

Circuit arrangement for powering a load.

The invention relates to a circuit arrangement for powering a load in accordance with the introductory part of the main Claim.

German Patent Application P 37 22 337.2 describes a circuit arrangement for transferring electric power from an alternating voltage source which is connected to
5 an energy storage device in given time intervals for the purpose of supplying it with energy, which arrangement has a switch which is periodically activated by a control circuit to withdraw the energy from an energy storage device. In this circuit arrangement high frequency disturbances produced therein are suppressed, *i.e.* isolated from the alternating voltage source, in that the control circuit makes the switch
10 conductive only outside the time intervals in which the alternating voltage source is connected to the energy storage device. This arrangement is used particularly in switched-mode power supplies which derive energy from an a.c. mains voltage and, owing to the switching cycles of the periodically activated switch, produce interference voltages and currents which should not be introduced into the a.c. mains voltage.
15 Connection and separation of the alternating voltage source and the energy storage device is preferably effected by means of a rectifier stage. In the time intervals in which the rectifier stage is in the conducting state for the purpose of recharging the energy storage device the activation of the switch is interrupted so that this switch does not introduce any interference into the alternating voltage source, *i.e.* the a.c. mains, *via*
20 the conducting rectifier stage.

However, interrupting the activation of the switch also interrupts the energy supply to a load powered by the switched-mode power supply so that this load is powered periodically and not uniformly.

From the publication "TELECOMMUNICATIONS AND RADIO
25 ENGINEERING", Vol. 41/42, No. 1, January 1987, Washington US, pp. 140-142; Braslavskiy *et al.*: "Transformerless line-synchronized rectifying voltage converters" a transformerless mains-synchronised rectifying voltage converter is known. This converter comprises an arrangement of three rectifiers, which operate at mains voltage,

and two energy-storage and voltage-divider circuits including capacitors which discharge alternately *via* a load. Since each of the energy-storage and voltage-divider circuits transfers power to the load during only one halfwave of the line voltage the purpose of providing two of these circuits is to dispense with a smoothing capacitance as used in
5 the case that only one energy-storage and voltage-divider is employed.

However, such a voltage converter circuit allows the passage of interference at any time merely as a result of the inseparable direct connection line between the mains terminals and the load. Moreover, the cited document neither provides any indication how such a circuit arrangement can be adapted to inhibit the
10 passage of interference.

It is an object of the invention to provide a circuit arrangement which with simple means ensures both a uniform energy supply to the load and a reliable suppression of interference from the load to the power supply mains and *vice versa*.

In a circuit arrangement of the type described in the opening paragraph
15 this object is achieved by a rectifier arrangement which for each terminal of the power supply mains comprises a rectifier stage constructed as a first arm of a bridge rectifier, for each rectifier stage an energy storage device which can be charged by and is connected to said stage as a complementary arm of the bridge rectifier, for each storage device a switching element for connecting each energy storage device to the load, and a
20 control circuit by which the switching elements can be rendered conductive outside charging time intervals (conductive phases of the rectifier stages) - cyclically following the charging of the energy storage devices from the power supply mains *via* the rectifier stages.

The invention enables the transfer of interference to be inhibited by means
25 of a simple circuit arrangement which provides a uniform, uninterrupted power supply to the load. Complex high-frequency filters of conventional types are not required for this purpose. The circuit arrangement enables interference originating from the power supply mains and from the load to be suppressed. It is suitable both for single-phase and for multi-phase power supply mains, *i.e.* power supply mains having an arbitrary
30 number of terminals each carrying an alternating voltage, and it is constructed in such a way that an adaptation to the number of terminals of the power supply mains is possible simply by joining circuit modules. The dimensioning of existing circuit parts then need

not be altered when further parts for additional terminals of the power supply mains are added.

In operation the energy storage devices are cyclically charged with energy from the power supply mains *via* the rectifier stages for all terminals of the power supply mains. In the same cycle, but shifted in time, the energy storage devices are then connected to the load *via* the switching elements to transfer the energy to this load. Preferably, the rectifier stages are of a type which is not controlled or which is turned on or off simply by the alternating voltage supplied thereto from the power supply mains. The control circuit is preferably controlled by the conductive phases of the rectifier stages to activate the switching elements.

The time intervals in which the switching elements can be rendered conductive (conductive phases of the switching elements) preferably adjoin one another in a non-overlapping manner. This ensures on the one hand that one of the energy storage devices is constantly connected to the load for transferring energy; on the other hand, a direct conductive connection between at least two energy storage devices is avoided. This makes it possible to avoid equalizing effects which occur between interconnected, differently charged energy storage devices and which cause energy losses.

In a circuit arrangement in accordance with the invention, in the case of a power supply mains having at least two terminals, starting from an instant at which the voltage on the associated terminal becomes smaller than at least one of the voltages on the other terminals the conductive phase of each switching element covers a part of the period of the alternating voltage, which part corresponds to the number of terminals of the power supply mains. For example, in the case of a two-terminal power supply mains energy from a first energy storage device is applied to the load *via* an associated switching element in the first half-cycle of the alternating voltage, whilst a second energy storage device is connected to the load *via* an associated second switching element in the second half-cycle of the alternating voltage. Likewise, the first energy storage device is charged by the power supply mains in the second half-cycle and the second energy storage device in the first half-cycle.

Similarly, the period of the alternating voltage in the case of a power supply mains having, for example, three terminals (for example a three-phase mains) is divided into three parts. The conductive phase of a rectifier stage is then preferably

situated in a part of the period in which the voltage on the power supply mains terminal connected to this rectifier stage is higher than the voltages on the two other terminals. If this ratio is reversed relative to at least one of the voltages on the two other terminals the conductive phase of the rectifier stage will be terminated, *i.e.* the rectifier stage changes will be cut off. The conductive phase of the associated switching element can then occur in the time interval beginning at this instant and lasting till the next conductive phase of the rectifier stage, thereby ensuring that the energy storage device is each time connected either to the power supply mains or to the load.

For a simple implementation of the afore-described method the voltages on the terminals of the power supply mains can be applied to the control circuit to control the switching elements. In the control circuit the voltages can be compared by means of simple comparator arrangements so as to realise the above criteria for starting and stopping the conductive phases of the switching elements. Apart from a comparison of the voltages on the individual terminals of the power supply mains, it is also possible to effect a comparison with a reference voltage level, for example a zero potential.

The switching elements are preferably constructed as transistors, and each time one diode is included in each energy transfer circuit between each one of the energy storage devices and the load *via* the associated switching element. These diodes effectively preclude equalizing effects between the energy storage devices in the case of different charges.

To suppress so-called common-mode currents, which flow evenly, specifically from the load, into all terminals of the power supply mains *via* parasitic capacitances and back *via* parts of the rectifier stages, the switching elements are advantageously connected to a first terminal of the load and the diodes are connected to a second terminal of the load and furthermore the nodes, disposed nearer the diodes, between the rectifier stages and the associated energy storage devices are cyclically interchanged in accordance with the sequence of the conductive phases. The diodes then have a dual function.

For a very simple and reliable control of the switching elements dependent on the conductive phases of the rectifier stages the control circuit comprises an impedance network for each switching element, each network having a tap connected to the associated terminal of the power supply mains, having a first end terminal connected to a control terminal of the switching element, and having a second end terminal

connected to that terminal of the associated energy storage device which is remote from the switching element. Moreover, this impedance network does not require a separate supply voltage. The control voltages supplied to the control terminals of the switching elements can be combined in a simple manner by means of further control voltages for
5 further control functions to be realised with the switching elements.

If the load is a switched mode power supply the switching elements can advantageously be used as chopper switches of the switched mode power supply to economize on parts. To this end the switching elements can be clocked with an additional control signal of a higher frequency during their conductive phases.

- 10 Particularly, the control circuit then also comprises a device for controlling the switching elements depending on the voltage across the energy storage device which instantaneously powers the load and on the power consumed by the load. The switching elements are controlled specifically by means of pulse-width modulated signals.

In a further advantageous embodiment the control circuit is constructed in
15 such a manner that after the occurrence of a disturbance in an alternating voltage of the power supply mains, which disturbs the charging of one of the energy storage devices, particularly after the drop-out of a halfwave of this alternating voltage, the cycles of the conductive phases of the switching elements are reduced by given time intervals after predetermined periods of time until the original relationship between the conductive
20 phases and the alternating voltage has been restored. Thus, it is achieved that the load is also continuously powered when a drop-out of an alternating voltage of the power supply mains occurs or the power supply mains exhibits a disturbance of a similar type or having a similar effect. In principle, it is also possible to bridge longer drop-outs of an alternating voltage by suitably dimensioning the energy storage devices. However,
25 the above switching sequence of the switching elements enables disturbances of the type described to be bridged without the dimensioning of the energy storage devices being changed. As a result, the immunity to disturbances can be achieved without a larger construction of the circuit arrangement. Owing to said switching sequence the sequence in which the conductive phases of the switching elements occur, particularly with
30 respect to that associated with the imperfectly charged energy storage device, is replaced by a sequence in which the switching elements are made conductive for those energy storage devices in which the energy has been stored at least substantially correctly. The associated switching element is not made conductive until the relevant

energy storage device has been charged again in the next period of the disturbed alternating voltage. In essence, the time intervals between the conductive phases are reduced as a result of the switching protocol so that in the intervals in which energy for the load is taken from the energy storage devices the energy missing in an energy storage device in a halfwave is supplied by the other energy storage devices until the normal operating condition, *i.e.* the original relationship of the conductive phases with the alternating voltage, is restored. In principle, other switching sequences are also possible but the said switching sequence adjoins the normal cyclic sequence and can be derived therefrom by simple control means.

Interference in an alternating voltage can be detected either by detection of this voltage at the input of the rectifier arrangement or of the voltages at the energy storage devices. The switching sequence in the case of interference is started, for example, when a charge below a threshold value is detected at one of the energy storage devices at the end of a halfwave of the associated alternating voltage.

Embodiments of the invention are shown in the drawings and will be described in more detail hereinafter. In the drawings

Fig. 1 shows a first embodiment,

Fig. 2 shows some diagrams to illustrate the operation of the arrangement shown Fig. 1,

Fig. 3 shows a second embodiment,

Figs. 4 and 5 show diagrams for different modes of operation of the arrangement shown in Fig. 3,

Fig. 6 shows a third embodiment,

Fig. 7 shows a fourth embodiment, and

Fig. 8 shows diagrams for an example of an interference suppression method.

Fig. 1 shows a first embodiment of a circuit arrangement for supplying a load 15 with energy from a power supply mains having two terminals 4 and 5, whose equivalent diagram is shown to include a voltage source 1 supplying an a.c. mains voltage UW and two balanced-to-earth mains impedances 2 and 3. The terminals 4, 5 of the power supply mains 1 to 5 are connected to a rectifier arrangement consisting in the present case of four diodes 7 to 10, in which the diodes 7 and 8 on the one hand and the diodes 9 and 10 on the other hand each represent a rectifier stage in the form of a

first arm of a bridge rectifier. The first rectifier stage constituted by the diodes 7, 8 is connected to the first terminal 4 of the power supply mains 1 to 5, and the second rectifier stage constituted by the diodes 9 and 10 is connected to the second terminal 5 of the power supply mains 1 to 5.

- 5 An energy storage device 11 or 12 is connected to each rectifier stage 7, 8 and 9, 10, respectively, as a complementary arm of the bridge rectifier, *i.e.* the d.c. terminals of the arm of the bridge rectifier in the associated rectifier stages 7, 8 or 9, 10 are connected by the energy storage device 11 or 12, respectively.

- 10 Each of the energy storage devices 11, 12 is connected to the load 15 *via* a switching element 13 and 14, respectively. If the associated switching element 13, 14 is conductive energy can flow from the energy storage device 11, 12, respectively, into the load 15. This energy flow is interrupted by turning off the switching elements 13, 14. The switching elements 13, 14 are activated by a control circuit, not shown in this Figure, *via* control terminals 16 and 17, respectively.

- 15 Fig. 2 shows some current and voltage waveforms to illustrate the operation of the circuit arrangement shown in Fig. 1 in normal operation. In Fig. 2a) the a.c. mains voltage UW is shown as a sinewave as a function of time *t*, starting with a positive halfwave. Figs. 2b) and 2c) show the voltages UC1 and UC2 across the first and the second energy storage device 11 and 12 as function of time, which devices take
20 the form of capacitors in the embodiment shown in Fig. 1. Fig. 2d) shows the voltage UL across the load 15 as a function of time.

- During the positive halfwave of the a.c. mains voltage UW the first switching element 13 is conductive, *i.e.* in its conductive phase, while the second switching element 14 is cut off. Consequently, only the first energy storage device 11 is
25 connected to the load 15. As long as the rectifier stages 7, 8 and 9, 10 are cut off the variation in time of the voltage UC1 across the first energy storage device 11 is only determined by the energy supply to the load 15, whilst the voltage UC2 across the second energy storage device 12 is constant. If the a.c. mains voltage UW exceeds the instantaneous value of the voltage UC2 at the instant *t*₁ the diode 10 of the second
30 rectifier stage will become conductive. A charging current IW flows from the power supply mains 1 to 5 into the second energy storage device 12 *via* this diode. The circuit for the charging current IW is closed *via* the equally conductive diode 7 of the first rectifier stage 7, 8. The voltage UC2 then increases with the a.c. mains voltage UW

until it decreases again after it has reached its peak at the instant t_2 . The diodes 7, 10 are then blocked, the voltage U_C remains subsequently constant, and the charging current I_W ceases.

At the zero-crossing of the a.c. mains voltage U_W at the instant t_3 the
5 switching elements 13, 14 are changed over by the control circuit. During the subsequent negative halfwave of the a.c. mains voltage U_W the second switching element 14 becomes conductive, whilst the first switching element 13 is cut off. The load 15 is now powered from the second energy storage device 12. Consequently, the voltage U_{C2} starts to decrease at the instant t_3 , whilst the voltage U_{C1} across the first
10 energy storage device 11 remains initially constant because it is still separated both from the load 15 and from the power supply mains 1 to 5.

If at the instant t_4 the magnitude of the a.c. mains voltage U_W , *i.e.* the instantaneous value of the voltage on the first terminal 4 of the power supply mains 1 to 5, exceeds the instantaneous value of the voltage U_{C1} across the first energy storage
15 device 11, charging of this device begins *via* the diode 8 of the first rectifier stage 7, 8 with a corresponding completion of the path of the charging current *via* the diode 9 of the second rectifier stage 9, 10. The now negative charging current I_W flows until the a.c. mains voltage U_W exceeds its peak at the instant t_5 and the diodes 8, 9 are consequently cut off again. The voltage U_{C1} therefore remains constant till the next
20 zero-crossing of the a.c. mains voltage U_W at the instant t_6 , whilst the voltage U_{C2} decreases continuously.

The described processes at the instants t_1 to t_5 are repeated after the instant t_6 .

For the described method of operation (normal operation) the conductive
25 phases of the associated rectifier stages 7, 8 and 9, 10 and the conductive phases of the connected switching elements 13, 14 are separated in time for each of the energy storage devices 11 and 12, respectively, so that the energy storage devices are connected either to the power supply mains 1 to 5 only or to the load 15 only. A through-connection between the power supply mains 1 to 5 and the load 15 is thereby
30 avoided so that no interference can be transferred *via* this path. However, as is shown in Fig. 2d), each time one of the energy storage devices 11, 12 is connected to the load 15 so that this load is powered continuously. Consequently, the voltage U_L across the load 15 assumes a value which differs from zero. The extent to which the voltages U_{C1}

and UC2' and hence the voltage UL decrease in the associated conductive phases of the switching elements 13, 14 is dependent on the energy consumption of the load 15. If this energy consumption and hence the current drained from the energy storage devices 11, 12 increases, the voltage UL will decrease at a faster rate during the individual
5 halfwaves of the a.c. mains voltage UW. The energy storage devices 11, 12 are preferably dimensioned in such a way that the voltage UL at the instant of zero-crossing of the a.c. mains voltage UW and hence at the instant of switching over between the conductive phases of the switching elements still has the minimum permissible voltage value at the maximal current consumption and, consequently, power consumption of the
10 load 15.

With the method of operation shown in Fig. 2 the first switching element 13 remains non-conductive outside the conductive phase of the diodes 8 and 9 in the time intervals between the instants t3 and t4 and between the instants t5 and t6. In principle, these time intervals may be used either by the rectifier stages 7, 8 and 9, 10
15 or by the switching elements 13, 14 to extend their conductive phases. Particularly in the case that the energy storage devices 11, 12 are discharged at a faster rate by the load 15 and, as a consequence, the voltages UC1 and UC2 decrease at a faster rate, the time interval between the instants t3 and t4 will at least be used partly for charging the energy storage devices 11 and 12. The time interval between the instants t5 and t6 may
20 then be used for extending the conductive phase of the switching element 13, which likewise applies to the conductive phase of the second switching element 14. However, in the time intervals in which the two switching elements 13, 14 are conductive the voltages of the two energy storage devices 11, 12 are equalised, which is attended with energy losses. In view of these energy losses it is therefore advantageous for the
25 conductive phases of the switching elements 13, 14 to adjoin one another in a non-overlapping manner.

Fig. 1 further shows a high-frequency filter 6 in broken lines, which may be arranged in the lines from the terminals 4 and 5 of the power supply mains to the rectifier arrangement 7 to 10. This filter can suppress possible interference of very high
30 frequencies, which interference may be transmitted by junction or parasitic capacitances of the diodes 7 to 10 under certain circumstances. However, such a high-frequency filter is to be provided only if very high-frequency interference components of a comparatively large amplitude occur.

Fig. 3 shows an embodiment of a circuit arrangement according to the invention for operation with a three-terminal power supply mains whose three terminals 21, 22, 23 carry the alternating voltages R, S and T of a three-phase mains. Fig. 4 illustrates a first mode of operation and Fig. 5 illustrates two further modes of operation of the arrangement shown in Fig. 3.

The rectifier arrangement shown in Fig. 3 has three rectifier stages with two diodes 24, 25; 26, 27 and 28, 29 each. In the same way as in Fig. 1 each rectifier stage 24, 25; 26, 27 and 28, 29 is connected to one of three energy storage devices 30, 31 and 32, respectively, in the form of capacitors. The energy storage devices 30 to 32 are each connected to the load 15 via switching elements 33, 34 and 35, respectively. The voltages appearing across the energy storage devices 30, 31 and 32 are referenced UCT, UCS and UCR, respectively, and the voltage across the load again bears the reference UL. The references GLR, GLS and GLT, and SR, SS and ST are state variables indicating, respectively, the conductive and cut-off states of the rectifier stages, particularly the diodes 24, 26, 28, and the conductive phases of the switching elements 33, 34, 35. The last letters of these references indicate the associated alternating voltage R, S, T of the three-phase mains.

Fig. 3 further shows a block diagram of a control circuit 36, which controls the switching elements 33, 34 and 35 via control terminals 37, 38 and 39, respectively. For a correct timing of the conductive phases of the switching elements 33 to 35 the alternating voltages R, S, T from the terminals 21 to 23 of the power supply mains and the voltages UCT, UCS, UCR across the energy storage devices 30 to 32 are applied to the control circuit. The corresponding lines are shown as dashed lines and dash-dot lines and bear the reference numerals 40, 41, 42 and 43, 44, 45.

In the diagram shown in Fig. 4 all the voltages and state variables as a function of time t are plotted on a common time axis. Fig. 4a) shows the alternating voltages R, S and T on the terminals 21, 22 and 23, respectively, of the power supply mains, which voltages are each 120° phase-shifted relative to one another in customary manner. These alternating voltages are not only used for charging the energy storage devices 30 to 32 via the rectifier stages 24 to 29 but they are also applied to the control circuit 36 via the lines 40 to 42. This control circuit detects, for example with the aid of comparator circuits known *per se*, at which instants the instantaneous values of the alternating voltages R, S, T correspond to each other in pairs or the difference between

a pair of these voltages changes sign. Subsequently, the conductive phases of the switching elements 33 to 35 are started *via* the control terminals 37 to 39. In the example shown in Fig. 4c) the conductive phase of the first switching element 33 is started when the value of the alternating voltage R on the first terminal 21 becomes
5 smaller than the value of the alternating voltage S on the second terminal 22. This conductive phase covers one third of the period of the alternating voltages R, S, T; in the diagram shown in Fig. 4 this is the time interval between the instants t13 and t15. In Fig. 4c) the state variable SR assumes the value "1" in this time interval. At the instant t15 the control circuit 36 detects the reversal of the sign of the difference
10 between the alternating voltages S and T and, likewise, a conductive phase for the second switching element 34 is started and continues until the instant t17, which is illustrated by means of the state variable SS in Fig. 4f). Likewise, the conductive phase of the third switching element 35, illustrated by means of the state variable ST in Fig. 4i), is started at the instant t17 on the basis of the comparison between the alternating
15 voltages T and R. Thus, the conductive phases are started at an instant at which the alternating voltage on the associated terminal becomes smaller than at least one of the other alternating voltages and, in a contiguous and non-overlapping manner, they cover a part of the period of the alternating voltages R, S, T, which part corresponds to the number of terminals of the power supply mains.

20 In addition to the advantages described with reference to Fig. 1 this provides a simple control of the conductive phases.

In accordance with the conductive phases of the switching elements 33, 34, 35 the energy storage devices 30, 31, 32 are connected to the load 15 and the voltages UCR, UCS and UCT across the storage devices decrease in conformity with
25 their discharge, the supply of energy to the load. These variations in the time intervals t13 to t15, t15 to t17 and t17 to t19 are shown, by way of example, in the diagrams shown in Figs. 4d), g) and k) and they recur with the period of the alternating voltages R, S, T. For the time interval t13 to t15 the variations as a function of time are accentuated by means of heavier solid lines.

30 In the present embodiment the energy storage devices 30, 31, 32 are charged during the time interval in which the alternating voltage R, S or T on the respective terminal 21, 22, 23 of the power supply mains exceeds the other alternating voltages. For the alternating voltage R on the first terminal 21 this is, for example, the

interval t_{11} to t_{12} in which the diode 24 becomes conductive, which is as a change of the variable GLR to the "1" state, and in which the voltage UCR follows the alternating voltage R. After surpassing of the peak value of the alternating voltage R at the instant t_{12} the value of the voltage UCR across the first energy storage device 30 remains
5 constant for the time being because the first rectifier stage, particularly the diode 24, is cut off, GLR accordingly assuming the value "0", and the conductive phase of the first switching element 33 has not yet started. In this time interval the state variable SR is still value "0". The relationships between the voltages and the state variables during charging of the energy storage devices have also been accentuated by means of heavy
10 solid lines for the example of the alternating voltage R; they are repeated correspondingly for the voltages UCS and UCT and the state variables GLS and GLT in the diagrams shown in Figs. 4e, g), h) and k).

The voltage U_L across the load 15 is shown in Fig. 4l); in the same way as in Fig. 2 it consists of the voltage waveforms UCR, UCS and UCT in the respective
15 conductive phases of the switching elements 33, 34, 35.

Fig. 5 illustrates two modifications of the mode of operation shown in Fig. 4; the voltages and state variables are therefore shown in the same sequence and in a similar manner. Now the conductive phases of the individual switching elements 33, 34, 35 are not started until an instant at which the respective alternating voltage R, S ,
20 T becomes smaller than all the other alternating voltages. In the example of the alternating voltage R this is shown for the time interval t_{14} to t_{16} and accentuated by a heavy solid line. On the other hand, the time intervals for charging the energy storage devices 30, 31, 32 remain unchanged, *i.e.* for the alternating voltage R between the instants t_{11} and t_{12} , t_{17} and t_{18} , etc. The time between a conductive phase of a
25 switching element 33, 34, 35 and the charging time interval of the associated energy storage device 30, 31, 32 is reduced in comparison with the mode of operation shown in Fig. 4, whilst the time between the charging time interval and the subsequent conductive phase of the associated switching element is increased to the same extent. For the remainder, however, the same processes occur and, consequently, the same
30 curves appear in the diagram.

Particularly when the load 15 is constructed as a switched mode power supply which can operate with a very low voltage U_L , the capacitance of the energy storage devices 30, 31, 32 can be so small that when the maximal energy is drawn by

the load 15 the voltage U_L at the end of the conductive phase of each switching element 33, 34, 35 decreases considerably or decreases at least substantially to the value of zero. This requires an adaptation of the operation of the chopper switch used in the switched mode power supply to these low voltages, particularly by means of a pulse-width modulation of the signals controlling this switch.

In Fig. 5 the resulting mode of operation is shown in broken lines. The timing of conductive phases of the switching elements 33, 34, 35 remains unchanged, only the voltages U_{CR} , U_{CS} and U_{CT} and, accordingly, the voltage U_L are shown to decrease to zero. As a result, the charging time intervals of the energy storage devices 30, 31, 32 start earlier, *i.e.* at the instants $t_{13'}$, $t_{15'}$, $t_{17'}$, $t_{19'}$, $t_{21'}$ and $t_{23'}$ instead of, as was hitherto the case, at the instants t_{13} , t_{15} , t_{17} , t_{19} , t_{21} and t_{23} , respectively. The start of the conductive phases of the rectifier stages, which has been shifted towards these earlier instants, is represented by the broken lines in the diagrams shown in Figs. 5b), e) and h) for the state variables GLR , GLS and GLT , respectively.

It appears that this dimensioning enables the overall value of the capacitances of the energy storage devices 30, 31, 32, which are constructed as capacitors, to be a factor of 5 smaller than the capacitances values normally used for the storage capacitors in conjunction with mains rectifiers. Nevertheless, no so-called mains hum is transferred by the switched mode power supply forming the load 15. Another advantage of this mode of operation is the extension of the charging time intervals for the energy storage devices 30, 31, 32 so that the harmonics of the charging currents taken from the terminals 21, 22, 23 of the power supply mains can be reduced in amplitude. This also contributes to a reduction of the interference caused by the load 15.

To dispense with separate chopper switches in the load 15 formed by a switched mode power supply the switching elements 33, 34, 35 can be controlled preferably by the control circuit 36 *via* the control terminals 37, 38, 39 during their respective conductive phases in conformity with the chopper switch, *i.e.* they are clocked in particular by signals which are pulse-width modulated in accordance with the energy taken up by the load. The control signal required for this is applied from the load 15 to the control circuit 36 *via* a load current control line 46. The control circuit 36 includes, for example, a clock oscillator whose clock signal is pulse-width modulated

by the control signal and which is applied to the control terminals 37, 38, 39 in accordance with the conductive phases.

Fig. 6 shows a modification of the arrangement of Fig. 1, which corresponding parts bearing the same reference numerals. In addition, a control circuit 18 is shown, which circuit performs the corresponding functions of the control circuit 36 in Fig. 3 for the two-terminal power supply mains of the present embodiment. In the same way as in Fig. 3, the voltages on the terminals 4, 5 of the power supply mains 1 to 5 are applied to this control circuit *via* lines 51, 52 and the voltages UC1 and UC2 across the energy storage devices 11, 12 are applied to this circuit *via* lines 53, 54.

10 If the switching elements 13, 14 are transistors it is efficient if in each energy transfer circuit a diode is arranged between one of the energy storage devices 11 and 12 and the load 15, which circuit is closed *via* the switching elements 13 and 14, which diode handles the reverse voltage which appears across one of the switching elements 13 or 14 during the conductive phase of the other switching element in the case of different charges of the energy storage devices 11 and 12. These diodes can be arranged directly in series with the switching elements 13, 14.

In Fig. 6 the diodes, which have reference numerals 55 and 56, are arranged in the energy transfer circuit between the energy storage devices 11, 12 and the load 15 not directly in series with the switching elements 13, 14 but connected to a second terminal of the load 15, which terminal is remote from the switching elements 13, 14. In addition, the nodes situated between the rectifier stage 7, 8 or 9, 10, and the respective energy storage device 11 or 12 and disposed nearer the diodes 7, 9 of the rectifier arrangement, are cyclically interchanged. With a two-terminal power supply mains this interchange can be simply carried out by connecting the diode 7 of the rectifier arrangement to the second energy storage device 12 instead of to the first energy storage device 11 and by connecting the diode 9 to the first energy storage device 11 instead of to the second energy storage device 12. In the case of multi-phase power supply mains these terminals must be cyclically interchanged in accordance with the sequence of the conductive phases of the associated switching elements.

30 Owing to this step not only the exchange of energy between the energy storage devices 11 and 12 is interrupted but the diodes 55, 56 in this arrangement also contribute to a substantial reduction of so-called common-mode interference currents. These common-mode interference currents are produced particularly if, as explained

with reference to Fig. 3, the switching elements 13, 14 are clocked simultaneously as chopper switches for the load 15. This results in very steep transients of the electric potential on the node between the switching elements 13, 14 and the load 15. These transients are produced relative to earth *via* a parasitic capacitance 57 which is always present in the circuit arrangement and are introduced into the power supply mains 1 to 5 *via* the earth terminal of this mains. During the conductive phases of the rectifier stages, in which the diodes 7 and 9 conduct alternately, circuits for the common mode interference currents would be closed *via* these diodes and the mains impedances 2 and 3 as well as the load 15. The diodes 55, 56 interrupt these circuits for the common-mode interference currents because one of the two diodes 55, 56, *i.e.* the one connected to the instantaneously conducting diode 7 or 9 in the rectifier arrangement 7 to 10, is cut off, *i.e.* is currentless because the associated switching element 13 or 14 is cut off.

Fig. 7 shows a modification of the circuit arrangement shown in Fig. 1 with a control circuit of very simple construction. This circuit is situated in a part 191, 192 for each of the switching elements 14 and 13, respectively. For each of these switching elements 13, 14 the control circuit 191, 192 comprises an impedance network of two resistors 161, 162 and 171, 172, respectively. Each part 191, 192 of the control circuit, *i.e.* each impedance network, is connected to the respective terminal 4, 5 of the power supply mains by means of a tap, in the relevant example the node between the resistors 161, 162 and 171, 172, and is connected to one of the control terminals 16, 17 of the switching elements 13 and 14, respectively, by means of a first end terminal, *via* the resistors 161 and 171, respectively. The parts 191, 192 of the control circuit are connected to the terminal of the associated energy storage device 11, 12 which is remote from the switching element by means of a second end terminal, *via* the resistors 162 and 172, respectively. In the present example the switching elements 13, 14 each comprise a PNP transistor 131 and 141, respectively. The transistors 131, 141 have their emitters connected to the associated energy storage devices 11 and 12, respectively, their bases to the control terminals 16 and 17, respectively, and their collectors to the load 15. Moreover, a diode 132, 142 is arranged in series with each of the collectors to handle the reverse voltage in the case of differently charged energy storage devices 11, 12. In a modification of the arrangement the diodes 132 and 142 can be arranged in the same way as the diodes 55 and 56 in Fig. 6. When the node common to the diodes 7, 9 of the energy storage devices 11, 12 and the resistors 162, 172 in

Fig. 7 is separated the last-mentioned resistors remain connected to the associated energy storage devices 11 and 12, respectively.

The arrangement shown in Fig. 7 simply enables the switching elements 13, 14 to be controlled depending on the conductive phases of the rectifier stages and, particularly, the diodes 8 and 10 in these stages. The PNP transistors 131 and 141 can be turned on only when a negative voltage relative to the emitter terminal (diode forward voltage of approximately 0,7 V) appears on their base terminals, for which reason the associated diode 8, 10 of the corresponding rectifier stage must be reverse-biased with at least this voltage and thus should not conduct. The diode forward voltage or the base-emitter forward voltage of the PNP transistors 131, 141 thus provides a "safety margin" between the conductive phase of the rectifier stage and the conductive phase of the associated switching elements. Thus, these conductive phases cannot overlap one another in time. The resistance values of the resistors 161, 162, 171, 172 are as high as possible in order to reduce the losses caused by these resistors and to reduce a possible coupling of interference *via* the current paths formed by these resistors. Yet, to obtain sufficiently large base currents on the control terminals 16, 17, *i.e.* base currents which ensure that the PNP transistors 131, 141 are turned on without any problem, use is made of transistors having a maximal current gain. Preferably, the switching elements 13, 14 may also be formed with Darlington transistors.

The arrangement of the control circuit 191, 192 shown in Fig. 7 has the additional advantage that the control signals supplied by this circuit to the control terminals 16, 17 can be combined simply with further control signals for the switching elements 13, 14, for example for clocking the switching elements 13, 14, by coupling suitable logic gates to the control terminals 16, 17.

Besides for clocking of the switching elements 13, 14 it is preferable to use such additional control signals also for bridging disturbances in an alternating voltage of the power supply mains which disturb the charging of one of the energy storage devices, particularly the drop-out of a halfwave of this alternating voltage, without a drop-out of the voltage across the load 15. To this end the cycles of the conductive phases of the switching elements 13, 14 are reduced by given lengths of time after predetermined time intervals until the original relationship between the conductive phases and the alternating voltage is restored. For this purpose the control signals on the control terminals 16, 17 for the switching elements 13, 14 in the example of Fig. 7 are

simply inverted for a given length of time. However, this measure can also be applied to a circuit arrangement with a multi-terminal power supply mains, for example as shown in Fig. 3. The assignment of the control signals to the switching elements 33, 34, 35 is then cyclically interchanged. This cyclic interchange generally covers a plurality of steps before the original relationship between the conductive phases and the alternating voltage is restored.

The processes will now be described in detail for a simple example of a two-terminal power supply mains. For this purpose, Fig. 8 shows, in the same way as Fig. 2 and using the same references, some voltages and the state variables as function of time for a circuit arrangement as shown on Fig. 1 or Fig. 7. In addition to the voltages known from Fig. 2 the diagrams in Figs. 8b), c), e) and f) show state variables, in the same way as the state variables in Figs. 4 and 5, for the on states and off states of the diodes 7, 10, of the second switching element 14, of the diodes 8, 9 and of the first switching element 13, respectively. As in Fig. 2, normal operation is shown in solid lines, operation in the case of a disturbance, to be described hereinafter, being shown in broken lines. In contrast to the mode of operation illustrated in Fig. 2, Fig. 8 relates to a mode of operation in which the energy storage devices 11, 12 are discharged completely during the conductive phases of the associated switching elements 13, 14. In Figs. 8b) and e) the conductive phases of the rectifier stages, *i.e.* of the diodes 7, 10 and 8, 9, then already start at the zero crossing of the a.c. mains voltage UW and end at their subsequent peak, respectively, whilst each conductive phase of the switching elements 13, 14, shown in Figs. 8 f) and c), respectively, invariably covers a halfwave of the a.c. mains voltage UW. In the same way as the voltages UC1 and UC2, shown in Figs. 8g) and d), the voltage UL across the load 15, shown in Fig. 8h), also decreases to zero. Since the beginnings of the conductive phases of the rectifier arrangement 7 to 10 coincide with the zero-crossings of the a.c. mains voltage UW, the instants t_4 , t_7 , t_{10} , t_{13} etc. will be identical to the instants t_3 , t_6 , t_9 , t_{12} etc.; the first-mentioned instants have therefore been omitted in the diagram shown in Fig. 8a) in comparison with Fig. 2a).

The disturbance illustrated in Fig. 8 is a complete drop-out of the first negative halfwave of the a.c. mains voltage UW, which voltage thus disappears in the time interval between the instants t_3 and t_6 . Operation is still normal till the instant t_3 . In the time interval between the instants t_3 and t_5 , however, the first energy storage

device 11, which has been discharged until the instant t_3 , is not recharged; the voltage UC1 consequently keeps the value zero reached at the instant t_3 . The associated conductive phase of the first rectifier stage, particularly the diode 8, drops out; in Fig. 8e) the corresponding state variable remains in the "0" state. Until now the disturbance has no influence on the power supply of the load 15 because up to the instant t_6 the second energy storage device 12 initially supplies power and the voltage UC2 decreases to zero as in normal operation.

The control circuit is now constructed in such a manner that during change-over of the conductive phases of the switching elements 13, 14, *i.e.* during the start of the conductive phase of the first switching element 13 which follows in normal operation, it detects whether a correct charging of the first energy storage device 11 has occurred. If this charging does not occur in the case of disturbed operation, the control circuit automatically advances the cycle of the conductive phases by a given time interval. In the example shown in Fig. 8 one half-cycle of the a.c. mains voltage UW is skipped from the normal switching cycle of the switching elements 13, 14, *i.e.* the cycle of the conductive phases is thus reduced by this time interval. Thus, the end of the conductive phase of the second switching element 14 at the instant t_6 is not followed by a cut-off state which lasts until the instant t_9 , as in normal operation, but by the state which in normal operation, viewed from the instant t_6 , would still lie in the future for the time interval by which the cycles are reduced in the case of the present disturbance. This is the next conductive phase of the second switching element 14 starting at the instant t_9 in normal operation. This conductive phase now follows, starting at the instant t_6 ; likewise, in the operation of the first switching element 13 the cycle of conductive phases is also advanced by the time interval between the instants t_6 to t_9 , and the instant t_6 is followed by a similar sequence of states as would occur in normal operation from the instant t_9 .

In accordance with the changed states of the switching elements 13, 14 the load 15 is powered *via* the second switching element 14 and thus from the second energy storage device 12 in the interval between the instants t_6 and t_9 , whilst the first energy storage device 11 remains separated from the load 15 for the time being. At the same time the second energy storage device 12 is charged by the power supply mains in the interval between the instants t_6 and t_8 . In the case of such a long disturbance as described above the interference-suppressing isolation between the power supply mains

1 to 5 and the load 15 is eliminated for short time intervals. In the interval between the instants t_8 and t_9 , however, the conductive phase of the first rectifier stage, particularly of the diode 7, is terminated from the instant at which the a.c. mains voltage U_W decreases at a faster rate than the voltage U_{C2} across the second energy storage device 14 due to powering of the load 15, so that the isolation of the power supply mains 1 to 5 from the load 15 is restored. This is effected at the instant t_8' . In the time interval between the instants t_8' and t_9 the load 15 is powered from the second energy storage device 14 in the same way as in normal operation.

At the instant t_9 the switching elements 13, 14 change states in the cycle newly started from the instant t_6 ; the first switching element 13 becomes conductive and the second switching element 14 is cut off. Consequently, the discharge of the second energy storage device 14 by the supply of power to the load 15 remains interrupted for the time being; since the second energy storage device 14 has neither started yet the voltage U_{C2} remains constant for the time being. However, simultaneously with the conductive phase of the first switching element 13 the second rectifier stage, *i.e.* the diode 9, is also conductive. Consequently, both the first energy storage device 11 and the load 15 are energized from the power supply mains 1 to 5 as from the instant t_9 . The isolation between the load 15 and the power supply mains 1 to 5 is eliminated again in this time interval.

After a predetermined time interval, *i.e.* from the instant t_6 till the instant t_{11} in the present example, the cycles of the conductive phases of the switching elements 13, 14 are once more reduced by a given time interval, again by one half-cycle of the a.c. mains voltage U_W . As a result, the original relationship between the conductive phases and the a.c. mains voltage U_W is restored as from the instant t_{11} so that in this respect the normal operation of the circuit arrangement has been restored. Consequently, the first switching element 13 is set to the cut-off state and the second switching element 14 to the conductive state at the instant t_{11} . The first energy storage device 11 has reached its maximum charge again at the instant t_{11} and initially remains in this state; the second energy storage device 12 is again connected to the load 15 via the second switching element 14 and is further discharged thereby.

The first switching element 13 is set to the conductive state and the second switching element 14 is set to the cut-off state, as in normal operation, at the instant t_{12} . The load 15 is then powered again from the first energy storage device 11,

the second energy storage device 12 again being charged from the power supply mains 1 to 5. Thus, normal operation has also been restored as regards the charging conditions of the energy storage devices 11, 12.

The resulting waveform of the voltage U_L across the load 15 in Fig. 8h) shows that without a larger dimensioning of the energy storage devices the afore-described control of the switching elements 13, 14 also enables an uninterrupted power supply of the load 15 to be achieved for the described disturbance.

Another method of overcoming disturbances which cause drop-outs in the charging of the energy storage devices could be to charge the two energy storage devices 11, 12 in parallel and simultaneously powering the load 15 by means of the halfwave subsequent to the disturbed halfwave of the a.c. mains voltage U_W . However, the isolation between the power supply mains 1 to 5 and the load 15 would then also be eliminated for that time, additional energy losses owing to recharging processes between the two energy storage devices 11, 12 would occur, and finally, as a result of the diodes 55, 56 and 132, 142, the circuitry would have to be extended in order to enable a charge equalisation between the energy storage devices 11, 12 and thus a parallel charging of the energy storage devices 11, 12 to be realised.

In the same way as in the above example for a two-terminal power supply mains it is possible to preclude a disturbance of one of the alternating voltages on the terminals of a multi-phase supply mains in the case of similar disturbances without having to increase the capacitance of the energy storage devices. The number of steps in which the cycles of the conductive phases are reduced preferably corresponds to the number of terminals. A drop-out in the charging process of one of the energy storage devices at the beginning of the conductive phase of the associated switching element in principle always results in a change-over to the next switching element and the start of a conductive phase for this switching element because, unlike the disturbed storage device, the corresponding energy storage device contains enough energy to power the load. Returning to the original cycle of conductive phases is then effected by means of further steps.

CLAIMS:

1. A circuit arrangement for powering a load (15) from a power supply mains (1 to 5; 21, 22, 23) having at least one alternating voltage (UW; R, S, T), which load (15) can be powered from the power supply mains (1 to 5; 21, 22, 23) via a rectifier arrangement (7 to 10), energy storage devices (11; 12; 30; 31; 32) and
5 switching elements (13; 14; 33; 34; 35), which energy storage devices (11; 12; 30; 31; 32) can alternately be discharged into the load (15) via the switching elements (13; 14; 33; 34; 35) which are switchable by means of a control circuit (18; 36; 191, 192), characterized in that for each terminal (4, 5; 21, 22, 23) of the power supply mains the rectifier arrangement (7 to 10) comprises a rectifier stage (7, 8; 9, 10; 24, 25; 26, 27;
10 28, 29) constructed as a first arm of a bridge rectifier, each time one of the energy storage devices (11; 12; 30; 31; 32) is associated with and can be charged by each of said rectifier stages, each of the energy storage devices (11; 12; 30; 31; 32) is connected to the associated rectifier stage (7, 8; 9, 10; 24, 25; 26, 27; 28, 29) as a complementary arm of the bridge rectifier, and each time one of the switching elements
15 (13; 14; 33; 34; 35) has been provided to connect each of the energy storage devices (11; 12; 30; 31; 32) to the load (15), which switching elements (13; 14; 33; 34; 35) can be rendered conductive outside charging time intervals (conductive phases of the rectifier stages (7, 8; 9, 10; 24, 25; 26, 27; 28, 29)), cyclically following the charging of the energy storage devices (11; 12; 30; 31; 32) from the power supply mains (1 to 5;
20 21, 22, 23) via the rectifier stages (7, 8; 9, 10; 24, 25; 26, 27; 28, 29).
2. A circuit arrangement as claimed in Claim 1, characterized in that time intervals in which the switching elements (13; 14; 33; 34; 35) can be rendered conductive (conductive phases of the switching elements) adjoin one another in a non-overlapping manner.
- 25 3. A circuit arrangement as claimed in Claim 2, in conjunction with a power supply mains (1 to 5; 21, 22, 23) having at least two terminals, characterized in that the circuit arrangement is constructed in such a manner that starting from an instant at which the voltage on the associated terminal (4, 5; 21, 22, 23) of the power supply



mains (1 to 5, 21, 22, 23) becomes smaller than at least one of the voltages on the other terminals (4, 5; 21, 22, 23) the conductive phase of each switching element (13; 14; 33; 34; 35) covers a part of the period of the alternating voltage (UW; R, S, T), which part corresponds to the number of terminals (4, 5; 21, 22, 23).

5 4. A circuit arrangement as claimed in Claim 1, 2 or 3, characterized in that the voltages on the terminals (4, 5; 21, 22, 23) of the power supply mains (1 to 5; 21, 22, 23) can be applied to the control circuit (18; 36; 191, 192) to control the switching elements (13; 14; 33; 34; 35).

5. A circuit arrangement as claimed in Claim 1, 2, 3 or 4, characterized in
10 that the switching elements (13; 14; 33; 34; 35) are constructed as transistors (131; 141) and in that each time one diode (132; 142; 55; 56) is included in each energy transfer circuit between each one of the energy storage devices (11; 12; 30; 31; 32) and the load (15) via the associated switching element (13; 14; 33; 34; 35).

6. A circuit arrangement as claimed in Claim 5, characterized in that the
15 switching elements (13; 14; 33; 34; 35) are connected to a first terminal of the load (15) and the diodes (55, 56) are connected to a second terminal of the load (15) and in that the nodes, disposed nearer the diodes (55; 56), between the rectifier stages (7, 8; 9, 10) and the associated energy storage devices (11; 12) are cyclically interchanged in accordance with the sequence of the conductive phases.

20 7. A circuit arrangement as claimed in any one of the preceding Claims, characterized in that the control circuit (191, 192) comprises an impedance network (161, 162; 171, 172) for each switching element (13; 14), each network having a tap connected to the associated terminal (4; 5) of the power supply mains (1 to 5), having a first end terminal connected to a control terminal (16; 17) of the switching element (13;
25 14), and having a second end terminal connected to that terminal of the associated energy storage device (11; 12) which is remote from the switching element (13; 14).

8. A circuit arrangement as claimed in any one of the preceding Claims, characterized in that the load (15) is a switched mode power supply, and in that the switching elements (13; 14; 33; 34; 35) serve as chopper switches of said switched
30 mode power supply.

9. A circuit arrangement as claimed in Claim 8, characterized in that the control circuit (18; 36) comprises a device for controlling the switching elements (13; 14; 33; 34; 35) depending on the voltage across the energy storage device (11; 12; 30;



31; 32) which instantaneously powers the load (15) and on the power consumed by the load (15).

10. A circuit arrangement as claimed in any one of the preceding Claims, characterized in that the control circuit (18; 36) is constructed in such a manner that
- 5 after the occurrence of a disturbance in an alternating voltage (UW; R, S, T) of the power supply mains (1 to 5; 21, 22, 23), which disturbs the charging of one of the energy storage devices (11; 12; 30; 31; 32), particularly after the drop-out of a halfwave of said alternating voltage, the cycles of the conductive phases of the switching elements (13; 14; 33; 34; 35) are reduced by given time intervals after
- 10 predetermined periods of time until the original relationship between the conductive phases and the alternating voltage (UW; R, S, T) has been restored.