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(54) METHOD OF REGULATING THE ELECTRICAL POWER DELIVERED TO
 A CONSUMER FROM AN ALTERNATING CURRENT NETWORK AND
 MEANS FOR PERFORMING THE METHOD

(71) I, POUL HAHN EVERS, of Danish nationality, of Castelletto di Pura, 6984 Pura, Switzerland, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a method of regulating the electrical power delivered to a consumer from an alternating current network by adjusting the current flow angle by means of a power switching device connected in the current path to the consumer, which is switched on at the beginning of a half-wave of the network alternating voltage at a phase angle of zero degrees at approximately zero degrees and is switched off at a phase angle corresponding to the desired current flow angle.

It is already known to effect power regulation of the described type by simply using the so-called phase angle control with thyristors or triacs as power switching devices. In such method, during each half-wave of the network alternating voltage after the zero passage the consumer is connected thereto with such a phase angle delay that the residual phase angle of the half-wave until the next succeeding zero passage corresponds to the desired current flow angle. In particular, if the connection of the consumer to the alternating current network is effected at a rather large phase angle, i.e. at a relatively high instantaneous voltage of the network, considerable current peak values will occur at the instant of connection, especially for capacitive consumers. These current peaks excessively load the network and cause, in adjacent high-frequency consumers, for example radio and television apparatus, undesirable high-frequency disturbances even when disturbance protective means are provided for the power switching device.

In the United States Patent Specification 3,525,882 and the British Patent Specification 1,047,904 there are already disclosed

power switching devices which can be connected to an alternating current network, which allow an adjustable electrical power to be delivered to the consumer by arranging that, in each half-wave of the rectified but not smoothed network voltage, at the cross-over point of the network voltage a semiconductor switching element connected in series with the consumer is switched to the on condition and, at a predetermined, adjustable phase angle within the same half-wave, is again switched off. By this method the result is achieved that, upon connecting the consumer to the rectifier arrangement, which is used for rectifying the network alternating voltage, undesirable current peaks are avoided during the half-waves of the rectified network alternating voltage, and nevertheless a free choice of the current flow angle is ensured during each half-wave.

For performing the above mentioned method it is possible, according to United States Patent Specification 3,525,882 to use thyristors or similar switching devices as the power switching means, but this demands the arrangement of series connected rectifiers, because these thyristors do not exhibit sufficient blocking capability under reversed polarity conditions. Moreover difficulties are encountered should a parallel connection of the thyristors be necessary to effect the power switching. Moreover, the use of thyristors as power switching devices in the inventive method is a disadvantage in so far as costly circuit arrangements must be provided for producing the necessary cutting off pulses.

According to British Patent Specification 1,047,904 the difficulties referred to can be avoided by providing as the power switching device a transistor, which is controlled by a bistable trigger circuit. Nevertheless this arrangement is not suitable for the accurate switching of large loads at predetermined phase angles and with low losses because a considerable control power must be brought into effect and an unacceptably

high level of heating of the transistor takes place in consequence of the losses. Moreover these disadvantages may not be avoided in the known arrangement by connecting a plurality of transistors in parallel; on the contrary difficulties encountered then become even greater, particularly in respect of the control of the transistors. In addition the known arrangement does not permit the transistor, which is provided as the power switching element, to switch off at a desired phase angle between 0 and 180° of the half-wave of the rectified network alternating voltage.

The purpose of the present invention is to provide a method of the first mentioned type and a circuit arrangement for its performance, which, by the use of transistors as power switching elements for an alternating current network to the consumer, will allow a loss-free and precisely timed control of the transistors whilst avoiding unacceptable heating effects, even for any desired level of consumer currents, and to do this at any desired time instant during each half-wave of the network alternating voltage.

For solving this problem, the method of the above mentioned type is characterized in that there is employed a power switching device comprising at least two parallel connected transistors, the collector-emitter paths of which are connected in the current path to the consumer, and which are alternately switched in at a switching frequency which is higher than the network frequency in such manner that the time periods of their "on" conditions overlap and the alternate switching in of the transistors takes place in each half cycle of the network alternating voltage from the beginning of each half cycle until the desired current flow angle is reached.

The control of the transistors is effected preferably in each case by a transformer in order that the control power may be kept low. Advantageously each transistor is controlled by a control voltage applied to the primary side of each transformer and having an at least approximately rectangular wave form of gated pulses and gated space intervals, said intervals each including a wave segment, the polarity of which is opposite to that of the gated pulses in order to render the remanence of the transformer ineffective.

According to a preferred feature of the method of the invention, by the use of a second power switching device the consumer can be damped and discharged in each half-wave of the network alternating voltage, in which case the second power switching device becomes effective after each interruption of the connection of the

consumer to the network has been brought about by switching out the first power switching device, and said second power switching device becomes ineffective before every reconnection of the consumer with the network brought about by the switching in of the first power switching device.

This preferred feature makes it possible by the periodic connection of the consumer to the alternating current network in the zero cross-over point of the network alternating voltage, to bring about in the consumer at least substantially complete discharge approximating to the ideal condition. By these means it becomes possible to avoid the risk of formation of current peaks at the instant of connection, this resulting on the one hand in the avoidance of high frequency disturbance effects and furthermore the avoidance of overloading the network switching device effecting the connection of the consumer to the network.

Accordingly, the second power switching device, which damps and discharges the consumer, becomes effective when the first power switching device, which connects the consumer to the alternating current network, is ineffective. Thus it is possible for the energy stored in the consumer to be discharged through the consumer and through the second power switching device, whilst said second device is effective, in the time interval before the next reconnection of the first power switching device at the next zero cross-over point of the network alternating voltage, so that at the time instant of the said reconnection not only is there no voltage at the terminals of the consumer, but also there is no electrical or mechanical energy stored in the consumer. Therefore no current peaks can be established upon reconnection of the consumer to the alternating current network.

An advantageous practical form of the above described preferred feature provides that in the second power switching device at least one transistor is used, whose collector-emitter path is arranged in a current path lying parallel to the consumer, which transistor is switched on and switched off in a time interval occurring between the interruption of the connection and the reconnection of the consumer with the network, this switching being effected at a switching frequency which is higher than the network frequency, whilst the switching off period of the transistor occurs during a time which is shorter than the storage time of the transistor. Having regard to this storage time, it is advantageous to employ a Darlington transistor, the cost of which is, nevertheless, only slightly higher than that of a conventional transistor. Darlington transistors exhibit at the present time storage periods of about 15 to 20 micro-

seconds, so that the storage effect of the Darlington transistor can be utilized for bridging over the gated space intervals.

5 In order that the power applied in controlling the transistor can be kept small, it is advantageous to employ for controlling the transistor a control voltage having an at least approximately rectangular characteristic, and to deliver this to the transistor
10 through a transformer.

In the performance of the above defined inventive method there is employed a circuit arrangement characterized by the feature that the first mentioned power switching
15 device comprises at least an arrangement of two transistors connected in series with the consumer and having parallel connected collector-emitter paths, together with an arrangement of rectifiers for correct
20 polarity delivery of the network alternating voltage, wherein there is connected in the base-emitter circuit of each transistor the secondary winding of an associated transformer, the primary winding of which is
25 connected to a circuit arrangement for generating the control voltage for the transistors.

For performing the above described preferred feature, the inventive circuit arrangement
30 may contain, connected in parallel to the consumer, a second power switching device, which comprises the series circuit of the collector-emitter path of a transistor, e.g. a Darlington transistor, furthermore an
35 arrangement of rectifiers for correct polarity delivery to the transistor of the voltage applied to the consumer, and a load, whilst in the base-emitter circuit of the transistor there is connected the secondary
40 winding of a transformer, the primary winding of which is connected to a circuit arrangement for generating the control voltage for the transistor.

45 An advantageous practical form of this circuit arrangement consists of rectifiers arranged in a rectifier bridge, one diagonal of which is connected parallel to the consumer, and to the other diagonal of which there is connected the collector-emitter
50 path of the transistor.

For the purpose of receiving the stored energy upon discharge of the consumer, the load which is connected in parallel to the consumer may be an ohmic resistance
55 and a choke.

The herein described methods and circuit arrangements can be applied for the regulation of any desired types of consumer driven by an alternating current network,
60 in particular those of a highly capacitive character or those with exceptionally reflective characteristics, as well as consumers with reactive load compensation.

65 An important application of the invention consists in the regulation of the brilliance

of on electrical lighting installation. In particular the method can advantageously be used for the regulation of fluorescent tubes in a lighting installation whilst having only the slightest interference with an existing system, and bringing with it optimal compensation of the reactive power and small regulating losses. In particular the above defined discharge of the total consumer network provides constant conditions
70 at the start of each half-wave and diminishes the risk of extinction by the suppression of random glow discharges through participating starters during the transient decay process, such as would occur
75 in the absence of this switching device for discharge and damping

A further field of application is the regulation of the driving powers of electric motors. In this field the absence of high
80 peak current values when employing the inventive method means that there is a reduction in the stressing of the internal motor insulation caused by parasitic capacitances, in contrast to the conditions obtaining when the known regulation by phase angle control is employed, as well as a reduction in the bearing stresses due to peak torques. In particular, in consequence of the above defined discharge of the consumer, there is achieved, on account of the absence of a change of current direction, which would otherwise inevitably result from the transient effects following the switching off of the network switching device for current supply, an optimal integration of the impressed current in the motor and therefore an added improvement in the steady running behaviour of the motor.
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Further applications of the invention are possible in the field of electrical ignition for combustion processes.
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Practical examples of the inventive method and of circuit arrangements for its performance will now be described in more detail with reference to the accompanying drawings, in which:
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Fig. 1 is a diagram of current plotted against time in a consumer when using the known method of regulation by phase angle control,
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Fig. 2 is a diagram of the current plotted against time in a consumer when using the inventive method of regulation,
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Fig. 3 is a circuit diagram of a first practical form of the power switching device for performing the inventive method,
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Fig. 4 is a diagram of the control voltages as a function of time in respect of the power switching device of fig. 3,
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Fig. 5 is a circuit diagram of a second practical form of the power switching device,
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Fig. 6 is a diagram of the current consumption plotted with respect to time in a
125 130

consumer with periodic interruption of the consumer from the alternating current network and respective reconnection of the consumer with the network, when the consumer has stored electrical energy,

Fig. 7 is a diagram of the voltage established at a consumer corresponding to fig. 6 plotted as a function of time,

Fig. 8 is a diagram of the voltage established at a consumer corresponding to fig. 6 plotted as a function with respect to time when using a preferred feature of the inventive method,

Fig. 9 is a circuit diagram of an arrangement for regulating the brilliance of a lighting installation having a second power switching device for performing the preferred feature of the method of the invention,

Fig. 10 is a diagram showing the control pulses used in the arrangement of fig. 9 plotted with respect to time.

In fig. 1 there is shown as a function of time the current flowing through a consumer according to a known method of regulation by phase angle control. From the first zero cross-over point t_0 up to a later time instant t_1 the relevant power switching device remains blocked, i.e. no current flows. At the time instant t_1 the power switching device is switched on, i.e. the consumer is connected to the network, so that a sudden current increase takes place at a high velocity, which causes the already described current peaks and high frequency disturbances to occur. The current continues to flow until the next zero cross-over point t_0' .

Fig. 2 shows the corresponding current graph with respect to time in a method of regulation in accordance with the invention. The aforementioned power switching device is here already switched on at the time instant t_0 of the first zero cross-over point, so that the network alternating current already flows through the consumer from the instant of cross-over of the alternating voltage, and the sudden current surge is avoided. At a later time instant t_2 , corresponding to the desired current flow angle, the power switching device is blocked so that the current flowing through the consumer sinks to zero until the power switching device is again switched on at the next zero transit.

In the practical example represented in fig. 3 a consumer V is connected through a power switching device LS1 to terminals N of an alternating current network. The power switching device LS1 comprises two transistors T1 and T2, which are in parallel connection in that their respective collector and emitter paths are connected together in parallel. The connected collectors and emitters of the transistors T1 and

T2 are connected across one diagonal of a rectifier bridge G1, which has in each branch a rectifier D1, D2, D3 and D4 respectively, for example one or more diodes. The other diagonal of the rectifier bridge is connected in series with the consumer V. The rectifier bridge serves the purpose of protecting the transistors from faulty poling and to make possible the full-wave operation of the power switching device here shown.

For the purpose of controlling the transistors T1 and T2 the bases thereof are connected in each case through a current limiting resistance R1 and R2 to the secondary winding of a driver transformer TR1 and TR2 respectively. To the primary windings of the respective transformers there are delivered control voltages U1 and U2, which will be further described herein, for which purpose the primary windings are connected to separate output terminals of a control voltage generator SG1. The control of the transistors T1 and T2 through the transformers makes it possible by the use of impedance matching to keep the necessary control power low; this method of control also makes possible a potential separation of the bases of the two transistors. Instead of using two transistors T1 and T2 it is also possible, in accordance with the loading, to provide a greater number of transistors connected in parallel in the same manner.

With the object firstly of obtaining precise switching instants for the transistors T1 and T2, and thereby to achieve a precisely determined current flow angle, and secondly in order to keep the dimensions of the driving transformers TR1 and TR2 small, the control voltage generator SG1 is so designed that it delivers at its output terminals control signals, the frequency of which is substantially higher than that of the network frequency, and amounts for example to around 10 kHz. The control signals are also preferably at least approximately rectangular, whilst the control signals delivered at the two respective output pairs of terminals of the control signal generator SG1 are mutually displaced in time but overlap each other.

The control voltages U1 and U2, which are preferably delivered by the control voltage generator SG1, are represented schematically in fig. 4 as a function of the time. The control voltage U1 is a rectangular voltage with gating pulses I and spacing intervals L, in which the control voltage falls to zero value. However, within the space intervals L there are provided additional pulses Z, the polarity of which is opposite to those of the gating pulses I. The control voltage U2 exhibits the same time characteristic as the control voltage

U1, but is time displaced with respect to it so that the gating pulses I of the control voltage U2 occur at the same time as the space intervals L of the control voltage U1. As will be seen from fig. 4 the gating pulses I of the control voltages U1 and U2 overlap each other during the time period Δt .

The mode of operation of the power switching device of fig. 3 is as follows, assuming as a basis the signal voltages U1 and U2 of fig. 4.

At the beginning of a half-wave of the network alternating voltage (phase angle equal to zero degrees) the control voltage generator SG1 is opened and delivers control voltages U1 and U2 to the primary windings of the driving transformers TR1 and TR2 respectively. Initially there is delivered through the one transformer, e.g. the transformer TR1, the control voltage U1, with the gating pulse I, to the transistor T1, so that the latter becomes current conducting. Before the beginning of the saturation of the transformer TR1 the gating pulse I of the control voltage U2 is delivered by transformer TR2 and brings the transistor T2 into the current conducting condition, and indeed this happens during the time that the transistor T1 is still current conducting on account of the overlapping of the control voltages U1 and U2, so that in the consumer V there is obtained a continuous current flow. The space interval L of the control voltage U1 now blocks the transistor T1, whilst the additional pulse Z of reverse polarity occurring within that interval removes the remanent magnetization in the transformer, and thus increases the power capability for the next succeeding current conducting phase of the transistor T1. This operation repeats itself alternately for the transistors T1 and T2, so that the loading distributes itself uniformly over the two participating transistors T1 and T2, whilst the current flowing through the consumer V assumes continuously the course of the network alternating voltage in the respective half-wave. For achieving the desired current flow angle, the control voltage generator SG1 is then blocked at the corresponding phase angle of the half-wave, so that a further control of the transistors T1 and T2 into the current conducting condition is omitted until the beginning of the next half-wave of the network alternating voltage. The diodes D1 to D4 of the rectifier bridge G1 here provide for the correct poling in accordance with the alternating sign of the half-waves.

In an example the pulse frequency of the control voltages U1 and U2 was 10 kHz, the voltage of the gated pulses +10V, the voltage of the additional pulses -10V, and the transformation ratio of the trans-

formers TR1 and TR2 was 3:1. The generation of the control voltages U1 and U2 as well as the adjustment of the desired current flow angle by the starting and blocking of the control voltage generator SG1 can quite easily be effected with known means, in particular by means of digital circuit arrangements.

A further practical form of the power switching device, which is capable of switching a larger current and which generates a smaller thermal loss is represented in fig. 5. In the power switching device LS2 here shown there are provided two arrangements of parallel connected transistors T3, T4 and T5, T6 respectively, the control of which is effected, as in the practical example of fig. 3, by the individually allocated driving transformers TR3, TR4, TR5 and TR6, together with current limiting resistances R3, R4, R5 and R6. For achieving the correct poling for a full-wave driving operation, a rectifier D5 and D6 respectively, e.g. a diode, is connected in series to each arrangement TR3, TR4 and TR5, TR6 of parallel connected transistors. These two series circuits are connected in parallel and are situated in the current path of the network in series with the consumer V, so that the current flow directions of the arrangements of the transistors and the rectifier, with reference to the network or consumer connection side of the said parallel circuit, are opposite to each other in the one branch and the other branch of the parallel circuit. The primary windings of the transformers TR3 to TR6 are connected to suitable output terminals of a control voltage generator SG2 for delivering the appertaining control voltages U3, U4, U5 and U6. The course taken by the control voltages U3 to U6 differs from that of the control voltages U2 and U3 of fig. 3 solely by reason of the fact that, in dependence upon the existing polarity of the network alternating voltage, the control can be discontinued of that particular arrangement of transistors T3, T4 or T5, T6 respectively which happens to be in the non-loaded condition.

In the practical example of fig. 5 thermal losses occur only at two rectifiers D5, D6. Moreover the current loading distributes itself over four transistors T3 to T6.

In the described methods and circuit arrangements it is conceded that at the time instant of disconnection any stored electrical or magnetic energy will cause transient oscillation and will be dissipated in the consumer. In such a case it is to be expected that a voltage peak will occur. Because in most cases the consumer load will include both inductive and capacitive components, it will also not be possible to avoid changes of current direction in the consumer.

Furthermore it is necessary to have regard to parity between the electrical condition in the consumer and in the network when the current supply to the consumer is renewed, because otherwise it must be expected that additional current peaks will result.

In fig. 6 there is shown, on a basis corresponding to that of fig. 2, the time function of a current taken by a consumer from an alternating current network, wherein the consumer is connected to the network in each half-wave at the zero cross-over point of the network alternating voltage, i.e. at the time instants t_0, t_2, t_4 , etc., and disconnected from the network at a later time instant t_1, t_3, t_5 , etc. corresponding to the desired current flow angle. It can be shown that, in consequence of the storage of energy, strong current peaks will occur at each reconnection of the consumer with the network at the time instants t_0, t_2, t_4 , etc., as indicated in fig. 6. Such current peaks cause considerable high frequency disturbing voltages, and moreover place a load on the switching device which is used for effecting the disconnection and reconnection of the consumer with the network, the switching element of said switching device usually being in the form of a semiconductor arrangement which is sensitive to current and voltage peaks.

The cause of the voltage peaks of fig. 6 is shown in fig. 7, which indicates the corresponding time function of the voltage at the consumer. The consumer is disconnected from the network at the time point t_1 . In consequence of energy storage, the voltage at the consumer then falls off, for example in accordance with the full line of the curve and tends to continue a course along the dashed line. Because, at the time instant t_2 , at the zero cross-over point of the network alternating voltage a reconnection of the consumer with the network is established, the decay process must be interrupted and the voltage at the consumer must of necessity follow the network voltage. The corresponding surge in the consumer voltage indicated at the time instant t_2 in fig. 7, from a value differing from zero value to a practically zero value in the zero cross-over point of the network alternating voltage, gives rise to the current peak shown in fig. 6 at the time instant t_2 as well as at the corresponding time instants t_4 , etc. at the beginning of a new commutation phase.

According to a preferred feature of the inventive method, at all of the time instants t_1, t_3, t_5 , etc. or shortly thereafter, i.e. after the disconnection of the consumer from the network, the consumer is damped and its energy content substantially short circuited. The mode of operating this

method is shown in fig. 8. From this it is clear that, as a result of the imposed damping and discharge beginning from the time instants t_1, t_3, t_5 , etc., the voltage assumes a strongly attenuated course, so that at the time instants t_2, t_4 , etc., at which the consumer is reconnected to the network, the voltage has practically assumed the zero value. The current taken by the consumer from the network therefore no longer exhibits the current peaks at the time instants t_2, t_4 , etc. shown in fig. 6, but in other respects takes the form of fig. 6.

In fig. 9 there is shown schematically an arrangement for regulating the brilliance of a lighting installation. In this arrangement the consumer, which is connected through a first power switching device to the terminals N of an alternating current network comprises a plurality of ballast devices VG and a plurality of fluorescent tubes LR, of which only one of which is shown in the drawing, as well as the appertaining glow starter GS. The first power switching device is the same as the power switching device LS1 of fig. 3 and therefore contains the rectifier bridge G1 with the four diodes D1 to D4 and the two transistors T1 and T2, whose respectively connected collectors and emitters are connected to one diagonal of the rectifier bridge G1. The other diagonal is connected through two windings W1 and W2 of a choke DR in series to the above mentioned consumer. The choke windings W1 and W2 together with the parallel connected condensers C1 and C2 function both as disturbance protective members as well as protective means for the semiconductor elements present in the illustrated arrangement.

For the purpose of controlling the transistors T1 and T2, the bases thereof are, like those in fig. 3, connected through current limiting resistances R1, R2 and driving transformers TR1, TR2 to a control voltage generator SG3, which delivers the control voltages U1 and U2. The graph of the control voltages U1, U2 has already been described with reference to fig. 4 and is again shown in fig. 10.

A second power switching device for periodically damping and discharging the consumer contains, according to fig. 9, a further rectifier bridge G2 with four diodes D7 to D10, one diagonal of which rectifier bridge is connected through a limiting and load resistance R7, as well as through a further winding W3 of the choke DR, parallel to the consumer containing the ballast devices VG and the fluorescent tubes LR. In the other diagonal of the rectifier bridge G2 there is connected the collector-emitter path of a Darlington transistor T7, whose base is connected through a current limiting resistance R8 to the secondary

winding of a further driving transformer TR7. To the primary winding of the transformer TR7 there is delivered a control voltage U7, for which purpose the latter is connected to further output terminals of the control voltage generator SG3. The control voltage U7, like the control voltages U1 and U2, is rectangular and has a substantially higher frequency as compared with the network frequency. Preferably the control voltage U7 exhibits the same shape and frequency as the control voltages U1 and U2, as is represented in fig. 10, but the control voltage U7 contains no additional pulses of opposite polarity. As will be seen in fig. 10 and will be further described later, the control voltage generator SG3 periodically delivers the control voltage U7 at times when there is no delivery of control voltages U1 and U2 from the control voltage generator SG3.

At the beginning of a half-wave of the network alternating voltage (phase angle equal to zero degrees corresponding to the time instants t_0 , t_2 , t_4 , etc. in fig. 8) the control voltage generator SG3 delivers the control voltages U1 and U2 to the primary windings of the driving transformers TR1 and TR2, as is already described with reference to fig. 3. For obtaining the desired current flow angle, the control voltage generator SG3 then interrupts, at the corresponding phase angle of the half-wave, corresponding to the time instants t_1 , t_3 , t_5 , etc. in fig. 8, the delivery of the control voltage U1 and U2, so that a further control of the transistors T1 and T2 into the current conducting condition is suspended until the beginning of the next half-wave. The diodes D1 to D4 of the rectifier bridge G1 provide in this case for the correct poling in correspondence with the alternating sign of the half-waves.

Allowing for a slight delay taking into account the storage and discharge times of the semiconductor elements, the control voltage generator SG3 delivers, following the last pulse of the control voltages U1, U2, and within the same half-wave, the rectangular control voltage U7 (fig. 10) so that the Darlington transistor T1 becomes current conducting. Because the pulse gaps of the control voltage U7 are smaller than the storage time of the Darlington transistor T7, the current conducting condition of the transistor T7 is continuous. The time period during which the transistor T7 is in the conducting condition provides, through the rectifier bridge G2, i.e. the diodes D7, D9 or D8, D10 according to the polarity of the respective half-wave, the load resistance R7 and the winding W3 of the choke DR, a current path parallel to the consumer. Accordingly it is possible for the electrical energy stored in the con-

sumer to discharge continuously through the Darlington transistor T7, this being indicated in fig. 9 by the condenser C3 shown in dashed lines indicating a compensating and parasitic capacitance.

As is evident from fig. 10, the control voltage generator SG3 interrupts the delivery of the control voltage U7 shortly before the next zero cross-over point of the network alternating voltage, i.e. shortly prior to the instant when the control voltage generator SG3 again brings the transistors T1 and T2 alternately into the conducting condition by means of the control voltages U1 and U2.

In the reconnection of the consumer to the network after the completion of periodic separation from the network, the suppression of current peaks, which is effected by the described discharge of the consumer for the purpose of power regulation is indeed involved with losses, but these are nevertheless acceptable and are not significant as compared with the achieved advantage of the avoidance of current peaks. For example the arrangement represented in fig. 9 may be for the regulation of a fluorescent tube lighting installation, which is designed for a nominal current of 35 A, and which includes for complete compensation of the fluorescent tubes a parallel capacitance of 450 microfarads. This capacitance will, in the most unfavourable case, be charged to a voltage of 300 V, so that for each half-wave an energy of 135 mWs is to be expended, because the residual component in the form of non-capacitively stored energy is dissipated through the ballast devices and the fluorescent tubes. The total efficiency of the arrangement shown in fig. 9 is therefore degraded by only 1.7%.

The control of the transistors T1, T2, T7 through transformers makes it possible to maintain the necessary control power small by impedance matching. Furthermore this method makes possible the potential separation of the bases of the transistors. The generation of rectangular control signals U1, U2, U7 having a substantially higher frequency than that of the network can, as shown, be effected by a single control voltage generator SG3, so that the latter can be of relatively simple design.

WHAT I CLAIM IS:—

1. A method of regulating the electrical power delivered to a consumer from an alternating current network by adjusting the current flow angle by means of a power switching device connected in the current path to the consumer, which is switched on at the beginning of a half-wave of the network alternating voltage at a phase angle of zero degrees or approximately zero de-

grees and is switched off at a phase angle corresponding to the desired current flow angle, characterized by the feature that there is employed a power switching device comprising at least two parallel connected transistors, the collector-emitter paths of which are connected in the current path to the consumer, and which are alternately switched in at a switching frequency which is higher than the network frequency in such manner that the time periods of their "on" conditions overlap and the alternate switching in of the transistors takes place in each half cycle of the network alternating voltage from the beginning of each half cycle until the desired current flow angle is reached.

2. A method according to claim 1, characterized by the feature that the transistors are each controlled through a transformer.

3. A method according to claim 2, characterized by the feature that each transistor is controlled by a control voltage of at least approximately rectangular wave form having gated pulses and space intervals, wherein the space intervals include a wave segment the polarity of which is opposite to that of the gated pulses in order to render the remanence of the transformer ineffective.

4. A method according to one of claims 1 to 3, characterized by the feature that by the use of a second power switching device the consumer is damped and discharged in each half-wave of the network alternating voltage, in which case the second power switching device becomes effective after each interruption of the connection of the consumer to the network has been brought about by switching out the first power switching device, and said second power switching device becomes ineffective before every reconnection of the consumer with the network brought about by the switching in of the first power switching device.

5. A method according to claim 4 wherein in the second power switching device at least one transistor, in particular a Darlington transistor is used, whose collector-emitter path is arranged in a current path lying parallel to the consumer, characterized by the feature that the transistor is switched on and switched off in a time interval occurring between the interruption of the connection and the reconnection of the consumer with the network, this switching being effected at a switching frequency which is higher than the network frequency, whilst the switching off period of the transistor occurs during a time which is shorter than the storage time of the transistor.

6. A method according to claim 5,

characterized by the feature that for the purpose of controlling the transistor there is used a control voltage of at least approximately rectangular wave form, which is delivered to the transistor through a transformer.

7. A circuit arrangement for performing the method according to claim 1, characterized by the feature that the power switching device comprises at least an arrangement of two transistors (T1, T2; T3, T4, T5, T6) connected in series with the consumer (V) and having parallel connected collector-emitter paths, together with an arrangement of rectifiers (D1, D2, D3, D4; D5, D6) for correct polarity delivery of the network alternating voltage, wherein there is connected in the base-emitter circuit of each transistor (T1, T2; T3, T4, T5, T6) the secondary winding of an associated transformer (TR1, TR2; TR3, TR4, TR5, TR6) the primary winding of which is connected to a circuit arrangement (SG1; SG2) for generating the control voltage for the transistors.

8. A circuit arrangement according to claim 6, characterized by the feature that for achieving full-wave operation there is provided a rectifier bridge (G1), the one diagonal of which is series connected with the consumer (V) and the other diagonal is connected to the parallel connected arrangement of the two transistors (T1, T2).

9. A circuit arrangement according to claim 7, characterized by the feature that for achieving full-wave operation there are provided in series with the consumer (V) a parallel arrangement of two respective sets of parallel connected transistors (T3, T4; T5, T6) and a respective rectifier (D5; D6) in series with each set, so that the current flow directions in the respective sets of transistors and the rectifier with reference to the network or consumer side of the said parallel circuit arrangement are opposite in the two branches of said parallel circuit arrangement.

10. A circuit arrangement according to one of claims 7 to 9, characterized by the feature that it contains, connected in parallel to the consumer (VG, LR) a second power switching device, which comprises the series circuit of the collector-emitter path of a transistor, e.g. a Darlington transistor (T7), furthermore an arrangement of rectifiers (G2) for correct polarity delivery to the transistor (T7) of the voltage applied to the consumer, and a load (R7, W3), whilst in the base-emitter circuit of the transistor (T7) there is connected the secondary winding of a transformer (TR7), the primary winding of which is connected to a circuit arrangement (SG3) for generating the control voltage for the transistor (T7).

11. A circuit arrangement according to claim 10, characterized by the feature that the rectifier arrangement (G2) is a rectifier bridge, one diagonal of which is connected parallel to the consumer (UG, LR) and the other diagonal is connected to the collector-emitter path of the transistor (T7). 25
12. A circuit arrangement according to claim 10, characterized by the feature that the load contains an ohmic resistance (R7) and a choke (DR, W3). 30
13. A circuit arrangement according to claim 10, characterized by the feature that the circuit arrangement (SG3) for generating the control voltage for the transistors (T1, T2) of the first power switching device also delivers the control voltage for the transistor (T7) of the second power switching device. 35
14. A circuit arrangement according to claim 12, wherein the consumer is connected to the alternating current network through said first-mentioned power switching device, which is connected to the consumer through at least one protective choke, characterized by the feature that the choke contained in the load is formed by a separate winding (W3) of the said protective choke (DR). 40
15. A method of regulating the electrical power delivered to a consumer from an alternating current network substantially as hereinbefore described with reference to the accompanying drawings. 35
16. A circuit arrangement for regulating the electrical power delivered to a consumer from an alternating current network substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings. 40

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Fig.1

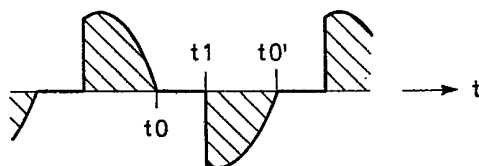


Fig.2

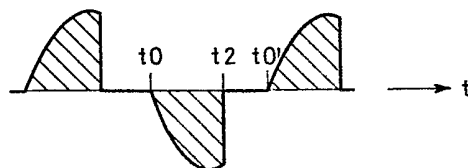


Fig.3

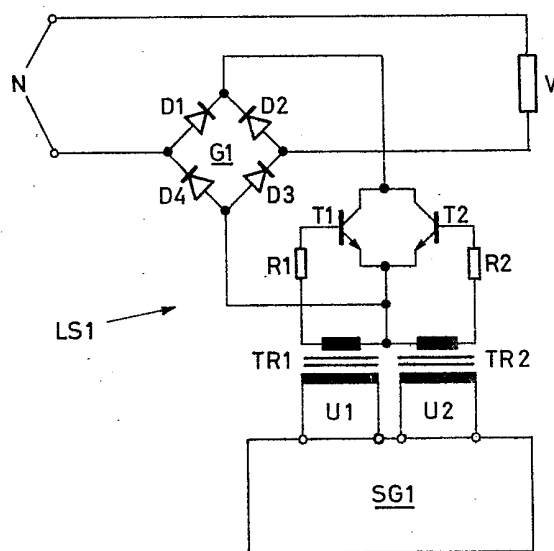


Fig. 4

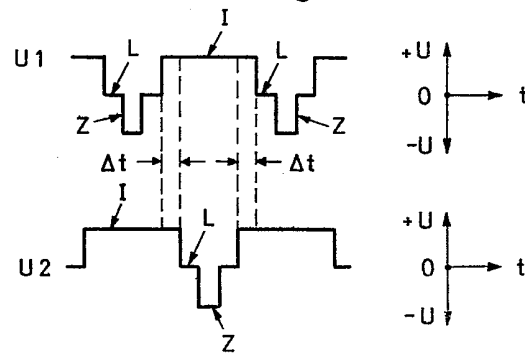


Fig. 5

