United States Patent

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[33] **Italy**
[31] **17499A/68 and 23827A/68**

[54] **VOLTAGE REGULATOR FOR APPARATUS OPERATED BY ALTERNATING CURRENT, PARTICULARLY A STEPLESS SPEED CONTROLLER FOR ELECTRIC MOTORS**
8 Claims, 3 Drawing Figs.

[52] **U.S. Cl.** **323/7,** 318/228, 323/50, 323/60, 323/87, 323/88
[51] **Int. Cl.** **G05f 1/20**
[50] **Field of Search** ..... 323/6, 7, 8, 50, 60, 62, 85—88; 318/228, 229, 230, 211

[56] **References Cited**

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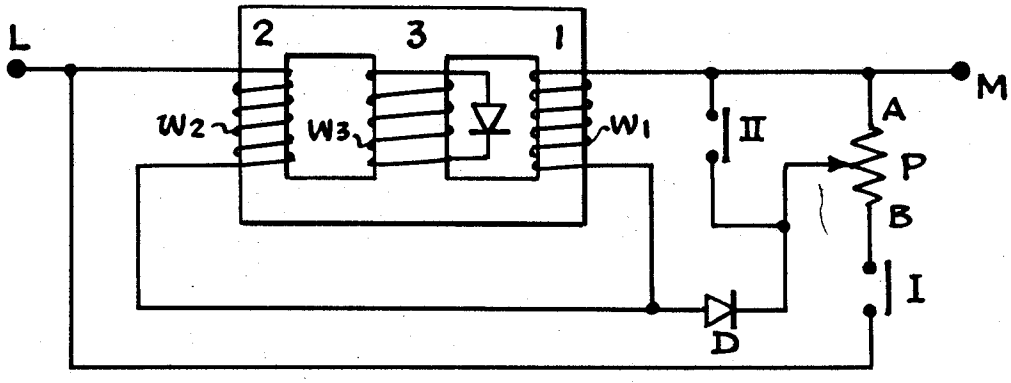
ABSTRACT: Three electrical windings are connected by a paramagnetic frame in a manner such that there is a first magnetic flux path interconnecting the intermediate winding and one end winding, and a second magnetic flux path interconnecting the intermediate winding and the other end winding. The intermediate winding has a diode in series therewith so that current will only flow in one direction through the intermediate winding. The two end windings are connected in series between the power supply connection and the motor connection with the arrangement being such that the magnetic flux in the two paths balances out where the paths pass through the intermediate winding. One end winding is shunted by a diode connected in series with variable resistance means.



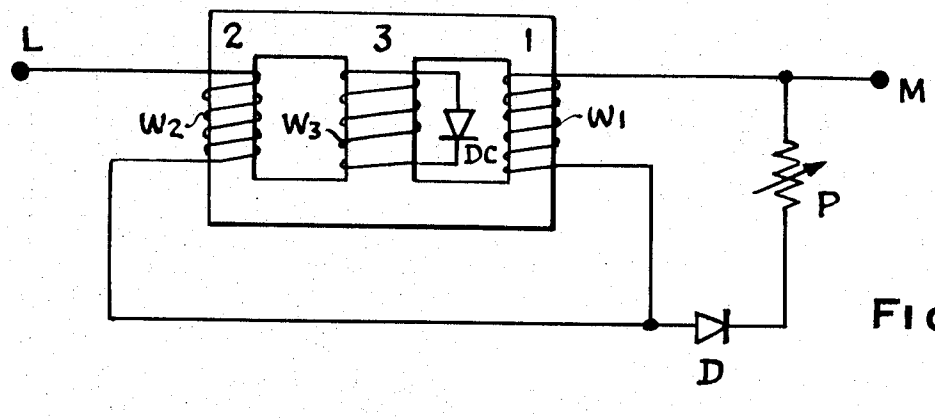


FIG.1

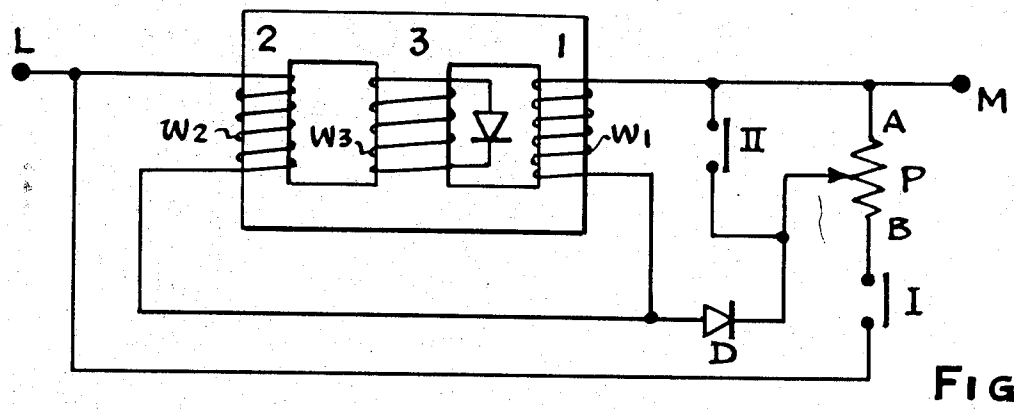


FIG.2

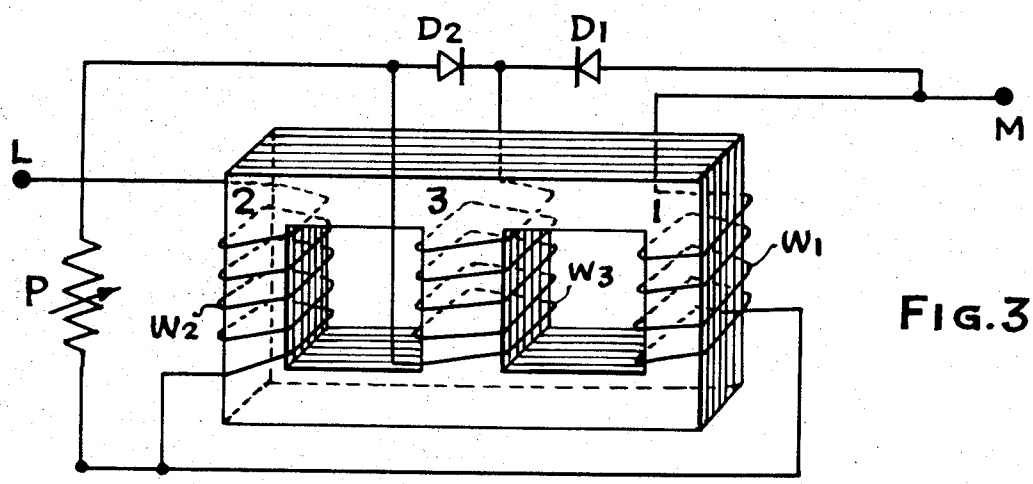


FIG.3

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VOLTAGE REGULATOR FOR APPARATUS OPERATED BY ALTERNATING CURRENT, PARTICULARLY A STEPLESS SPEED CONTROLLER FOR ELECTRIC MOTORS

BACKGROUND OF THE INVENTION

The present invention relates to an arrangement for regulating the supply voltage for apparatus operated with alternating current, and particularly to a continuously adjustable speed controller, to be connected in series with the load, for electric motors.

Numerous forms of construction, based essentially on two principles, are known for speed controllers for motors. One principle, which also leads to a more complete solution, consists in simultaneously varying, in mutual dependence on one another, the frequency and value of the supply voltage of an electric motor; according to the second principle, on the other hand, only the supply voltage of a motor is controlled.

The arrangement according to the invention is intended to work in accordance with this second principle.

As a rule, there are readily available on the market speed controllers of this type in fact the supply voltage is varied either with the aid of variable impedances or with the aid of transformers, or else with the aid of electronic circuits which are generally constructed essentially with controllable crystal diodes. In practice the control system utilizing controllable crystal diodes has been successful, particularly because of space requirements and cost.

A considerable disadvantage of a controller of this type is to be seen in the fact that the alternating voltage serving as supply voltage for the motor no longer has a sine-law variation but a compound wave form. This circumstance has the consequence that although controllers of this type are highly suitable for controlling commutator motors, they are not particularly suitable for controlling capacitor motors and completely fail when used for motors with screened poles.

The problem underlying the invention now consists in providing by simple means a voltage regulator for apparatus operated by alternating current, particularly a continuously adjustable speed controller, to be connected in series with the load, for electric motors which does not have the above-mentioned disadvantages. This controller should in particular be suitable for controlling motors having screened poles. It should mainly supply an output voltage the variation of which approximates substantially to a sine shape.

In a continuously adjustable speed controller for electric motors which is to be connected in series with the load and which works according to the above-mentioned principle, this problem is solved according to the invention by a magnetic Wheatstone bridge having three magnet arms each provided with a winding, while the current absorbed by the load and flowing through two windings connected in series with one another produces in the two appertaining magnet arms magnetic fluxes which, when the bridge is balanced, cancel one another in the third magnet arm, the winding of which is short-circuited at least for one of the current half-waves, whereas a switch element by which the flow of one of the two current half-waves is adjustable is connected in parallel with one of the two windings connected in series.

Not only does this regulator according to the invention solve the problem posed, but it is also suitable quite generally for controlling electric motors of any kind.

A further development of the present invention is based on an arrangement for controlling the supply voltage for apparatus operated with alternating current, particularly a continuously adjustable speed controller, to be connected in series with the load, for electric motors, which utilizes the above-mentioned magnetic Wheatstone bridge having three magnet arms each with one winding, wherein the current absorbed by the load and flowing through two windings connected in series with one another produces in the two appertaining magnet arms magnetic fluxes which, when the bridge is balanced, cancel one another in the third magnet arm, the winding of which is short-circuited at least for one of the current half-waves, whereas a switch element, by which the flow of one of the two current half-waves is adjustable, is connected in parallel with one of the two windings connected in series, and this further development aims at improving the efficiency of the regulator.

According to this further development of the invention this aim is achieved through the fact that the switch element which is connected in parallel with one of the two windings connected in series, and by which the flow of one of the two current half-waves is adjustable, is disposed in series with the third winding in such a manner that the current passing through this switch element flows through the third winding in the same direction as the current which is then induced in this third winding when the magnetic bridge is unbalanced.

The improvement of efficiency which can be achieved by these additional measures provides in particular the advantage that it is thus also possible to control motors of greater power without excessive power loss at the adjusting switch element, for example, a potentiometer.

Further details of the invention will be explained more fully below with the aid of examples illustrated in the drawings, although the invention is not in any way restricted thereto.

More specifically, in the diagrammatical drawings,

FIG. 1 illustrates an example of embodiment according to the general solution principle of the invention;

FIG. 2 a modification of the circuit shown in FIG. 1 which is suitable for practical purposes; and

FIG. 3 illustrates another example of embodiment with improved efficiency according to the further development of the invention.

In FIG. 1 the regulator consists essentially of a magnet circuit having three arms 1, 2, 3, which can also be conceived as two closed magnetic circuits lying side by side.

The magnetic circuit in FIG. 1 can in fact be regarded as if the arm 1 formed a first magnetic circuit with the right-hand half of the arm 3, whereas the arm 2 formed a second magnetic circuit with the left-hand half of the arm 3. The intended mode of operation can now be achieved arbitrarily either by using two magnetic circuits separated from one another or with a single magnetic circuit, as illustrated in FIG. 1.

The W1 W1 and W2 provided on the magnet arms 1 and 2 are connected in series with one another, the direction in which they are wound being so selected that the two magnetic fluxes produced by these windings are at first equal to one another and flow in opposite directions in the magnet arm 3, so that the resultant magnetic flux in the last-mentioned arm becomes equal to zero when the control element connected in parallel with the winding W1 does not carry current.

On the magnet arm 3 there is provided a winding W3 which is preferably short-circuited by a diode DC. If the use of this diode is not desirable, the central winding may be replaced by a short circuit ring (not illustrated).

A switch element the purpose of which is to adjust the flow of a current half-wave is connected in parallel (as a shunt) with one of the two outer windings, in the present case the winding W1.

In FIG. 1 this switch element is constituted by a series connection consisting of a diode D and an adjustable resistor P.

In practical embodiments this switch element may be formed either by a transistor or by a controllable crystal diode or other switch element which in a manner known in itself is suitable for stepless variation of the current flowing through the shunt.

In operation the regulator is connected by its terminals L, M in series with the load, which is preferably constituted by an electric motor.

The mode of operation of the regulator may be explained in the following manner:

The shunt D, P is first so adjusted as to be impermeable to current. In this case a voltage drop limiting the feeding of the load is produced in the regulator. The latter thus acts in the

first instance as a series impedance. A current is then gradually allowed to flow through the shunt. This can be achieved for example by adjusting the resistor P illustrated in FIG. 1. Through the adjustment of this resistor a part of the one current half-wave is passed through the shunt, so that through the winding W1 there flows a current of asymmetrical wave shape, in which for example the negative peak value will be greater than the positive peak value, since part of the positive half-wave is passed through the shunt.

The winding W1 therefore allows an asymmetrical magnetic flux to be formed, which during one half-wave is smaller than the magnetic flux produced by the winding W2. Consequently, the magnetic flux resulting from the two magnetic fluxes in the arm 3 is no longer equal to zero but induces a voltage in the short-circuited winding W3.

This process has the result that the impedance in the winding W2 is reduced when a current of asymmetrical wave shape flows through the winding W1.

Together with the process just explained there is also a saturation process, which is due to the increase in current in the windings W1 and W2 and which leads to a further decrease in impedance.

Measurements made on an apparatus constructed for practical purposes showed that the power loss occurring at the shunt corresponds approximately to one-tenth of the apparent power in the entire apparatus. If an adjustable resistor is used as regulating means, the apparatus permits in practice the use of a resistor of this type the lower loss of which amounts to only about one-tenth of the power loss which would occur in the case of regulation with the aid of an adjustable resistor simply connected in series with the load.

For the purpose of achieving operation with improved economy, the circuit arrangement illustrated in FIG. 2 can be used in practice.

A circuit arrangement of this type is used in order to make do with a magnetic building block of the smallest possible dimensions. In order to enable the load to be operated with full supply voltage in the case of a circuit arrangement of the type illustrated in FIG. 1, the winding resistance must on the one hand be extremely low, while on the other hand no stray fluxes should occur in the magnetic circuit, although these conditions obviously cannot be fulfilled in practice.

In order to overcome this difficulty and at the same time to ensure that it is still possible to achieve stepless regulation, the following measures were taken (see FIG. 2), the action of which is likewise described below.

In a first working stage the control is adjusted to the maximum value possible: the contactors I and II of a switch (not otherwise illustrated) are closed and the adjustable tap of the potentiometer P is situated at the end point B.

In a second working stage the aforesaid tap is moved from the end position B to the end position A, so that the tapped resistance increases and the major portion of the current is forced to flow through the impedance W2. As soon as the tap reaches the end point A, the contactors I and II are opened, whereupon the tap is moved in the opposite direction from A to B and the mode of operation previously described is brought about until the tap once again reaches the end point B, which corresponds to the highest possible effective resistance of the potentiometer P in accordance with FIG. 2 and consequently to the lowest power supplied to the load.

With maximum voltage in the motor the regulator is therefore practically short-circuited and in no way limits the maximum power at the load.

In other practical embodiments, which will not be further discussed here, magnetic circuits differing considerably from the embodiments discussed have also been used, but without departing from the general principle of the solution provided by the invention.

It may further be mentioned that instead of interlinked magnetic circuits it is also possible to use closed magnetic circuits lying parallel side by side. The magnetic flux produced by the two actual impedance windings may also be divided into two parts, in which case two short circuit windings should then appropriately be provided instead of a single short circuit winding W3. In addition, the regulator may be constructed in the form of a four-pole instead of a two-pole network, in which case the regulator can then in practice act as a primary circuit of a transformer, from the secondary circuit of which the regulated voltage can be taken. In some cases this last-mentioned solution provides the advantage of greater freedom in the utilization of the apparatus.

In FIG. 3, which illustrates another example of embodiment with improved efficiency in accordance with a further development of the invention, which likewise makes use of the general solution principle of the invention, the regulator consists once again essentially of a magnetic circuit with three arms 1, 2, 3. Here again the windings W1 and W2 provided on the magnet arms 1 and 2 are connected in series with one another, while the direction in which they are wound is selected so that the two magnetic fluxes produced by these windings are first equal to one another and flow in opposite directions in the magnet arm 3, so that the resultant magnetic flux in said arm becomes equal to zero when the regulator P connected in parallel with the winding W1 does not carry current.

On the magnet arm 3 there is once again provided a winding W3 which is short-circuited by a diode D2.

Once again a switch element serving to adjust the flow of the one current half-wave is provided for one of the two outer windings, here for example the winding W1. In FIG. 3 this switch element is also formed by a series connection consisting of a diode D1 and an adjustable resistor P. In this embodiment also this switch element may be formed either by a transistor or by a controllable crystal diode or other switch element which in a manner known in itself is able to effect stepless variation of the current flowing through the shunt.

Between the diode D1 and the adjustable resistor P the third winding W3, in parallel with which a second diode D2 is connected, is now connected in series in this embodiment.

According to an important feature of the aforesaid further improvement of the invention, the direction in which the third winding W3 is wound and the polarity of the two diodes D1 and D2 are selected so that the current passing through this adjustable resistor P flows through the third winding in the same direction as the current which is inducted in this third winding when the magnetic bridge is out of balance.

The principle of the invention may naturally also be put into practice with other circuit arrangements, while in all cases the effect is achieved of increasing the ampere windings in the third magnet arm and thus the magnetic potential difference in said arm.

In the example of embodiment illustrated in FIG. 3 this magnetic potential difference tends to counteract the voltage produced by the magnet arm 1 and thus to reduce the current induced in the winding W2.

Given suitable dimensions of the switch elements it is possible by the measures described to increase to a considerable extent and even to double the efficiency of the regulator, compared with a regulator which is constructed simply in accordance with the general solution principle of the invention.

I claim:

1. A continuously adjustable speed regulator for alternating current electric motors and having a motor connection and a supply connection by which it may be connected in series between the motor and a source of alternating current, said regulator comprising:

two electrical windings connected in series between said connections;

a conductor device defining a third winding and forming a closed electric circuit through said winding which circuit will pass current only in one direction;

first paramagnetic means defining a first magnetic circuit between a first of said two windings and said third winding such that with a given current flow in a given direction through said two windings a magnetic flux of a given magnitude passes in one direction through said third winding;

second paramagnetic means defining a second magnetic circuit between the second of said two windings and said third winding such that with said given current flow in said given direction through said two windings a magnetic flux of said given magnitude passes through said third winding in the opposite of said one direction, whereby said magnetic flux of said second paramagnetic means cancels the magnetic flux of the first paramagnetic means; and

electrical shunt means connected in parallel with one of said two windings, said shunt means being adjustable for selectively varying the current flow in one direction through said one winding.

2. A regulator according to claim **1**, characterized in that an electronic switch element with controllable resistance serves as said shunt means.

3. A regulator according to claim **1**, characterized in that the regulator acts as primary circuit of a transformer and thus constitutes a four-pole regulator.

4. A regulator as set forth in claim **1**, wherein said shunt means comprises a diode and a variable resistor connected in series with each other.

5. A regulator as set forth in claim **1**, wherein said shunt means comprises:

switch means having two simutaneously operating contractors;

a pontentiometer having two ends and a tap;

means connecting said two ends of said potentiometer and one of said contactors in series between said motor connection and said supply connection;

a diode; and

means connecting the diode to said tap and connecting said diode and the other contactor in parallel to said one winding.

6. A regulator as set forth in claim **1**, wherein said shunt means is connected in series with said third winding, the connection being such that current flowing in said one direction through said one winding coincides with current flowing in said one direction through said third winding.

7. A regulator as set forth in claim **6**, wherein:

said conductor device includes said third winding and a first diode connected in series therewith and defining a first junction between one end of the third winding and the diode and a second junction between the other end of the third winding and the diode; and

said shunt means includes a second diode connected between the first junction and one end of said one winding, and variable resistance means connected between the second junction and the other end of said one winding.

8. A regulator as set forth in claim **1**, wherein said conductor device includes said third winding and a unidirectional current flow means connected in series therewith.

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,568,042 Dated March 2, 1971

Inventor(s) Alberto Della Casa

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 24, "fact" should read --which--. Column 2, line 44, "Wl", first occurrence, should read --windings--. Column 4, line 44, "inducted" should read --induced--. Column 4, line 69, "electric" should read --electrical--. Column 5, line 25, "contractors" should read --contactors--

Signed and sealed this 29th day of June 1971.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

WILLIAM E. SCHUYLER, J
Commissioner of Patent