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(54) Title: ELECTRIC SWITCH ARRANGEMENT AND METHOD FOR COUPLING ELECTRIC POWER SOURCE WITH LOAD

Abstract: An electric switch arrangement (4) and a method for coupling of an electric power source (2) with a load (3). The electric switch arrangement comprises at least one electric switch unit (5) to be coupled between the electric power source and the load. At least one crowbar circuit (6) is to be coupled to the output of the electric switch unit in parallel with the load, and at least one control unit (7) is configured to control the operation of the electric switch unit and the crowbar circuit. The control unit is configured to control the electric switch unit to a closed state to allow a current flow through the electric switch unit and to an open state to prevent a current flow through the electric switch unit. The control unit is configured to control the crowbar circuit to a closed state to allow a current flow through the crowbar circuit and to an open state to prevent a current flow through the crowbar circuit.

FIG. 1.
ELECTRIC SWITCH ARRANGEMENT AND METHOD FOR COUPLING ELECTRIC POWER SOURCE WITH LOAD

FIELD OF THE INVENTION

The present invention relates to an electric switch arrangement and a method for coupling an electric power source with a load.

BACKGROUND OF THE INVENTION

In electric circuits loads are connected to electric power sources typically with electric switch units in such a way that in a closed state the electric switch unit allows a current flow through the electric switch unit and in an open state the electric switch unit prevents the current flow through the electric switch unit.

In case of faults occurring in the electric circuit or in the load, or in case of changes in operational conditions of the electric circuit, it may be necessary to disconnect the load from the electric power source by controlling the electric switch unit to the open state, i.e. by opening the electric switch unit. During the opening of the electric switch unit, especially if the electric switch unit comprises a mechanical switch, inductive current of the load may cause an electric arc in the electric switch unit. The electric arc damages the electric switch unit by causing melting or encrusting of metal material of the electric switch unit and thereby reduces the operating life of the electric switch unit.

BRIEF DESCRIPTION OF THE INVENTION

An object of the present invention is to provide a new type of electric switch arrangement and a method for coupling an electric power source with a load.

The invention is characterized by the features of the independent claims.

According to an embodiment an electric switch arrangement comprises at least one electric switch unit to be coupled between an electric power source and a load, at least one crowbar circuit to be coupled to an output of the electric switch unit in parallel with the load, and at least one control unit configured to control the operation of the electric switch unit and the crowbar circuit, wherein the control unit is configured to control the electric switch unit to a closed state to allow a current flow through the electric switch unit and to an open state to prevent a current flow through the electric switch unit.
unit and wherein the control unit is configured to control the crowbar circuit to a closed state to allow a current flow through the crowbar circuit and to an open state to prevent a current flow through the crowbar circuit.

According to an embodiment of the electric switch arrangement the control unit is configured to connect the load to the electric power source by controlling the electric switch unit to the closed state and to disconnect the load from the electric power source by controlling the electric switch unit to the open state, and wherein the control unit is configured to connect the crowbar circuit to the load by controlling the crowbar circuit to the closed state and to disconnect the crowbar circuit from the load by controlling the crowbar circuit to the open state, and wherein the control unit is configured, for disconnecting the load from the electric power source, to control the crowbar circuit to the closed state for providing a closed electric circuit between the crowbar circuit and the load and to control the electric switch unit to the open state.

According to an embodiment of the electric switch arrangement the crowbar circuit comprises at least one semiconductor switch and the control unit is configured to turn the semiconductor switch to a conducting state to allow a current flow through the crowbar circuit and to turn the semiconductor switch to a non-conducting state to prevent a current flow through the crowbar circuit.

According to an embodiment the electric switch arrangement comprises a driving circuit, which is configured to control the crowbar circuit to the closed and open states as controlled by the control unit.

According to an embodiment of the electric switch arrangement the driving circuit is an optocoupler driver.

According to an embodiment of the electric switch arrangement the electric switch unit comprises at least one of a mechanical switch and a semiconductor switch.

According to an embodiment the electric switch arrangement comprises at least one overvoltage protective device coupled in parallel with at least one of a mechanical switch and a semiconductor switch comprised by the electric switch unit.

According to an embodiment the electric switch arrangement is intended for use in direct current applications and the crowbar circuit comprises at least one diode and at least one semiconductor switch connected in series with the diode.
According to an embodiment the electric switch arrangement is intended for use in 1-phase alternating current applications and the crowbar circuit comprises a 1-phase diode bridge and at least one semiconductor switch connected in series with an output of the 1-phase diode bridge.

According to an embodiment the electric switch arrangement is intended for use in 3-phase alternating current applications and the crowbar circuit comprises a 3-phase diode bridge being a type of a six-pulse bridge rectifier and at least one semiconductor switch connected in series with an output of the 3-phase diode bridge.

According to an embodiment of the electric switch arrangement the control unit is configured to provide a pulsed control signal to control the crowbar circuit to the closed and open states repeatedly.

According to an embodiment of the electric switch arrangement the crowbar circuit comprises a current transducer connected in series with the semiconductor switch for measuring the current through the semiconductor switch in the crowbar circuit.

According to an embodiment the electric switch arrangement comprises a desaturation detection unit for detecting an overvoltage between a collector and an emitter of the semiconductor switch in the crowbar circuit.

According to an embodiment of a method for coupling an electric power source with a load an electric switch unit coupled between the electric power source and the load is controlled to a closed state to allow a current flow between the electric power source and the load through the electric switch unit and to an open state to prevent a current flow between the electric power source and the load through the electric switch unit and a crowbar circuit coupled to an output of the electric switch unit in parallel with the load is controlled to a closed state to allow a current flow through the crowbar circuit and to an open state to prevent a current flow through the crowbar circuit.

According to an embodiment of the method, for disconnecting the load from the electric power source, the crowbar circuit is controlled to the closed state for providing a closed electric circuit between the crowbar circuit and the load and the electric switch unit is controlled to the open state.

According to an embodiment of the method the crowbar circuit comprises at least one semiconductor switch and the semiconductor switch in the crowbar circuit is turned to a conducting state to allow the current flow through the crowbar circuit and to a non-conducting state to prevent a current
flow through the crowbar circuit.

According to an embodiment of the method a pulsed control signal is provided to control the crowbar circuit to the closed and open states repeatedly.

According to an embodiment of the method the current through the semiconductor switch in the crowbar circuit is measured and the semiconductor switch in the crowbar circuit is controlled to the non-conducting state when the current through the semiconductor switch exceeds an overcurrent limit of the semiconductor switch.

According to an embodiment of the method a voltage between a collector and an emitter of the semiconductor switch in the crowbar circuit is detected and the semiconductor switch in the crowbar circuit is controlled to the non-conducting state when the voltage between the collector and the emitter of the semiconductor switch in the crowbar circuit exceeds an overvoltage limit value set for the voltage between the collector and the emitter of the semiconductor switch.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following the invention will be described in greater detail by means of preferred embodiments with reference to the accompanying drawings, in which

Figure 1 shows schematically an electric switch arrangement applicable to direct current applications or 1-phase alternating current applications;

Figure 2 shows schematically an electric switch arrangement applicable to 3-phase alternating current applications;

Figures 3a to 3f show schematically different electric switch units applicable to direct current applications;

Figures 4a to 4f show schematically different electric switch units applicable to alternating current applications;

Figure 5 shows schematically a crowbar circuit applicable to direct current applications;

Figure 6 shows schematically a crowbar circuit applicable to 1-phase alternating current applications and

Figure 7 shows schematically a crowbar circuit applicable to 3-phase alternating current applications.
DETAILED DESCRIPTION OF THE INVENTION

Figure 1 shows schematically an electric circuit 1. The electric circuit 1 of Figure 1 may be a direct current circuit or a 1-phase alternating current circuit. The electric circuit 1 comprises an electric power source 2, such as a power station or a power line or a power transformer, a load 3, such as an electric motor, and an electric switch arrangement 4, through which load 3 is connected to the electric power source 2.

The electric switch arrangement 4 of Figure 1 comprises an electric switch unit 5 connected between the electric power source 2 and the load 3, an input 5' of the electric switch unit 5 being connected to the electric power source 2 and an output 5" of the electric switch unit 5 being connected to the load 3. The electric switch unit 5 may be controlled to a closed state to allow a current flow between the electric power source 2 and the load 3 through the electric switch unit 5 and to an open state to prevent a current flow between the electric power source 2 and the load 3 through the electric switch unit 5. An internal structure and the operation of some electric switch units 5 are disclosed later in connection with Figures 3a to 3f and 4a to 4f.

The electric switch arrangement 4 of Figure 1 further comprises a crowbar circuit 6 connected to the output 5" of the electric switch unit 5 in parallel with the load 3. The crowbar circuit 6 may be controlled to a closed state to allow a current flow through the crowbar circuit 6 and to an open state to prevent a current flow through the crowbar circuit 6. An internal structure and the operation of some crowbar circuits 6 are disclosed later in connection with Figures 5, 6 and 7.

The electric switch arrangement 4 of Figure 1 further comprises a control unit 7, which is configured to control the operation of the electric switch unit 5 and the crowbar circuit 6. The control unit 7 is connected to the electric switch unit 5 with a control line CL_S, which provides a communication line between the control unit 7 and the electric switch unit 5 to allow the control unit 7 to monitor and control the operation of the electric switch unit 5. The control unit 7 is connected to the crowbar circuit 6 with a control line CL_C, which provides a communication line between the control unit 7 and the crowbar circuit 6 to allow the control unit 7 to monitor and control the operation of the crowbar circuit 6. The control unit 7 may for example be microprocessor- or a signal processor-based data-processing equipment, which, on the basis of hardware- and/or software-based applications, monitors and controls the
operation of the electric switch unit 5 and the crowbar circuit 6.

The control unit 7 is configured to control the electric switch unit 5 to a closed state to allow a current flow through the electric switch unit 5 and to control the electric switch unit 5 to an open state to prevent the current flow through the electric switch unit 5. The control unit 7 is thus configured to connect the load 3 to the electric power source 2 by controlling the electric switch unit 5 to the closed state and to disconnect the load 3 from the electric power source 2 by controlling the electric switch unit 5 to the open state. The control unit 7 is further configured to control the crowbar circuit 6 to a closed state to allow a current flow through the crowbar circuit 6 and to control the crowbar circuit 6 to an open state to prevent the current flow through the crowbar circuit 6. The control unit 7 is thus configured to connect the crowbar circuit 6 to the load 3 by controlling the crowbar circuit 6 to the closed state and to disconnect the crowbar circuit 6 from the load 3 by controlling the crowbar circuit 6 to the open state.

For connecting the load 3 to the electric power source 2 to allow the load 3 to operate, the electric switch unit 5 is controlled, by means of the control unit 7, to the closed state to allow a current flow between the electric power source 2 and the load 3 through the electric switch unit 5. Before the electric switch unit 5 is controlled to the closed state, the crowbar circuit 6 is controlled, by means of the control unit 7, to the open state to prevent any current to flow through the crowbar circuit 6, if the crowbar circuit 6 is not already in the open state.

For disconnecting the load 3 from the electric power source 2, for example due to a fault occurring in the electric circuit 1 or in the load 3, or in case of changes in operational conditions of the electric circuit 1, the crowbar circuit 6 is controlled, by means of the control unit 7, to the closed state to provide a closed electric circuit between the crowbar circuit 6 and the load 3 and the electric switch unit 5 is controlled, by means of the control unit 7, to the open state to disconnect the current flow between the electric power source 2 and the load 3.

The crowbar circuit 6 controlled to the closed state thus provides the closed electric circuit comprising the crowbar circuit 6 and the load 3 such that the inductive load current of the load 3 may flow through the crowbar circuit 6. When the inductive load current flows through the crowbar unit 6, the inductive load energy is absorbed in the resistive parts of the load. The crowbar unit 6
thus prevents the inductive load current from flowing through the electric switch unit 5 and thus prevents the inductive load current possibly from creating a harmful electric arc in the electric switch unit 5 to be opened.

When the load 3 is disconnected from the electric power source 2, the crowbar circuit 6 may be controlled to the closed state either before or at the same time or after the electric switch unit 5 is controlled to the open state. If the crowbar circuit 6 is controlled to the closed state before the electric switch unit 5 is controlled to the open state, all the inductive load current of the load 3 flows through the crowbar circuit 6 and all the inductive load energy is absorbed in the resistive parts of the load 3. If the crowbar circuit 6 is controlled to the closed state either at the same time or after the electric switch unit 5 is controlled to the open state, some inductive load current may flow through the electric switch unit 5 for a short time period and possibly create a minor electric arc in the electric switch unit 5. In these cases, however, most of the inductive load current flows through the crowbar circuit 6 and is absorbed in the resistive parts of the load 3 and thus diminish the effect of a possible electric arc in the electric switch unit 5.

Figure 2 shows schematically another electric circuit 1. The electric circuit 1 of Figure 2 is a 3-phase alternating current circuit. The electric circuit 1 of Figure 2 comprises an electric power source 2, load 3 and an electric switch arrangement 4, as well as three phase lines L1, L2 and L3, through which the load 3 is connected to the electric power source 2. The electric switch arrangement 4 comprises three electric switch units 5, one electric switch unit 5 for each phase line L1, L2 and L3. The electric switch arrangement 4 further comprises a crowbar circuit 6 connected to the outputs 5" of the electric switch units 5 in parallel with the load 3. Further the electric switch arrangement 4 of Figure 2 comprises a control unit 7 arranged to control the operation of the electric switch units 5 and the crowbar circuit 6. The control unit 7 is connected to the electric switch units 5 with control lines CL_SA, CL_SB and CL_SC and to the crowbar circuit 6 with a control line CL_C.

When connecting the load 3 to the electric power source 2 and when disconnecting the load 3 from the electric power source 2, the combined operation of the electric switch units 5, the crowbar circuit 6 and the control unit 7 is the same as disclosed above, the only difference being that in the embodiment of Figure 2, there are altogether three electric switch units 5, which must be controlled either to the closed state or open state.
The 3-phase electric circuit 1 of Figure 2 could also be provided with only single electric switch unit 5, if this single electric switch unit 5 was provided with means for interrupting the power supply from the electric power source 2 to the load 3 in all three phases A, B and C substantially simultaneously. The arrangement of Figure 2 comprising separate electric switch units 5 in each phase is, however, preferable, because in the arrangement of Figure 2, the load 3 may still be operated if the power supply from the electric power source 2 to the load 3 is interrupted in only one or two phases and if a structure of the load 3 and a structure of the electric circuit 1 allows this kind of use of the load 3.

Figures 3a, 3b, 3c, 3d, 3e and 3f show schematically different embodiments of possible electric switch units applicable to direct current applications. For the sake of clarity, Figures 3a to 3f disclose only the electric power source 2, the load 3 and the electric switch unit 4 but no crowbar circuit.

Figure 3a discloses schematically an electric switch unit 5 comprising only a mechanical switch 9. The state of the mechanical switch 9 is controlled through a control line CL_M, which is connected to the control line CL_S of the control unit 7 shown for example in Figure 1. In Figure 3a the electric switch unit 5 is shown in an open state.

Figure 3b discloses schematically an electric switch unit 5 comprising the mechanical switch 9 and a varistor 10 connected in parallel with the mechanical switch 9. The varistor 10 may for example be a metal oxide varistor (MOV). The varistor 10 is a kind of overvoltage protective device for protecting the electric switch unit 5 against overvoltages. Instead of using the varistor 10 also other overvoltage protective devices may also be used.

Figure 3c discloses schematically an electric switch unit 5 comprising only a semiconductor switch 11. A state of the semiconductor switch 11 is controlled through a control line CL_SS, which is connected to the control line CL_S of the control unit 7 shown for example in Figure 1. Figure 3d, in turn, discloses schematically an electric switch unit 5 comprising the semiconductor switch 11 and the varistor 10 connected in parallel with the semiconductor switch 11.

Figure 3e discloses schematically an electric switch unit 5 comprising both the mechanical switch 9 and the semiconductor switch 11 connected in parallel with each other. The state of the mechanical switch 9 is
controlled by the control unit 7 through the control line CL_M and the state of the semiconductor switch 11 is controlled by the control unit 7 through the control line CL_SS, meaning that there are two separate control lines from the control unit 7 to the electric switch unit 5, one control line for the mechanical switch 9 and the other control line for the semiconductor switch 11. Figure 3f, in turn, discloses schematically an electric switch unit 5 comprising the mechanical switch 9, the semiconductor switch 11 and the varistor 10, all connected in parallel with each other.

Figures 4a, 4b, 4c, 4d, 4e and 4f show schematically different embodiments of possible electric switch units applicable to alternating current applications. For the sake of clarity, Figures 4a to 4f disclose only the electric power source 2, the load 3 and the electric switch unit 5 for a single phase but no crowbar circuit 6.

Figure 4a discloses schematically an electric switch unit 5 comprising only a mechanical switch 9. A state of the mechanical switch 9 is controlled through the control line CL_M, which is connected to the control line CL_S of the control unit 7 shown for example in Figure 1. In Figure 4a the electric switch unit 5 is shown in an open state. Figure 4b, in turn, discloses schematically an electric switch unit 5 comprising the mechanical switch 9 and a varistor 10 connected in parallel with the mechanical switch 9.

Figure 4c discloses schematically an electric switch unit 5 comprising two branches 12a, 12b connected in parallel with each other, both of the branches 12a, 12b comprising a series connection of a semiconductor switch 11 and a diode 13, different branches reserved for different half-cycles, i.e. positive and negative half-cycles of the load current. A state of the semiconductor switch 11 in the first branch 12a is controlled by the control unit 7 through a control line CL_SSa and a state of the semiconductor switch 11 in the second branch 12b is controlled by the control unit 7 through a control line CL_SSa. Thus in the embodiment of Figure 4c, there are two different control lines from the control unit 7 to the electric switch unit 5. The electric switch unit 5 in Figure 4d, in turn, further comprises a varistor 10 connected in parallel with the semiconductor switches 11.

Figure 4e discloses schematically an electric switch unit 5 comprising a mechanical switch 9 connected in parallel with the series connections of the semiconductor switches 11 and the diodes 13 in different branches 12a, 12b as shown in Figure 4c. A state of the mechanical switch 9 is
controlled by the control unit 7 through the control line CL_M and the states of
the semiconductor switches 11 are controlled by the control unit 7 through the
control lines CL_SSa and CL_SSb as disclosed above. Thus in the
embodiment of Figure 4e, there are altogether three different control lines from
the control unit 7 to the electric switch unit 5. The electric switch unit 5 in
Figure 4f, in turn, comprises further a varistor 10 connected in parallel with the
mechanical switch 9 and the semiconductor switches 11.

In Figures 3b, 3d, 3f, 4b, 4d and 4f, the electric switch unit 5 comprises an overvoltage protective device integrated into the electric switch
unit 5. Instead of including the overvoltage protective device in the electric
switch unit 5, the overvoltage protective device may be a device external to the
electric switch unit 5 and connected in parallel to the electric switch unit 5. As
already said above in connection with Figure 3b, in all embodiments of Figures
3b, 3d, 3f, 4b, 4d and 4f, the varistor 10 represents only a kind of overvoltage
protective device for protecting the electric switch unit 5 against overvoltages
and instead of using the varistor 10 other overvoltage protective devices may
also be used.

Figures 3a to 3f and 4a to 4f disclose only some possible
implementations of the electric switch unit 5 and, in practice, the electric switch
unit 5 in the electric switch arrangement 4 may be any kind of electric switch
unit 5 capable of disconnecting the power supply between the electric power
source 2 and the load 3. The electric switch unit 4 may thus for example be a
switch assembly comprising a main switch and a contributory switch connected
in series with the main switch, wherein the main switch and the contributory
switch each comprise at least one pair of contacts such that an opening of the
contacts either at the main switch or the contributory switch will disconnect the
power supply through the switch assembly. In that kind of switch assembly, the
contributory switch may be arranged to provide a fast disconnection of the
power supply through the switch assembly by opening the contacts in the
contributory switch first. The opening of the contacts in the contributory switch
may thereafter be arranged to cause an opening of the contacts in the main
switch. The opening of the contacts in the main switch will retain the
interruption of the power supply through the switch assembly, whereby the
contacts in the contributory switch may either stay open or be closed without
causing a restart of the power supply through the switch assembly as long as
the contacts in the main switch are open.
Figure 5 shows schematically a crowbar circuit 6 applicable to direct current applications. For the sake of clarity, Figure 5 does not disclose the electric power source 2, the load 3 and the electric switch unit 4. The crowbar circuit 6 is connected between positive (+) and negative (-) terminals of the DC lines after the electric switch unit 4 and in parallel to the load 3 (as schematically shown in Figure 1). The crowbar circuit 6 of Figure 5 comprises a semiconductor switch 14 and a diode 15 connected in series with the semiconductor switch 14. The semiconductor switch 14 is connected so that a body diode of the semiconductor switch 14, if there is any body diode, is reverse-biased. In the embodiment of Figure 5, the semiconductor switch 14 comprises a body diode 16. The crowbar circuit 6 of Figure 5 further comprises a current transducer 18. The crowbar circuit 6 in Figure 5 is surrounded by a broken line.

The current flow through the crowbar circuit 6 of Figure 5 is allowed by controlling the crowbar circuit 6 to the closed state, in which closed state of the crowbar circuit 6 the semiconductor switch 14 is turned to a conducting state to allow the current flow through the semiconductor switch 14 and thus through the whole crowbar circuit 6. In the conducting state of the semiconductor switch 14, the current flow from a collector of the semiconductor switch 14 to an emitter of the semiconductor switch 14 is allowed by activating a gate of the semiconductor switch 14. Correspondingly, the current flow through the crowbar circuit 6 of Figure 5 is prevented by controlling the crowbar circuit 6 to the open state, in which open state of the crowbar circuit 6 the semiconductor switch 14 is turned to a non-conducting state to prevent the current flow through the semiconductor switch 14, i.e. through the whole crowbar circuit 6. In the non-conducting state of the semiconductor switch 14, the current flow from the collector to the emitter is prevented by inactivating the gate of the semiconductor switch 14.

The state of the semiconductor switch 14 is controlled by the control unit 7. In the embodiment of Figure 5, a driving circuit 16 is provided between the control unit 7 and the semiconductor switch 14, whereby the driving circuit 16 is configured to turn the semiconductor switch 14 to the conducting state and non-conducting state as controlled by the control unit 7. The driving circuit 16 may be an optocoupler driver, for instance.

When the crowbar circuit 6 is controlled to the closed state, i.e. to the state in which the current flow through the crowbar circuit 6 is allowed, the
control unit 7 provides an active control signal in a control line CL_C connected to the driving circuit 16. In response to the active control signal provided by the control unit 7 in the control line CL_C, the driving circuit 16 activates the gate of the semiconductor switch 14 through a control line CL_G.

When the crowbar circuit 6 is controlled to the open state, i.e. to the state in which the current flow through the crowbar circuit 6 is prevented, the control unit 7 provides an inactive control signal in the control line CL_C. In response to this inactive control signal provided by the control unit 7 in the control line CL_C, the driving circuit 16 does not activate or inactivates the gate of the semiconductor switch 14 through the control line CL_G. The inactive control signal may also be replaced by an arrangement, wherein no control signal provided by the control circuit is the same as the inactive control signal.

The semiconductor switch 14 used in the crowbar circuit 6 is fully controllable so that it can be turned on and off at will, whereby the crowbar circuit 6 may be considered to be an active crowbar circuit. The semiconductor switch 14 can thus be an Insulated Gate Bipolar Transistor (IGBT), Gate Turn-Off Thyristor (GTO) or Integrated Gate Commutated Thyristor (IGCT), for example.

In the embodiment shown in Figure 5, the electric switch arrangement comprises a driving circuit 17 configured to control the state of the crowbar circuit 6 as controlled by the control unit 7. Alternatively, the control unit 7 may be connected directly to the gate of the semiconductor switch 14 in the crowbar circuit 6 or the driving circuit may be integrated in the control unit 7.

As stated above, the crowbar circuit 6 of Figure 5 further comprises a current transducer 18, which is connected in series with the semiconductor switch 14. The current transducer 18 is configured to measure the current flowing through the crowbar circuit 6. The current transducer 18 is a current transducer with good accuracy, wide frequency bandwidth and good galvanic isolation between the primary and secondary. An example of a current transducer of this kind is a Closed Loop Hall Effect current transducer. The measured current value is transferred to the control unit 7 through a measurement line ML_C and the control unit 7 controls the operation of the semiconductor switch 14 in the crowbar circuit 6 on the basis of this current measurement. The current transducer 18 may also be left out from the crowbar
circuit 6 if it is assumed that there will be no overcurrent event in the crowbar circuit 6.

As disclosed above, when the crowbar circuit 6 is in the closed state and the electric switch unit 5 is in the open state, the inductive load current flows through the crowbar circuit 6 and the load energy is absorbed in the resistive parts of the load 3. However, if the load 3 is active, having both inductive and mechanical energy stored, the mechanical energy can sustain or even increase the current through the crowbar circuit 6, which could eventually destroy the semiconductor switch 14 in the crowbar circuit 6. To prevent this, the current transducer 18 measures the current through the semiconductor switch 14 in the crowbar circuit 6 and if the value of the current is too big, i.e. the current exceeds the overcurrent limit set for the current flowing through the semiconductor switch 14, the control unit 7 generates a control signal to turn the semiconductor switch 14 to the non-conducting state. After the current flow through the crowbar circuit 6 is prevented, the rest of the load energy can be absorbed in the overvoltage protective device of the electric switch unit 5. If there is no overvoltage protective device for protecting the electric switch unit 5, the rest of the load energy may create an electric arc in the electric switch unit 5. Because the crowbar circuit 6 directs at least part of the load energy to be absorbed in the resistive parts of the load 3, the power of a possible electric arc appearing in the electric switch unit 5 is not as high as it would be without the crowbar circuit 5.

According to an embodiment, the control unit 7 is configured to provide a pulsed control signal for turning the semiconductor switch 14 in the crowbar circuit 6 to the conducting state and non-conducting state repeatedly. Then the energy stored in the load is absorbed partly in the resistive parts of the load 3 and partly burnt off in the electric switch unit 5 or in the overvoltage protective device of the electric switch unit 5. The energy is absorbed in the resistive parts of the load when the crowbar circuit 6 is controlled to the closed state by turning the semiconductor switch 14 to the conducting state and, when the crowbar circuit 6 is controlled to the open state by turning the semiconductor switch 14 to the non-conducting state, the energy is absorbed in the electric switch unit 5 or in the overvoltage protective device of the electric switch unit 5. This way the energy absorbed in the electric switch unit 5 or in the overvoltage protective device of the electric switch unit 5 may be decreased and thus increase the lifetime of the electric switch unit 5 or the
overvoltage protective device of the electric switch unit 5.

When the pulsed control signal is used to turn the semiconductor switch 14 in the crowbar circuit 6 to the conducting state and non-conducting state repeatedly, the lengths of time when the semiconductor switch is turned to the conducting state and non-conducting state may be equal, or the time period when the semiconductor switch is turned to the conducting state may be shorter or longer than the time period when the semiconductor switch is turned to the non-conducting state. This way the energy absorbed in the resistive parts of the load and in the electric switch unit 5 or in the overvoltage protective device of the electric switch unit 5 may be varied. When the pulsed control signal is used to control the state of the crowbar circuit 6, the crowbar circuit 6 does not necessarily contain the current transducer 18 but a combination of the pulsed control signal and the current transducer 18 may also be utilized in the control of the crowbar circuit 6.

According to an embodiment, the driving circuit 17 comprises a desaturation detection unit 19 for detecting desaturation of the semiconductor switch 14 in the crowbar circuit 6, as shown schematically in Figure 5. The desaturation detection unit 19 could also be external to the driving circuit 17 but connected to it. The desaturation of the semiconductor switch 14 in the crowbar circuit 6 is detected when the desaturation detection device 19 detects that a voltage between the collector and emitter of the semiconductor switch is over an overvoltage limit value set for that voltage. In Figure 5 the desaturation is detected through a measurement line ML_OV.

When the desaturation of the semiconductor switch 14 is detected, the driving circuit 17 may automatically turn the semiconductor switch 14 to a non-conducting state and the driving circuit 17 or the desaturation detection unit 19 provides a fault status signal to the control unit 7 through a fault status line FS. After receiving the fault status signal, the control unit 7 may generate a reset signal to the driving circuit 17 through the control line CL_C and activate the driving circuit 17 to turn the semiconductor switch 14 again to the conducting state.

In the embodiment comprising the desaturation detection unit 19, an overcurrent event in the semiconductor switch 14 is thus detected by detecting the overvoltage event between the collector and emitter of the semiconductor switch 14, whereby the current transducer 18 may be left out from the crowbar circuit 6, if desired.
Figure 6 shows schematically a crowbar circuit 6 applicable to 1-phase alternating current applications. For the sake of clarity, Figure 6 does not disclose the electric power source 2, the load 3 and the electric switch unit 5. The crowbar circuit 6 is connected between L and N terminals of the phase line at the output of the electric switch unit 5 and in parallel with the load 3 (as schematically shown in Figure 1). The crowbar circuit 6 of Figure 6 comprises the semiconductor switch 14, the current transducer 18 and a 1-phase diode bridge 20. The 1-phase diode bridge 20 of Figure 6 is a 1-phase full wave rectifier having input points 22 connected to the terminals L and N of the phase line and output points 23 providing an output of the 1-phase diode bridge 20. The semiconductor switch 14 and the current transducer 18 are connected in series and the series connection of the semiconductor switch 14 and the current transducer 18 is further connected in series with the output of the 1-phase diode bridge 20, between the output points 23 of the 1-phase diode bridge 20. The crowbar circuit 6 in Figure 6 is again surrounded by a broken line.

The operation of the crowbar circuit 6 in Figure 6, as well as the control of the operation of the crowbar circuit 6 in Figure 6, is similar to the operation of the crowbar circuit 6 and the control of the operation of the crowbar circuit 6 intended for direct current applications and explained above in connection with Figure 5. Similarly, as explained in connection with the embodiment of the crowbar circuit 6 intended for direct current applications, in the crowbar circuit 6 for 1-phase alternating current applications, the current transducer 18 may be left out, the pulsed control signal may be used to control the state of the semiconductor switch 14, and/or the desaturation detection unit 19 may be implemented.

Figure 7 shows schematically a crowbar circuit 6 applicable to 3-phase alternating current applications. For the sake of clarity, Figure 6 does not disclose the electric power source 2, the load 3 and the electric switch unit 5. The crowbar circuit 6 is connected between the terminals of the phase lines L1, L2 and L3 at the output of the electric switch unit 5 and in parallel with the three-phase load 3 (as schematically shown in Figure 2). The crowbar circuit 6 of Figure 6 comprises the semiconductor switch 14, the current transducer 18 and a 3-phase diode bridge 21 being a type of a six-pulse bridge rectifier. The 3-phase diode bridge 21 comprises input points 22 connected to the phase lines L1, L2, L3 and output points 23. In the crowbar circuit 6 of Figure 7 the
semiconductor switch 14 and the current transducer 18 are connected in series and the series connection of the semiconductor switch 14 and the current transducer 18 is further connected in series with the output of the 3-phase diode bridge 21. The crowbar circuit 6 in Figure 7 is again surrounded by a broken line.

The operation of the crowbar circuit 6 in Figure 7, as well as the control of the operation of the crowbar circuit 6 in Figure 7, is similar to the operation of the crowbar circuit 6 and the control of the operation of the crowbar circuit 6 intended for direct current applications and explained above in connection with Figure 5. Similarly, as explained in connection with the embodiment of the crowbar circuit 6 intended for direct current applications, in the crowbar circuit 6 for 3-phase alternating current applications, the current transducer 18 may be left out, the pulsed control signal may be used to control the state of the semiconductor switch 14, and/or the desaturation detection unit 19 may be implemented.

The disclosed electric switch arrangement may be utilized both in direct-current applications and alternating-current applications of any operating frequencies. Therefore, the disclosed electric switch arrangement may be utilized for example in frequency converter applications for electric motor control.

Referring back to Figure 2, Figure 2 further discloses further a user interface 8, which may comprise a display unit and a keyboard unit, for example, through which an operator or a supervisor of the electric circuit 1 may receive information about the operation of the electric circuit 1 and control the operation of the electric circuit 1. With regard to the electric switch arrangement 4, the user interface 8 may for example provide visual and/or numerical information about the state of the electric switch units 5 and the crowbar circuit 6, the currents flowing through the electric switch units 5 and the crowbar circuit 6, if proper current measurements are available, and input voltage provided by the electric power source and load voltage. The user interface 8 may also show information about overcurrent limit values set for the crowbar circuit 6 and the electric switch unit 5 and means for setting the overcurrent and overvoltage limit values set for the crowbar circuit 6 and the electric switch unit 5 and the overvoltage protective device of the electric switch unit 5. The user interface 8 may also provide history data about earlier operating situations and limit value settings. The same kind of user interface 8
may also be attached to the electric circuit 1 of Figure 1 relating to the direct current circuit or the 1-phase alternating current circuit applications.

It will be obvious to a person skilled in the art that, as the technology advances, the inventive concept can be implemented in various ways. The invention and its embodiments are not limited to the examples described above but may vary within the scope of the claims.
Claims

1. An electric switch arrangement (4) comprising
at least one electric switch unit (5) to be coupled between an electric
power source (2) and a load (3),
at least one crowbar circuit (6) to be coupled to an output of the
electric switch unit (5) in parallel with the load (3), and
at least one control unit (7) configured to control the operation of the
electric switch unit (5) and the crowbar circuit (6), wherein
the control unit (7) is configured to control the electric switch unit (5)
to a closed state to allow a current flow through the electric switch unit (5) and
to an open state to prevent a current flow through the electric switch unit (5) and wherein
the control unit (7) is configured to control the crowbar circuit (6) to a
closed state to allow a current flow through the crowbar circuit (6) and to an
open state to prevent the current flow through the crowbar circuit (6).

2. The electric switch arrangement as claimed in claim 1, wherein
the control unit (7) is configured to connect the load (3) to the
electric power source (2) by controlling the electric switch unit (5) to the closed state and to disconnect the load (3) from the electric power source (2) by
controlling the electric switch unit (5) to the open state, and wherein
the control unit (7) is configured to connect the crowbar circuit (6) to the
load (3) by controlling the crowbar circuit (6) to the closed state and to disconnect the crowbar circuit (6) from the load (3) by controlling the crowbar circuit (6) to the open state, and wherein
the control unit (7) is configured, for disconnecting the load (3) from the
electric power source (2), to control the crowbar circuit (6) to the closed state for providing a closed electric circuit between the crowbar circuit (6) and the load (3) and to control the electric switch unit (5) to the open state.

3. The electric switch arrangement as claimed in claim 1 or 2,
wherein
the crowbar circuit (6) comprises at least one semiconductor switch
(14) and
the control unit (7) is configured to turn the semiconductor switch
(14) to a conducting state to allow a current flow through the crowbar circuit (6)
and to turn the semiconductor switch (14) to a non-conducting state to prevent
a current flow through the crowbar circuit (6).
4. The electric switch arrangement as claimed in claim 3, wherein the electric switch arrangement (4) comprises a driving circuit (17), which is configured to control the crowbar circuit (6) to the closed and open states as controlled by the control unit (7).

5. The electric switch arrangement as claimed in claim 4, wherein the driving circuit (17) is an optocoupler driver.

6. The electric switch arrangement as claimed in any one of the preceding claims, wherein the electric switch unit (5) comprises at least one of a mechanical switch (9) and a semiconductor switch (10).

7. The electric switch arrangement as claimed in any one of the preceding claims, wherein the electric switch arrangement (4) comprises at least one overvoltage protective device coupled in parallel with at least one of a mechanical switch (9) and a semiconductor switch (10) comprised by the electric switch unit (5).

8. The electric switch arrangement as claimed in any one of the preceding claims, wherein the electric switch arrangement (4) is intended for use in direct current applications and the crowbar circuit (6) comprises at least one diode (15) and at least one semiconductor switch (14) connected in series with the diode (15).

9. The electric switch arrangement as claimed in any one of claims 1 to 7, wherein the electric switch arrangement (4) is intended for use in 1-phase alternating current applications and the crowbar circuit (6) comprises a 1-phase diode bridge (20) and at least one semiconductor switch (14) connected in series with an output of the 1-phase diode bridge (20).

10. The electric switch arrangement as claimed in any one of claims 1 to 7, wherein the electric switch arrangement (4) is intended for use in 3-phase alternating current applications and the crowbar circuit (6) comprises a 3-phase diode bridge (21) being a type of a six-pulse bridge rectifier and at least one semiconductor switch (14) connected in series with an output of the 3-phase diode bridge (21).

11. The electric switch arrangement as claimed in any one of the preceding claims, wherein the control unit (7) is configured to provide a pulsed control signal to control the crowbar circuit (6) to the closed and open states repeatedly.

12. The electric switch arrangement as claimed in any one of claims 1 to 11, wherein the crowbar circuit (6) comprises a current transducer (18)
connected in series with the semiconductor switch (14) for measuring the current through the semiconductor switch (14) in the crowbar circuit (6).

13. The electric switch arrangement as claimed in any one of claims 1 to 11, wherein the electric switch arrangement (4) comprises a desaturation detection unit (19) for detecting an overvoltage between a collector and an emitter of the semiconductor switch (14) in the crowbar circuit (6).

14. A method for coupling an electric power source (2) with a load (3), wherein

an electric switch unit (5) coupled between the electric power source (2) and the load (3) is controlled to a closed state to allow a current flow between the electric power source (2) and the load (3) through the electric switch unit (5) and to an open state to prevent a current flow between the electric power source (2) and the load (3) through the electric switch unit (5) and

a crowbar circuit (6) coupled to an output of the electric switch unit (5) in parallel with the load (3) is controlled to a closed state to allow a current flow through the crowbar circuit (6) and to an open state to prevent a current flow through the crowbar circuit (6).

15. A method as claimed in claim 14, wherein, for disconnecting the load (3) from the electric power source (2), the crowbar circuit (6) is controlled to the closed state for providing a closed electric circuit between the crowbar circuit (6) and the load (3) and

the electric switch unit (5) is controlled to the open state.

16. A method as claimed in claim 14 or 15, wherein

the crowbar circuit (6) comprises at least one semiconductor switch (14) and

the semiconductor switch (14) in the crowbar circuit (6) is turned to a conducting state to allow a current flow through the crowbar circuit (6) and to a non-conducting state to prevent a current flow through the crowbar circuit (6).

17. A method as claimed in any one of preceding claims 14 to 16, wherein a pulsed control signal is provided to control the crowbar circuit (6) to the closed and open states repeatedly.

18. A method as claimed in any one of preceding claims 14 to 17, wherein the current through the semiconductor switch (14) in the crowbar circuit (6) is measured and
the semiconductor switch (14) in the crowbar circuit (6) is controlled to the non-conducting state when the current through the semiconductor switch (14) exceeds an overcurrent limit of the semiconductor switch (14).

19. A method as claimed in any one of preceding claims 14 to 17, wherein

a voltage between a collector and an emitter of the semiconductor switch (14) in the crowbar circuit (6) is detected and

the semiconductor switch (14) in the crowbar circuit (6) is controlled to the non-conducting state when the voltage between the collector and the emitter of the semiconductor switch (14) in the crowbar circuit (6) exceeds an overvoltage limit value set for the voltage between the collector and the emitter of the semiconductor switch (14).
FIG. 1.

FIG. 2
A. CLASSIFICATION OF SUBJECT MATTER
See extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: H03K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

FI, SE, NO, DK

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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☐ Further documents are listed in the continuation of Box C.  ☒ See patent family annex.

* Special categories of cited documents:

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- "&" document member of the same patent family

Date of the actual completion of the international search 03 September 2013 (03.09.2013)

Date of mailing of the international search report 10 September 2013 (10.09.2013)

Name and mailing address of the ISA/FI

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