

Yamachi et al.

[45] **Aug. 15, 1972**

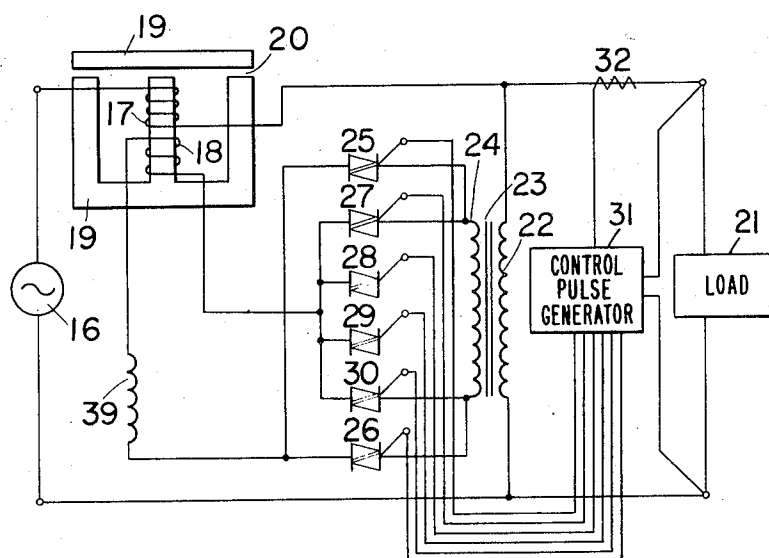


FIG. 1

PRIOR ART

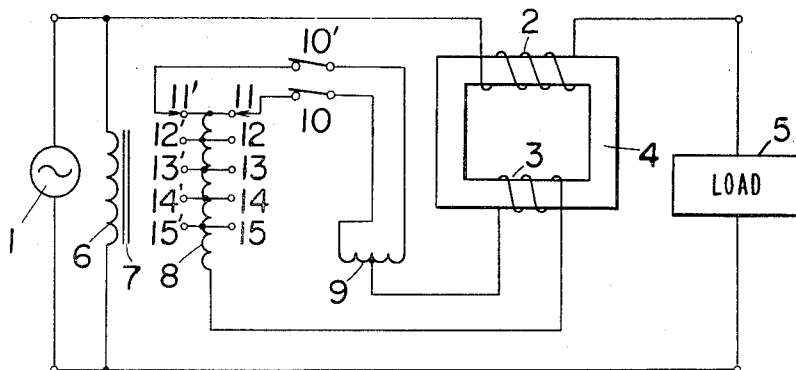


FIG. 2a

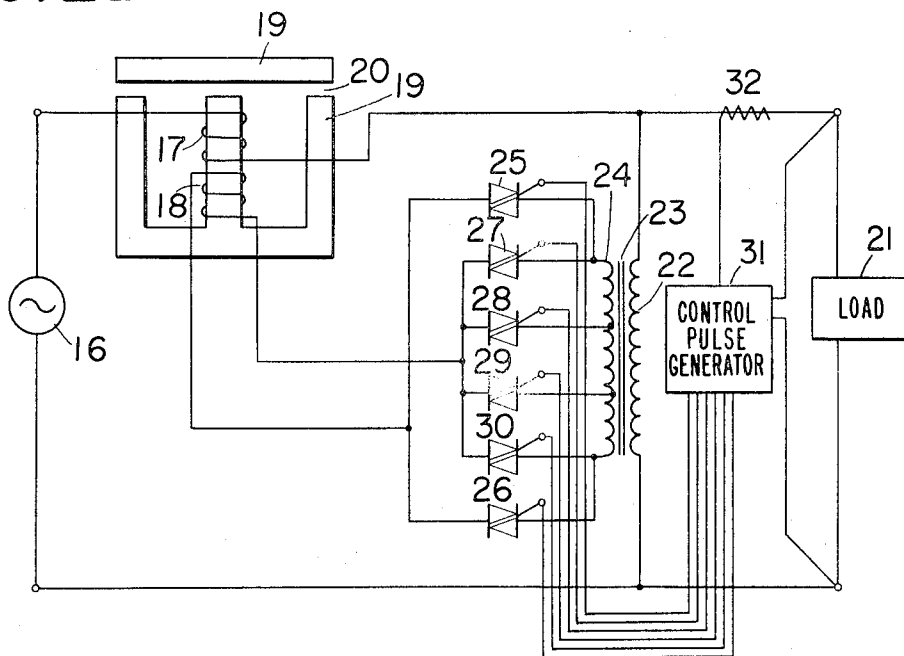


FIG. 3

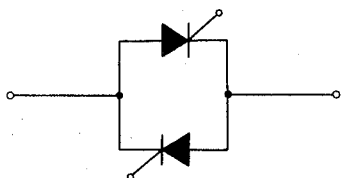
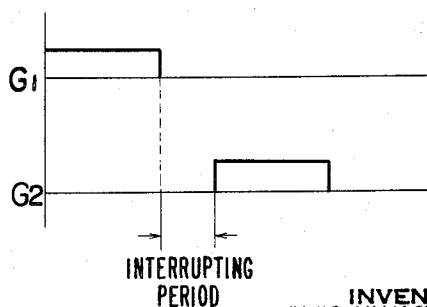


FIG. 4



INVENTOR
YUKIO YAMACHI
HIROHIKO FUJII
BY HIROSHI KOSUGE
KOICHI MORITA

Asakura, Kubo, Kato & Saito
ATTORNEYS

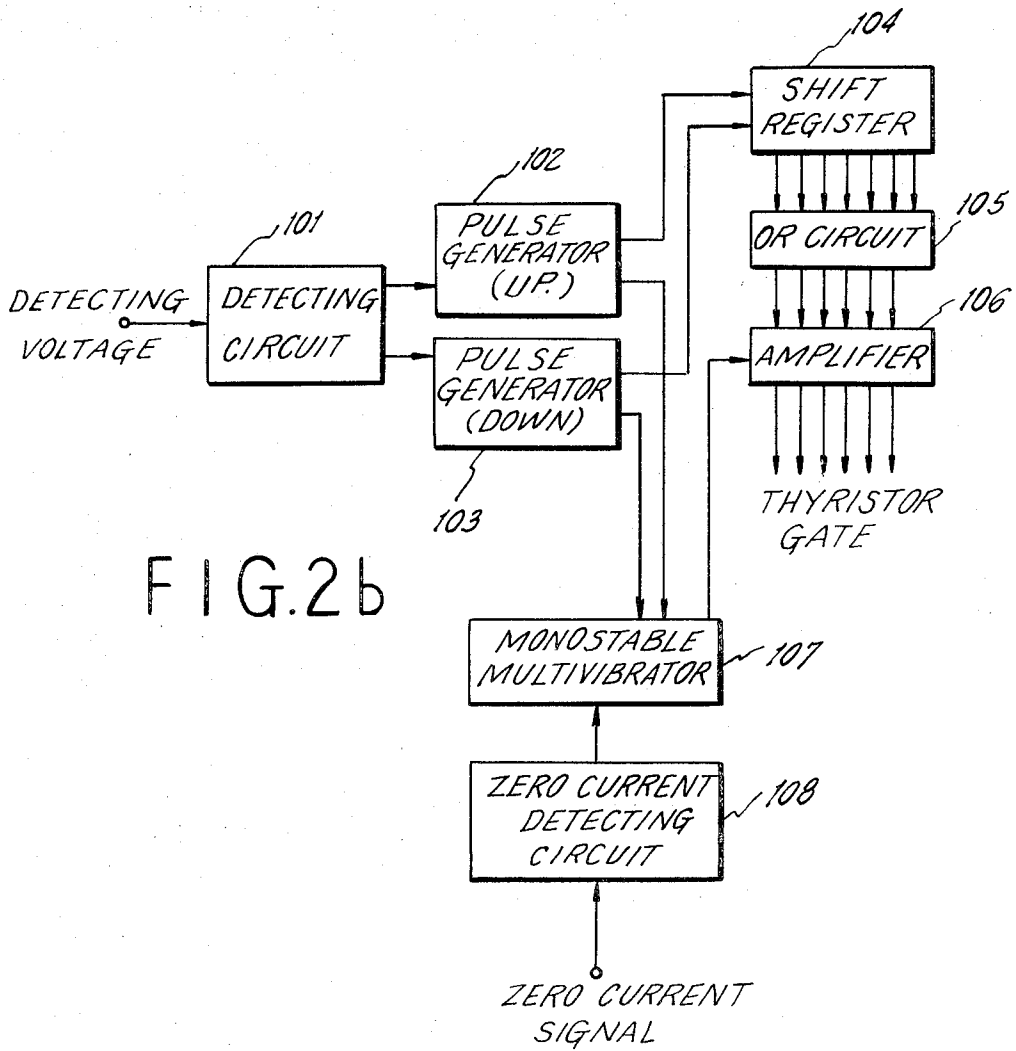


FIG. 5

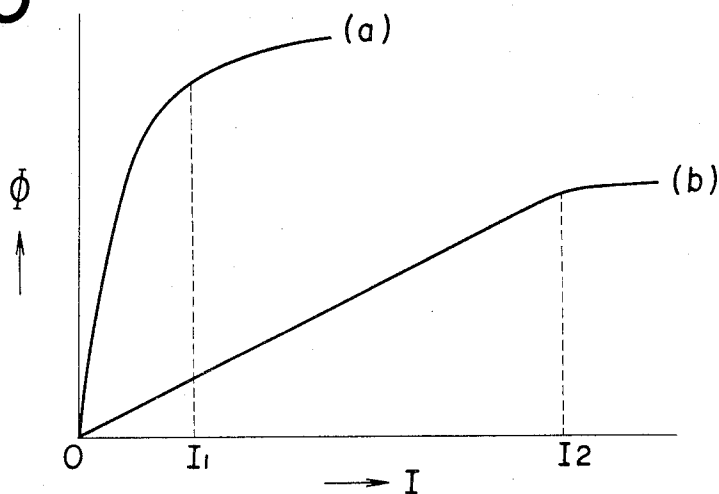


FIG. 6a

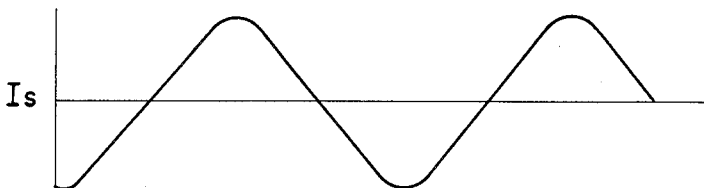


FIG. 6b

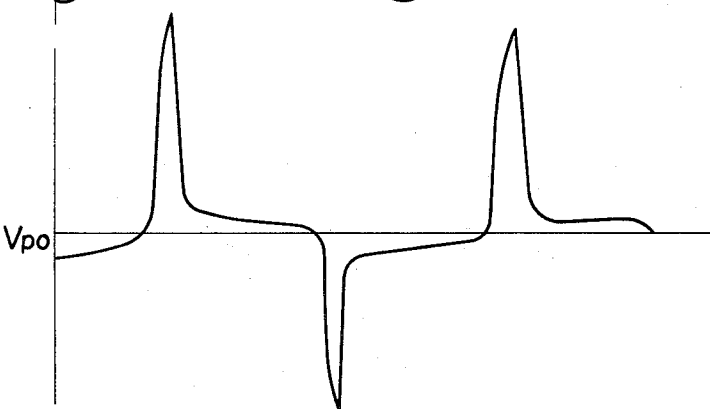
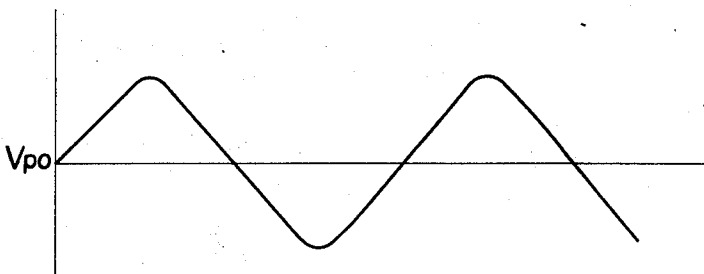


FIG. 6c



INVENTOR
YUKIO YAMACHI
HIROHIKO FUJII
BY HIROSHI KOSUGE
KOICHI MORITA

Ostrolenk, Faber, Gerbasi & Hoffman
ATTORNEYS

FIG. 7

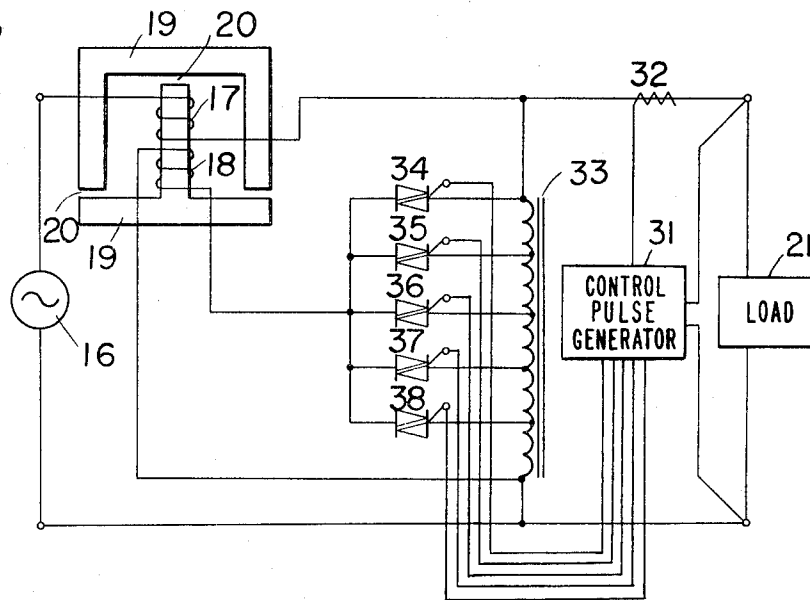


FIG. 8

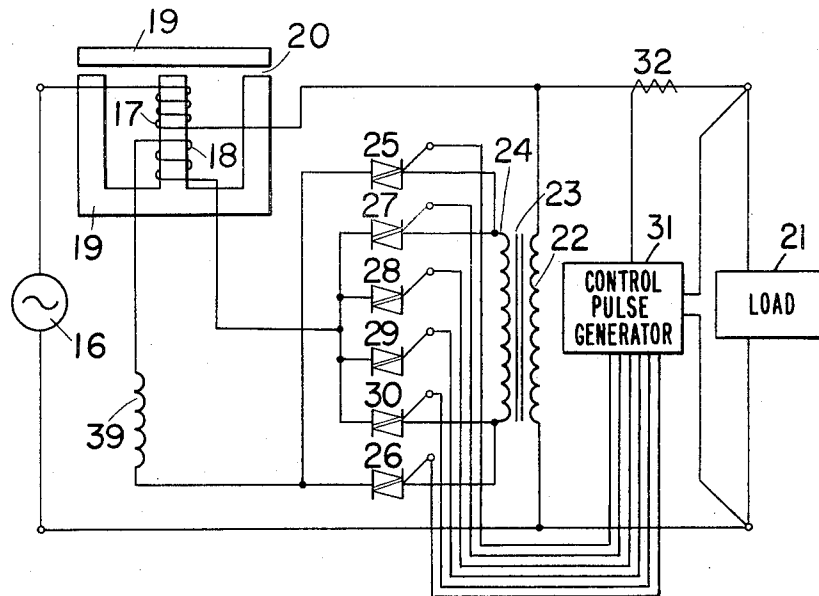
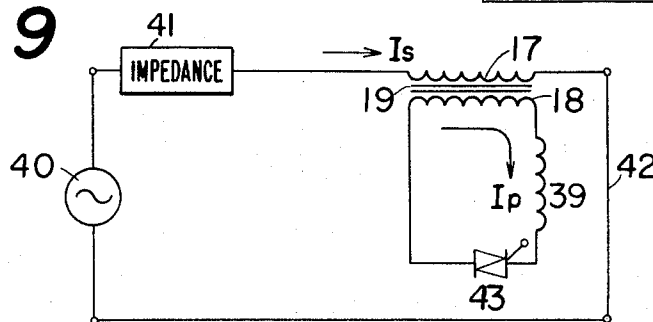


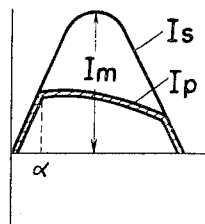
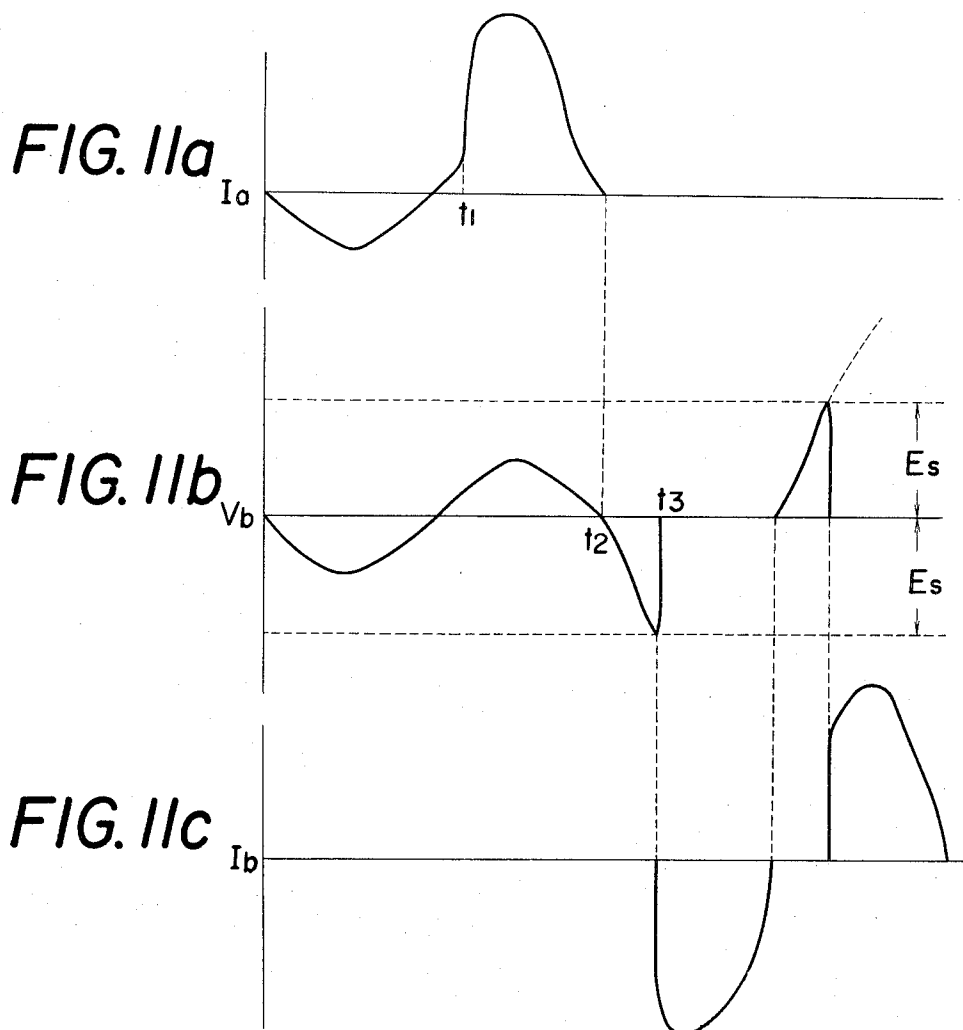
FIG. 9



INVENTOR
YUKIO YAMACHI
HIROHIKO FUJII
HIROSHI KOSUGE
BY KOICHI MORITA

Osakabe, Faber, Lott & Hoffman
ATTORNEYS

FIG. 10



INVENTOR
YUKIO YAMACHI
HIROHIKO FUJII
HIROSHI KOSUGE
BY KOICHI MORITA

Ostrolenk, Faber, Lieb & Hoffman
ATTORNEYS

FIG. 12

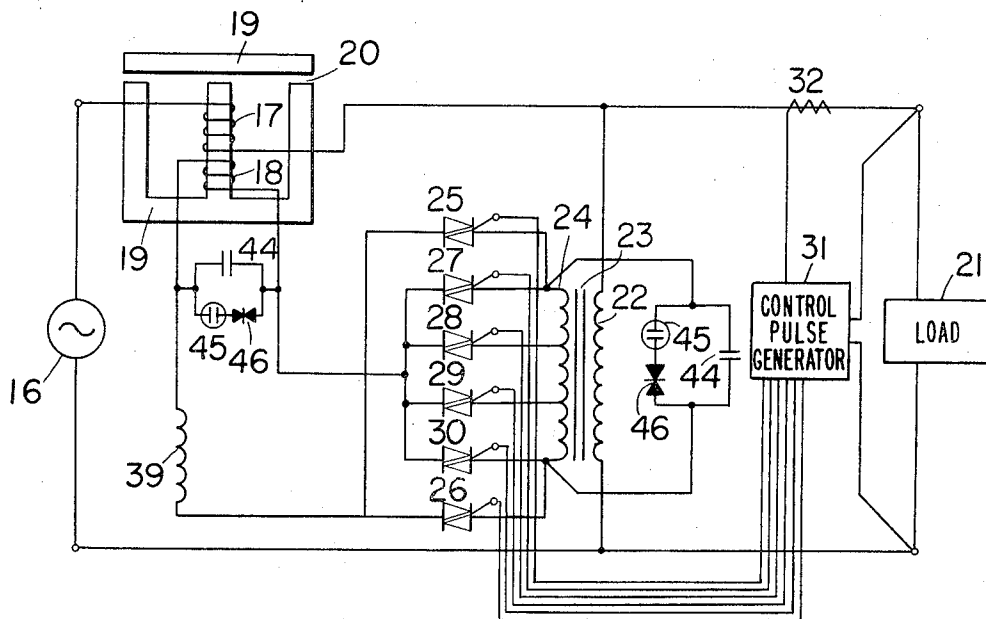


FIG. 13a

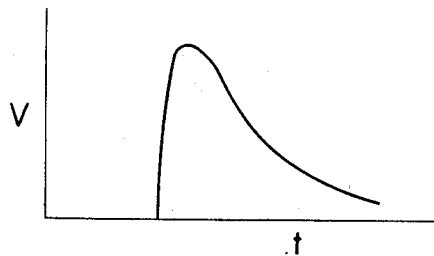
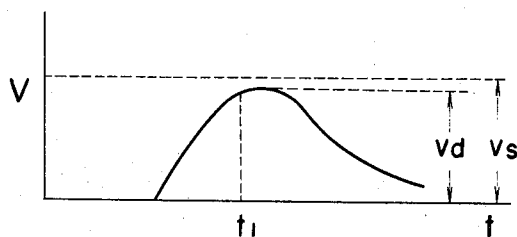


FIG. 13b



INVENTOR
YUKIO YAMACHI
HIROHIKO FUJII
HIROSHI KOSUGE
BY KOICHI MORITA

Ostrolenk, Haber, Lieb & Saffren
ATTORNEYS

VOLTAGE REGULATOR UTILIZING THYRISTOR SWITCH MEANS

This application is a continuation-in-part of copending application, Ser. No. 707,079 filed Feb. 21, 1968, now abandoned.

This invention relates to a voltage regulator, and more particularly to the type in which a transformer is connected in series with an a.c. power line and the output voltage of the transformer (hereinafter called a series transformer) is superposed on the input voltage of the a.c. circuit, whereby the output voltage from this circuit is allowed to be regulated.

Heretofore, a voltage regulator having such a series transformer is well known, and FIG. 1 of the attached drawing illustrates a circuit diagram of the conventional voltage regulator which is operable during the loaded condition. In FIG. 1, a series transformer is connected with an a.c. power line extending from the power source 1 and the series transformer is composed of the secondary winding 2, primary winding 3, and the iron core 4. The voltage induced across the secondary winding 2 is superposed on the input voltage from the power source 1, and the resultant output voltage is furnished to a load 5. With this arrangement, the induced voltage in the secondary winding 2 can be varied by changing the voltage applied on the primary winding 3 of the series transformer, and this voltage can be changed by the use of a separate exciting transformer having primary winding 6, iron core 7, and a secondary winding 8 and connected in parallel with the a.c. line. Taps 11, 11', 12, 12', 13, 13', 14, 14', 15, 15', are provided on the secondary winding 8 of the exciting transformer, and with these taps changed from one to another the induced voltage in the series transformer can be changed. When the tap connection is desired to be changed, a switch 10 is at first opened and the connection is transferred from tap 11 to tap 12, whereupon the local current created in the circuit is limited by a current limiting reactor 9. Then the switch 10' is opened and the connection is shifted from tap 11' to tap 12' at no load condition. Upon completion of the transferring of the taps, current will be flown from these circuits through the current limiting reactor 9. However, because the direction of these currents are reversed relative to one another, magnetic fluxes induced therein cancel each other, and there is thus no disadvantageous effect to the series transformer.

In this kind of the conventional voltage regulator, since mechanical contacts are utilized, much difficulties were experienced in maintenance and operation, rendering this kind of construction utterly unsuitable for the voltage regulator.

In recent time, various thyristors such as reverse blocking triode thyristors, bidirectional triode thyristors, bi-directional diode thyristors, and so on have been developed, and many of the mechanical switches in various applications are replaced by these electronic switches.

In some of the applications, mere replacement of the mechanical switches by these electronic switches will render reasonably good results. However, in other cases where thyristors are utilized, for instance, in the voltage regulator as in the case of the present invention, wherein the output voltage of the series transformer is superposed on the input voltage from the a.c.

power line, some difficult problems are encountered. The thyristors cannot be operated at more than their rated voltage and current. For this reason, sufficient care must be exercised to prevent the electronic switches from carrying abnormal voltage and current.

When the contactless tap changing circuit is utilized for the voltage regulator, each of the thyristors are connected in parallel. As this result, the voltage is always applied across the terminals of all of the thyristors, and if an abnormally high voltage is generated in this circuit, other thyristors than those to be operated at that moment might be brought into operation, with the subsequent loss of the operation of the voltage regulator. Moreover, when the taps of a transformer are transferred through these thyristors, should any of the two thyristors be operated simultaneously, a local current will flow through the circuit with resultant damages of these thyristors and others.

For this reason, parallel operation of two thyristors at the same time should by all means be avoided. Furthermore, when all of the thyristors are turned off abruptly, this means that one of the windings of the series transformer is disconnected, and high voltage will be induced in the winding just as the case of opened secondary winding of a current-transformer. These and other difficulties should be overcome in the application of thyristors to the voltage regulator, and the present invention is directed to the solution of this problem.

Accordingly, the primary object of the present invention is the provision of contactless voltage regulator utilizing thyristors and which is easy to maintain, provides good stability, and is particularly suitable for use on power distribution and transmission lines.

A second object of the present invention is to provide a voltage regulator in which the thyristors are protected from the over-current which may be present in the circuit.

A third object of the present invention is to provide a voltage regulator in which the thyristors are protected from abnormally high voltages which may be present in the circuit.

These and other objects of the present invention can be fulfilled by the following embodiments of the invention:

The first embodiment of the present invention is characterized in that a series transformer having an iron core of high excitation type with air-gaps is superposed on the a.c. power line; an excitation transformer is connected across the a.c. power line, secondary winding of which is connected to a plurality of taps which, in turn, are connected to associated thyristors; said thyristors being connected with the primary winding of said series transformer and operable in such a manner that the voltage applied to the primary winding of said series transformer is thereby adjusted to a desired value, and the output voltage from this voltage regulator can be regulated.

The second embodiment of the present invention is characterized in that said embodiment further includes an inductive reactance connected in series with the primary winding of the series transformer in which a high excitation type iron core is utilized.

The third embodiment of the present invention is characterized in that when an over current flows in the circuit of the first embodiment as a result of, for in-

stance, short-circuit in the load, the first half cycle of said over current is flown through the thyristor operating in the normal condition, but the next half cycle of the over-load current is once blocked off from all of the thyristors, because they are operated to their non-conductive state at that time, and when the voltage created across the thyristors exceeds a predetermined value, only some specific thyristors having larger capacity than others are rendered conductive, thus forming a closed circuit through the primary winding of the series transformer, whereby the over-current flows through these specific thyristors and the remaining thyristors are protected from the over current condition.

The fourth embodiment of the present invention is characterized in that, across the ends of the primary winding of the series transformer and the secondary winding of the exciting transformer, there is connected a capacitor in parallel with a series connected varister and a discharge tube, whereby the thyristors are protected from abnormally high voltage generated within the a.c. circuit.

These and other embodiments of the present invention will be more clearly understood from the following description when it is read with the accompanying drawing in which,

FIG. 1 is a circuit diagram of a conventional voltage regulator;

FIG. 2a is a circuit diagram of a voltage regulator according to the present invention;

FIG. 2b shows a block diagram of circuits included within the control pulse generator of FIG. 2a;

FIG. 3 is a diagram showing the connection of the thyristor;

FIG. 4 is a waveform diagram showing the control signal of the thyristor;

FIG. 5 shows the characteristic curve of the iron core of the transformer;

FIGS. 6a, 6b and 6c are waveform diagrams of the voltage induced in the primary winding of the series transformer;

FIG. 7 is a circuit diagram showing another embodiment of the present invention;

FIG. 8 is a circuit diagram showing still another embodiment of the present invention in which an inductive reactance is provided in the circuit;

FIG. 9 is a schematic diagram useful in explaining the operation of the circuit shown in FIG. 8.

FIG. 10 is a waveform diagram useful in explaining the current to be limited in the circuit of FIG. 8;

FIGS. 11a, 11b and 11c are waveform diagrams useful in explaining an embodiment provided with an over current protecting device according to the present invention; FIG. 12 is a circuit diagram of an embodiment of the present invention wherein an over voltage protecting circuit is provided;

FIGS. 12a, 12b, and 12c are waveform diagrams useful in explaining the over voltage protecting device used in FIG. 8.

FIGS. 13a and 13b are waveform diagrams useful in explaining the overvoltage protecting device used in FIG. 8.

Now referring to FIG. 2a which illustrates an embodiment of the present invention, electric power is furnished from an a.c. power source 16 to a load 21 through the secondary winding 17 of a series trans-

former. The series transformer comprises a primary winding 18, secondary winding 17, and an iron core 19. The iron core is of a high excitation type which includes air gaps 20 within the magnetic path, and the reason why this type of core is used will be explained later on.

The output voltage furnished to the load 21 can be adjusted to a desired value by varying the induced voltage in the secondary winding 17 of the series transformer, which is in turn varied by changing the voltage applied on the primary winding 18 of the series transformer. To change the voltage applied on the primary winding 18, an excitation transformer is connected across the a.c. circuit. The excitation transformer is composed of a primary winding 22, a secondary winding 24, and an iron core 23. A plurality of taps are provided on the secondary winding 24 of the excitation transformer and thyristors 25, 26, 27, 28, 29 30, are connected as shown with these taps. The input voltage of the primary winding 18 of the series transformer is applied through a pair of chosen thyristors which are connected in parallel, and the control of these thyristors is carried out by the application of a control signal obtained from a control pulse generator 31 to the gates of these thyristors, and this pulse generator 31 is so arranged that it can produce control pulses by detecting the output voltage of the a.c. power line and the line current by means of a current transformer 32.

Thyristors 25, 26 are utilized for reversing polarity of the voltage applied to the primary winding 18 of the series transformer, and thyristors 27, 28, 29, 30 are used for transferring the taps. The variation of the supply voltage to the primary winding 18 of the series transformer depending on the thyristors operated at that time is indicated in the following table with the assumption that the intermediate voltage between each of the taps of the secondary winding 24 of the excitation transformer is 90v.

Operating Thyristors Supply voltage

25, 30	-270V
25, 29	-180V
25, 28	-90V
26, 30	0
26, 29	+90V
26, 28	+180V
26, 27	+270V

Thus, a voltage depending on the ratio between the primary winding 18 and the secondary winding 17 of the series transformer is produced in the secondary winding 17, and this voltage is superposed on the input voltage 16 of the a.c. line so that a regulated output voltage of this device is obtained.

The control of thyristor is accomplished by means of signals from the control pulse generator 31. Said control pulse generator 31 consists of the circuits shown in detail in FIG. 2b.

The variation in voltage is detected by means of a detecting circuit 101. In accordance with the detected value, the thyristor to be controlled is selected and then it is conducted. When a line voltage is of the set value in the case of FIG. 2a, the thyristors 26 and 30 are actuated. If the line voltage drops, the tap should be stepped up, and therefore the pulse generator 102 is

caused to operate and applies a pulse to multistage, bidirectional shift register 104. The signal passes through an OR circuit 105 and an amplifier 106 and is applied to the gates of the thyristors 26 and 29. As a result, the line voltage varies. This variation is again detected by the detecting circuit 101. If this value is below the set value, the thyristors 26 and 28 are caused to operate. When the set value is reached, balancing is carried out.

When a line voltage is high, a pulse generator 103 is caused to operate and continues to operate until the set value is reached in the thyristors 25 and 28 and the thyristors 25 and 29 and the thyristors 25 and 30.

When the thyristors are to be changed over, an interrupting period is provided as shown in FIG. 4. In other words, when a command signal to change over the thyristors is received from the pulse generator 102 or 103, this signal is applied to a monostable multivibrator 107. By means of the signal from said monostable multivibrator 107, the application of trigger signal from the amplifier 106 to the thyristors gate is stopped.

Based on the above-described operation, the stoppage of the thyristor action is detected by means of a zero current detecting circuit 108 and then signals are applied to the monostable multivibrator 107 to permit the supply of trigger signal from the amplifier 106 to the thyristors gate.

In other words, an interrupting period is provided between a command signal from the pulse generator 102 or 103 for changeover of the thyristors and a zero current detecting signal.

The remarkable feature of the present invention is that the high excitation type iron core including air-gaps within the magnetic path is utilized for the series transformer. When the thyristors are operating at any one pair of positions indicated in the above table, if a thyristor, for instance, the operation of thyristor 27 is to be transferred to thyristor 28, and if the thyristor 28 is activated while the thyristor 27 is still operating, a local current is flown through the closed circuit formed through these thyristors 27, 28, and the resultant current may damage these thyristors. Though this damage might be prevented by the utilization of far larger size of the thyristors, this would surely be much too uneconomical.

For this reason, it is necessary that a certain interrupting period is provided between the gate signal G1 for the thyristor 27 and the gate signal G2 for the thyristor 28, so that the two thyristors 27, 28 are never operated at the same time. Provision of the interrupting period, however, causes open-circuit of the primary winding 18 of the series transformer. Besides, there are some other cases where all of the thyristors are required to be brought into inoperable state, and in all of these cases, the primary winding 18 of the series transformer is at the opened condition.

Now the operation of the series transformer when the primary winding 18 is at the opened state will be more closely examined. Supposing that an iron core of the ordinary characteristics as shown in FIG. 5 waveform (a) is utilized, and also a comparatively large current is flowing through the secondary winding of the transformer, then the series transformer operates just like a current transformer and a high voltage will be induced in the primary winding 18. This condition is in-

indicated in FIGS. 6a, 6b, and 6c. When a line current as indicated in FIG. 6 (a) flows through the a.c. circuit, the whole of this current operates as the excitation current for the series transformer and a high magnetic flux corresponding to this current will be created in the magnetic core. This is because the primary winding 18 is opened and no compensating flux can be induced in the magnetic path. As a result, a high voltage is induced across the terminals of the primary winding 18, the waveform of which is indicated in FIG. 6(b). Because, depending on the characteristics of the iron core as indicated in FIG. 5(a), the variation rate of the magnetic flux is large in the region of the small current, and the value of the voltage $E=Nd\phi/dt$, wherein N is the number of windings, ϕ is magnetic flux and t is time, is also high. On the other hand, when the current approaches the saturating region, the variation rate of the magnetic flux is low and the induced voltage also is decreased.

As shown in FIG. 6(b), the steep high voltage exceeds the maximum allowable blocking voltage of the thyristors, causing the breakdown and damage of the thyristors and other elements, which is also accompanied by the deformation of the output voltage and other difficulties.

According to the present invention, there is provided a device which can overcome above described difficulties even if the primary winding 18 of the series transformer is opened. For this purpose, a high excitation type iron core including air-gaps in the magnetic path is used for the series transformer. Since the iron core has a characteristic as shown in FIG. 5 by waveform (b), the variation rate of the magnetic flux can be maintained at a small value in the heavy current region. This variation rate is also low throughout the whole range of the current and straight, so that the induced voltage $E=Nd\phi/dt$ can be maintained low and the output waveform can be sinusoidal as shown in FIG. 6(c).

As described above, according to the present invention a high excitation type iron core is provided in the series transformer, and transferring of the taps with the use of the thyristors is thereby enabled.

Although, in the above described voltage regulator, bidirectional triode thyristors are utilized, it is of course possible to use various kind of thyristors, for example, the reverse blocking triode thyristor connected in a reverse parallel combination as shown in FIG. 3.

FIG. 7 illustrates still another embodiment of the present invention, which is basically similar to that indicated in FIG. 2. In this embodiment, the electric power is furnished from the power source 16 to a load 21 through the secondary winding 17 of the series transformer. The core 19 of the series transformer is provided with air-gaps 20 as shown and made into high excitation type. The input circuit for the primary winding 18 of the series transformer includes an auto-transformer connected across the a.c. power line. The winding 33 of the auto-transformer is provided with a plurality of taps, and thyristors 34, 35, 36, 37, 38, are connected with these taps to change the voltage furnished to the primary winding 18 of the series transformer. This embodiment is used for a comparatively low a.c. power line.

FIG. 8 illustrates still another embodiment of the invention in which a protecting device is provided against

the over current which may be caused as a result of, for instance, a short circuit in the load. The construction of FIG. 8 is almost similar to that of FIG. 2, hence the same reference numbers are used for the same circuit elements. The only difference from FIG. 2 is that an inductive reactance 39 is used in the circuit and also an iron core saturable at high current region is employed in the series transformer. The characteristic curve of this iron core is the curve b in FIG. 5. In this characteristic, the iron core is saturated at the current I_s . From the view point of the short circuit current protection, it will be advantageous that the iron core is made of a material having a typical rectangular hysteresis loop.

However, as was already disclosed, since the air-gaps are provided in the magnetic path, the flux variation is comparatively small at the small current region. As a result, it is not proper to use an idealistic rectangular hysteresis material for this case. It should be noticed that, in the case of FIG. 8, because of the large difference between the short circuit current and the rated current, an iron core exhibiting magnetic saturation at a comparatively high current region would be suitable to the purpose. An equivalent circuit of this embodiment of the circuit shown in FIG. 8, when the output terminal is shorted, is illustrated in FIG. 9.

In FIG. 9, it will be seen that an a.c. power source 40 is connected with the secondary winding 17 of the series transformer through the power source impedance 41 and the output terminal is shorted at the point 42. In this case, the short circuit current flowing through the circuit is limited by the power source impedance 41. By this current, a voltage is induced in the primary winding 18 of the series transformer and a current I_p corresponding to the short circuit current I_s might appear in the circuit containing primary winding 18 if the reactance 39 were not inserted in the circuit, and as a result the thyristor 43 might be broken down.

However, in accordance with the present invention, the reactance 39 is inserted in series with primary winding 18 and the thyristor 43. Saturation characteristic as shown in FIG. 10 is used for the series transformer. In explaining the operation, let it be assumed that the short circuit current is $I_s = I_m \sin \omega t$, wherein I_m is the maximum value of electric current, and that the number of turns of the primary and secondary windings are equally represented by N , the primary and secondary current will be almost equal and represented as $I_s \approx I_p$. Though this relation is true for the small current region as shown in FIG. 11, the relation is not satisfied in the larger current region. The reason of this will be explained as follows;

Supposing the inductance of the reactance 39 is L , the induced voltage in the reactance 39 is;

$$V_L = di/dt$$

Since the thyristors 43 are conducting, most of this voltage is applied to the primary winding 18 of the series transformer, and the flux density of the iron core is increased by this voltage. Supposing that the saturating flux density of the iron core of the series transformer is B_s , and that the sectional area of the iron core is A , and the phase angle at which the iron core is saturated is α , then

$$\int_0^{\alpha/\omega} V_L dt = I_m \sin \alpha, \text{ wherein}$$

L = Inductance of non-saturable reactor

V_L = Induced voltage of reactor 39, and

I_m = Maximum value of current.

and after the time when the phase angle becomes α , the iron core of the series transformer will be saturated. When the iron core 19 is once saturated, the function of the series transformer is lost and can be considered as a mere reactor. As a result, the correspondence between the current in the primary winding I_p and the current in the secondary winding I_s will also be lost. Hence, the peak value of the current I_p in the primary winding is expressed by $I_m \sin \alpha = N A B_s / L$.

This means that the short circuit current has no relation with this value which is determined solely by the inductance L of the non-saturable reactor and by the transformer. FIG. 11 indicates this relation, and the current I_p is limited at the point corresponding to the phase angle α . After this point, a current due to the degeneration of the stored energy from the non-saturable reactor 39 will be flown as indicated in the same figure. Thus reason, if the surge current capacity of the thyristors withstanding to the short circuit current is once given, the inductance L of the non-saturable reactance 39 can be determined as follows:

$$L = N A B_s / I_m \sin \alpha$$

When a reactance having this inductance is utilized, the thyristor can be surely protected from the short circuit current.

Although the thyristors can be protected by the above described protecting method, a still more economical design of the voltage regulator will be explained.

Taking the device of FIG. 8 in consideration, when the load 21 is shorted and a short circuit current is flown through the circuit, one half cycle of the a.c. short circuit current limited as described above by the reactance 39 will be flown through the now operating thyristors. For this reason, the thyristors should have a capacity to withstand such limited short circuit current for one half cycle. In addition, some of the specifically selected thyristors will be given far larger capacity than the above described value. For instance in FIG. 8, the thyristors 26 and 30 are determined to serve as the thyristors having far more capacity than other thyristors.

Now, assuming the thyristors 26 and 29 are operating, and a short circuit occurs in the load 21, the short circuit current is flown through the circuit. This short circuit current, limited by reactance 39, flows through the thyristors 26, 29. As shown in FIG. 12(a), when the short circuit occurs at the time t_1 , a half cycle of this short circuit flows through the thyristors. However, when the a.c. short circuit current proceeds into the next half cycle, all of the thyristors are rendered inoperable. When all of the thyristors are rendered inoperable, that is, in a non-conductive state, the primary winding 18 of the series transformer is opened, and a high voltage is induced just like the current transformer. If no appropriate measure is taken, this high voltage will cause some of the thyristors to break down, and a local current will flow through thus rendered conductive thyristors.

To prevent the above mentioned difficulties, the device in accordance with the present invention is provided with specifically selected thyristors 26, 30 which

are rendered conductive during the next half cycle of the a.c. short circuit current, whereby a short circuit current is flown through the primary winding of the series transformer. This conduction of the specific thyristors occurs at the moment t_3 of FIG. 12(b) when the value of the high voltage of a half cycle starting from the moment t_2 rises up to a predetermined value E_s . When the thyristors 26 and 30 conduct, the short circuit current flows through the thyristors as shown in FIG. 12(c), and the over voltage induced in the primary winding 18 of the series transformer is thereby suppressed.

As is apparent from the above description, with the provision of the specific thyristors of sufficient capacity to carry short circuit current safely, all the rest of the thyristors are not required to have so much capacity corresponding to the short circuit current. That is, when the capacity of the specific thyristors is determined to a value to withstand about 20 cycles of the short circuit current, the capacity for the rest of the thyristors can be reduced to a small one to withstand only a half cycle of the short circuit current, and much economy of the device can be obtained. Though in the above explanation the specific thyristors selected are the thyristors 26 and 30, it is of course possible to utilize another pair of the thyristors.

In FIG. 13 still another embodiment of the present invention is illustrated. The constitution of this embodiment is basically identical to that of FIG. 8, and like reference numbers are used for like elements. The only difference of this embodiment from FIG. 8 is that a parallel circuit comprising a series connected discharge tube 45 and a varister 46 as one branch of the parallel circuit and a capacitor 44 as the other branch, is connected across the primary winding 18 of the series transformer and the secondary winding 24 of the excitation transformer. When the voltage regulator is operated in the actual application, abnormal voltage may be induced in the a.c. line, for instance, by the induction of a surge to lightning, and the abnormal voltage is transmitted to the secondary winding 17 and then to the primary winding 18 of the series transformer. In other cases, such abnormal voltage may be transmitted from the primary winding 22 to the secondary winding 24 of the excitation transformer.

As a result, the abnormal voltage enters the circuit including the thyristors 25, 26, 27, 28, 29, 30 whereby the thyristors may be damaged.

In order to protect the thyristors from these abnormal voltages, the embodiment of the present invention provides a parallel circuit comprising a discharge tube 45 and a varister 46 connected in series and a capacitor, and connecting this parallel circuit across the terminals of the primary winding 18 of the series transformer and the secondary winding of the excitation transformer, the above mentioned abnormal voltage can be minimized.

The operation of this circuit is explained as follows: When a steep voltage as shown in FIG. 14(a) is induced, the capacitor 44 begins to charge and flattens the wave front of this voltage. When the voltage rises up as shown in FIG. 14(b) and reaches the discharge voltage V_d of the discharge tube 45 at the time t_1 , the

discharge tube 45 starts discharging and further increase of the height of the voltage is thereby suppressed. Since the internal resistance of the discharge tube 45 is very small, the circuit might be short circuited if the varister 46 were not inserted. The varister 46 has a non-linear voltage-current characteristic, and the current varies widely with only small changes of the voltage. For this reason, the varister 46 can be used effectively for absorption of the abnormal voltage, and with the provision of the over voltage protecting circuit, the thyristors are protected from the abnormal voltage induced in this circuit.

As described above, according to the present invention, there is provided a voltage regulator wherein thyristors are utilized and operated satisfactorily by the provision of the protecting device.

The voltage regulator according to the present invention is particularly adapted for use on distribution lines. In the distribution lines, maintenance of the line voltage is not easy for a place remote from the substation. In that case, the voltage regulator automatically supplies a constant line voltage. Since the voltage regulator according to the present invention has no mechanical contacts, and satisfactory protection against the over voltage and current is provided, the maintenance of the system is extremely simple and suitable for use with distribution lines for which constant supervision is not possible or is not desirable.

What is claimed is:

1. A voltage regulator for use between a power source and a load comprising:
 - a series transformer having an iron core and primary and secondary windings wound about said core; said secondary winding being coupled between said source and said load;
 - an excitation transformer having input means coupled across said load and output means including an output winding having a plurality of taps;
 - a plurality of thyristors each having first and second control terminals, said first terminals being coupled to an associated one of said taps;
 - means for connecting the remaining terminals of said thyristors to said primary winding;
 - means for sensing the voltage across said load;
 - a control pulse generator coupled to said sensing means for generating control pulses only upon the occurrence of changes in the voltage across said load from a desired voltage level;
 - gating means coupled to said control pulse generator for applying control pulse signals to the control terminals of selected ones of said thyristors to maintain a constant voltage output across said load;
 - said iron core being adapted to saturate in the presence of high current; and inductance means coupled between the primary winding of said series transformer and the second terminals of said thyristors, said iron core and said inductance means protecting said thyristors against damage from current surges which may occur due to short-circuit conditions such as the short circuiting of said load.

* * * * *