices of Fig. 1 have been shown in conditions existing while the rectifier system is supplying energy to a direct current load. But it can be appreciated that, when the rectifier system is initially connected to the alternating current power supply by the main switch MS, assuming that all devices are in proper condition for operation, the relay 1B is energized from the phase wire PH1, through fuse 18, windings of relay 1B, to the common bus C. A similar connection is provided for each of the other relays 2B and 3B. When all three relays 1B, 2B and 3B have closed their respective contacts 15, 25 and 35, the timing device TD is energized from the phase wire PH3 through fuse 38, windings of timing device TD, contacts 15, 25, 35 in series, to the common bus C. When the timing device TD closes its contact 51 after a predetermined time, the relay E is connected across the phase wire PH3 and the common bus C so that it closes its front contacts 14, 24 and 34 to apply energy from the respective phase wires to the anodes of the low capacity tubes LT for the several phases. This of course does not occur until after the cathodes of these tubes have been properly heated, as above mentioned.

The low load tube (LT, for example, has potential applied from the phase wire PH1 through fuse 18, front contact 14 to the anode of this tube (LT, and since its cathode is heated, the positive half-cycles of the phase PH1 are passed through the tube LT to the cathode and through the resistor 1R to the positive direct current bus 50. A similar operation occurs for each of the tubes LT so that a direct current potential is provided across the positive bus 50 and the common bus C, it of course being understood that this direct current potential is formed by the positive half-cycles of a three-phase alternating current supply so that the vectorial summation of these positive half-cycles which occur 120° apart gives a direct current potential with a so-called ripple. The peaks of the ripples occur every 120° of vector rotation of the alternating current supply. This direct current potential is represented in Fig. 4 by the solid line 68 formed by the alternating current potential from the several phases which have been indicated by dotted lines. But for the purpose of this discussion, the direct current potential will be considered to have an average value, especially with respect to the use of this potential for the supply of the bias on the grids of the control tubes CT. Also, the connection of the condensers VC across a portion of the potentiometers VR serves to reduce the ripple effect in the supply of a direct current biasing potential.

The potential applied to the anode of the low capacity tube LT is also applied to the anode of the high capacity tube HT, but the high capacity tube HT does not conduct and supply direct current load because it must be fired by its associated control tube CT for each positive half-cycle upon which it is to act. This potential applied to the anodes of each pair of rectifying tubes LT and HT will be considered throughout the discussion as the principal potential; and the principal potentials for the three phases have been indicated in Fig. 2 by the solid line sine curves 61, 62 and 63 respectively.

As above mentioned, the primary winding of the transformer 13 is connected across the phase two by a circuit from the phase wire PH2 including fuse 28, and front contact 24 of relay E, but its secondary winding terminals are so connected to the condenser 1C and the plate of the control tube ICT that the out-put voltage is advanced in phase 180°. In other words, when the principal potential of phase one is positive, the principal potential of phase two is positive 120° later, so that during the major portion of the positive half-cycle of the principal potential of phase one, the principal potential of phase two is negative. But, with the potential of phase two advanced 180° by the transformer 13, a positive half-cycle of charging potential, indicated by the dotted line curve 64 in Fig. 2, occurs during the positive half-cycle of the principal potential of phase one. This is accomplished for each of the phases by the respective transformers 13, 23 and 33, so that phase three is advanced 180° providing a positive half-cycle indicated by the dotted line curve 65 during the positive half-cycle of the principal potential for phase two; and similarly, the phase one is advanced by the transformer 33 as indicated by the dotted line curve 66 so as to have a positive half-cycle occur during the positive half-cycle of the principal potential of phase three.

For convenience in the discussion, specific consideration will be given to the functioning of the

apparatus associated with phase one, it being understood that the apparatus for each of the other phases operates similarly. However, there is an interrelation between the apparatus for the three phases of Fig. 1 which must be considered in addition to the specific consideration of the functioning of the apparatus for a single phase. Because of this condition, it is convenient to first consider the diagrams of Figs. 3A, 3B, 3C and 3D which apply more particularly to a single phase of the three-phase disclosure of Fig. 1, and then consider the diagrams of Figs. 6A, 6B and 6C for the single phase disclosure of Fig. 7, to more fully understand the interrelated functioning of the apparatus for the several phases of Fig. 1.

Thus, in Fig. 3A, the curve 67 of the graph may be said to represent a positive half-cycle of the principal potential of phase one. The positive half-cycles of phase two, as advanced in the secondary of the transformer 13 (see curve 64 of Fig. 2), are applied to the condenser 1C through the limiting resistor 1LR, so that the potential applied to the plate or anode of the control tube ICT lags vectorially with respect to the positive half-cycle supplied by the secondary winding of transformer 13, and is represented in the graph of Fig. 3A by the curve 68 leading curve 67. This particular phase displacement designated by the reference character N°, may be adjusted by proper choice of the resistance 1LR in its relationship to the capacity of the condenser 1C. If there were no phase displacement due to this combination, that is, if resistor 1LR were zero, the peak of the positive potential applied to the plate of the control tube ICT would occur when the principal potential is 30° into its positive half-cycle. But, it is desirable that the charging potential for condenser 1C shall be at an effective value prior to the point at which the control tube ICT is rendered active to allow the condenser 1C to supply the starting pulse energy to the ignitor element 16. Thus, in practicing the invention, it has been found desirable to provide that the number of degrees indicated by the reference character N° shall be 30° or less, as for example 25°. In other words, the peak of the starting pulse potential represented by the curve 68 leads the principal potential represented by the curve 67 by a number of degrees represented by the reference character N°.

It is also desirable, for reasons later explained, that there be a proper value limiting resistor in the excitation circuit for the tube 1HT, so as to limit the flow of current from the secondary of transformer 13 after the single short duration starting pulse has been applied to the emersion-ignitor element 16 from the condenser 1C through the plate of the control tube ICT to the cathode, inductive reactor 10, the starting element 16, through the mercury pool to the other side of the condenser. Thus, the peak of the starting pulse potential is indicated by the curve 68 in Fig. 3A and occurs a certain number of vectorial degrees after the initial starting point for the positive half-cycle of the principal potential curve 67.

This lead of the charging potential 68 is particularly desirable because the tube 1HT will not discharge or allow the flow of current from its anode in response to the positive half-cycle potential represented by curve 67 until such potential has reached a predetermined value, such as, for example, 20 volts as indicated by the dotted line 69 in Fig. 3A (note points where line 69 crosses curve 67). But when any voltage above

this critical predetermined value is present on the anode of the tube IHT, this tube will allow the passage of positive current upon the passage of the start pulse through the ignitor element 16. This discharge or firing action occurs more positively and more efficiently if at that time the starting pulse is at a substantial value; while with the principal potential on the anode of the tube IHT at a maximum, the starting pulse through the ignitor element 16 may be of a smaller value. For this reason, it can be seen that it is very desirable to have an effective value charge on the condenser IC during the early part of the half-cycle of the principal potential, and also to have the effective value of such charge to be extended over the range of the various points in the half-cycle during which the control tube ICT will cause the firing of the tube IHT.

With reference to Fig. 3A for example, it will be seen that the principal potentials of phase three and two are represented by the sine curves 79 and 89 respectively; and a dotted line 81 has been drawn parallel to the zero base line and passing through the point where curve 79 intersects the curve 67 and the point where the curve 67 intersects the curve 89. This dotted line 81 represents the actual potential at which the low capacity tube ILT as well as the high capacity tube IHT may become conductive, for reasons presently to be pointed out. It will be noted that this potential represented by line 81 is slightly above the critical potential represented by line 69, which line 81 is at a value equal to one-half of the maximum value of the principal potentials. This is because the principal potentials are of the three-phase type intersecting each other at their 30° points.

The variable resistor IVR is connected across the bus wires 50 and C so that an average negative potential indicated by the line 70 of Fig. 3A is provided as a bias on the grid of the control tube ICT. This control tube ICT has a variable range of critical grid values for the positive half-cycle of potential applied to its anode. Although this critical grid characteristic may vary for different tubes, one possible characteristic has been indicated in Fig. 3A by the dotted line curve 71. With a small load across the buses 50 and C, assuming of course that the load switch LS is closed, and that the circuit breaker relay CB is energized closing front contact 53, the potential drop across the resistor IR is represented by the curve 72 in Fig. 3A, this curve being in phase with the principal potential 67, because the current through this resistor IR is supplied by the principal potential through the low capacity rectifier tube ILT.

It will be noted that current flows downwardly through the variable resistor IVR so that the upper terminal of the resistor IVR is positive and is connected to the cathode of the control tube ICT through the mercury pool, ignitor element 16 of tube IHT, reactor 10, to thereby give the grid of the control tube ICT its negative bias. However, the load current flow through the resistor IR flows to the right to the bus 50 so that the left-hand terminal of the resistor IR is positive. As such resistor IR is in the grid circuit for the control tube ICT, its potential drop is subtracted from the bias supplied by the variable resistor IVR. This is indicated in Fig. 3A by the base of curve 72 being on the negative bias line 70, but because the potential drop indicated by curve 72 is not sufficient to reduce the negative bias on the tube ICT to a critical point indicated

by the dotted line curve 71, the control tube ICT does not allow flow of a starting pulse.

It will be noted that, as above mentioned, the variable resistor VR receives energy from the bus 50, which energy is supplied to such bus 50 by all of the phases, and as above mentioned, the average direct current potential is indicated by the line 70, rather than the actual instantaneous values for this current. Also, the ripples of the biasing potential are somewhat smoothed out by the condenser IVC shunting a portion of the potentiometer which provides the negative bias on the grid of the control tube ICT.

It should further be noted that the solid line 70 connects with the solid line curve 72 and that these interconnected lines may be assumed to be the actual bias on the grid of the control tube, the line 70 being continued dotted under the curve 72 merely to indicate that such continued negative bias would be present if it were not for the drop in potential across the resistor IR caused by the load current supplied by the low capacity tube ILT.

In this connection, it may be noted that the low capacity tubes ILT have somewhat similar characteristics as the high capacity tubes IHT, in that such tubes do not become conductive until the potential applied to their anodes reaches a predetermined value, such as, for example, 20 volts. For this reason, the tube ILT, for example, could not become conductive to supply load current through resistor IR until the potential on its anode has reached the predetermined value represented by the line 69 crossing the curve 67. However, with reference to Fig. 3A it will be seen that the value of the principal potential of phase three represented by curve 79 is at a greater value than the value of the principal potential represented by the curve 67. Thus, the low capacity tube ILT does not become conductive at its predetermined critical value, but waits until the principal potential of phase three represented by curve 79 drops below the dotted line 81 and the principal potential for phase one represented by curve 67 rises above the line 81. In other words, the tube ILT actually becomes conductive somewhat later than the point where curve 67 intersects the line 69. Similarly, the tube ILT ceases to be conductive near the end of the positive half-cycle represented by the curve 67 when the potential of such phase drops below the line 81. In this way the curve 72, which represents the potential drop across the resistor IR, must begin and end between the dotted lines 82 and 83 although if it were not for the three phase supply, the actual limits might be represented by the vertical dotted lines 84 and 85.

Thus, the low current supplied by the tube ILT causes a potential drop across the resistor IR forming what might be termed a squared curve 72 falling exactly beneath that portion of the principal potential represented by the solid line portion of curve 67 and during which time the high capacity tube IHT might also become conductive. The current which flows through the tube ILT of course takes the sine curve characteristic, but such characteristic is cut off at the ends as represented by the curve 72 due to the limited time during which the tube ILT is conductive. It also may be noted here, that the high capacity tube IHT may become conductive between the same points represented by lines 82 and 83 during which the low capacity tube ILT is conductive. Because of this, the high capacity tube IHT will have a sufficient potential on its

anode at the earliest possible instant at which a start pulse can be supplied to its starting electrode 16 due to the potential drop across the resistor 1R, which will be discussed in connection with Fig. 3C.

In brief, under low load conditions, the low capacity tube 1LT carries such load throughout that portion of each positive half-cycle of phase one during which the low load is not carried by the tubes 2LT and 3LT of the other phases; and this low load may vary within a range having a maximum value just below that point which will produce a sufficiently high potential drop across the resistor 1R to reduce the negative bias on the control tube 1CT to that point where the curve 72 will become tangent to or intersect the curve 71.

When the load current supplied by the low capacity tube 1LT reaches a level during any positive half-cycle of phase one greater than such tube 1LT should provide, then the potential drop across the resistor 1R is sufficient during that positive half-cycle then being rectified to cause the bias on the grid of the tube 1CT to reach the critical value of the tube as indicated in Fig. 3B by the point 73 where the curve 73 is tangent to the grid curve 71. This causes the control tube 1CT to become conductive and allow the charge on the condenser 1C to flow through the control tube 1CT, the reactor 10, and the emersion-ignitor element 16 of tube 1HT, to fire the tube 1HT. This relatively high starting pulse, such as forty amperes for example, has a duration of but a few micro-seconds and immediately renders the tube 1HT active to discharge or allow a flow of current for substantially the entire remaining portion of the positive half-cycle of the principal potential. This flow of current is represented by the shaded area beneath the curve 67 in Fig. 3B.

It will be noted that the flow of current through the tube 1HT to the bus 50 substantially short circuits the tube 1LT and resistor 1R. This effective shorting of the resistor 1R reduces the potential drop across it to substantially zero so that the negative bias on the control tube 1CT is restored for the remaining portion of the positive half-cycle then being rectified by the tube 1HT. Inasmuch as the charge on the condenser 1C is entirely dissipated through the ignitor element 16, and the inductance 10 tends to give a negative swing or oscillation to the potential in the excitation circuit following the initial surge of igniting pulse current, the potential on the anode of the control tube 1CT is reduced to substantially zero so that the now negative grid obtains control of the current flow. The grid thus gaining control of the current flow in tube 1CT prevents further flow of current through the excitation circuit for the remaining portion of the positive half-cycle then being rectified, although the charge on the condenser 1C may begin to be built up as permitted by the limiting resistor 1LR. In brief, the organization is such as to prevent any follow-through current in the ignitor or excitation circuit. In other words, the resistor 1R serves several purposes namely, that of controlling the bias on the grid of the control tube 1CT in accordance with the load during the half-cycle being rectified by the tube 1LT, serving to provide a proper operation of the tube 1HT in combination with the tube 1LT, and also reducing the bus voltage under normal light loads, so as to permit the over-compounding voltage effect when shorted during the conductivity of the high ca-

capacity tube 1HT. This portion of the positive half-cycle of the principal potential for phase one during which the tube 1HT supplies power is indicated in Fig. 3B by the shaded portion, and the tube 1HT ceases to conduct as soon as the principal potential of phase one falls below line 81 and phase two begins to carry the load. It will be noted in Fig. 3B that the dotted line 74, indicating the time at which the control tube 1CT is rendered active, passes through a point on the curve 68 representing the firing potential, and this firing potential on the plate of the control tube 1CT substantially above the effective potential value of that positive half-cycle. There is a short time of a few micro-seconds between the critical grid control represented by dotted line 74 in Fig. 3B and the actual conductivity of tube 1HT represented by dotted line 75, and during this time the tube 1LT continues to carry the load.

Fig. 3C represents positive half-cycles in which the load current through the resistor 1R is increased. This increased load current value increases the potential drop across the resistor 1R and subtracted from the bias represented by line 70 gives the curve 80 indicating the actual bias on the tube 1CT. The curve 80 crosses the critical grid curve 71 at point 76 which is substantially at a time in the positive half-cycle of the principal potential for phase one that the low capacity tube 1LT becomes conductive. More specifically, the low capacity tube 1LT becomes conductive at a point where the principal potential represented by curve 67 for phase one rises above the principal potential for phase three represented by curve 79 as above explained. Assuming a relatively high load, the initial conductivity of the low capacity tube 1LT allows the load current through the resistor 1R to rise substantially perpendicularly in accordance with the voltage then existent on the anode of the tube 1LT. With reference to Fig. 3C, it will be seen that at such time the firing potential on the plate of the control tube 1CT has reached a point 77 which is substantially above the effective value of the firing potential so that the tube 1HT is supplied with a proper starting pulse through the emersion-ignitor element 16. After a few micro-seconds following the positive swing of the grid bias beyond its critical value, the high capacity tube 1HT becomes conductive, shunting the low capacity tube 1LT and the resistor 1R. Thus, the bias on the control tube immediately returns to its negative value represented by the solid line 70. Thus, there is short time of a few micro-seconds during which there is a heavy load flow of current through the low capacity tube 1LT before the high capacity tube 1HT becomes conductive but this heavy load current may be carried by the low capacity tube 1LT without harming it because of the very short duration of such load requirement, and because of the fact that the current is limited well below the maximum current allowable for the tube 1LT by the resistor 1R. Also, the supply of the heavy load current through the high capacity tube 1HT raises the potential across the load because there is no resistor, such as 1R now included in the rectifying circuit. In this way, over-compounded voltage regulation is provided. The shaded area beneath the curve 67 of Fig. 3C represents the portion of the positive half-cycle of the principal potential for phase one during which the tube 1HT ceases to conduct as soon as the principal potential for phase one falls below the principal poten-

tial for phase two which occurs along the dotted line 81.

With reference to Figs. 3B and 3C, it will be seen that the curves 78 and 80 representing the bias on the grid of the control tube ICT for different loads, would form sine curves if the heavy capacity tube IHT failed to conduct current for the different load conditions indicated. Actually, the rendering active of the heavy capacity tube IHT, shunts the low capacity tube 1LT in series with the resistor 1R so that the current passing through such resistor is substantially reduced to zero because the impedance of the tube 1LT in series with the resistor 1R is substantially higher than the impedance of the tube IHT when it is discharging or conducting. For this reason, the current passing through the resistor 1R will substantially drop to zero as soon as the heavy capacity tube IHT is rendered active, so that obviously the potential across the resistor 1R drops and the resulting bias on the grid of the tube ICT does not follow the complete sine curves. This transitory condition has been indicated in the graphs of Figs. 3B and 3C, but its characteristic is somewhat conjectural and may actually differ slightly from the curve shown although the same results will be obtained.

Furthermore, the question of whether or not the bias on the grid of the control tube ICT is actually raised to a positive value, is relatively immaterial insofar as the practice of the present invention is concerned, in view of the fact that the control tube ICT is of the type which has a "trigger" action characteristic. In other words, once this control tube ICT becomes active, current continues to flow through such tube regardless of the particular bias on the grid, within the usual control range, until the anode potential is reduced below a critical value with the bias on the grid being of a non-triggering value. However, the resistor 1LR is so proportioned that at the instant at which the condenser 1C discharges through the control tube ICT, the potential on the anode of the tube ICT drops below the above mentioned critical value and the tube ICT becomes non-conducting.

To recapitulate the operation of the three-phase rectifier system, it will be seen that the low continuous loads are supplied by the rectifier tubes 1LT, 2LT and 3LT until such loads reach values above the predetermined value at which these low capacity tubes should operate, and then on each positive half-cycle of each phase in which the load rises above the predetermined value, a start pulse is provided for the high capacity tube associated with the particular phase then having a positive half-cycle. The point in the positive half-cycle of the principal potential at which the high capacity tube HT for that phase is ignited or fired, is dependent upon the magnitude of the load. But it will be seen that lowest load supplied by the heavy duty tube, such as tube IHT will give a higher direct current voltage than is supplied to the buses 50 and C by the low capacity tubes LT. This is because the impedance of the tubes LT and their associated resistors R is higher than the impedance of the heavy duty tubes and therefore causes a greater potential drop in the circuit. In this way the voltage is over-compounded from the low continuous load to the minimum heavy load, while the voltage is still further over-compounded over the varying range of heavy loads by the supply of a greater portion of each positive half-cycle in accordance with the load demand up to the maxi-

mum point of regulation represented by Fig. 3C.

It should also be noted that the energization of the protective relay PR is by direct current and should one of the tubes fail, or become overheated, this protective relay PR is deenergized causing the circuit breaker CB to open and disconnect the direct current load. Although it is not shown, the circuit breaker CB may be of the stick type requiring manual restoration before the direct current load can again be supplied with energy.

As above mentioned, the low capacity rectifier tubes LT may be able to supply a continuous load of six amperes for example, while the heavy duty tubes HT may be able to supply high load currents as high as five or six hundred amperes or perhaps even two thousand amperes for a few micro-seconds although their normal continuous rating is an average of approximately fifty amperes. In this way, the system is particularly adapted to supply sudden high loads which are existent only for a few cycles of the principal potential, and still provide that the heavy duty tubes will have a considerable life because of their actual use occurring only a small percentage of the time. Similarly, the control tubes CT may be of the type having a continuous rating of about two or three amperes but for the duration of the starting pulses which is but a few micro-seconds, they will withstand a surge current of forty to fifty amperes which is required for igniting the heavy duty tubes. It should of course be understood that the various quantities mentioned may be varied in accordance with practice and design of the tubes, but they have been mentioned so as to give an idea of the relative differences in the high and low load currents which may be supplied by such a rectifier system as is disclosed herein. It should also be mentioned that insofar as the graphs of Figs. 3A, 3B and 3C are concerned, a resistive load is assumed on the direct current buses, but if an inductive load is applied, the operation is in general the same although the wave shape of the current carried by each tube will differ somewhat.

Double-wave single phase rectifier of Fig. 7.

Although the preferred form of the invention is particularly adaptable to the rectification of three-phase alternating currents, the same principles may be applied to the rectification of single phase currents. This is illustrated in the disclosure of Fig. 7, where a single phase of alternating current potential is supplied to the primary of a transformer T' through a master switch MS', which transformer T' has a center-tapped secondary to supply the principal potentials for the anodes of the rectifier tubes 1LT', 1HT', 2LT' and 2HT'. These tubes have the same characteristics as explained in detail for the tubes of Fig. 1 having corresponding letter reference characters.

The center-tapped secondary of the transformer T' in effect supplies two phases of alternating current, one lagging the other by 180°. The potentials of these two phases have been indicated in Fig. 5 by the sine waves 101 and 102, the negative portion of each complete cycle for each phase being shown dotted and the positive portion of each cycle for each phase being shown solid. For convenience in the disclosure, the potential supplied by the lower half of the secondary of the transformer T' is considered to be phase one and the potential supplied by the upper half of the secondary of the transformer T' is considered to be phase two, each phase having

the phase wires PH1 and PH2. The common or center connection to the transformer is designated 103. A suitable discharge resistor is connected across the upper portion of the secondary of the transformer T⁷ to allow any excess voltages across such coils to be dissipated for reasons similar to those pointed out in connection with Fig. 1.

Associated with each of the two phases of alternating current as supplied by the secondary of the transformer T⁷ is a group of electric discharge tubes and other devices. Some of these devices have been given the same letter reference characters to indicate their similar functions but these letters have been made distinctive by their preceding numerals 1 and 2 associated therewith, as the case may be, to show the particular phase of alternating current with which such devices are associated. Inasmuch as these reference characters are similar to those used in Fig. 1, they have been made distinctive for Fig. 7 by the use of distinctive exponents.

The system of Fig. 7 as a whole has devices similar to those disclosed and described in detail in connection with Fig. 1 and including relays 1B⁷, 2B⁷, PR⁷, CB⁷, E⁷ and TD⁷. A protective thermal device PT⁷ is also associated with the high capacity tubes for reasons similar to those pointed out in connection with Fig. 1.

The low capacity tubes LT⁷ and the control tubes CT⁷ have their heater elements supplied with energy from their respective phases through suitable transformers in a similar manner as described for corresponding tubes of Fig. 1.

Each phase has associated therewith a variable resistor VR⁷ with a condenser VC⁷ connected across a portion thereof. Also, a resistor R⁷ is included in the circuit for each low capacity tube LT⁷.

Inasmuch as the potentials supplied by the secondaries of the transformer T⁷ are 180° apart, and neither can be used for the start pulse potentials for the excitation circuits, a special phase shifting device PS is required to advance one phase potential sufficiently that it may be separated into two phases by a mid-tapped secondary of a transformer 104 in a manner as to produce potentials on the anodes of the control tubes 1CT⁷ and 2CT⁷ in a similar manner as supplied for corresponding tubes of Fig. 1. In other words, a potential should be applied to the anode of the control tube 1CT⁷ leading the principal potential applied to the anodes of its associated tubes 1LT⁷ and 1HT⁷ by thirty vectorial degrees, or less for reasons pointed out in connection with Fig. 1. With reference to Fig. 6A, the principal potential is represented by the curve 167. The firing or start pulse potential on the anode of the control tube 1CT⁷ is represented by the curve 168.

In other words, the phase shifting device PS takes the potential of phase one, as illustrated, and advances it the required amount so that the left-hand portion of the secondary of transformer 104 will apply a potential with a proper phase displacement for the anode circuit of the control tube 1CT⁷; while the right-hand portion of the secondary of transformer 104 advances such potential 180° in phase relationship with respect to the potential supplied to the anode circuit of control tube 1CT⁷ which brings it into a proper phase relationship for the anode circuit of the control tube 2CT⁷.

This of course assumes that the limiting reactors LR⁷ and C⁷ are of such values as to bring the firing potential across the condensers to the de-

sired 30° or less relationship with respect to the principal potentials applied to the rectifying tubes LT⁷ and HT⁷, such firing potentials being represented in Fig. 6A by the curve 168, and the distance of lead with respect to the principal potential 167 being indicated by the reference character N°. It will be noted that the curves of Fig. 6 corresponding to similar curves in Fig. 3 have been given similar number reference characters preceded by the hundreds digit one.

Each of the excitation circuits for the high capacity tubes HT⁷ includes an air core inductance 110 and 120.

The variable resistors VR⁷ supply a negative bias for the grids for their respective control tubes, which bias of course includes ripples which may be assumed to be represented by the solid lines curves of Fig. 5, although these curves are not identical to the actual potentials because of the conducting characteristics of the low capacity tubes LT⁷ which tends to cut off the rectification of each principal potential supply before it reaches zero. The ripples, however, of the biasing potential are smoothed somewhat by the condensers, such as condenser 1VC⁷, so that the bias is considered to be of an average value represented by the solid line 170 of Fig. 6A, for example. Thus, a predetermined negative bias is placed on the grid of the control tube 1CT⁷, for example, which prevents that tube from becoming conductive regardless of the potential on its anode. The low capacity tube 1LT⁷ does not become conductive until the potential on its anode reaches a predetermined value, as represented by the line 169 intersecting the curve 167 in Fig. 6A, and when this low capacity 1LT⁷, for example, becomes conductive, it supplies current to the direct current load through the resistor 1R⁷. This load current causes a potential drop across the terminals of the resistor 1R⁷ which is positive with respect to the negative bias on the grid of the control tube 1CT⁷ and is subtracted therefrom to form a curve 112 in Fig. 6A. Assuming that the load is relatively low, this reduction in the negative bias on the grid of the control tube 1CT⁷ does not intersect the dotted line curve 171 indicating the critical values of grid bias at which such tube 1CT⁷ will become conductive.

It will be noted that the curve 112 extends between the lines 184 and 185 making the curve 112 of Fig. 6A slightly longer than the curve 72 of Fig. 3A. In other words, this curve 112 extends throughout the conductive period of the low capacity tube 1LT⁷ as determined by the minimum voltage on its anode at which it will become conductive. With respect to Fig. 3A, the curve 72 is made shorter because of the characteristics of the three-phase system, for reasons pointed out in connection therewith. This difference in operation is the main difference between the systems of Fig. 7 and Fig. 1 with the exception that the firing potentials for the excitation circuits in Fig. 7 are provided through a phase shifting device PS and an associated transformer 104.

It will be noted that the successive Figs. 6B, 6C and 6D represent different load values which will cause the high capacity tube 1HT⁷, for example, to be fired at different points in the positive half-cycles of phase one. These will not be explained in detail, but reference should be made to Fig. 6D, for example, to note that an extremely heavy load will cause the high capacity tube 1HT⁷, for example, to be conductive throughout the portion of the positive half-cycle of the phase one between the points where the line 169 inter-

sects the curve 167. In other words, the tubes 1LT⁷ and 1HT⁷ have substantially the same starting characteristics, that is, the minimum anode voltage at which they will become conductive is approximately 20 volts, for example, as represented by the line 169 of Fig. 6, so that regardless of the value of the high load current to be supplied, the control tube 1CT⁷, for example, cannot be triggered off by a rise in potential on its grid to allow the flow of a start pulse prior to the time that there is a sufficient potential on the anode of the high capacity tube 1HT⁷ for it to become conductive.

But if the load level is above a predetermined value when the tube 1LT⁷ becomes conductive, the grid bias for the control tube 1CT⁷ at once changes to a tripping value for initiating a start pulse, and the high capacity tube 1HT⁷ becomes conductive after a few micro-seconds. The conductivity of the high capacity tube 1HT⁷ shunts the resistor 1R⁷ and the tube 1LT⁷ so that the grid bias on the control tube 1CT⁷ is restored to its normal negative value. The potential on the anode of the control tube 1CT⁷ is reduced to substantially zero at the end of the start pulse in the excitation circuit of the high capacity tube 1HT⁷, so that the negative grid again obtains control of the control tube 1CT⁷ to prevent any follow through current in the excitation circuit after the initial start pulse for that particular positive half-cycle of the principal potential. The load current is carried by the low capacity tube 1LT⁷ for the few micro-seconds between its becoming conductive and the becoming conductive of the high capacity tube 1HT⁷, but this heavy load for a few micro-seconds does not harm the low capacity tube because of the very duration of such demand, and because of the fact that such current is limited by resistor 1R well below the maximum allowable current for tube 1LT⁷.

It will be readily apparent that each of the phases of Fig. 7 operate in the same manner, but inasmuch as their principal potentials are separated by 180°, there is no limiting effect of one phase upon the other with respect to the time at which the other phase may become effective to carry the load, as explained in connection with the three-phase rectifier system of Fig. 1. Thus, the disclosure of Fig. 7 shows how the principles of the present invention may be embodied in a double-wave rectifier for single phase alternating currents.

It is noted that limiting reactors 1LR⁷ and 2LR⁷ are employed in place of the limiting resistors 1LR and 2LR of Fig. 1, but it is to be understood that resistors may be employed in Fig. 7 if desired and similarly reactors may be employed in Fig. 1 in place of resistors if desired.

The operation of the control relays for determining the time at which potentials may be applied to the anodes of the tubes, the overload protection, and the like, is the same as described in connection with Fig. 1.

This form of the invention disclosed in Fig. 7 shows what is termed as a double-wave rectifier for single phase alternating currents, but it is to be understood that a half-wave rectifier might be provided without departing from the principles and scope of the present invention as disclosed in this Fig. 7.

In considering the graphs of Figs. 2, 3A, 3B, 3C, 4, 5, 6A, 6B, 6C and 6D, it should be understood that these graphs are not drawn to the

scale of any set value, but have been drawn to merely graphically represent what is believed to be the relationships between the different potentials involved in the operation of the systems of the present invention. Thus, the assigning of specific values to an actual embodiment of the invention would of course determine the relative shapes and sizes of the different curves and positions of the lines in the graphs, but such changes and variations are to be considered to be merely engineering equivalents and not an alteration of the principles underlying the invention.

Having described two forms of a rectifier system as specific embodiments of the present invention, it is to be understood that these forms have been selected to facilitate in the disclosure of the invention rather than to limit the number of forms which it may assume; and it is further understood that various modifications, adaptations and alterations may be applied to the specific form shown to meet the requirements of practice, without in any manner departing from the spirit or scope of the present invention except as limited by the appended claims.

What we claim is:

1. In combination, an alternating current supply circuit, a main electric discharge device having anode and a cathode with an ignitor element associated with said cathode, an auxiliary electric discharge device having an anode and a cathode, circuit means for connecting the anodes and cathodes of said electric discharge devices in multiple in a manner to supply unidirectional currents to a load circuit from said supply circuit whereby said auxiliary electric discharge device normally transfers relatively small currents to the load circuit and said main electric discharge device transfers relatively large currents to said load circuit when it is rendered conductive, an excitation circuit connected between the cathode and the ignitor element of said main electric discharge device and including a control electric discharge device having an anode, a cathode and a control grid for transmitting a unidirectional impulse of current to said ignitor element to render said main electric discharge device conductive each time said grid is energized at a critical value, and means for energizing said grid at a critical value for each positive half-cycle of potential applied to the anodes of said main and auxiliary discharge devices during which the load current rises above a predetermined value.

2. In combination, an alternating current supply circuit, a load circuit, electric translating apparatus connected between said circuits to supply said load circuit with direct current and comprising, a main electric valve having an anode, a cathode and an emersion-ignitor control member in contact with said cathode for transferring relatively large currents from said supply circuit to said load circuit when rendered conductive, an auxiliary electric valve having an anode and a cathode in multiple with the anode and cathode of said main electric valve for normally transferring relatively small currents from said supply circuit to said load circuit, an excitation circuit connected between the ignitor control member and the cathode of said main electric valve for rendering said main valve conductive upon its energization by a start pulse, and control means governed in accordance with the load current supplied by said auxiliary electric valve for effecting the transmission of a momentary start pulse of

unidirectional current through said excitation circuit to render said main electric valve conductive for each positive half-cycle of said alternating current supply circuit in which the load current supplied by said auxiliary electric valve rises above a predetermined value.

3. In combination, an alternating current supply circuit, a load circuit, electric translating apparatus connected between said circuits to supply said load circuit with direct current, said translating apparatus comprising, a main electric valve having an anode, a cathode and an emersion-ignitor control member in contact with said cathode for transferring relatively large currents from said supply circuit to said load circuit when rendered active, a minor electric valve having an anode and a cathode in multiple with the anode and cathode of said main electric valve for normally transferring relatively small currents from said supply circuit to said load circuit, an excitation circuit connected between the ignitor control member and the cathode of said main electric valve for rendering said main valve active upon its energization by a start pulse, and separate electronic control means for at times supplying a momentary start pulse to said excitation circuit, whereby said main electric valve is rendered active to supply the current to the load circuit and said minor electric valve is shunted by said main electric valve.

4. In combination, an alternating current supply circuit, an electric valve having an anode and a cathode of the heated type connected with said alternating current supply circuit to a load circuit in a manner to normally supply unidirectional currents to said load circuit at a relatively low load level, a heavy duty electric discharge device having an anode, a cathode, and an emersion-ignitor control member in contact with said cathode and so connected between said alternating current supply circuit and said load circuit as to supply uni-directional currents at a relatively high current level when said control member is rendered active, a resistor unit connected in series with said electric valve and said load circuit but not in series with said heavy duty electric discharge device, and control circuit means for supplying a start pulse to said emersion-ignitor control member for each positive half-cycle of alternating current in which the level of the load for that half-cycle rises above a predetermined value, said control circuit means being governed in accordance with the potential drop across said resistor unit.

5. In combination, an alternating current supply circuit, a main electric discharge device having an anode and a cathode with an ignitor element associated with said cathode, an auxiliary electric discharge device having an anode and a cathode, circuit means for connecting the anodes and cathodes of said electric discharge devices in a multiple combination, said multiple combination being connected in series with a direct current load circuit to said alternating current supply circuit, whereby said auxiliary electric discharge device normally supplies a relatively small direct current to the load circuit, an excitation circuit connected between the cathode and the ignitor element of said main electric discharge device and including a control electric discharge device having an anode, a cathode and a grid for transmitting a uni-directional impulse of current to said ignitor element to render said main electric discharge device conductive when said grid is energized at a critical value, means

for normally negatively energizing said grid to render said control electric discharge device non-conductive, and means for decreasing the negative bias on said grid in accordance with the load supplied by said auxiliary electric discharge device in a manner to render said control electric discharge device conductive during each positive half-cycle of potential applied to said main electric valve during which the direct current load supplied by said auxiliary electric discharge device rises above a predetermined value, whereby said auxiliary and said main electric discharge devices are selectively rendered active during each positive half-cycle of alternating current in accordance with the level of the load for that half-cycle.

6. In combination, an alternating current supply circuit, an electric valve of the mercury vapor type having an anode and a heated cathode connected between said alternating current supply circuit and a load circuit for supplying unidirectional current to said load circuit at a relatively low current level, an electric discharge device having an anode and a cathode with an emersion-ignitor control member in contact with said cathode, said anode and said cathode being connected in multiple with the anode and cathode of said electric valve so as to supply when rendered active uni-directional currents from said alternating current supply circuit to said load circuit at a relatively high current level, a resistor unit connected in series with said electric valve so as to have a potential drop across its terminals in accordance with the relatively low current level, an excitation circuit including a control electric valve having an anode and a cathode with a controlling grid, said anode and cathode being included in said excitation circuit to supply a start pulse to said emersion ignitor control member each time said grid is energized at a critical value, and control circuit means for said grid including said resistor element so connected as to energize said grid at said critical value whenever the low level load current through said resistor unit rises above a predetermined value, whereby said electric discharge device is rendered active during each positive half-cycle of alternating current during which the load level rises above a predetermined value to thereby supply the relatively high currents required for the load and at the same time to shunt said electric valve and said series resistance unit to provide overcompounded voltage regulation.

7. In combination, an alternating current supply circuit, a load circuit, an electric valve of the mercury vapor type having an anode and a heated cathode connected in series with a resistor unit in a manner to transfer relatively low currents from said alternating current supply circuit to said load circuit, a heavy duty electric discharge device having an anode, a cathode and an emersion-ignitor control member in contact with said cathode, and said anode and cathode being connected in multiple with said electric valve and series resistor in a manner to transfer relatively high currents from said supply circuit to said load circuit when said control member is rendered active, a control electric valve of the mercury vapor type having an anode and a heated cathode with a controlling grid, circuit means including an impulse supplying condenser, connecting the anode and cathode of said control valve in series with said emersion-ignitor control member and its associated cathode, cir-

cuit means for supplying an alternating current potential across said condenser having an advanced phase relationship with respect to the alternating current phase of said supply circuit, and circuit means for governing the biasing potential on said control grid in accordance with the potential drop across said resistor, whereby said electric discharge device is rendered active by a start pulse being passed through its emersion ignitor control member near the beginning of each positive half-cycle of alternating current applied to the anode of said electric valve and the anode of said electric discharge device in which the current through said electric valve rises above a predetermined level, said start pulse being of an effective value because of the advanced phase of the potential supplied to said condenser.

8. In combination, a three-phase alternating current supply, a load circuit, electric translating apparatus connected between said three-phase alternating current supply and said load circuit in a manner to provide uni-directional current in said load circuit, said translating apparatus comprising for each phase, an electric valve having an anode and a cathode of the heated type, an electric discharge device having an anode and a cathode with an associated emersion-ignitor control member, a control electric valve having an anode a heated cathode and a control grid, circuit means for connecting the anode and cathodes of said electric valve and said discharge device in multiple in a manner to transfer uni-directional current from its phase of alternating current supply to said load circuit, said electric valve being normally active and said discharge device being active only when supplied with a start pulse through said emersion-ignitor control member, excitation circuit means including said anode and cathode of said control electric valve connected in series with an impulse supplying condenser in a manner to provide a start pulse for said emersion-ignitor control member each time said control grid is energized at a critical value, circuit means for supplying a potential across said impulse condenser from the following phase of the supply circuit advanced 180° by a transformer, circuit means normally providing a negative bias on said control grid from the potential of said load circuit, and circuit means arranged to reduce the negative bias on said control grid in accordance with the load supplied by said electric valve of the associated phase so as to energize said grid at said critical value when the current through said electric valve rises above a predetermined value.

9. In combination, an alternating current supply circuit, a low capacity electric valve having an anode and a cathode of the heated type connected with said alternating current supply circuit to a load circuit in a manner to normally supply unidirectional currents to said load circuit at a relative low load level, a high capacity electric discharge device having an anode, a cathode and an emersion-ignitor control member in contact with said cathode, said high capacity electric discharge device being connected in multiple with said low capacity electric valve for at times supplying unidirectional current at a relatively high current level when said control member is rendered active, a resistor unit connected in series with said low capacity electric valve only, and control circuit means including a separate grid controlled electric valve for supplying a single start pulse of relatively short

duration near the beginning of each positive half-cycle of alternating current in which the potential drop across said resistor rises above a predetermined value, said single start pulse being in the order of a few micro-seconds.

10. In combination, an alternating current supply circuit, a load circuit, an electric valve of the mercury-vapor type having an anode and a heated cathode connected in series with a series resistor unit in a manner to transfer relatively low currents from said alternating current supply circuit to said load circuit, a high capacity electric discharge device having an anode, a cathode, and an emersion-ignitor control member in contact with said cathode, and said anode and cathode being connected in multiple with said electric valve and series resistor in a manner to transfer relatively high currents from said supply circuit to said load circuit when said control member is rendered active, and acting when thus conductive to effectively short-circuit said electric valve and series resistor, a control electric valve of the mercury-vapor type having an anode and a heated cathode with controlling grid, circuit means including an impulse supplying condenser connecting the anode and cathode of said control electric valve in series with said emersion-ignitor control member and its associated cathode, circuit means for supplying an alternating current potential across said condenser having an advanced phase relationship with respect to the alternating current phase of said supply circuit and including a limiting resistor, and circuit means for governing the biasing potential on said control grid in accordance with the potential drop across said series resistor, whereby said electric discharge device is rendered active by a single start pulse being passed through its emersion-ignitor control member near the beginning of each positive half-cycle of alternating current applied to the anode of said electric valve and the anode of said electric discharge device whenever the current through said electric valve rises above a predetermined level, said start pulse being of an effective value and of relatively short duration because of the restoration of the normal negative bias on the grid of said control tube as soon as said electric discharge device becomes conductive and effectively short-circuits said series resistor.

11. In combination, a single-phase alternating current supply circuit, a load circuit, a transformer having its primary connected to said single-phase alternating current supply and its secondary provided with a mid-tap to supply two different phase potentials separated by 180°, electric translating apparatus connected between said two different phase alternating current potentials and said load circuit in a manner to provide unidirectional current in said load circuit, said translating apparatus comprising for each phase, an electric valve having an anode and a cathode of the heated type, an electric discharge device having an anode and a cathode with an associated ignitor member, a control electric valve having an anode and a heated cathode with a control grid, circuit means for connecting the anodes and cathodes of said electric valve and said discharge device in multiple in a manner to transfer uni-directional current from its phase of alternating current to said load circuit, said electric valve being normally active and said discharge device being rendered active only when supplied with a start pulse through its ignitor control member, excitation circuit means including said anode and cathode of said control elec-

tric valve connected in series with an impulse supplying condenser in a manner to supply a start pulse for said emersion-ignitor control member each time said grid is energized at a critical value, circuit means normally providing a negative bias on said control grid from the potential of said load circuit, circuit means arranged to reduce the negative bias on said control grid in accordance with the load supplied by said electric valve of the associated phase so as to energize said grid at said critical value when the current through said electric valve rises above a predetermined value, and a phase shifting device and an associated transformer supplied with alternating current from one of said phases and arranged to apply a potential across said impulse condenser for each phase with a potential advanced with respect to that associated phase to thereby cause the potential for said start pulse for each phase to be advanced approximately 30° with respect to the potential of the principal potential of the associated phase.

12. In combination, an alternating current supply circuit, a load circuit, an electric valve of the mercury vapor type having an anode and a cathode connected in series with a series resistor unit in a manner to transfer relatively low currents from said supply circuit to said load circuit, a heavy duty electric discharge device having an anode, a cathode and an emersion-ignitor control member in contact with said cathode, said anode and cathode of said discharge device being connected in multiple with said electric valve and series resistor in a manner to transfer relatively high currents from said supply circuit to said load circuit when said electric discharge device is rendered active, an excitation circuit connected between the cathode and control member of said electric discharge device for transmitting a start pulse of current to said control member for each successive positive half-cycle of alternating current applied to the anodes of said electric valve and said electric discharge device to render said electric discharge device conductive, said start pulse for any given positive half-cycle occurring at a point in that half-cycle determined in accordance with the load current transmitted for that positive half-cycle through said electric valve in a manner to cause said point to occur earlier in any positive half-cycle with an increase in the load current, whereby said electric valve and series resistor is shunted by the conductivity of said electric discharge device to thereby cause an increase in the voltage of the current supplied to said load, and whereby said series resistor protects said electric valve from excessive loads on any positive half-cycle prior to the rendering conductive of its associated heavy duty discharge device.

13. In combination, an alternating current circuit, a load circuit, an electric valve of the mercury vapor type having an anode and a cathode connected in series with a resistor unit in a manner to transfer relatively low currents; a heavy duty electric discharge device having an anode, a cathode and an emersion-ignitor control member in contact with said cathode, and said anode and cathode being connected in multiple with said electric valve and series resistor in a manner to transfer relatively high currents from said supply circuit to said load circuit when said electric discharge device is rendered active, an excitation circuit connected between cathode and control member of said electric discharge device for transmitting a start pulse of current to said

control member to render said electric discharge device conductive at a point in the positive half-cycle of alternating current applied to the anode of said electric valve and said electric discharge device, said point determined by the load current transmitted to load through said electric valve and series resistor, in such a manner to cause said point to occur earlier in the positive half-cycle with increase in said load current, said electric valve and resistor being shunted out by said electric discharge device earlier with increase in load thereby resulting in a rise in load voltage.

14. In a rectifier system, an alternating current supply circuit, a main electric discharge device having an anode and a cathode with an ignitor element associated with said cathode, an auxiliary electric discharge device having an anode and a cathode, a resistor unit, circuit means for connecting said anodes of said devices to one terminal of said alternating current supply and for connecting the cathode of said auxiliary electric discharge device through said resistor to the cathode of said main electric discharge device and then to one terminal of a direct current load circuit, said circuit means also connecting said other terminal of said alternating current supply to the other terminal of the direct current load circuit, whereby said auxiliary electric discharge device normally is capable of supplying uni-directional current to the load circuit through said resistor from said alternating current supply circuit, and excitation circuit means governed by the potential drop across said resistor for supplying a momentary impulse of current to said ignitor element of said main electric discharge device for each positive half-cycle of said alternating supply during which the current in said resistor rises above a predetermined value, whereby said main electric discharge device supplies current to the load circuit and shunts said auxiliary electric discharge device and said resistor at that point in each positive half-cycle of alternating current in which the current through said resistor flowing to said load circuit rises above a predetermined value.

15. In a rectifier system, an alternating current supply circuit, a low capacity electric valve having an anode and a cathode of the heated type connected between said alternating current supply circuit and a load circuit in a manner to normally supply uni-directional current to said load circuit at a relatively low load level, a high capacity electric discharge device having an anode, a cathode and an ignitor control member, said anode and cathode of said discharge device being connected in multiple with said low capacity electric valve and a resistance unit in series with said low capacity electric valve, a separate grid controlled electric valve for supplying a single start pulse of a few micro-seconds duration to said ignitor control member when its grid is energized at a critical potential, and circuit means for energizing said grid of said grid controlled electric valve in accordance with the potential drop across said resistor, whereby such grid is energized at said critical value at that point in each positive half-cycle applied to the anodes of said low capacity electric valve and said high capacity discharge device at which the current supplied by said low capacity electric valve rises above a predetermined value.

16. In a rectifier system, a low capacity electric valve and a high capacity electric discharge device connected in multiple between an alter-

nating current supply circuit and a load circuit, said low capacity electric valve being normally active and said high capacity electric valve requiring the energization of an excitation circuit in order to be rendered active, and circuit means automatically acting to energize the excitation circuit of said electric discharge device at different points in the positive half-cycles of alternating current applied to said electric valve and said discharge device in accordance with the power requirements of said load circuit, said means being governed in accordance with the current flow through said low capacity electric valve at the beginning of each such positive half-cycle, whereby over-compounded voltage regulation is provided for said load circuit.

17. In a rectifier system, an alternating current supply circuit, an electric discharge device of the mercury-arc type connected to a load circuit and having a control member which must be energized during each positive half-cycle of alternating current in order for said device to be rendered conductive, and means for automatically energizing the control member of said electric discharge device at different points in the positive half-cycles applied to said device in accordance with the impedance of said load circuit, said means including a low capacity electric valve for supplying the initial load at the beginning of each positive half-cycle through a series resistor to test the impedance of said load circuit, whereby automatic voltage regulation is provided for said load circuit.

18. In a rectifier system, an electric discharge device of the ionizable gaseous type connected between an alternating current supply and a direct current load circuit to allow the flow of uni-directional current to said load circuit and having an ignitor member which must be energized for a few micro-seconds during each positive half-cycle of alternating current in order for said discharge device to be rendered conductive for the remainder of that half-cycle, and means for automatically energizing the ignitor member of said electric discharge device at different points in the positive half-cycles applied to said device in accordance with the impedance of said load circuit comprising, a low capacity electric valve and a series resistor connected in multiple with said electric discharge device for supplying the initial load at the beginning of each positive half-cycle of alternating current, and circuit means governed by the voltage drop across said resistor due to the value of the current supplied by said low capacity electric valve at the beginning of each positive half-cycle for determining the point in that positive half-cycle at which a momentary impulse of energy is supplied to said ignitor element.

19. In a rectifier system, an alternating current supply circuit, an electric discharge device of the mercury-arc type connected between said supply circuit and a load circuit, said discharge device having a control member which must be momentarily energized during each positive half-cycle of alternating current in order for said device to

be rendered conductive, and means, including a resistor and a low capacity electric valve for supplying a current pulse through said load circuit near the beginning of each positive half-cycle of alternating current, for automatically energizing the control member of said electric discharge device at different points in the positive half-cycles of alternating current applied to said device in accordance with the voltage drop across said resistor during said current pulse, to thereby render said electric discharge device conductive at different points in the positive half-cycles of alternating current dependent upon the impedance of the load circuit for those half-cycles since the voltage drop across said resistor during each current pulse near the beginning of a positive half-cycle is a measure of the load impedance for that positive half-cycle of alternating current.

20. In a rectifier system, an alternating current supply circuit, a series resistor, a low capacity valve having an anode and a cathode connected in series with said resistor between said supply circuit and a load circuit in a manner to normally supply uni-directional current to said load circuit at a relatively low load level, a high capacity electric discharge device having an anode, a cathode and an ignitor control member, said anode and cathode of said discharge device being connected in multiple with said low capacity electric valve and said series resistor between said supply circuit and said load circuit, and means for at times supplying momentary start pulses to said ignitor control member at selected points in the positive half-cycles of alternating current, said means including a grid controlled electric valve of the gaseous type, excitation circuit means for connecting said ignitor control member in series with the anode of said control electric valve and in series with a condenser and an inductance, means for charging said condenser through a limiting resistor, and circuit means normally providing a negative bias on the grid of said grid controlled electric valve, which bias is controlled in accordance with the potential across said series resistor to reduce said negative bias to select the point in the cycle at which said control electric valve is rendered conductive to discharge said condenser through said excitation circuit in accordance with the impedance of the load circuit, whereby said control grid is at times energized to initiate a pulse in said excitation circuit at selected points in the positive half-cycles depending on the load impedance, and whereby the negative bias of said control grid is restored to normal upon the rendering conductive of said discharge device to terminate said pulse in the excitation circuit when said condenser becomes discharged and the potential on the anode of said control tube is reduced to substantially zero by reason of the inclusion of said inductance in series with said condenser and by reason of the inclusion of said limiting resistor in said means for charging said condenser.

HARRY H. SEIFERT,
WILLIAM W. SEIFERT.