(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 017 870 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
15.05.2013 Bulletin 2013/20

(51) Int Cl.:
H01H 59/00 *(2006.01)*

(21) Application number: **07110554.8**

(22) Date of filing: **19.06.2007**

(54) **Micro-electromechanical system based soft switching**

Sanfte Umschaltung auf der Basis eines mikroelektromechanischen Systems

Commutation souple basée sur un système micro-électromécanique

(84) Designated Contracting States:
DE FR GB IT

(43) Date of publication of application:
21.01.2009 Bulletin 2009/04

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Description

[0001] The invention relates generally to switching devices and more particularly to micro-electromechanical system based switching devices.

[0002] Traditionally, electromechanical contactors are employed in control gear, where the electromechanical contactors are capable of handling switching currents up to their interrupting capacity. Electromechanical contactors may also find application in power systems for switching currents. However, fault currents in power systems are typically greater than the interrupting capacity of the electromechanical contactors. Accordingly, to employ electromechanical contactors in power system applications, it may be desirable to protect the contactor from damage by backing it up with a series device that is sufficiently fast acting to interrupt fault currents prior to the contactor opening at all values of current above the interrupting capacity of the contactor.

[0003] Previously conceived solutions to facilitate use of contactors in power systems include vacuum contactors, vacuum interrupters and air break contactors, for example. Unfortunately, contactors such as vacuum contactors do not lend themselves to easy visual inspection as the contactor tips are encapsulated in a sealed, evacuated enclosure. Further, while the vacuum contactors are well suited for handling the switching of large motors, transformers and capacitors, they are known to cause damaging transient overvoltages, particularly when the load is switched off. US 2006/0202933 discloses a microelectromechanical switch including a first mechanism for selectively applying an electrostatic force between a first flexible surface and a second flexible surface.

[0004] Furthermore, the electromechanical contactors generally use mechanical switches. However, as these mechanical switches tend to switch at a relatively slow speed, predictive techniques are required in order to estimate occurrence of a zero crossing, often tens of milliseconds before the switching event is to occur. Such zero crossing prediction is prone to error as many transients may occur in this time.

[0005] The present invention provides a system as defined in claim 1 and a method as defined in claim 9.

[0006] Various features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

FIG. 1 is a block diagram of an exemplary MEMS based switching system, in accordance with aspects of the present technique;

FIG. 2 is a schematic diagram illustrating an exemplary MEMS based switching system, in accordance with aspects of the present technique;

FIG. 3 is a schematic diagram illustrating an exemplary MEMS based switch module, in accordance with aspects of the present technique;

FIG. 4 is a schematic diagram illustrating an exemplary MEMS based switch array, in accordance with aspects of the present technique;

FIG. 5 is a schematic diagram illustrating a system model of the exemplary MEMS based switching system, in accordance with aspects of the present technique;

FIG. 6 is a flow chart depicting steps of operating the exemplary MEMS based switching system, in accordance with aspects of the present technique;

FIG. 7 is a graphical representation of exemplary simulation results representative of closing of a MEMS switch in the MEMS based switching system of FIG. 2, in accordance with aspects of the present technique; and

FIG. 8 is a graphical representation of exemplary simulation results representative of opening of a MEMS switch in the MEMS based switching system of FIG. 2, in accordance with aspects of the present technique.

[0007] In accordance with certain embodiments of the present invention, systems and methods for micro-electromechanical system based arc-less switching are described herein. In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of various embodiments of the present invention.

[0008] FIG. 1 illustrates a block diagram of an exemplary soft switching system 10, in accordance with various aspects of the present invention. As illustrated in FIG. 1, the soft switching system 10 includes switching circuitry 12, detection circuitry 14, and control circuitry 16 operatively coupled together. The detection circuitry 14 may be coupled to the switching circuitry 12 and configured to detect an occurrence of a zero crossing of an alternating source voltage in a load circuit (hereinafter "source voltage") or an alternating current in the load circuit (hereinafter referred to as "load circuit current"). The control circuitry 16 may be coupled to the switching circuitry 12 and the detection circuitry 14, and may be configured to facilitate arc-less switching of one or more switches in the switching circuitry 12 responsive to a detected zero crossing of the alternating source voltage or the alternating load circuit current. In one embodiment, the control circuitry 16 may be configured to facilitate arc-less switching of one or more MEMS switches comprising at least part of the switching circuitry 12.

[0009] In accordance with one aspect of the invention, the soft switching system 10 may be configured to perform soft or point-on-wave switching whereby one or more MEMS switches in the switching circuitry 12 may be closed at a time when the voltage across the switching circuitry 12 is at or very close to zero, and opened at a time when the current through the switching circuitry 12 is at or close to zero. By closing the switches at a time when the voltage across the switching circuitry 12 is at or very close to zero, pre-strike arcing can be avoided by keeping the electric field low between the contacts of the one or more MEMS switches as they close, even if multiple switches do not all close at the same time. Similarly, by opening the switches at a time when the current through the switching circuitry 12 is at or close to zero, the soft switching system 10 can be designed so that the current in the last switch to open in the switching circuitry 12 falls within the design capability of the switch. As alluded to above and in accordance with one embodiment, the control circuitry 16 may be configured to synchronize the opening and closing of the one or more MEMS switches of the switching circuitry 12 with the occurrence of a zero crossing of an alternating source voltage or an alternating load circuit current.

[0010] Turning to FIG. 2, a schematic diagram 18 of one embodiment of the soft switching system 10 of FIG. 1 is illustrated. In accordance with the illustrated embodiment, the schematic diagram 18 includes one example of the switching circuitry 12, the detection circuitry 14 and the control circuitry 16.

[0011] Although for the purposes of description FIG. 2 only illustrates a single MEMS switch 20, the switching circuitry 12 may nonetheless include multiple MEMS switches depending upon e.g., the current and voltage handling requirements of the soft switching system 10. In one embodiment, the switching circuitry 12 may include a switch module including multiple MEMS switches coupled together in a parallel configuration to divide the current amongst the MEMS switches. In another embodiment, the switching circuitry 12 may include an array of MEMS switches coupled in a series configuration to divide the voltage amongst the MEMS switches. In yet a further embodiment, the switching circuitry 12 may include an array of MEMS switch modules coupled together in a series configuration to concurrently divide the voltage amongst the MEMS switch modules and divide the current amongst the MEMS switches in each module. In one embodiment, the one or more MEMS switches of the switching circuitry 12 may be integrated into a single package 28.

[0012] The exemplary MEMS switch 20 may include three contacts. In one embodiment, a first contact may be configured as a drain 22, a second contact may be configured as a source 24, and the third contact may be configured as a gate 26. In one embodiment, the control circuitry 16 is coupled to the gate contact 26 to facilitate switching a current state of the MEMS switch 20. Also, in certain embodiments, damping circuitry 29 may be coupled in parallel with the MEMS switch 20 to delay appearance of voltage across the MEMS switch 20. As illustrated, the damping circuitry 29 may include a snubber capacitor 30 coupled in series with a snubber resistor 32, for example.

[0013] Additionally, the MEMS switch 20 may be coupled in series with a load circuit 34 as further illustrated in FIG. 2. In a presently contemplated configuration, the load circuit 34 may include a voltage source V_{SOURCE} 36, and may possess a representative load inductance L_{LOAD} 38 and a load resistance R_{LOAD} 40. In one embodiment, the voltage source V_{SOURCE} 36 (also referred to as an AC voltage source) may be configured to generate the alternating source voltage and the alternating load current I_{LOAD} 42.

[0014] As previously noted, the detection circuitry 14 may be configured to detect occurrence of a zero crossing of the alternating source voltage or the alternating load current I_{LOAD} 42 in the load circuit 34. The alternating source voltage is sensed via the voltage sensing circuitry 46 and the alternating load current I_{LOAD} 42 is sensed via the current sensing circuitry 48. The alternating source voltage and the alternating load current may be sensed continuously or at discrete periods for example.

[0015] A zero crossing of the source voltage may be detected through e.g., use of a comparator such as the illustrated zero voltage comparator 52. The voltage sensed by the voltage sensing circuitry 46 and a zero voltage reference 54 may be employed as inputs to the zero voltage comparator 52. In turn, an output signal 56 representative of a zero crossing of the source voltage of the load circuit 34 may be generated.

[0016] Similarly, a zero crossing of the load current I_{LOAD} 42 may also be detected through use of a comparator such as the illustrated zero current comparator 60. The current sensed by the current sensing circuitry 48 and a zero current reference 58 may be employed as inputs to the zero current comparator 60. In turn, an output signal 62 representative of a zero crossing of the load current I_{LOAD} 42 may be generated.

[0017] The control circuitry 16, in turn utilizes the output signals 56 and 62 to determine when to change (e.g., open or close) the current operating state of the MEMS switch 20 (or array of MEMS switches). More specifically, the control circuitry 16 may be configured to facilitate opening of the MEMS switch 20 in an arc-less manner to interrupt or open the load circuit 34 responsive to a detected zero crossing of the alternating load current I_{LOAD} 42. Additionally, the control circuitry 16 may be configured to facilitate closing of the MEMS switch 20 in an arc-less manner to complete the load circuit 34 responsive to a detected zero crossing of the alternating source voltage.

[0018] The control circuitry 16 determines whether to switch the present operating state of the MEMS switch 20 to a second operating state based at least in part upon a state of an Enable signal 64. The Enable signal 64 may be generated as a result of a power off command in a contactor application, for example. In one embodiment, the Enable signal 64 and the output signals 56 and 62 may be used as input signals to a dual D flip-flop 66 as shown. As will be described in further detail with respect to FIGs. 7-8, these signals may be used to close the MEMS switch 20 at a first source voltage zero after the Enable signal 64 is made active (e.g., rising edge triggered), and to open the MEMS switch 20 at the first load current zero after the Enable signal 64 is deactivated (e.g., falling edge triggered). With respect to the illustrated schematic diagram 18 of FIG. 2, every time the Enable signal 64 is active (either high or low depending upon the specific implementation) and either output signal 56 or 62 indicates a sensed voltage or current zero, a trigger signal 72 may be generated. In one embodiment, the trigger signal 72 may be generated via a NOR gate 70, for example. The trigger signal 72 may in turn be passed through a MEMS gate driver 74 to generate a gate activation signal 76 which may be used to apply a control voltage to the gate 26 of the MEMS switch 20 (or gates in the case of a MEMS array).

[0019] As previously noted, in order to achieve a desirable current rating for a particular application, a plurality of MEMS switches may be operatively coupled in parallel (e.g., to form a switch module) in lieu of a single MEMS switch. The combined capabilities of the MEMS switches may be designed to adequately carry the continuous and transient overload current levels that may be experienced by the load circuit. For example, with a 10-amp RMS motor contactor with a 6X transient overload, there should be enough switches coupled in parallel to carry 60 amps RMS for 10 seconds. Using point-on-wave switching to switch the MEMS switches within 5 microseconds of reaching current zero, there will be 160 milliamps instantaneous, flowing at contact opening. Thus, for that application, each MEMS switch should be capable of "warm-switching" 160 milliamps, and enough of them should be placed in parallel to carry 60 amps. On the other hand, a single MEMS switch should be capable of interrupting the amount of current that will be flowing at the moment of switching.

[0020] FIG. 3 illustrates a schematic diagram of one embodiment of a MEMS based switch module 92. As illustrated, the switch module 92 may include a plurality of MEMS switches operatively coupled in parallel between leads 98 and 100. In one embodiment, the plurality of MEMS switches in the switch module 92 may include one or more load contacts 94. In accordance with one embodiment, control circuitry 16 (see FIG. 1) may generate one or more signals to cause the plurality of load contacts 94 to initiate opening or closing at substantially the same time. Due to slight variations in design between the load contacts 94, it is quite likely that not all of load contacts will open or close simultaneously. As such, there will likely be one load contact that is the last to switch and thus carry the entire current of the switch module 92 for a brief period of time (e.g., on the order of a few microseconds). The load contacts 94 may thus be designed to be relatively small and still handle the steady state load current I_{LOAD} 42 (see FIG. 2) of the load circuit 34 (see FIG. 2), which is also rather small (e.g., on the order of about 50 mA to about 1 Ampere).

[0021] The last switch in the switch module 92 to open, however, may be called upon to interrupt from about 10 mA to 100 mA depending upon the design of the switch array and the switching controls. In one embodiment, it may be desirable to employ a switching contact 102 in addition to the one or more load contacts 94 to facilitate final interruption of the load current in the switch module 92. The switching contact 102 may be designed to handle a larger current than the load contacts 94. Although the increased current carrying capability of the switching contact 102 may require that the switching contact be larger than the load contacts 94, a fewer number of switching contacts 102 may be used.

[0022] Also, in certain embodiments, a non-linear resistor 104, such as a varistor, may be employed to absorb any residual inductive energy from the switch module 92. The non-linear resistor 104 may include a metal oxide varistor (MOV), for example. Such a non-linear resistor 104 may be included in the design of the switch module 92 so as to clip the peaks of the recovery voltage and/or absorb any residual inductive energy from the load circuit. The MOV may be selected based on peak voltage, peak current, and energy absorption characteristics. In certain embodiments, the peak voltage of the load circuit may be set to approximately 1.6 times the peak of the steady-state voltage rating. The 1.6 factor helps control the amount of energy absorbed by the MOV. The current rating may be set to the peak current that is expected to be flowing when the contacts open.

[0023] In addition, the switch module 92 may include a snubber circuit coupled across the non-linear resistor 104. The snubber circuit may include a snubber capacitor C_{SNUB} 106 coupled in series with a snubber resistor R_{SNUB} 108. The snubber capacitor C_{SNUB} 106 may facilitate improvement in transient voltage sharing during the sequencing of the opening of the MEMS switches. Furthermore, the snubber resistor 108 may suppress any pulse of current generated by the snubber capacitor C_{SNUB} 106 during closing operation of the switch module 92. Additionally, the switch module 92 may include a leakage contact 110 coupled in series with the non-linear resistor 104. It may be noted that the leakage contact 110 may include a MEMS switch. This leakage contact 110 may be configured to reduce steady state leakage current through the switch module 92 by removing the effect of any capacitive and non-linear resistive elements (e.g., such as non-linear resistor 104, C_{SNUB} 106 and R_{SNUB} 108) from the switch module 92. The switch module 92 may also include one or more leakage resistors 112, 114, where the leakage resistors 112, 114 may be configured to provide a conductive path for any leakage current in the switch module 92.

[0024] Just as a plurality of MEMS switches may be operatively coupled in parallel to form a switch module to achieve a desirable current rating, a plurality of MEMS switches or switch modules may be operatively coupled in series to achieve a desirable voltage rating. FIG. 4 is a schematic diagram illustrating an exemplary MEMS based switch array 116 in accordance with one embodiment. As illustrated in FIG. 4, the switch array 116 may include a plurality of switch modules 118 operatively coupled in series. It may be noted that each of the plurality of switch modules 118 may include at least one MEMS switch. In one embodiment, one or more of switch modules 118 may represent the switch module 92 of FIG. 3. In a presently contemplated configuration, the switch array 116 is shown as including two or more switch modules 118 operatively coupled in series between leads 122 and 124. The number 'M' of modules to be coupled in series may be determined by the peak voltage rating for the soft switching system 10 (see FIG. 1).

[0025] Furthermore, each of the plurality of switch modules 118 may include a respective grading resistor R_{GRADE} 126 coupled across each of the plurality of switch modules 118. The grading resistor(s) R_{GRADE} 126 may provide a conductive path for steady state voltage grading in the face of a very slight leakage current to ground. More specifically, in the switch array 116 leakage currents from MEMS switches to ground may result in a very uneven voltage distribution when all the MEMS switches are open. Steady state voltage sharing may be accomplished via the grading resistor(s) R_{GRADE} 126, which allow a fraction of a microampere to flow through the switch array 116 to force an even voltage distribution in the face of leakage current to ground. The grading resistor(s) R_{GRADE} 126 may be selected based on the line to ground leakage currents expected through the MEMS switches. Additionally, the switch array 116 may also include capacitors 130, 132 configured to facilitate controlling rate of rise of recovery voltage.

[0026] Referring now to FIG. 5, a schematic diagram 134 of a system model of the exemplary MEMS based switching system is illustrated. The exemplary MEMS based switching system 134 is shown as including a switch array 136, such as the switch array 116 of FIG. 4. As shown, the MEMS based switching system 134 includes an alternating current (AC) voltage source V_{SOURCE} 138, a source inductance L_{SOURCE} 140, and a source resistance R_{SOURCE} 142. The AC voltage source 138, a source inductance L_{SOURCE} 140, and a source resistance R_{SOURCE} 142 may be representative of the Thevenin equivalent circuit of the power source that can arise from e.g., the secondary of a transformer in the delivery of power to the switch array 136. Furthermore, the source inductance L_{SOURCE} 140 may be representative of a combined inductance of buses and cables viewed by the switch array 136.

[0027] In addition, the MEMS based switching system 134 is shown as including a passive load, where the passive load may include a load inductance L_{LOAD} 146 coupled in series with a load resistance R_{LOAD} 148. The MEMS based switching system 134 may also include a source capacitor C_{SOURCE} 144 and a load capacitor C_{LOAD} 150. The source (C_{SOURCE} 144) and load (C_{LOAD} 150) capacitors may control the rate of rise of the recovery voltage across the switch array 136. Without such source and load capacitors, there is a possibility of arcing in the switch array 136 during interruption of an inductive load current. It may be noted that the source capacitor C_{SOURCE} 144 and load capacitor C_{LOAD} 150 may be coupled from line to ground rather than directly across the switch array 136 to suppress a capacitive leakage current through the switch array 136 when in an open or non-conducting state. Additionally, the source (C_{SOURCE} 144) and load (C_{LOAD} 150) capacitors may facilitate reducing voltage stress on the switch array 136 during load interruption.

[0028] Turning now to FIG. 6, a flow chart 196 illustrating one embodiment of a method for switching an exemplary MEMS based soft switching system from a present operating state to a second state is provided. As previously noted, detection circuitry and control circuitry may be operatively coupled to the switching circuitry, where the detection circuitry may be configured to detect a zero crossing of the AC source voltage or a AC load current, and the control circuitry may be configured to facilitate arc-less switching of the MEMS switches responsive to the detected zero crossing.

[0029] As illustrated in FIG. 6, a current level and/or a source voltage level in a load circuit may be monitored as indicated by block 198. In one embodiment, the current level and/or a source voltage level may be monitored via the detection circuitry 14 (see FIG. 1), for example. Additionally, as indicated by block 200, zero crossings of source voltage and the load current may be sensed by the detection circuitry, for example. A trigger signal may be generated responsive to the detected zero crossings as indicated by block 202. The trigger signal may be configured to facilitate switching of a present operating state of the MEMS switch as indicated by block 204.

[0030] Blocks 198-204 may be better understood with reference to FIGs. 7 and 8. FIG. 7 is a graphical representation 206 of exemplary simulation results representative of a MEMS switch closing at near zero voltage in a MEMS based soft switching system, in accordance with aspects of the present invention. As depicted in FIG. 7, a variation in amplitude 208 is plotted against a variation in time 210.

[0031] Response curve 212 represents a variation of amplitude of the Enable signal voltage as a function of time. Also, reference numeral 214 represents region on the response curve 212 where the Enable signal voltage has reached a steady logic high state. A variation of amplitude of the source voltage as a function of time is represented in response curve 216. In a similar fashion, a variation of amplitude of the load current as a function of time is embodied in response curve 218. Response curve 220 represents a variation of amplitude of the gate voltage as a function of time. Also, a region on the response curve 220 where the gate voltage is transitioned to a logic high state is indicated by reference numeral 222. Furthermore, reference numeral 224 represents a zero crossing of the source voltage.

[0032] As previously described with reference to FIG. 2, the source voltage and load current are continuously sensed via the detection circuitry. Furthermore, the detection circuitry is employed to detect zero crossings of the source voltage and the load current. This information regarding the detected zero crossings is then employed to set the state of the Enable signal. In the illustrated embodiment depicted by FIG. 7, the Enable voltage 212 is set to a logic high state in response to a detected zero crossing of the source voltage. Furthermore, the voltage of the Enable signal 212 is illustrated as achieving a steady high state at reference point 214.

[0033] In accordance with exemplary aspects of the present invention, the MEMS switch is closed at a first zero crossing of the source voltage after the Enable signal voltage achieves a steady logic high state. The first zero crossing of the source voltage 216 after the Enable signal 212 achieves a steady logic high state is represented by reference numeral 224. At the instant in time associated with the first source voltage zero crossing 224, the gate voltage 220 may be pulled high to facilitate switching the MEMS switch to a closed state. As a result, the load current starts to flow through the MEMS switch as indicated by response curve 218. Consequently, the MEMS switch is closed in an arc-less manner to complete the load circuit responsive to the detected zero crossing of the AC source voltage. In other words, the MEMS switch is closed at a near zero source voltage, thereby suppressing any arc that may be formed between the contacts of the MEMS switch.

[0034] FIG. 8 is a graphical representation 226 of exemplary simulation results representative of a MEMS switch opening at near zero current in a MEMS based soft switching system, in accordance with various aspects of the present invention. As depicted in FIG. 8, a variation in amplitude 228 is plotted against a variation in time 230.

[0035] Response curve 232 represents a variation of amplitude of the Enable voltage as a function of time. Also, reference numeral 234 represents a region on the response curve 232 where the Enable signal has reached a steady logic low state. A variation of amplitude of the source voltage as a function of time is represented in response curve 236. In a similar fashion, a variation of amplitude of the load current as a function of time is embodied in response curve 238. Response curve 240 represents a variation of amplitude of the gate voltage as a function of time. Furthermore, reference numeral 242 represents a region on the response curve 242 where the gate voltage is transitioned to a logic low state.

[0036] As can be seen from FIG. 8, the voltage of the Enable signal 232 that is currently in a logic high state is set to a logic low state in response to a detected zero crossing of the load current. Furthermore, the voltage of the Enable signal 232 is illustrated as achieving the logic low state at reference point 234.

[0037] The MEMS switch is opened at a first zero crossing of the load current after the Enable signal achieves a steady logic low state. The first zero crossing of the load current 238 after the Enable signal 232 achieves a steady low state is also represented by reference numeral 234. At the instant in time associated with the first load current zero crossing 234, the gate voltage 240 may be pulled low to facilitate switching the MEMS switch to an open state. Consequently, the source voltage that was previously in a non-conducting state begins to appear across the MEMS switch as indicated by response curve 236. Consequently, the MEMS switch is opened in an arc-less manner to interrupt a load circuit responsive to the detected zero crossing of the AC load current. In other words, the MEMS switch is opened at a near zero load current, thereby suppressing any arc that may be formed between the contacts of the MEMS switch.

Claims

1. A system (10), comprising:

a load circuit (34);
detection circuitry (14) configured to detect occurrence of a zero crossing of an alternating source voltage (36) or an alternating load current (42), the detection circuitry (14) configured to receive a voltage from voltage sensing circuitry (46) of the load circuit or a current from current sensing circuitry (48) of the load circuit (34) and to generate an output signal (56, 62) representative of a zero crossing of the alternating source voltage (36) or the alternating load current (42), respectively;
switching circuitry (12) coupled to the detection circuitry (14) and the load circuit (34), the switching circuitry (12) comprising a micro-electromechanical system switch (20); and
control circuitry (16) coupled to the detection circuitry (14) and the switching circuitry (12) and arranged to open the micro-electromechanical system switch (20) in response to receiving an output signal (56, 62) representative of a first zero crossing of the alternating load current (42) or alternating source voltage (36) after an enable signal (64) received by the control circuitry (16) has reached a steady state and arranged to close the micro-electromechanical system switch (20) in response to receiving an output signal (56, 62) representative of a first zero crossing of the alternating load current (42) or alternating source voltage (36) after an enable signal (64) received by the control circuitry (16) has reached a steady state.

2. The system (10) of claim 1, wherein the control circuitry (16) is configured to open the micro-electromechanical system switch (20) in an arc-less manner to interrupt a load circuit (34) responsive to the detected zero crossing of the alternating load current (42).

3. The system (10) of claim 1 or claim 2, wherein the control circuitry (16) is configured to close in an arc-less manner to complete a load circuit (34) responsive to the detected zero crossing of the alternating source voltage (36).

4. The system (10) of any preceding claim, further comprising a snubbing circuit (106, 108) configured to delay appearance of voltage across the micro-electromechanical system switch (20).

5. The system (10) of any preceding claim, wherein the switching circuitry (12) further comprises a switch module (92) coupled to the control circuitry (16) and the detection circuitry (14) and comprising a plurality of micro-electromechanical system switches (20), wherein the control circuitry (16) is configured to perform arc-less switching of at least one of the plurality of micro-electromechanical system switches (20) responsive to a detected zero crossing of an alternating source voltage (36) or alternating load current (42).

6. The system (10) of any preceding claim, wherein the switching circuitry (12) further comprises a plurality of switch modules (92) coupled in a series circuit.

7. The system of claim 6, wherein at least one of the plurality of switch modules (92) comprises:

a load contact; and
a switching contact.

8. The system (10) of claim 6 or claim 7, further comprising a grading resistor (126) coupled in parallel with at least one switch module (118).

9. A method (196) of operating the system of claim 1, comprising the steps of:

monitoring (198) an alternating source voltage (36) or an alternating load current (42) in a load circuit (34) coupled to switch circuitry (12) comprising a switch array (116, 136), wherein the switch circuitry comprises a plurality of switch modules (118) coupled in series, and the switch circuitry comprises a micro-electromechanical system switch (20);
detecting (200) a first occurrence of zero crossing of the alternating load current (42) or the alternating source voltage (36) after a prior receipt of an enable signal;
generating (202) a trigger signal (72) responsive to said first detected zero crossing, wherein the trigger signal (72) is arranged to switch a present operating state of the micro-electromechanical system switch (20); and
switching (204) a present state of each of the plurality of switch modules (118) responsive to the trigger signal (72).

10. The method (196) of claim 9, wherein switching the present state comprises:

triggering a load contact (94) and at least one switching contact (102) such that the load contact (94) is triggered prior to the at least one switching contact (102); opening the load contact (94) and the at least one switching contact (102) in an arc-less manner to interrupt a non-zero current in the switching circuitry such (12) that the load contact (94) is opened prior to the at least one switching contact (102); and
closing the load contact (94) and the at least one switching contact (102) in an arc-less manner to complete the switching circuit (12) while a non-zero voltage appears across the switch.

Patentansprüche

1. System (10), aufweisend:

eine Lastschaltung (34);
eine Detektionsschaltung (14), die zum Detektieren des Auftretens eines Nulldurchgangs einer Wechselspannungsquelle (36) oder eines Lastwechselstroms (42) eingerichtet ist, wobei die Detektionsschaltung (14) dafür eingerichtet ist, eine Spannung aus einer Spannungsmessschaltung (46) der Lastschaltung oder einen Strom aus einer Strommessschaltung (48) der Lastschaltung (34) zu empfangen und ein Ausgangssignal (56, 62) zu erzeugen, das einen Nulldurchgang der Wechselspannungsquelle (36) bzw. des Lastwechselstroms (42) repräsentiert;
einen mit der Detektionsschaltung (14) und der Lastschaltung (34) gekoppelten Schaltkreis (12), wobei der Schaltkreis (12) einen als mikroelektromechanisches System aufgebauten Schalter (20) aufweist; und
eine Steuerschaltung (16), die mit der Detektionsschaltung (14) und dem Schaltkreis (12) gekoppelt und dafür eingerichtet ist, den als mikroelektromechanisches System aufgebauten Schalter (20) in Reaktion auf den Empfang eines Ausgangssignals (56, 62) zu öffnen, das einen ersten Nulldurchgang des Lastwechselstroms (42) oder der Wechselspannungsquelle (36) repräsentiert, nachdem ein von der Steuerschal-

tung (16) empfangenes Freigabesignal (64) einen stabilen Zustand erreicht hat, und dafür eingerichtet ist, den als mikroelektromechanisches System aufgebauten Schalter (20) in Reaktion auf den Empfang eines Ausgangssignals (56, 62) zu schließen, das einen ersten Nulldurchgang des Lastwechselstroms (42) oder der Wechselspannungsquelle (36) repräsentiert, nachdem ein von der Steuerschaltung (16) empfangenes Freigabesignal (64) einen stabilen Zustand erreicht hat.

2. System (10) nach Anspruch 1, wobei die Steuerschaltung (16) dafür eingerichtet ist, den als mikroelektromechanisches System aufgebauten Schalter (20) in einer lichtbogenlosen Weise zu öffnen, um eine Lastschaltung (34) in Reaktion auf den detektierten Nulldurchgang des Lastwechselstroms (42) zu unterbrechen.

3. System (10) nach Anspruch 1 oder Anspruch 2, wobei die Steuerschaltung (16) dafür eingerichtet ist, den als mikroelektromechanisches System aufgebauten Schalter (20) in einer lichtbogenlosen Weise zu schließen, um eine Lastschaltung (34) in Reaktion auf den detektierten Nulldurchgang der Wechselspannungsquelle (36) zu vervollständigen.

4. System (10) nach einem der vorstehenden Ansprüche, das ferner eine Begrenzungsschaltung (106, 108) aufweist, die dafür eingerichtet ist, das Auftreten von Spannung über dem als mikroelektromechanisches System aufgebauten Schalter (20) zu verzögern.

5. System (10) nach einem der vorstehenden Ansprüche, wobei der Schaltkreis (12) ferner ein mit der Steuerschaltung (16) und der Detektionsschaltung (14) gekoppeltes Schaltermodul (92) aufweist und mehrere als mikroelektromechanisches System aufgebaute Schalter (20) aufweist, wobei die Steuerschaltung (16) dafür eingerichtet ist, ein lichtbogenloses Schalten von wenigstens einem der als mikroelektromechanisches System aufgebauten Schalter (20) in Reaktion auf einem detektierten Nulldurchgang einer Wechselspannungsquelle (36) oder Lastwechselstroms (42) durchzuführen.

6. System (10) nach einem der vorstehenden Ansprüche, wobei der Schaltkreis (12) ferner mehrere in einer Reihenschaltung angeordnete Schaltermodule (92) aufweist.

7. System (10) nach Anspruch 6, wobei wenigstens eines von den mehreren Schaltermodulen (92) aufweist:

einen Lastkontakt; und

einen Schaltkontakt.

8. System (10) nach Anspruch 6 oder Anspruch 7, das ferner einen parallel zu dem wenigstens einen Schaltermodul (118) geschalteten Abstufungswiderstand (126) aufweist.

9. Verfahren (196) zum Betreiben des Systems nach Anspruch 1 mit den Schritten:

Überwachen (198) einer Wechselspannungsquelle (36) oder eines Lastwechselstroms (42) in einer Lastschaltung (34), die mit einem eine Schalteranordnung (116, 136) aufweisenden Schaltkreis (12) gekoppelt ist, wobei der Schaltkreis mehrere in Reihe geschaltete Schaltermodule (118) aufweist, und der Schaltkreis einen als mikroelektromechanisches System aufgebauten Schalter (20) aufweist;
Detektieren (200) eines ersten Auftretens eines Nulldurchgangs des Lastwechselstroms (42) oder der Wechselspannungsquelle (36) nach einem vorhergehenden Empfang eines Freigabesignals;
Erzeugen (202) eines Auslösesignals (72) in Reaktion auf den ersten detektierten Nulldurchgang, wobei das Auslösesignal (72) dafür eingerichtet ist, einen momentanen Betriebszustand des als mikroelektromechanisches System aufgebauten Schalters (20) zu schalten; und
Schalten (204) eines momentanen Zustands von jedem der mehreren Schaltermodule (118) in Reaktion auf das Auslösesignal (72).

10. Verfahren (196) nach Anspruch 9, wobei das Schalten des momentanen Zustandes die Schritte umfasst:

Auslösen eines Lastkontaktes (94) und wenigstens eines Schaltkontaktes (102) dergestalt, dass der Lastkontakt (94) vor dem wenigstens einen Schaltkontakt (102) ausgelöst wird; Öffnen des Lastkontaktes (94) und des wenigstens einen Schaltkontaktes (102) in einer lichtbogenlosen Weise, um einen Nicht-Nullstrom in dem Schaltkreis (12) dergestalt zu unterbrechen, dass der Lastkontakt (94) vor dem wenigstens einem Schaltkontakt (102) geöffnet wird; und
Schließen des Lastkontaktes (94) und des wenigstens einen Schaltkontaktes (102) in einer lichtbogenlosen Weise, um den Schaltkreis (12) während des Auftretens einer Nicht-Nullspannung über dem Schalter zu vervollständigen.

Revendications

1. Système (10) comportant:

   un circuit de charge (34) ;
   des circuits de détection (14) conçus pour détecter la survenance d'un passage par zéro d'une tension alternative de source (36) ou d'un courant alternatif de charge (42), les circuits de détection (14) étant conçus pour recevoir du circuit de charge une tension de circuits de détection de tension (46) ou, de circuits de détection d'intensité (48) du circuit de charge (34), une intensité, et pour produire un signal de sortie (56, 62) représentant un passage par zéro respectivement de la tension alternative de source (36) ou de courant alternatif de charge (42) ;
   des circuits de commutation (12) couplés aux circuits de détection (14) et au circuit de charge (34), les circuits de commutation (12) comprenant un commutateur (20) de système micro-électromécanique ; et
   des circuits de commande (16) couplés aux circuits de détection (14) et aux circuits de commutation (12) et agencés pour ouvrir le commutateur (20) de système micro-électromécanique en réponse à la réception d'un signal de sortie (56, 62) représentant un premier passage par zéro du courant alternatif de charge (42) ou de la tension alternative de source (36) après qu'un signal de validation (64) reçu par les circuits de commande (16) a atteint un régime stable et agencés pour fermer le commutateur (20) de système micro-électromécanique en réponse à la réception d'un signal de sortie (56, 62) représentant un premier passage par zéro du courant alternatif de charge (42) ou de la tension alternative de source (36) après qu'un signal de validation (64) reçu par les circuits de commande (16) a atteint un régime stable.

2. Système (10) selon la revendication 1, dans lequel les circuits de commande (16) sont conçus pour ouvrir le commutateur (20) de système micro-électromécanique d'une manière sans arc afin d'interrompre un circuit de charge (34) en réponse au passage par zéro détecté du courant alternatif de charge (42).

3. Système (10) selon la revendication 1 ou la revendication 2, dans lequel les circuits de commande (16) sont conçus pour se fermer d'une manière sans arc afin de fermer un circuit de charge (34) en réponse au passage par zéro détecté de la tension alternative de source (36).

4. Système (10) selon l'une quelconque des revendications précédentes, comportant en outre un circuit d'amortissement (106, 108) conçu pour retarder l'apparition d'une tension dans le commutateur (20) de système micro-électromécanique.

5. Système (10) selon l'une quelconque des revendications précédentes, dans lequel les circuits de commutation (12) comprennent en outre un module de commutation (92) couplé aux circuits de commande (16) et aux circuits de détection (14) et comprenant une pluralité de commutateurs (20) de système micro-électromécanique, les circuits de commande (16) étant conçus pour exécuter une commutation sans arc d'au moins un commutateur parmi la pluralité de commutateurs (20) de système micro-électromécanique en réponse à un passage par zéro détecté d'une tension alternative de source (36) ou d'un courant alternatif de charge (42).

6. Système (10) selon l'une quelconque des revendications précédentes, dans lequel les circuits de commutation (12) comprennent en outre une pluralité de modules de commutation (92) couplés à un circuit série.

7. Système selon la revendication 6, dans lequel au moins un des différents modules de commutation (92) comprend:

   un contact de charge ; et
   un contact de commutation.

8. Système (10) selon la revendication 6 ou la revendication 7, comportant en outre une résistance d'échelonnement (126) montée en parallèle avec le/les modules de commutation (118).

9. Procédé (196) pour faire fonctionner le système selon la revendication 1, comportant les étapes de :

   contrôle (198) d'une tension alternative de source (36) ou d'un courant alternatif de charge (42) dans un circuit de charge (34) couplé à des circuits de commutation (12) comprenant un groupe de commutateurs (116, 136), les circuits de commutation comprenant une pluralité de modules de commutation (118) montés en série, et les circuits de commutation comprennent un commutateur (20) de système micro-électromécanique ;
   détection (200) d'une première survenance de passage par zéro du courant alternatif de charge (42) ou de la tension alternative de source (36) après la réception préalable d'un signal de validation ;
   production (202) d'un signal d'activation (72) en réponse audit premier passage par zéro détecté, le signal d'activation (72) étant conçu pour commuter un état instantané de fonctionnement

du commutateur (20) de système micro-électro-mécanique; et
commutation (204) d'un état instantané de chacun des différents modules de commutation (118) en réponse au signal d'activation (72).

10. Procédé (196) selon la revendication 9, dans lequel la commutation de l'état instantané comprend :

l'activation d'un contact de charge (94) et d'au moins un contact de commutation (102) de telle sorte que le contact de charge (94) soit activé avant le/les contact(s) de commutation ; l'ouverture du contact de charge (94) et du/des contact (s) de commutation (102) d'une manière sans arc afin d'interrompre un courant non nul dans les circuits de commutation de telle sorte (12) que le contact de charge (94) s'ouvre avant le/les contact(s) de commutation (102) et
fermeture du contact de charge (94) et du/des contact(s) de commutation (102) d'une manière sans arc afin de fermer le circuit de commutation (12) pendant qu'une tension non nulle apparaît dans le commutateur.

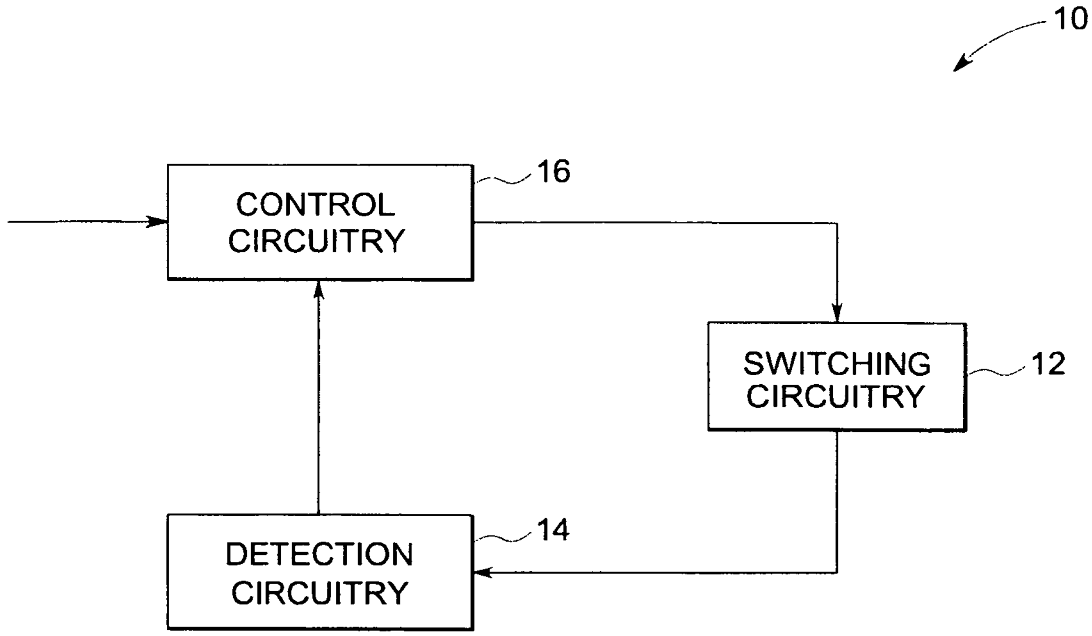
10
CONTROL CIRCUITRY
16
SWITCHING CIRCUITRY
12
DETECTION CIRCUITRY
14

FIG. 1

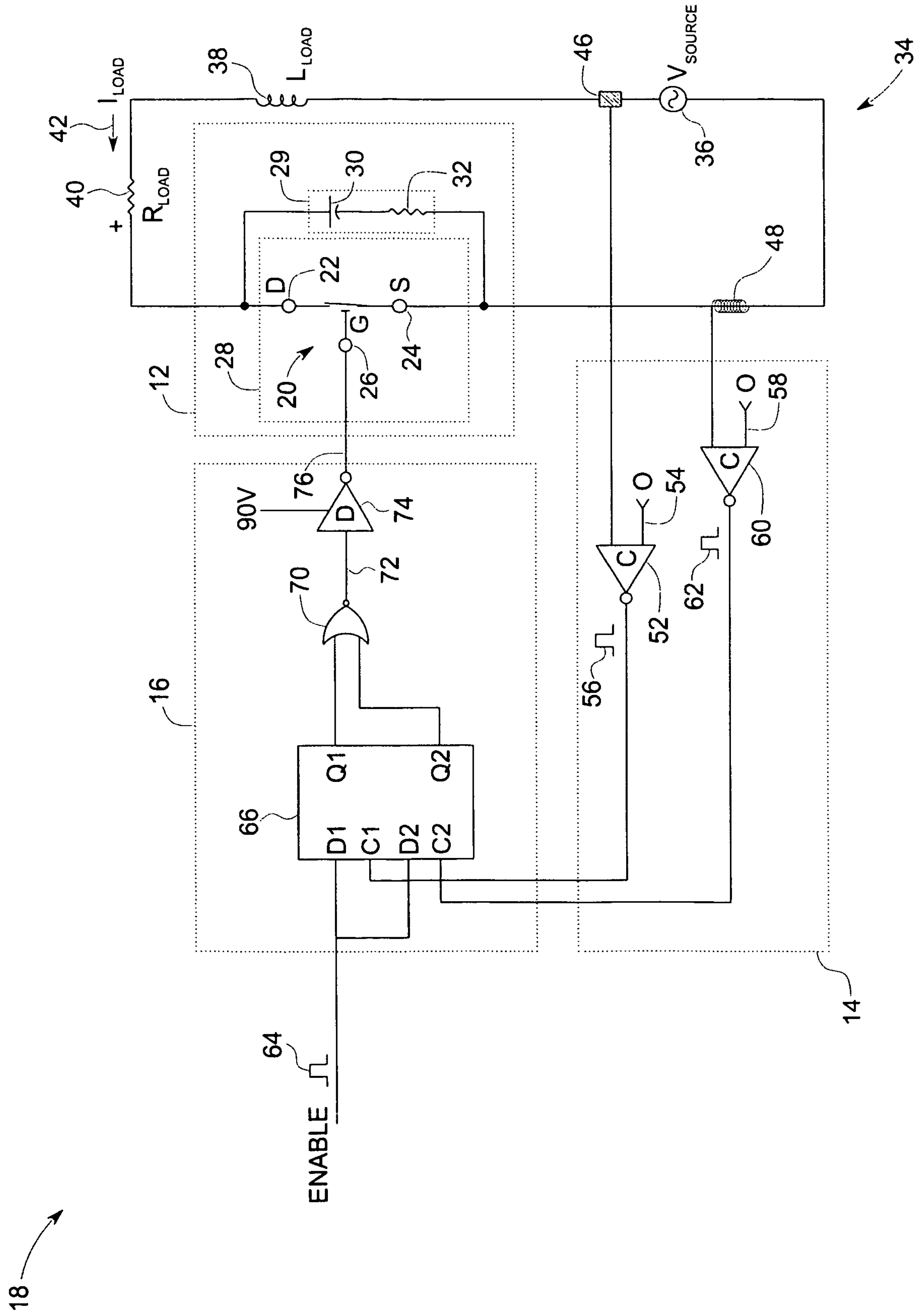
ENABLE
D1
C1
D2
C2
Q1
Q2
90V
D
C
C
O
O
D
G
S
I_LOAD
R_LOAD
L_LOAD
V_SOURCE
+

FIG. 2

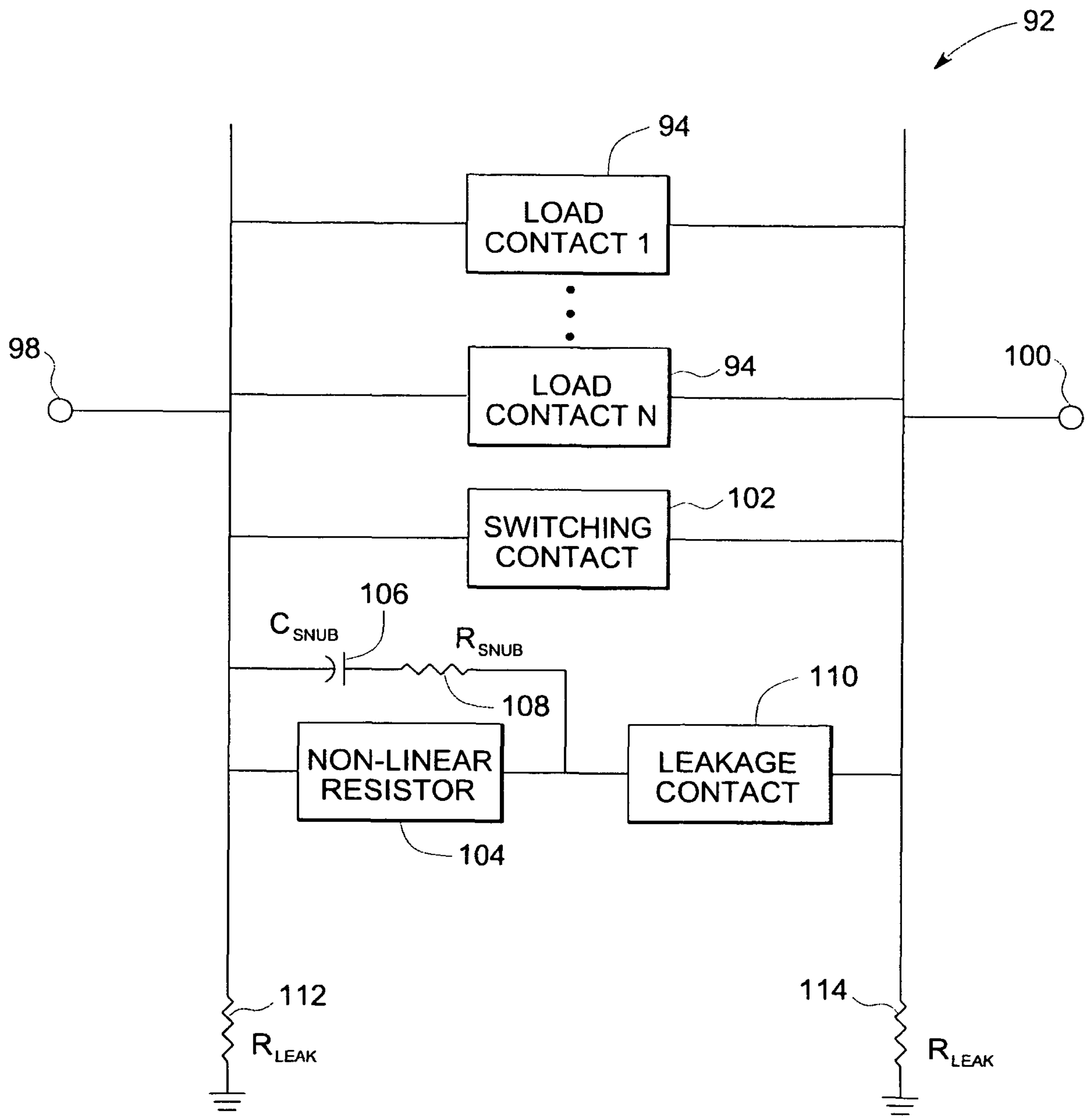
92
94
LOAD CONTACT 1
LOAD CONTACT N
94
98
100
SWITCHING CONTACT
102
106
C SNUB
R SNUB
108
110
NON-LINEAR RESISTOR
LEAKAGE CONTACT
104
112
R LEAK
114
R LEAK

FIG. 3

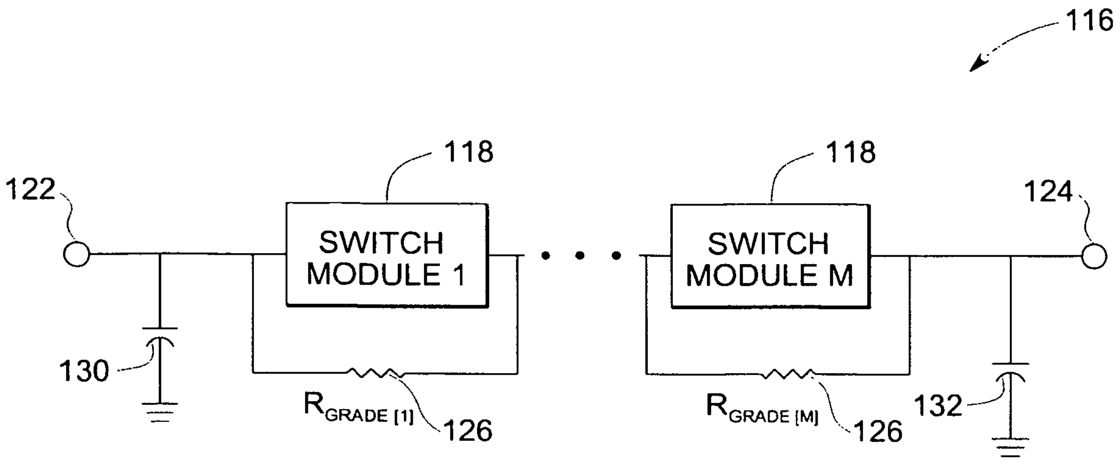
116
118
118
122
124
SWITCH MODULE 1
SWITCH MODULE M
130
132
R GRADE [1]
R GRADE [M]
126
126

FIG. 4

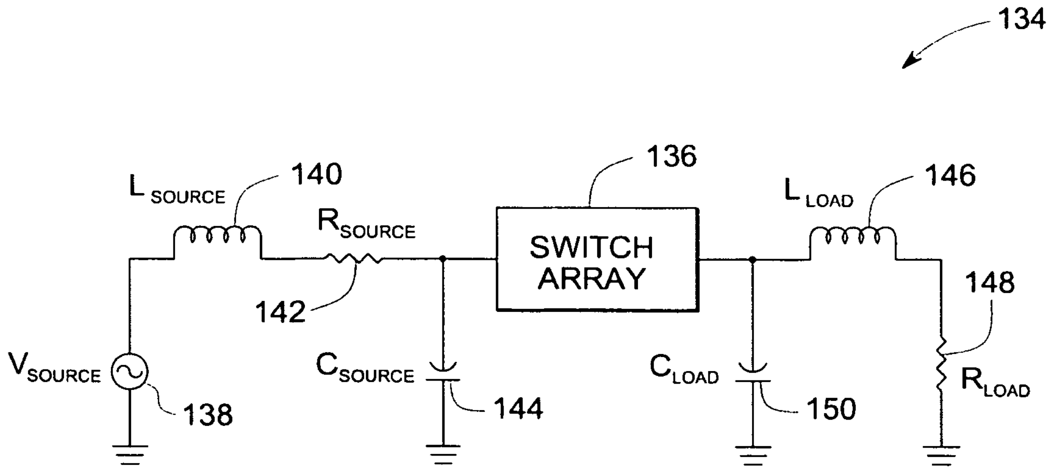
134
136
140
146
L SOURCE
R SOURCE
SWITCH ARRAY
L LOAD
148
142
V SOURCE
C SOURCE
C LOAD
R LOAD
138
144
150

FIG. 5

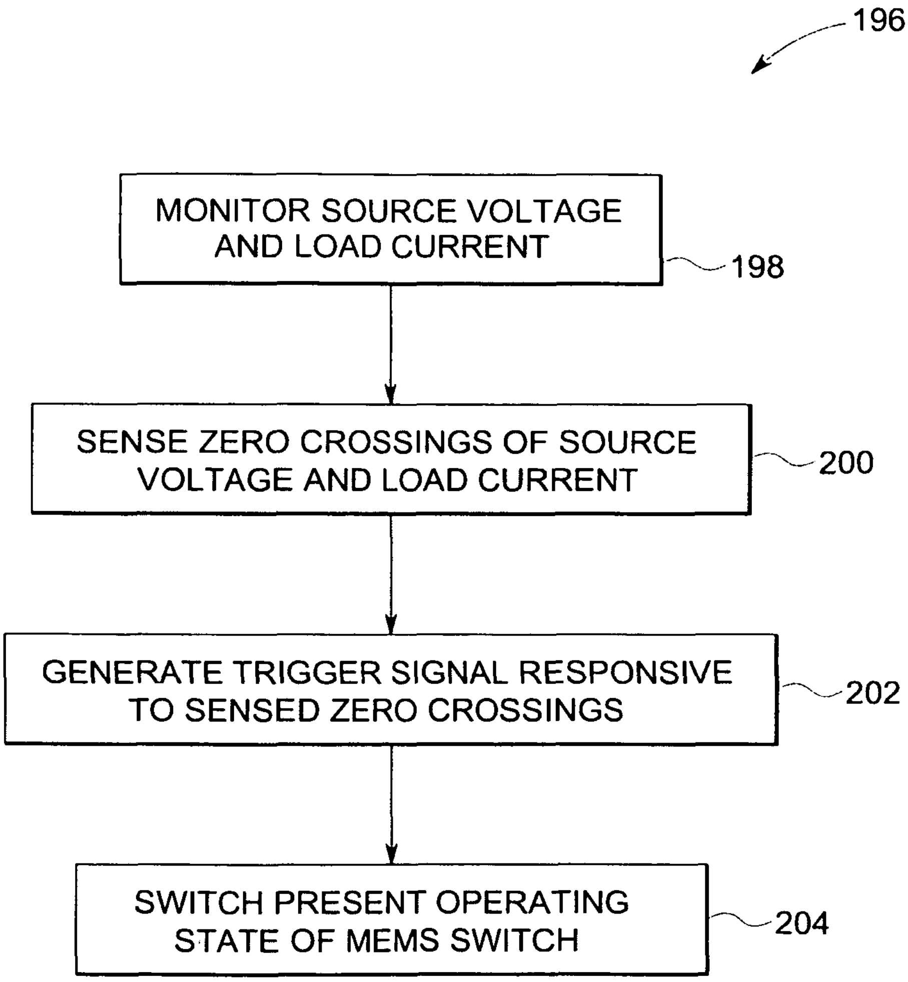
196
MONITOR SOURCE VOLTAGE AND LOAD CURRENT
198
SENSE ZERO CROSSINGS OF SOURCE VOLTAGE AND LOAD CURRENT
200
GENERATE TRIGGER SIGNAL RESPONSIVE TO SENSED ZERO CROSSINGS
202
SWITCH PRESENT OPERATING STATE OF MEMS SWITCH
204

FIG. 6

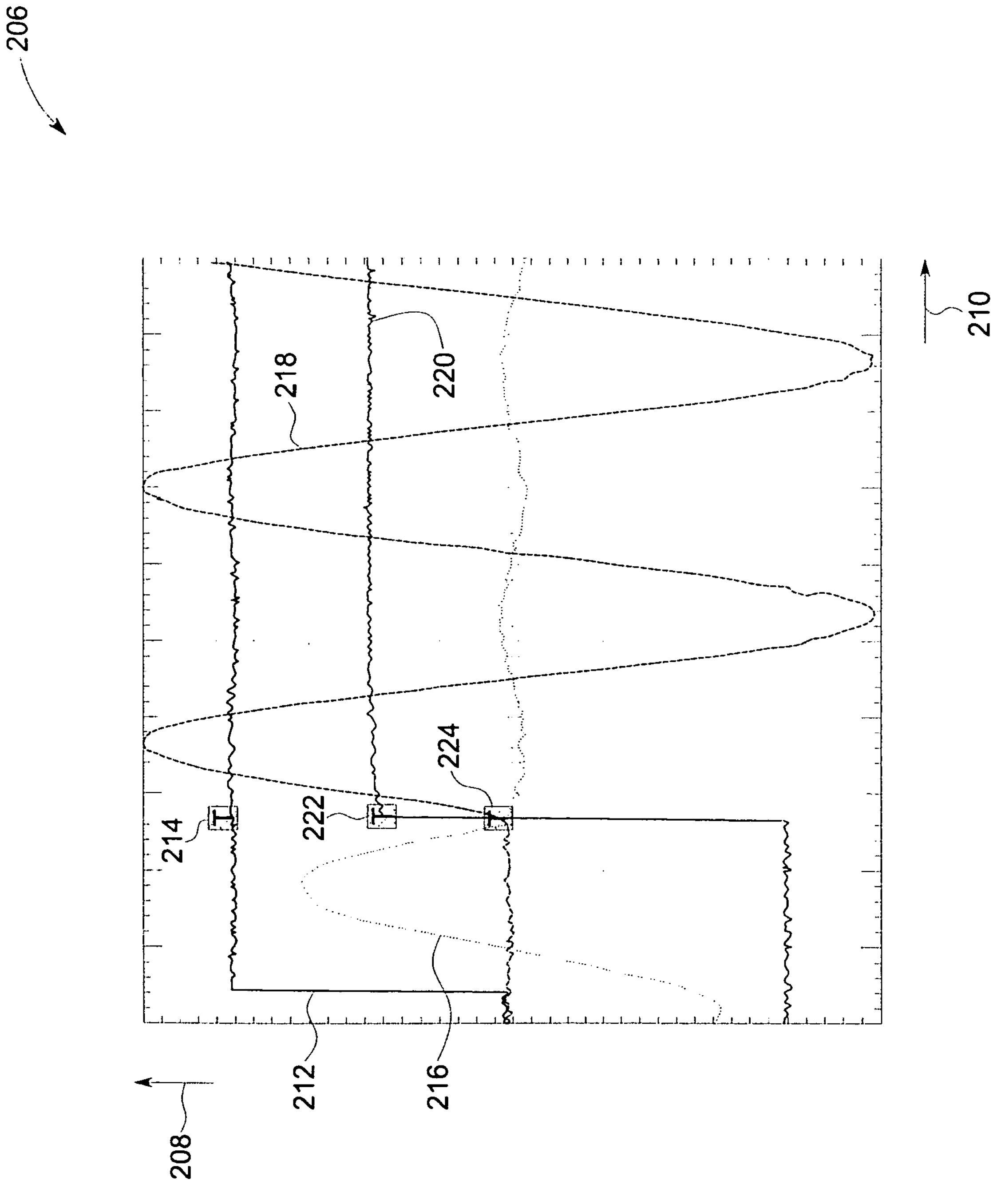

FIG. 7

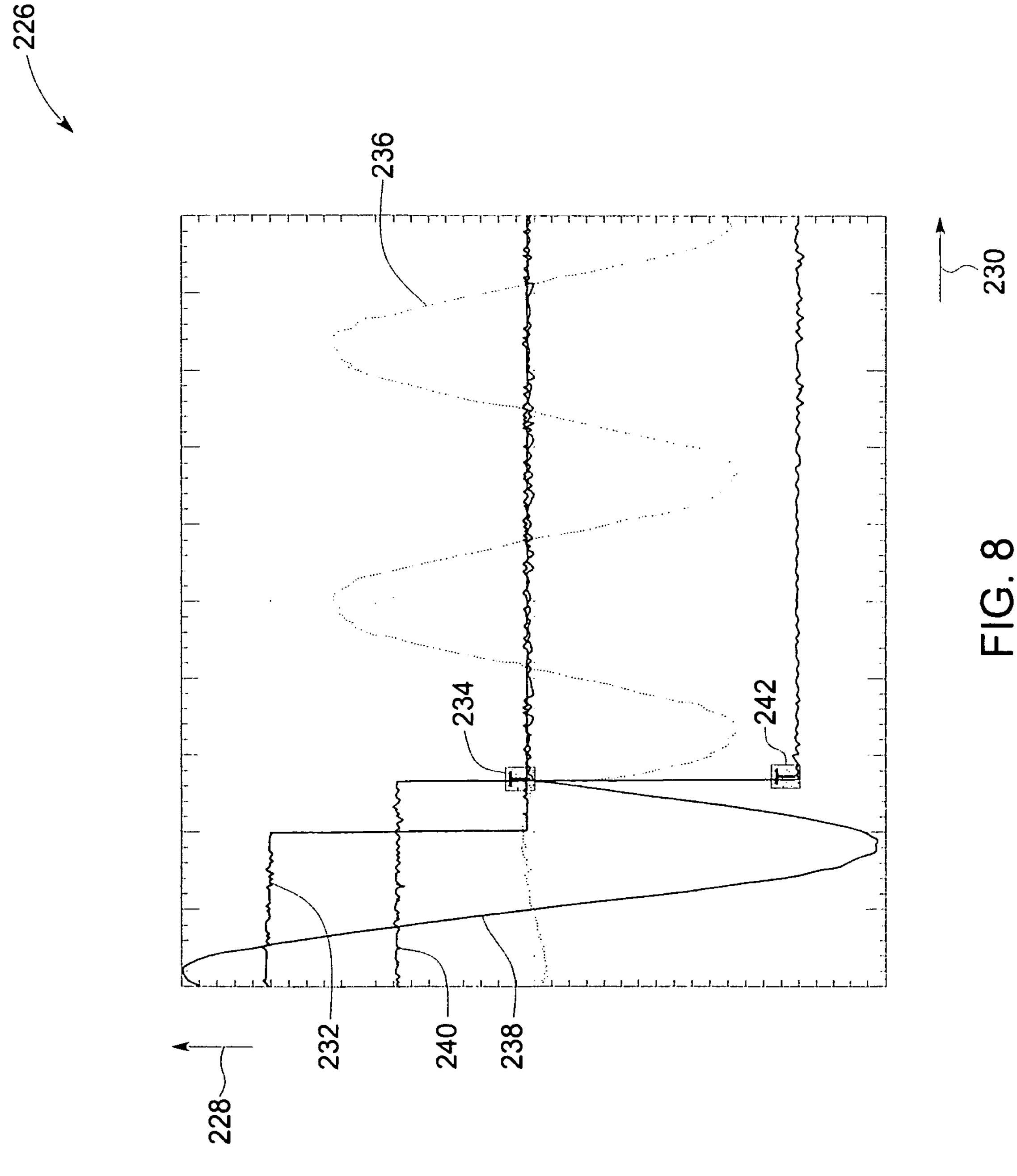

FIG. 8

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

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