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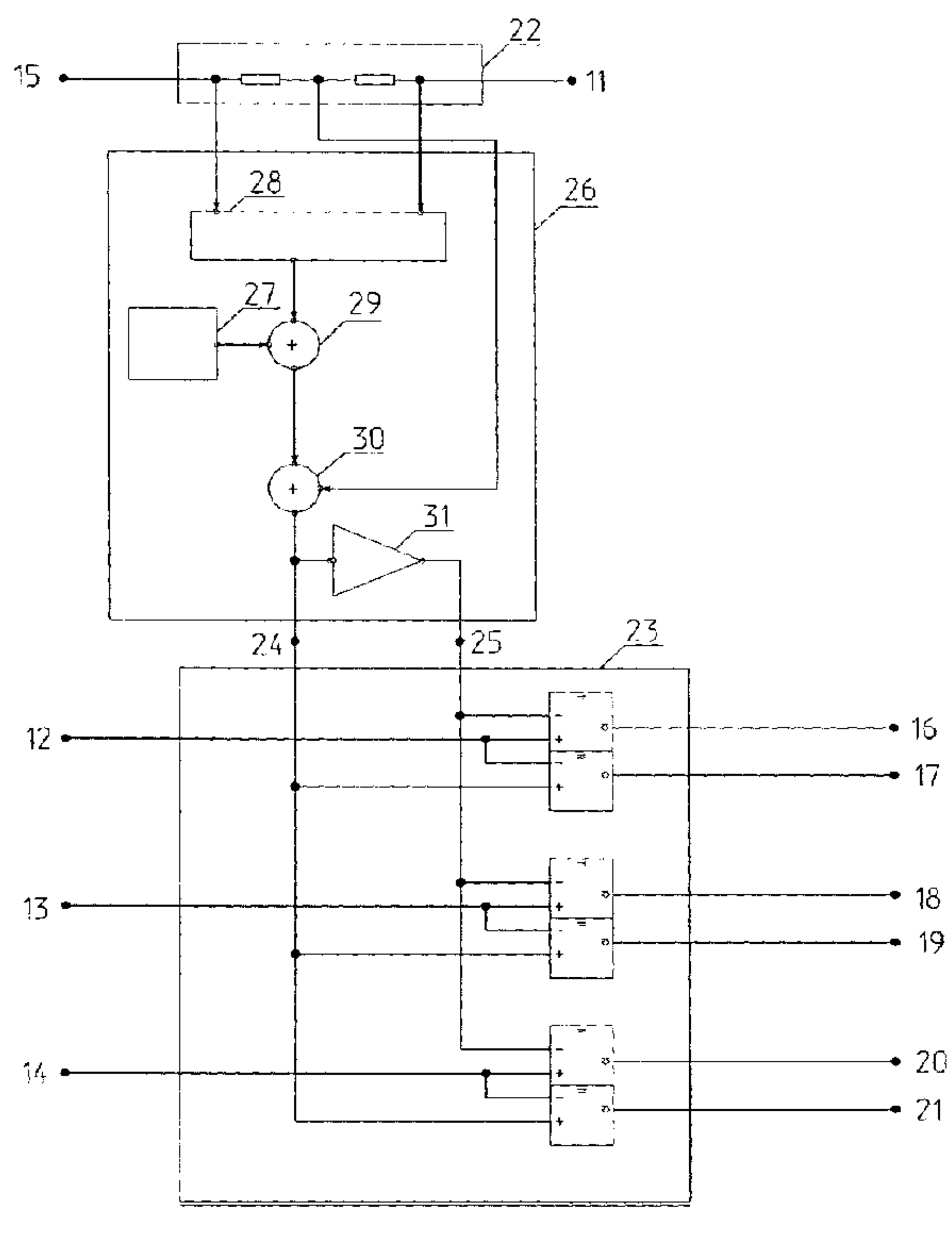
(54) Titre : PROCEDE DE COMMANDE D'UN MOTEUR ELECTRIQUE ET DISPOSITIF POUR L'EXECUTER
(54) Title: METHOD OF CONTROLLING AN ELECTRIC MOTOR AND DEVICE FOR CARRYING IT OUT



(57) Abrégé/Abstract:
The invention relates to electric engineering, in particular to methods for controlling an ac electronic motor . The inventive control method consists in starting and rotating a rotor upon EMF signals in current-free sections of an armature winding, in converting the EMF signals into discrete logical level signals by a normaliser, in detecting switching points by means of a microcontroller and in displacing said points according to a load current quantity, the rotor speed of rotation and the inductance of the armature winding sections, wherein the switching points are calculated and displaced with respect to bridging times of the free sections EMF whose voltage levels are different from zero. The inventive device is characterised in that it comprises a reference level displacing unit (26), which is arranged in the normaliser between a divider 22 and a comparator unit (23) and which consists of a current sensor (27), a voltage sensor (27), two adders (29, 30) and an inverter (31).

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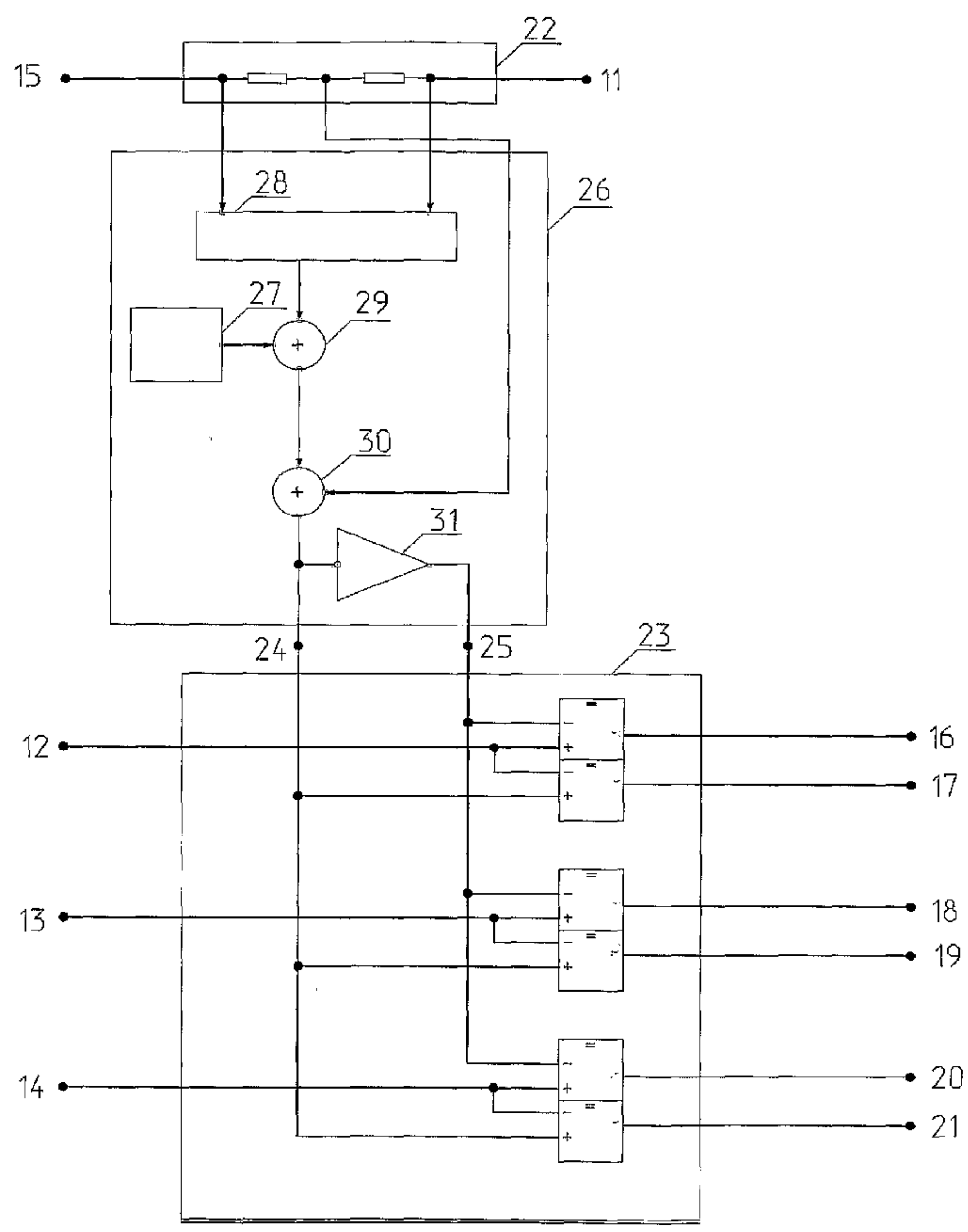
(54) Title: METHOD FOR CONTROLLING AN AC ELECTRONIC MOTOR AND DEVICE FOR CARRYING OUT SAID METHOD

(54) Название изобретения: СПОСОБ УПРАВЛЕНИЯ ВЕНТИЛЬНЫМ ЭЛЕКТРОДВИГАТЕЛЕМ И УСТРОЙСТВО ДЛЯ ЕГО ОСУЩЕСТВЛЕНИЯ



(57) Abstract: The invention relates to electric engineering, in particular to methods for controlling an ac electronic motor . The inventive control method consists in starting and rotating a rotor upon EMF signals in current-free sections of an armature winding, in converting the EMF signals into discrete logical level signals by a normaliser, in detecting switching points by means of a microcontroller and in displacing said points according to a load current quantity, the rotor speed of rotation and the inductance of the armature winding sections, wherein the switching points are calculated and displaced with respect to bridging times of the free sections EMF whose voltage levels are different from zero. The inventive device is characterised in that it comprises a reference level displacing unit (26), which is arranged in the normaliser between a divider 22 and a comparator unit (23) and which consists of a current sensor (27), a voltage sensor (27), two adders (29, 30) and an inverter (31).

(57) Реферат: Изобретение относится к области электротехники, а именно к способам управления вентильным электродвигателем. Способ управления включает пуск и вращение ротора по сигналам ЭДС в свободных от тока секциях обмотки якоря, преобразование сигналов ЭДС нормализатором в дискретные сигналы логического уровня, определение микроконтроллером моментов коммутации и их смещение в зависимости от величин тока нагрузки, скорости вращения ротора и индуктивности секций якорной обмотки, при этом моменты коммутации вычисляют и

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В отношении двубуквенных кодов, кодов языков и других сокращений см. "Пояснения к кодам и сокращениям", публикуемые в начале каждого очередного выпуска Бюллетеня PCT.

смещают относительно моментов перехода ЭДС свободных секций уровней напряжения, отличных от нуля. Особенностью устройства является наличие блока смещения опорного уровня (26), установленного в нормализаторе между делителем (22) и блоком компараторов (23), и состоящего из датчика тока (27), датчика напряжения (28), двух сумматоров (29), (30) и инвертора (31).

Method of controlling an electric motor and device for carrying it out

Technical Field to which the Invention relates

The invention relates to the field of electrical engineering, namely to methods of controlling an electric motor, and it can be used, in particular, for controlling a submersible electric motor used for driving a submersible pump for use in the petroleum industry for the recovery of petroleum.

Prior Art

A method of controlling an electric motor is known, which is carried out in the electric motor to be controlled and which consists in starting the electric motor in a synchronous mode and rotating the rotor in a valve mode in accordance with EMF signals in current-free sections of an armature winding.

A drawback of the known method is the poor degree of accuracy in determining the power key switching time, which leads to a reduction in the performance and service life of the electric motor.

A method is also known of controlling an electric motor, the sections of the armature winding of which are joined to form a "star" and are connected to the outputs of a full-wave frequency converter in the form of a three-phase bridge with bypass diodes, including starting and rotating the rotor in accordance with EMF signals in current-free sections of the armature winding, converting the EMF signals into discrete logic level signals by a normalizer, delivering the discrete signals to the inputs of a microcontroller, determining the switching times of the sections of the armature winding with respect to the transition times through zero EMF of the free sections by the microcontroller in accordance with a mathematical model of a given type of electric motor (Radim Višinka, Leoš Chalupa, Ivan Skalka. "Systems of controlling an electric motor on microcontrollers of the firm MOTOROLA", the journal "CHIP NEWS: digital control of the electric drive", No. 1, 1999, pp. 14 to 16).

A drawback of the known method is the absence of correction of the switching time in a manner dependent upon the magnitude of the load current, the rotational speed of the motor and the inductance of the motor with a supply cable during the operation of the motor and, as a result, the impossibility of controlling an electric motor having windings of higher inductance.

Closer to the disclosed technical solution in terms of the combination of essential features and the technical result to be achieved, is a method of controlling an electric motor, the sections of the armature winding of which are joined to form a "star" and are connected to the outputs of a full-wave frequency converter designed in the form of a three-phase bridge with bypass diodes, including starting and rotating the rotor in accordance with EMF signals in current-free sections of the armature winding, converting the EMF signals into discrete logic level signals by a normalizer, delivering the discrete signals to the inputs of a microcontroller, determining the switching times of the sections of the armature winding with respect to the transition times through zero EMF of the free sections by the microcontroller in accordance with a mathematical model of the given type of electric motor and shifting the switching time with respect to the transition times through zero EMF of the free sections in a manner dependent upon the magnitude of the load current, the rotational speed of the rotor and the inductance of the sections of the armature winding, in which case the flow time of the current through the bypass diode of the three-phase bridge is used for an integral estimation of the existing values of the load current, the rotational speed of the rotor and the inductance of the sections of the armature winding. A device for carrying out this method comprises a full-wave frequency converter designed in the form of a three-phase bridge with bypass diodes, a microcontroller and a normalizer, comprising a divider and a comparator unit having two reference level inputs (*cf.* Patent RU 2207700 C2, publ. 27.06.2003, Int.Publ.Cl.^{7} H02P 6/00, H02P 6/18, H02K 29/00, H02K 29/06).

A drawback of the given method is the limitation of the shift of the switching times by the EMF transition time of the zero free phase, this amounting to 30 electrical degrees, and, with respect to the delay of the normalizer filter and the calculation time of the switching times by the processor to be used after the intersection of the EMF of the zero free phase and of the occupying 10 to 15 electrical degrees (depending upon the frequency of rotation), the magnitude of the shift of the switching times to be achieved is in practice 15 to 20 electrical degrees.

As a result of the given deficiency, there is a reduction in the degree of efficiency of the electric motor and it is not possible to control electric motors with large distortion factors of the electromagnetic field which require a shift in switching to angles of more than 20 electrical degrees.

Disclosure of the invention

The object which the invention applied for aims to achieve is to provide an effective method of controlling various types of electric motors.

The technical result attained when the object posed is achieved consists in increasing the degree of efficiency of the electric motor and the possibility of controlling the electric motor with a large distortion factor of the electromagnetic field.

The technical result indicated is attained on account of the fact that in the method of controlling an electric motor, the sections of which are joined to form a star and are connected to the outputs of a full-wave frequency converter in the form of a three-phase bridge with bypass diodes, including starting and rotating the rotor in accordance with EMF signals in current-free sections of the armature winding, converting the EMF signals into discrete logic level signals by a normalizer, delivering the discrete signals to the inputs of a microcontroller, determining the switching times of the sections of the armature winding by the microcontroller in accordance with a mathematical model of the given type of electric motor and shifting the switching time of the sections in a manner dependent upon the magnitude of the load current, the rotational speed of the rotor and the inductance of the sections of the armature winding, the flow time of the current through the bypass diode of the three-phase bridge being used for an integral estimation of the existing values of the said sections, the switching times are calculated and shifted with respect to an EMF transition time of free voltage level sections which are different from zero and which correspond to a pre-determined positional angle of the rotor for given types of motor.

A device for carrying out the method comprises a full-wave frequency converter designed in the form of a three-phase bridge with bypass diodes, a microcontroller and a normalizer, comprising a divider and a comparator unit having two reference level inputs, and is characterized in that a unit for shifting the reference level containing a current sensor, a voltage sensor, two adders and an inverter is arranged between the divider and the comparator unit, the inputs of the first adder being connected to the current and voltage sensors, the inputs of the second adder being connected to the output of the first adder and to the mid-point of the divider, and the output of the second adder being connected to the first reference level input directly, and to the second reference level input by way of the inverter.

The presence of the unit for shifting the reference level in the device allows the calculation and shifting of the switching times to be carried out with respect to the transition of the EMF of free voltage level sections different from zero, and this allows large shift angles of the switching times to be achieved, which in turn makes it possible for the degree of efficiency of the electric motor to be increased and for different types of electric motors to be controlled, including electric motors with a large distortion factor of the electromagnetic field.

According to an aspect of the present invention, there is provided a method of controlling an electric motor, sections of which are joined to form a star and which are connected to outputs of a full-wave frequency converter designed to form a three-phase bridge with bypass diodes, the method comprising:

starting and rotating a rotor of the electric motor in accordance with EMF signals in current-free sections of an armature winding;

converting the EMF signals into discrete logic level signals by a normalizer;

delivering the discrete logic level signals to inputs of a microcontroller;

calculating a switching time of each section of the armature winding by the microcontroller in accordance with a mathematical model of the electric motor; and

shifting the switching time of each section in a manner dependent upon a magnitude of load current, rotational speed of the rotor and inductance of the section of the armature winding, flow time of current through the bypass diode of the three-phase bridge being used for an integral estimation of values of the load current, rotor speed and armature coil inductance values,

wherein each switching time is calculated and shifted with respect to a transition time when the EMF signal in a current-free section crosses a reference voltage level which is different from zero, which transition time is earlier than a time when the EMF signal in the current-free section crosses a zero voltage level.

According to another aspect of the present invention, there is provided a device for controlling an electric motor, comprising a full-wave frequency converter that forms a three-phase reverse diode bridge, a normalizer for conditioning and transforming EMF signals induced in current-free sections of an armature winding of the electric motor to logical signals, and a microcontroller for receiving the logical signals and for calculating a switching time of each section of the armature winding in accordance with a mathematical model of the electric motor and shifting the switching time of each section in a manner dependent upon a magnitude of load current, rotational speed of the rotor and inductance of the section of the armature winding, the flow time of the current through the bypass diode of the three-phase bridge being used for an integral estimation of values of the load current, rotor speed and armature coil inductance values,

wherein each switching time is calculated and shifted with respect to a transition time when the EMF signal in a current-free section crosses a reference voltage level which is different from zero, which transition time is earlier than a time when the EMF signal in the current-free section crosses a zero voltage level.

The invention is explained by the following illustrative materials:

Fig. 1 is a circuit diagram of a device for controlling an electric motor;

Fig. 2 is a circuit diagram of a normalizer with a unit for shifting the reference level, and

Fig. 3 is a diagram of the voltages of a section of a winding armature at the input of the normalizer.

The electric motor 1 has a permanent-magnet rotor 2, which performs the function of an inductor or a rotor 3 of soft magnetic material with an excitation winding 4. The sections of the winding armature 5, 6, 7 in a "star" formation are connected both to the outputs of a full-wave frequency converter 8 designed in the form of a three-phase bridge with bypass diodes and to the inputs 12, 13, 14 of a normalizer 9. The inputs 11 and 15 of the normalizer 9 are connected to a voltage source. The signals from the outputs 16, 17, 18, 19, 20, 21 of the normalizer 9 arrive at a microcontroller 10 which forms the controlling combinations for the frequency converter 8. The normalizer 9 comprises a divider 22 and a comparator unit 23 which has two reference level inputs 24 and 25. A unit 26 for shifting the reference level, which defines the thresholds of the comparators, is arranged between the divider 22 and the comparator unit 23.

The unit 26 for shifting the reference level comprises a current sensor 27, a voltage sensor 28, two adders 29 and 30 and an inverter 31. The inputs of the adder 29 are connected to the current sensor 27 and the voltage sensor 28, and the inputs of the adder 30 are connected to the output of the adder 29 and to the mid-point of the divider 22. The output of the adder 30 is connected to the reference level input 24 directly, and to the reference level input 25 by way of the inverter 31.

In the voltage diagram there are evident at the input of the normalizer 9:

– t the switch-off time from "+" of the power source,

– T	the time interval during which the current flows in the previous direction under the action of the EMF of the self-induction by way of the bypass diode of the frequency converter 8,
– Segments ab and cd	are intervals at which the voltage at the input of the normalizer 9 coincides with the back EMF of the section,
– U_{CM}	voltage for shifting the reference level, formed by the unit for shifting the reference levels in a manner dependent upon the voltage U_{num} and the load current,
– t1	the intersection time of the back EMF of the reference voltage level section corresponding to the angle α_0-n°,
– t2	the intersection time of the back EMF of section 6 with the zero level corresponding to the angle α_0,
– t3	the time of connecting section 6 to "–" of the power source,
– T1	the sum of the time for calculation of the switching time by the microcontroller and the delay of the normalizer filter,
– t4	the switching time in the absence of shifting, taking into consideration the armature reaction corresponding to the angle α_0+30°,
– t5	the time of disconnecting the section from "–" of the power source,
– t6	the time of connecting the section to "+" of the power source,
– T2	the maximum possible shifting of the switching times when

calculating them with respect to the intersection time of the back EMF with the zero level section,

– T3 the maximum possible shifting of the switching times when calculating them with respect to the intersection time of the back EMF with the reference level section U_{CM}.

Implementation of the invention applied for

The method applied for of controlling an electric motor is carried out in the following way during the operation of the device: After the start of the electric motor in accordance with EMF signals in current-free sections of the armature winding the microcontroller 10 issues controlling combinations in a cyclical manner for 120° key switching to the full-wave frequency converter 8. The rotor 2 or 3 starts to rotate. In the output of the I^{th} control combination, the frequency converter 8 disconnects, for example, section 6 from "+" of the source at the moment in time t in Fig. 3. The normalizer 9, which includes a unit for shifting the reference level, converts the voltage sections 6 at the input 13 into discrete logic level signals at the outputs 18, 19. These signals arriving at the inputs of the microcontroller 10 contain the following information:

– Time T (Fig. 3) – the flow time of the current in the previous direction under the action of the EMF of the self-induction by way of the bypass diode of the frequency converter 8;

– Time instant t1 (Fig. 3) – the transition time of the EMF of the section disconnected from the voltage level source corresponding to the angle α_0-n° in a manner dependent upon the level U_{CM}.

The microcontroller 10 calculates the time for connecting the section 6 to "–" of the power source (the time of the output of the I+1[th] combination), using the time period between the times t1, the transition of the EMF of the section disconnected from the voltage level source corresponding to the angle α_0-n°. The time T is used in order to allow for the reaction of the armature when determining the switching times. To this end the calculated time is shifted in magnitude in proportion to the time T. As is evident from Fig. 3, when calculating the switching times with respect to the intersection of the EMF with the zero free phase, the time t2 (the angle α_0), the interval T2 is the available switching range . This is linked to the fact that from 10 to 15 electrical degrees (the time T1) are involved in the delay of the normalizer filter and the time for the processor to calculate the switching times after the time t2.

In the method applied for, the interval T3 is the available switching range, since the delay of the filter and the calculation time are read off from the time t1 (the angle α_0–n°), and this makes it possible to achieve large shift angles of the switching times, which in turn allows the electric motor to be controlled with large distortion factors of the electromagnetic field.

The use of the present method of controlling an electric motor is particularly effective in systems where the length of the cable leading to the motor is substantial and varies within quite wide limits, for example in the recovery of oil by a submerged pump, the drive of which is in the form of a submerged electric motor, the control of which is carried out by an on-land control station which is positioned at a considerable distance from the borehole.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of controlling an electric motor, sections of which are joined to form a star and which are connected to outputs of a full-wave frequency converter designed to form a three-phase bridge with bypass diodes, the method comprising:

starting and rotating a rotor of the electric motor in accordance with EMF signals in current-free sections of an armature winding;

converting the EMF signals into discrete logic level signals by a normalizer;

delivering the discrete logic level signals to inputs of a microcontroller;

calculating a switching time of each section of the armature winding by the microcontroller in accordance with a mathematical model of the electric motor; and

shifting the switching time of each section in a manner dependent upon a magnitude of load current, rotational speed of the rotor and inductance of the section of the armature winding, flow time of current through the bypass diode of the three-phase bridge being used for an integral estimation of values of the load current, rotor speed and armature coil inductance values,

wherein each switching time is calculated and shifted with respect to a transition time when the EMF signal in a current-free section crosses a reference voltage level which is different from zero, which transition time is earlier than a time when the EMF signal in the current-free section crosses a zero voltage level.

2. A method according to claim 1, wherein each armature section is connected between first and second outputs of the three-phase bridge and the method further comprises:

determining the non-zero reference voltage level from a first voltage level associated with the first output, a second voltage level associated with the second output and the current supplied to the electric motor.

3. A device for controlling an electric motor, comprising a full-wave frequency converter that forms a three-phase reverse diode bridge, a normalizer for conditioning and transforming EMF signals induced in current-free sections of an armature winding of the electric motor to logical signals, and a microcontroller for receiving the logical signals and for calculating a switching time of each section of the armature winding in accordance with a mathematical model of the electric motor and shifting the switching time of each section in a manner dependent upon a magnitude of load current, rotational speed of the rotor and inductance of the section of the armature winding, the flow time of the current through the bypass diode of the three-phase bridge being used for an integral estimation of values of the load current, rotor speed and armature coil inductance values,

wherein each switching time is calculated and shifted with respect to a transition time when the EMF signal in a current-free section crosses a reference voltage level which is different from zero, which transition time is earlier than a time when the EMF signal in the current-free section crosses a zero voltage level.

4. A device according to claim 3, wherein the normalizer comprises first and second reference level inputs.

5. A device according to claim 3 or 4, wherein a reference level shift block is provided between a divider and a comparator block.

6. A device according to claim 5, wherein the reference level shift block comprises a current sensor and a voltage sensor.

7. A device according to claim 5, wherein the reference level shift block comprises adding means and an inverter.

8. A device according to claim 6, wherein the reference level shift block comprises adding means and an inverter.

9. A device according to claim 8, wherein the adding means includes a first adder having inputs connected to the current and voltage sensors.

10. A device according to claim 9, wherein the adding means includes a second adder having inputs connected to the first adder output and to the divider midpoint.

11. A device according to claim 10, wherein the second adder output is connected to the first reference level input directly and to the second reference level input by way of the inverter.

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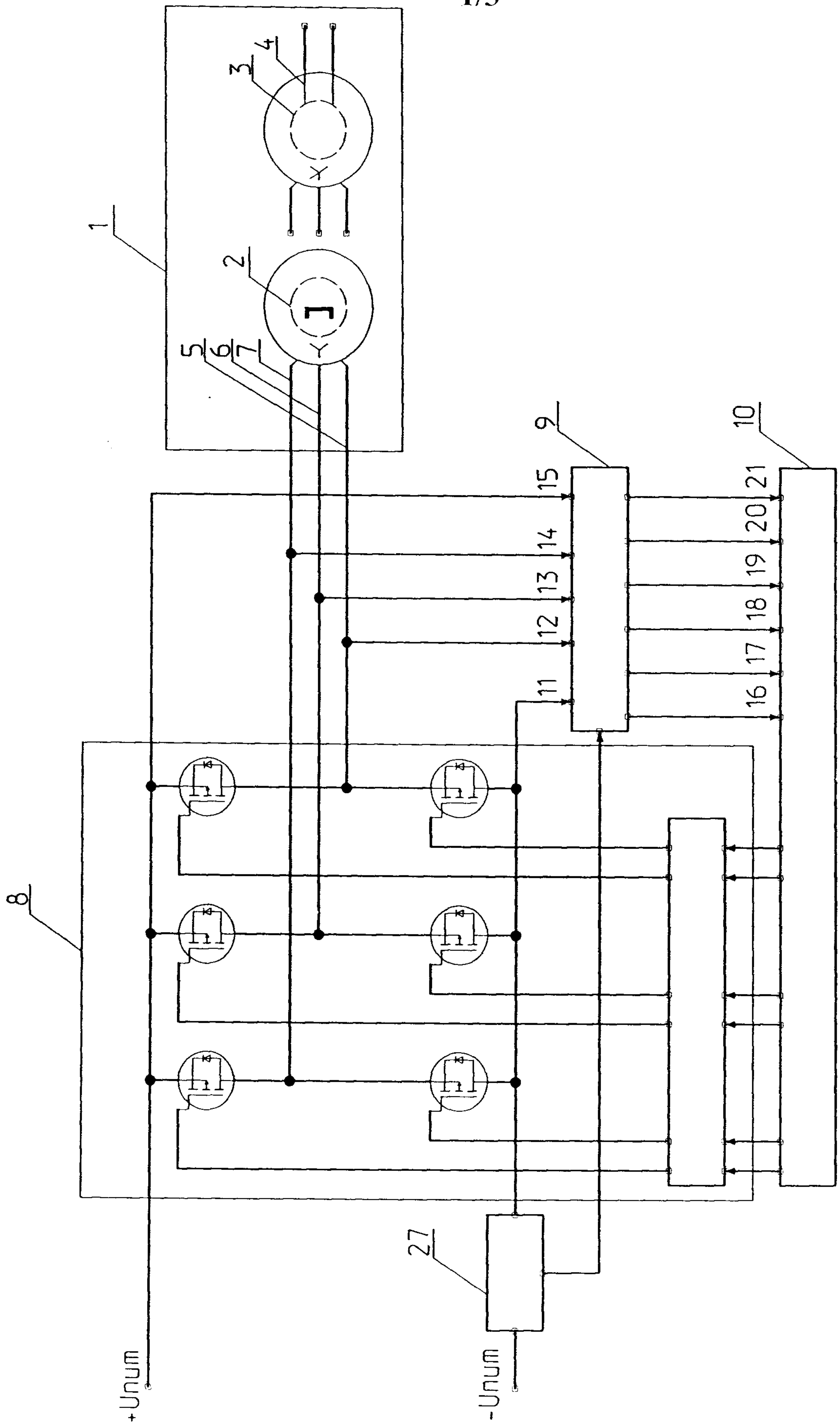


Figure 1

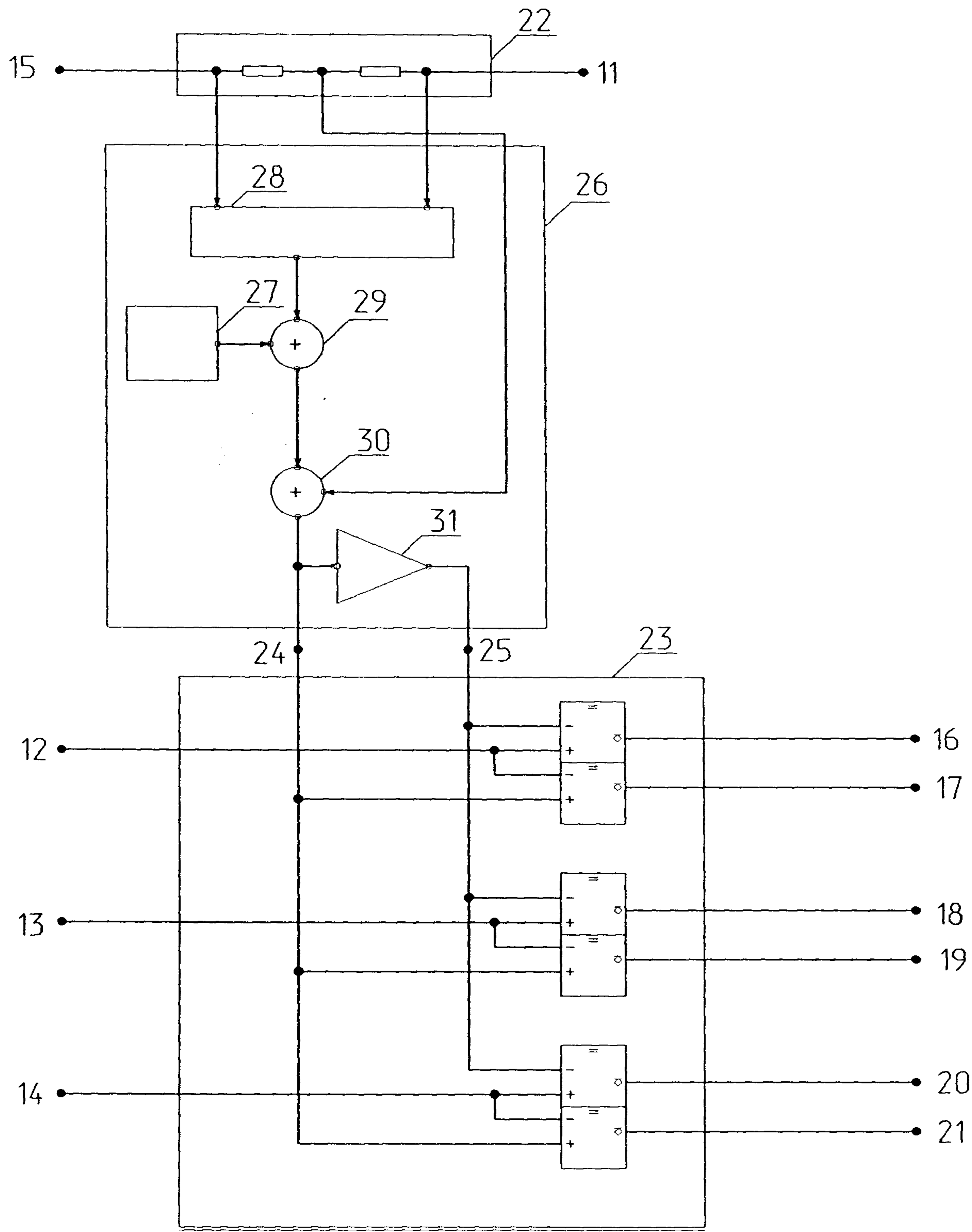


Figure 2

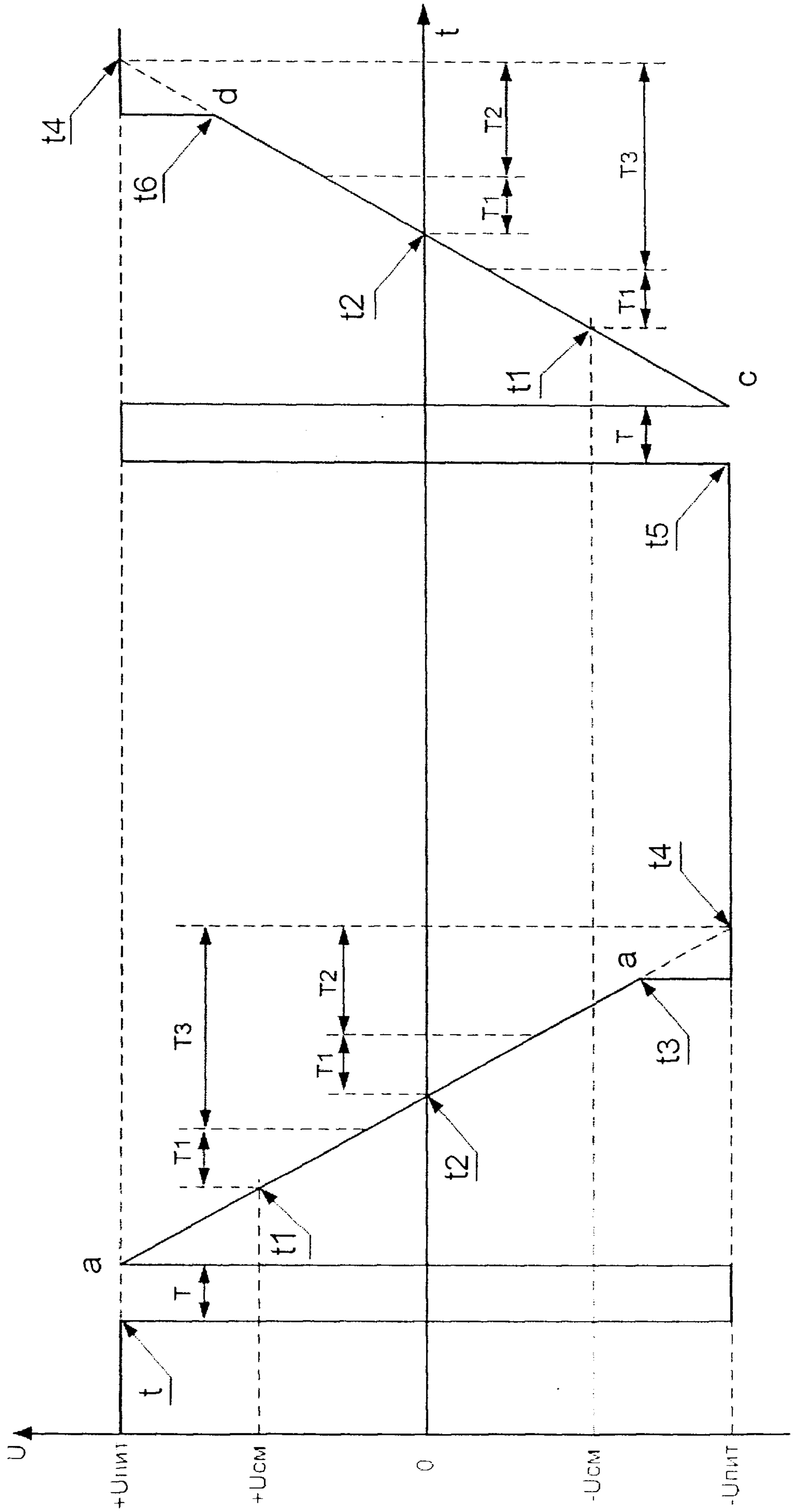
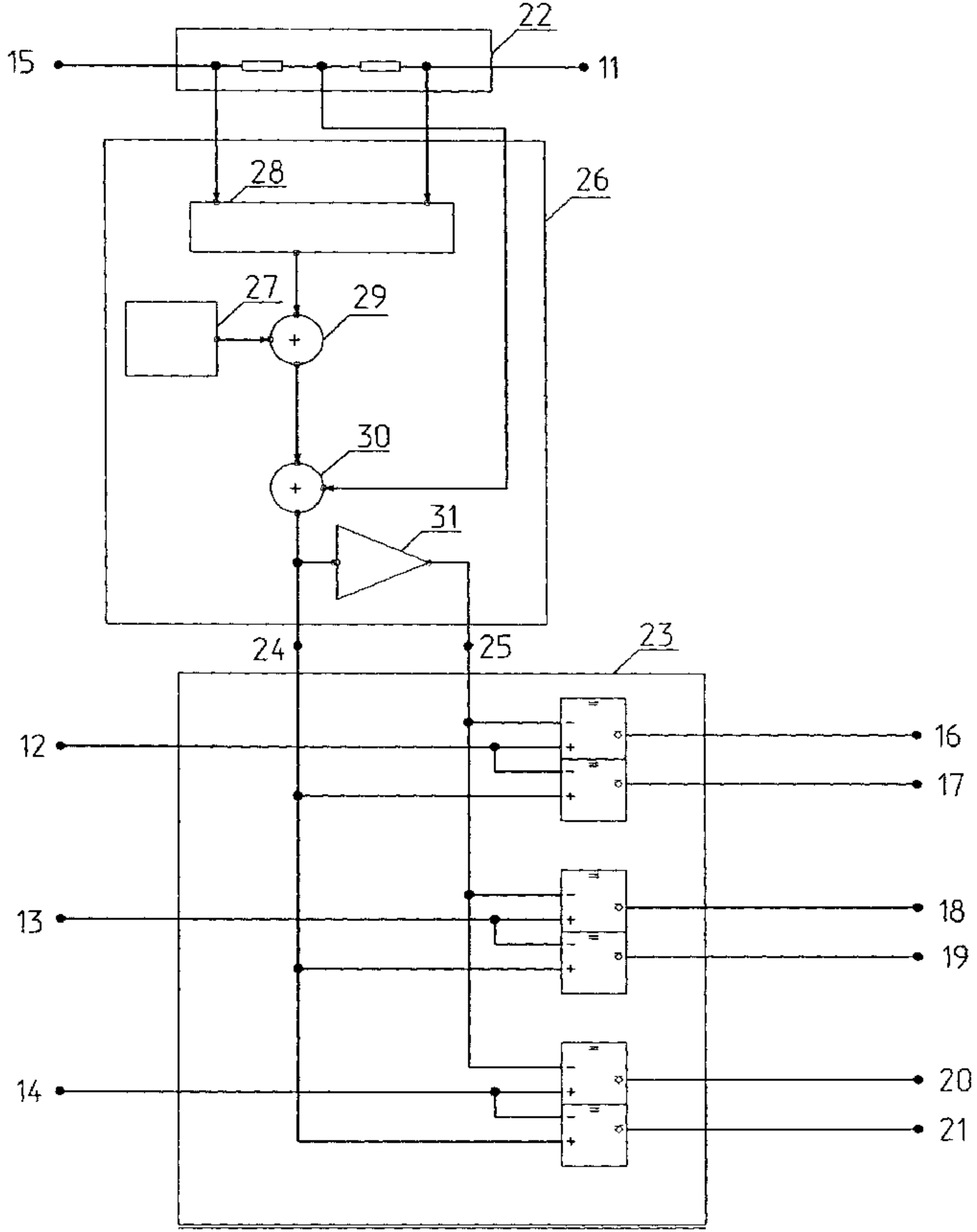


Figure 3



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