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# (54) SURGE PROTECTION CIRCUIT AND POWER SUPPLY FOR OPERATING FROM A DC GRID

ÜBERSPANNUNGSSCHUTZSCHALTUNG UND STROMVERSORGUNG ZUM BETRIEB AUS EINEM GLEICHSTROMNETZ

CIRCUIT DE PROTECTION CONTRE LES SURTENSIONS ET ALIMENTATION ÉLECTRIQUE POUR FONCTIONNER À PARTIR D'UN RÉSEAU À COURANT CONTINU

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(73) Proprietor: **Tridonic GmbH & Co KG**
**6851 Dornbirn (AT)**

(72) Inventor: **Klien, Dietmar**
**6850 Dornbirn (AT)**

(74) Representative: **Beder, Jens**
**Mitscherlich PartmbB**
**Patent- und Rechtsanwälte**
**Karlstraße 7**
**80333 München (DE)**

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## Description

**[0001]** The invention concerns the field of power electronics and driver devices for lighting applications, which operate on a power supply via a DC grid. In particular, a surge protection circuit and a DC-to-DC converter is proposed.

**[0002]** Most current power supply devices in building automation systems operate from a mains supply of the building. Depending on a region of installation of the building automation system, the mains supply may have the form of a 400 V/50Hz AC mains supply. Specific applications, such as emergency lighting systems, also integrate energy storage devices, e.g. batteries, for an alternate battery-backed operation in case of a mains supply failure.

**[0003]** In future applications, e.g. in an industrial environment including manufacturing sites, DC grids as power distribution networks for supplying individual devices will be increasingly common. A DC grid operating with a nominal 565 $V_{DC}$ nominal voltage may enable to integrate energy storage devices, renewable energy sources and a plurality of different industrial devices including, for example stationary robotic devices and machining centres of manufacturing cells, or elements of the building infrastructure, e.g. lifts, lighting or heating and ventilation systems. Figs. 4 and 5 of the attached figure sheets illustrate potential layouts for future industrial applications.

**[0004]** DC grids operating at high nominal DC voltages, e.g. in voltage ranges between 400 $V_{DC}$ and 800 $V_{DC}$, and, in particular, the cited 565 $V_{DC}$ voltage level for a passive rectification, or a 650 $V_{DC}$ voltage level for an active rectification with a power factor correction (PFC) may become the predominant or even exclusive source of electric energy at the manufacturing site. This results in changes to the power supply interfaces of other elements of the technical building infrastructure, e.g. lighting systems, emergency escape route signage, and air-conditioning systems. For sake of cost effectiveness, these further building infrastructure systems are increasingly required to rely DC-to-DC converter devices operating from the DC grid in order to generate and provide a DC load current to their respective electric load, e.g. to lighting modules.

**[0005]** US 2017/311400 A1 discloses a load control device for controlling power delivered from a power source to an electrical load, The load control device comprises a control circuit configured to control the load regulation circuit to control the power delivered to the electrical load. The control circuit is configured to operate in an AC mode when an input voltage is an AC voltage and in a DC mode when the input voltage is a DC voltage. The control circuit is configured to disable the power converter in the DC mode. The control circuit is configured to render a controllable switching circuit conductive in the AC mode, and non-conductive in the DC mode. The rectifier circuit is configured to rectify the input voltage to generate a rectified voltage when the input voltage is an AC voltage, and to pass through the input voltage when the input voltage is a DC voltage. US 2019/335552 A1 discloses a power circuit.

**[0006]** The integration of DC-to-DC converters, e.g. LED drivers, for direct operation from the DC grid poses some issues to adapt to the large DC voltage ranges due to overvoltage protection issues.

**[0007]** Current DC-to-DC converters use electronic components such as capacitors and semiconductors, e.g. MOSFETs, rated for voltages up to 650 V DC, which are sufficient to cope with the overvoltages, which may be encountered at the power supply interfaces of the current DC-to-DC converters to the current AC grid operating at nominal voltages of 400 $V_{AC}$, for example. This situation changes for the power supply interface with the DC grid at a nominal voltage of 565 $V_{DC}$ or even 800 $V_{DC}$. Voltage surges with voltages of, e.g. 1500 $V_{DC}$ may occur.

**[0008]** In order to operate the DC-to-DC converter directly from the DC grid, the engineers may have to rely on using electronic components in the DC-to-DC converter rated for significantly extended overvoltage ranges, which may occur on the DC grid. Nevertheless, such electronic components rated for higher voltages are significantly more expensive. The cost originating from using such electronic components rated to cope with these increased voltages will increase with the number of DC-to-DC converters required over a large manufacturing site significantly.

**[0009]** Instead of the 230 $V_{AC}$ or 400$V_{AC}$ power supply, a DC grid for a DC power supply may have voltages in ranges from 400 $V_{DC}$ to 800 $V_{DC}$. This simplifies integration of regenerative energy sources into the industrial DC grid on the manufacturing site and a reuse of battery sets from automotive applications for energy storage. This poses problems becoming apparent when comparing the nominal operating voltages of up to 800 $V_{DC}$ on the DC grid already close to destructive voltages of about 950 V even in an extended case for more expensive component families of semiconductors and electrolytic capacitors.

**[0010]** The situation worsens when considering voltage surges or voltage spikes on the DC grid. Voltage surges are sudden rises in excessive voltage for a short duration, e.g. lasting at least three nanoseconds or more. The term voltage spike usually refers to an increase in power of shorter duration.

**[0011]** Conventional surge protection circuits using varistors or suppression diodes will not react sufficiently accurate to protect the DC-to-DC converter device from the effects of voltage surges in case the nominal voltage level is at 565 $V_{DC}$ or 800 $V_{DC}$ and the electronic circuit to be protected by the current surge protection circuit includes electronic components rated for maximum admissible voltages of 950 V at maximum.

**[0012]** It is therefore desirable to design DC-to-DC converter devices, which are able to operate reliably from DC grids while simultaneously suited to cost sensitive application scenarios.

**[0013]** The electronic circuit including a surge protection circuit according to independent claim 1 and the DC-to-DC power supply device define the invention and provide an advantageous solution regarding these issues.

**[0014]** The features of the dependent claims define further advantageous embodiments.

**[0015]** The electronic circuit including a surge protection circuit for the power supply interface (DC grid interface) of a DC-to-DC converter device according to the first aspect comprises a DC grid interface comprising first and second DC input voltage lines. The surge protection circuit comprises a serial circuit element connected between the first and second DC input voltage lines (DC input voltage connections) configured to implement a low-pass filter, and a linear regulator circuit element including at least one transistor.

**[0016]** The surge protection circuit comprises the serial circuit element comprising a R-C element for implementing the low-pass filter including at least one resistor and a capacitor. A first terminal of the at least one resistor is connected with the first DC voltage input line and a second terminal of the at least one resistor is connected with a first terminal of the capacitor, and a second terminal of the capacitor is connected with the second DC voltage input line. A base of the at least one transistor is connected with the second terminal of the at least one resistor and the first terminal of the capacitor, and an emitter of the at least one transistor is connected with an output connection of the surge protection circuit.

**[0017]** The surge protection circuit is advantageous, as combining of the low-pass filter element for coping with the voltage surge in combination with the linear regulator circuit element providing an active circuit for immediate and fast reaction provide the capability to reliably cope with voltage surges even for high nominal voltages and only limited capability of electric components in the respectively succeeding electronic circuits to cope with excess voltages. Even for nominal voltages of the grid voltage of up to 800 $V_{DC}$, and rated voltages of 950 V for the electronic components, the surge protection circuit proves sufficient to protect electronic circuits, e.g. a converter circuit succeeding to the surge protection circuit, from potentially destructive voltage values.

**[0018]** The transistor of the linear regulator circuit element does not require additional measures against excessive DC voltages, e.g. DC voltages exceeding 1000 $V_{DC}$, as the surge protection circuit operates in the defined operational environment of the DC grid with nominal voltages around 650 $V_{DC}$. The low-pass filter element provides further protection for the transistor of the linear regulator circuit element.

**[0019]** Operating in the DC grid on high voltage levels for the nominal voltage, the insertion loss over the surge protection circuit may be negligible, as the current provided by the DC grid to the surge protection circuit is small for a given level of electric power.

**[0020]** The surge protection circuit for a DC-to-DC converter device according to an embodiment comprises the at least one transistor of the linear regulator circuit element in an emitter-follower circuit topology configuration.

**[0021]** Using the emitter-follower circuit topology enables to implement the linear regulator circuit element of the surge protection circuit with only small insertion losses, while simultaneously outputting a DC voltage that closely follows a DC voltage input to the linear regulator circuit element.

**[0022]** The low-pass filter element as serial element of the surge protection circuit provides an advantageous capability to filter out the overvoltage exceeding the nominal DC voltages.

**[0023]** The surge protection circuit for a DC-to-DC converter device may have the low-pass filter element comprising the R-C element including at least one resistor connected in series with a filter load of the low-pass filter and a capacitor connected in parallel with the filter load.

**[0024]** The in particular capacitor of the low-pass filter element enables to adjust the capability of the surge protection circuit with regard to a duration of voltage surges the surge protection circuit may cope with. Selecting the value of the capacitor below an upper capacitance value of the capacitor of the R-C element avoids an undesired drop in a DC voltage applied to an input of the linear regulator circuit element.

**[0025]** According to an embodiment, the surge protection circuit for a DC-to-DC converter device further comprises a diode connected between an emitter of the at least one transistor and a base of the at least one transistor.

**[0026]** The diode effectively protects the at least one transistor from a drop in the voltage provided by the DC grid to the DC-to-DC converter device. Integrating renewable energy sources directly onto the DC grid, for example, may result in sudden voltage drops in the DC voltage provided by the DC grid to the DC-to-DC converter device. Without the diode, the transistor will most probably suffer destruction due to voltage drop.

**[0027]** The surge protection circuit for a DC-to-DC converter device according to an embodiment may comprise a first transistor and at least one second transistor, wherein the first transistor and the at least one second transistor are connected in a Darlington configuration.

**[0028]** Using at least two transistors in a Darlington configuration enables to realize a sufficient gain for the emitter-follower with currently widely available transistors.

**[0029]** According to an embodiment, the surge protection circuit for a DC-to-DC converter device is configured to operate in a voltage range of a DC grid supply.

**[0030]** The surge protection circuit is particularly suited for the nominal voltage ranges used in DC grids for power supply at manufacturing sites due to the capability to cope with high nominal voltages and additional surge voltages from the DC grid on the one hand. On the other hand, the surge protection circuit provides a capability to use electronic components with rated voltages that are comparatively close above the nominal voltages of the DC grid, and which are therefore advantageous in terms of cost.

**[0031]** Thus, the manufacturing site may use a DC grid, and integrate energy storage devices and renewable energy sources without causing a disproportionate increase in cost for DC-to-DC converter devices due to the requirement for electronic components with high rated voltages capable to cope with voltage surges on the high DC voltage levels.

**[0032]** The surge protection circuit for the DC-to-DC converter device according to an embodiment is configured to operate in a nominal voltage range of the DC grid supply from 400 V DC to 800 V DC.

**[0033]** Therefore, the surge protection circuit is capable to cope with surge voltages in voltage ranges, which may be encountered on the DC grid on the one hand, and, on the other hand provides sufficient surge protection for electronic circuits of the DC-to-DC converter device arranged downstream on a power supply path, wherein the electronic circuits of the DC-to-DC converter device include electronic components rated for voltages up to 950 V.

**[0034]** According to an embodiment, the surge protection circuit for the DC-to-DC converter device is designed for the nominal voltage of the DC grid supply essentially corresponding to 650 V.

**[0035]** A power supply for generating a load current for an electric load from a DC supply voltage according to the second aspect comprises a converter circuit configured to generate the load current and to output the load current via an output interface to the electric load, and the electronic circuit including the surge protection circuit according to the first aspect connected between a DC grid interface for obtaining the DC supply voltage and the converter circuit.

**[0036]** The power supply may include electronic components at advantageous component cost, while simultaneously reliable operation from the DC grid is ensured.

**[0037]** The power supply according an embodiment includes the converter circuit comprising electric components with a voltage rating that exceeds a nominal voltage of the DC grid supply voltage and is smaller than an admissible maximum peak voltage the DC grid supply voltage. In particular, the voltage rating may exceed the nominal voltage of the DC grid supply voltage and may be less than two times the nominal voltage of the DC grid supply voltage. In particular, the voltage rating may exceed 800 V and is less or equal 950 V.

**[0038]** The power supply therefore includes readily available electronic components at advantageous component cost.

**[0039]** According to an embodiment, the power supply comprises an EMI filter circuit. The EMI filter circuit may be connected between the DC grid interface and the surge protection circuit.

**[0040]** Generally, an EMI choke as a characteristic example of the EMI filter circuit in combination with the capacitance included in a conventional surge protection circuit acts as series resonance circuit, which, when applying a DC voltage step to the DC grid interface of the power supply results in a large inrush current and a time-limited voltage overshoot almost twice the nominal voltage of the applied voltage step. The voltage overshoot easily exceeds the voltage rating of the electronic components of the power supply. The surge protection circuit also deals with this inrush current and maintains a bus voltage of the converter circuit arranged downstream of the surge circuit at the nominal voltage level. Thus, the DC-to-DC converter device may even address the inrush current problem, which is in particular present due the EMI filter circuit, in particular due to the inductance of the EMI filter circuit. The power supply according to an embodiment is a light driver configured to provide the load current to at least one lighting module.

**[0041]** Generally, light driver devices driving lighting modules are frequently employed types of DC-to-DC converter devices installed on the manufacturing site. The cost-effective solution presented by the power supply and the capability to operate safely from the DC grid enables a design engineer to provide a technically advantageous solution for lighting systems on manufacturing sites due to operating from the DC grid. Simultaneously the cost of the individual power supply using the surge protection circuit are advantageously low due to coping with voltage surges without having to use electronic components rated for excessive surge voltages.

**[0042]** The subsequent discussion of embodiments refers to the attached figure sheets, on which

Fig. 1 displays a simplified circuit diagram of an electronic circuit including a surge protection circuit according to an embodiment,
Fig. 2 displays a simplified circuit diagram of a known DC-to-DC converter device including surge protection as currently in use,
Fig. 3 illustrates the reaction of the known DC-to-DC converter device with surge protection as currently in use in a hot replacement scenario,
Fig. 4 displays a simplified structure of an industrial DC grid and its key elements, and
Fig. 5 illustrates the simplified structure of an industrial DC grid stabilizing energy availability in future industrial applications.

**[0043]** In the figures, same reference numbers denote same or corresponding elements. The discussion of embodiments dispenses with a discussion of same reference numbers for different figures wherever considered possible without adversely affecting comprehensibility.

**[0044]** Active electric circuits include energy supplying components whereas passive circuits include only passive components, which consume or store energy, e.g. either dissipate, absorb or store it in an electric field or a magnetic field.

Any circuit including an active component is an active circuit. An active component is an electronic component which supplies energy to the circuit, e.g. has the ability to control electrically an electron flow, e.g. flow of charges. Common examples for active components include, e.g. transistors and diodes.

**[0045]** Fig. 1 displays a simplified circuit diagram of an electronic circuit 10 including a surge protection circuit 1 according to an embodiment in an application scenario.

**[0046]** The electronic circuit 10 comprises an EMI filter circuit 11, and optionally a converter circuit 12.

**[0047]** The electronic circuit 10 includes a DC input interface (DC grid interface) to the DC grid (DC supply grid) for obtaining a DC supply voltage $V_{DC}$ via a positive DC input line L (positive DC input connection L) and a negative DC input line N (negative DC input connection L).

**[0048]** The DC grid voltage may, for example, correspond to a DC voltage between 400 $V_{DC}$ and 800 400 $V_{DC}$.

**[0049]** Fig. 1 depicts a line impedance $L_1$ of the DC grid.

**[0050]** Fig. 1 further shows a DC output interface of the electronic circuit 10 to an electrical load 15. The electrical load 15 may be a lighting module (LED module) including a plurality of light emitting diodes (LEDs), which the electronic circuit 10 provides with a bus voltage $V_{BUS}$ via a bus bar. The lighting module shown in fig. 1 also includes a DC-to-DC converter 15.1, which generates a LED current $I_{LED}$ as a particular example for the load current $I_{LOAD}$, and provides the LED current $I_{LED}$ to the LEDs. The DC-to-DC converter 15.1 may generate the load current $I_{LOAD}$ based on the bus voltage $V_{BUS}$ using a switched mode power supply (SMPS) topology. Arranging the DC-to-DC converter 15.1 in the electrical load 15, e.g. the lighting module, enables to use different electrical loads 15 connected to the same bus bar with the bus voltage $V_{BUS}$.

**[0051]** The electronic circuit 10 includes an optional driver circuit 12 that generates the bus voltage $V_{BUS}$ from a voltage $V_2$ input to the optional driver circuit 12. The optional driver circuit 12 is not limited to a particular SMPS configuration.

**[0052]** The optional driver circuit 12 may further generate one more internal supply voltages using low voltage power supply (LVPS) circuits as required for the optional driver circuit 12, and the other structural elements of the electronic circuit 10. The optional driver circuit 12 may in particular generate supply voltages required for active electronic circuit elements included in the surge protection circuit 1.

**[0053]** The electronic circuit 10 arranges the EMI filter circuit 11 connected, in particular directly connected, to the positive supply line connection L of the DC grid interface on the one hand and to an input (first input line, first input connection) of the surge protection circuit 1.

**[0054]** Electromagnetic interference (abbreviated as EMI) is a disruption that affects an electrical circuit because of either electromagnetic induction or externally emitted electromagnetic radiation. Generally, EMI refers to the interference from one electrical or electronic system to another electronic system caused by electromagnetic fields generated by the operation of the electronic system. EMI also refers to a disturbance generated by an external source that affects an electrical circuit by electromagnetic induction, electrostatic coupling, or electric conduction. The disturbance may degrade the performance of the electric circuit or even prevent the electric circuit from functioning entirely. The EMI filter circuit 11 blocks disturbances as near to the source as possible, preferably, before the disturbances enter the electronic circuit or before the disturbance leave the electronic circuit. Examples of the EMI filter circuit 11 arranged on a circuit board of the electronic circuit use respectively arranged capacitors and/or inductors. An EMI choke as an example of the EMI filter circuit 11 of fig. 1 shows an equivalent circuit diagram including an inductivity L2 serially connected with a resistor R2, and a capacitor C2 connected in parallel to the serially arranged inductivity L2 and resistor R2.

**[0055]** The EMI filter circuit 11 provides a reactive impedance to the electronic circuit 10, and, by determining the electric component values of the EMI filter circuit 11 respectively, a frequency characteristics of the EMI filter circuit 11 may be tuned to desired frequency ranges.

**[0056]** A line filter is an example for an EMI filter circuit 11. The line filter is an electronic filter circuit that is placed between electronic equipment and a line (power supply line, power supply connection) external to it, to attenuate conducted radio frequencies in this context as Radiated Frequency Interference (abbreviated as RFI, sometimes also referenced under to term electromagnetic interference EMI) - between the line and the electronic equipment. In particular, an AC line filter is used between the AC power line (AC power supply connection) and the equipment, e.g. a SMPS or a similar electronic circuit. The line filter may be used to attenuate EMI in either direction of the power supply connection. For example, for controlling emissions: It may be used to reduce the unintentional conducted emission from the equipment, to a level sufficiently low to pass regulatory limits, e.g. in FCC part 15. This is of importance for example in switched mode power supplies often employed in DC-to-DC converter circuits. For sake of completeness, in order to provide immunity, the line filter may be used to reduce the level of EMI entering the equipment, to a level sufficiently low not to cause any undesired behaviour.

**[0057]** The surge protection circuit 1 of the DC-to-DC converter device 10 combines two functional elements.

**[0058]** A first functional element of the surge protection circuit 1 is a serial circuit element 2 connected between the output of the EMI filter circuit 11 connected with the first input connection of the surge protection circuit 1 and the terminal N of the DC grid interface. The serial circuit element 2 is configured to implement a low-pass filter.

**[0059]** The first functional element of the surge protection circuit 1 is the serial circuit element 2, which includes a resistor R7 and a capacitor C5, which together constitute a low-pass filter circuit in the arrangement of fig. 1. A first connection of the resistor R7 is connected with the first input connection (first input line) of the surge protection circuit 1. A second connection of the resistor R7 is connected with the first connection of the capacitor C5. A second connection of the capacitor C5 is connected with the second input connection (second input line) of the surge protection circuit 1.

**[0060]** The first functional element 2 of the surge protection circuit 1 corresponds to a low-pass filter, comprising the R-C element including at least one resistor that corresponds to the resistor R7, connected in series with a filter load of the low-pass filter and at least one capacitor that corresponds to the capacitor C5 connected in parallel with the filter load of the low-pass filter.

**[0061]** At the capacitor C5, the average DC voltage from the DC supply grid of nominally 650 V, and up to 800 V, or for example down to 400 V provided via the DC grid interface of the DC-to- electronic circuit 10, may apply.

**[0062]** Generally, a simple low-pass filter circuit may comprise the resistor R7 in series with a load to the low-pass filter, and the capacitor C5 in parallel with the load of the low-pass filter. The capacitor C5 acts as a reactance, and blocks low-frequency signal components, forcing them through the filter towards the load of the low-pass filter instead. In case of providing high frequency signal components to the low-pass filter, the reactance drops, and the capacitor C5 effectively functions as a short circuit. The combination of resistor R7 and capacitor C5 connected in series determines a time constant of the low-pass filter. The corner frequency, or cutoff- frequency $f_C$ (in Hz), of the low-pass filter is determined by the time constant as

$$fc = \frac{1}{2\pi RC} = \frac{1}{2\pi R7C5}; \qquad (1)$$

with the resistor R7 in Ω and the capacitance C5 in Farad.

**[0063]** Simulation results show that capacitances of 100 nF for the capacitor C5 achieve good results and effectively attenuate surge voltages in a voltage range of up to 1500 V for a duration of about 100 μs occurring at the DC grid interface of the electronic circuit 10 at a nominal DC grid voltage of 650 $V_{DC}$. In this case, the voltages $V_{IN2}$ and $V_{BUS}$ are maintained at a nominal voltage of 650 $V_{DC}$ of the DC grid due to the surge protection circuit 1.

**[0064]** In an alternate simulation scenario, the capacitance of 100 nF for the capacitor C5 achieves good results and effectively attenuates surge voltages in a voltage range of up to 1500 V for a duration of about 100 μs occurring at the DC grid interface of the electronic circuit 10 for a nominal DC grid voltage of 880 $V_{DC}$. In this case, the voltages $V_{IN2}$ and $V_{BUS}$ are also maintained at a nominal voltage of 880 $V_{DC}$ of the DC grid due to the surge protection circuit 1, as simulation shows.

**[0065]** Determining the capacitance value of C7 may have to take into regard that a duration of the attenuation of voltage surges is a desired effect of the determined capacitance value of C7. On the other hand, selecting the capacitance value of C7 to large may adversely affect the voltages $V_{IN1}$, $V_{IN2}$ and $V_{BUS}$. $V_{IN1}$, $V_{IN2}$ and $V_{BUS}$ may show voltage drops in cases, in which the capacitance of C7 shows large capacitance values and the size of the load 15 varies significantly, in particular, sudden load steps occur.

**[0066]** A second functional element of the surge protection circuit 1 corresponds to a linear regulator circuit element 3 including at least one transistor Q1, Q2.

**[0067]** The at least one transistor Q1, Q2 may be in connected in an emitter-follower circuit topology. A collector of the at least one transistor Q1, Q2 is connected with the first input connection of the surge protection circuit 1. An emitter of the at least one transistor Q1, Q2 is connected with a first output connection (first output line) of the surge protection circuit 1. A base of the at least one transistor Q1, Q2 is connected with the second connection of the resistor R7 and the first connection of the capacitor C5.

**[0068]** An emitter-follower, also referred as a common collector amplifier is one of three basic single-stage bipolar junction transistor (abbreviated as BJT) amplifier topologies, typically used as a voltage buffer. Generally, the emitter-follower circuit topology uses the base terminal of the transistor as input, the emitter corresponds to an output, and the collector is common to both the emitter and the collector, e.g., it may be tied to ground reference or a power supply rail.

**[0069]** As illustrated in fig. 1, the the surge protection circuit 1 may comprise a first transistor Q1 and at least one second transistor Q2 instead of a single transistor, wherein the first transistor Q1 and the at least one second transistor Q2 are connected in a Darlington configuration.

**[0070]** Generally, a Darlington configuration refers to an electronic circuit topology including at least two transistors. Also called a Darlington pair, the Darlington configuration or circuit topology is an electronic circuit comprising two bipolar transistors with the emitter of a second transistor Q2 of the two transistors Q1, Q2 connected to the base of the first transistor Q1 of the two transistors Q1, Q2. The first transistor Q1 amplifies a current amplified by the second transistor Q2 further. In the Darlington configuration, the collectors of both transistors Q1, Q2 are connected with each other. The Darlington configuration has a significantly higher current gain than each transistor of the two transistors Q1, Q2 taken separately.

**[0071]** Thus, the surge protection circuit 1 may use the two transistors Q1, Q2 in a Darlington configuration in order to provide sufficient current gain in application scenarios, in which one transistor with sufficient current gain is not available.

**[0072]** If the averaged DC voltage is applied at the base of the transistors Q1, Q2, a corresponding voltage applies at the emitter of the transistor Q2 and at the emitter of the transistor Q1. The configuration of the linear regulator circuit element 3 implementing the second functional element of the surge protection circuit 1 is essentially an emitter follower. Almost no voltage drop occurs between the collector of the second transistor Q2, the emitter of the second transistor Q2, and the emitter of the first transistor Q1.

**[0073]** In particular, a voltage drop between the emitter of the transistor Q2, and the emitter of the transistor Q1 may correspond to about 0.7 V.

**[0074]** Thus, almost no, or at least only negligible electric losses are added by the surge protection circuit 1 along the DC supply path from the DC grid interface of the electronic circuit 10 to the optional driver circuit 12 of the electronic 10 and the bus interface to the bus bar.

**[0075]** The linear regulator circuit element 3 implemented using the transistors Q1, Q2 of the surge protection circuit 1 passes a voltage $V_{IN2}$ corresponding to the DC grid voltage to the optional driver circuit 12.

**[0076]** Alternatively, the surge protection circuit 1 may provide the voltage $V_{IN2}$ directly to the bus bar. Then the voltage $V_{IN2}$ essentially corresponds to a bus voltage $V_{BUS}$.

**[0077]** Fig. 1 and the associated portions of the description refer to the transistors Q1, Q2 as bipolar transistors. The surge protection circuit 1 may use other transistor technologies instead of the bipolar transistors shown in fig. 1 as NPN transistors Q1, Q2.

**[0078]** Alternatively, the transistors Q1, Q2 may be Metal Oxide Semiconductor Field Effect Transistors (MOSFETs), for example. The analogous field-effect transistor circuit topology to the Darlington configuration is the common-drain amplifier circuit topology.

**[0079]** Furthermore, the surge protection circuit 1 may arrange a diode D7 as a further functional element of the surge protection circuit 1 between an emitter of the first transistor Q1, which is connected to the output connection of the surge protection circuit 1, and the base of the second transistor Q2.

**[0080]** In particular, an anode of the diode D7 is connected with the emitter of the first transistor Q1, and a cathode of the diode D7 is connected with the base of the second transistor Q2 in case the surge protection circuit 1 includes two transistors Q1, Q2 in a Darlington configuration according to fig. 1.

**[0081]** Alternatively, the anode of the diode D7 is connected with the emitter of the transistor Q1, and a cathode of the diode D7 is connected with a base of the transistor Q1 in case the surge protection circuit includes only a single transistor Q1, different from the embodiment illustrated in fig. 1.

**[0082]** The diode D7 provides the effect of protecting the transistors Q1, Q2 in case the DC grid voltage $V_{DC}$, and in consequence the voltages $V_{IN2}$ and $V_{IN2}$ drop significantly, e.g. to values down to 400 V, for example due to stability problems in the DC supply grid originating from an integration of renewable energy sources into the DC grid.

**[0083]** The output of the surge protection circuit 1 is connected, in particular directly connected with the input of the optional driver circuit 12.

**[0084]** Alternatively, the output of the surge protection circuit 1 is directly connected, to the bus interface of the electronic circuit 10.

**[0085]** The presence of the surge protection circuit 1, has the effect that short voltage surges in the DC grid are now admissible. Characteristically, voltage surges are defined for up to 1200 V peak for a duration of up to 100 $\mu$s in the DC supply grid. The low-pass filter implemented by the first functional element of the surge protection circuit 1 is designed to filter these defined voltage surges out. A voltage applied over capacitor C5 remains at the nominal voltage of 650 V, the first transistor Q1 blocks the overvoltage, e.g. the 1200 V less 650 V, at the expense of a small power loss. The power loss is small, as the first transistor Q1 does not entirely block the voltage, but only for a duration of 100 $\mu$s of the voltage surge. By designing the cooling characteristics of the arrangement of the transistors Q1, Q2 in the surge protection circuit 1 respectively, the surge protection circuit 1 may cope with the additional power dissipation due to a corresponding dynamic heat resistance. Thus, a junction temperature of transistors Q1, Q2 does not increase immediately with the power loss due to the voltage surge.

**[0086]** Fig. 2 displays a simplified circuit diagram of a known DC-to-DC converter device 21 from prior art including surge protection as currently in use.

**[0087]** The DC-to-DC converter device 21 includes most functional elements of the electronic circuit 10 discussed with reference to fig. 1. In particular, with respect to the EMI filter circuit 22 and the converter circuit 24, reference to the corresponding EMI filter circuit 11 is considered sufficient.

**[0088]** The converter circuit 24 may be a known DC-to-DC converter circuit implemented in a switched mode power supply topology. The converter circuit 24 generates a load current $I_{LOAD}$.

**[0089]** The DC-to-DC converter device 21 employs a conventional surge protection means 23. The surge protection means 23 comprises a voltage-dependent resistor, which fig. 2 shows with an equivalent circuit including the elements ideal capacitor C4, ideal resistor R5 and ideal inductivity L5 in a series connection. The surge protection means 23 is connected from a positive polarity DC supply line (positive polarity DC supply connection) to a negative polarity DC supply line (negative polarity DC supply connection) at the DC grid interface of the DC-to-DC converter device 21 in order to protect the electric components of the converter circuit 24 from overvoltage.

**[0090]** Generally, known means to protect electronic circuits from voltage surges may use Voltage Dependent Resistors (abbreviated as VDR), usually referred to as a varistor. Varistors are nonlinear two-element semiconductors that decrease in their resistance value for an increasing voltage. Voltage dependent resistors are often used as surge suppressors for sensitive electronic circuits. The resistance of a varistor is variable and depends on the voltage applied. The resistance decreases when the voltage increases. In case of excessive voltage increases, their resistance drops dramatically. This behaviour makes varistors suitable to protect electronic circuits during voltage surges. Causes of a voltage surge can include lightning strikes and electrostatic discharges. The most common type of a VDR is the metal oxide varistor (abbreviated as MOV).

**[0091]** As an alternative to VDRs, known means to protect electronic circuits from voltage surges may be devised around Negative Temperature Coefficient (abbreviated as NTC) thermistors that have less resistance at higher temperatures. Generally, a thermistor is a type of resistor whose resistance is strongly dependent on temperature, more so than in standard resistors. Thermistors are divided based on their conduction model. NTC thermistor are widely used as inrush current limiters, temperature sensors, while PTC thermistors are used as self-resetting overcurrent protectors, and self-regulating heating elements. An operational temperature range of a thermistor is dependent on the probe type and may typically be between -100 °C and 300 °C.

**[0092]** Fig. 3 illustrates the reaction of the known DC-to-DC converter device 21 with surge protection as currently in use in a hot replacement scenario.

**[0093]** In particular, when an electrical device is turned on, the electrical device may draw a current significantly larger than a nominal current during standard operation of the electrical device. The large current drawn for s short time after applying a DC voltage step to the electrical device is referenced an inrush current, sometimes also denoted as input surge current or switch-on surge. The inrush current is the maximal instantaneous input current drawn by the electrical device when applying a voltage step to the input of a power supply interface of the electrical device. Alternating-current electric motors and transformers may draw several times their nominal current under full-load conditions when first energized, for a few cycles of the input waveform. In case of power converters, which often include SMPS circuits, inrush currents with current values significantly exceeding a steady-state current value may occur due to the charging current of an input capacitance of the power converter. Selecting and designing dimensions of over-current-protection devices such as fuses and circuit breakers requires more complicated considerations when high inrush currents have to be taken into account. An over-current protection has to react quickly to overload or short-circuit faults on the one hand, but on the other hand must not interrupt the operation circuit when the usually harmless inrush current flows.

**[0094]** The circuit diagram of fig. 2 arranges an EMI choke including the inductivity L2 in series with the capacitor C4 of the equivalent circuit diagram of the conventional surge protection circuit 23. The inductivity L2 and the capacitor C4 in combination represent a serial oscillation circuit, whose reaction to an applied voltage step is discussed with reference to fig. 3.

**[0095]** The simulation depicted in fig. 3 bases on the circuit topology of the known DC-to-DC converter device 21 according to fig. 2 and shows on the ordinate (y-axis) the bus voltage $V_{BUS}$ in volts over the course of time t shown on the abscissa (x-axis) in seconds. At the DC grid interface of the DC-to-DC converter device 21, a voltage step with an amplitude of 650 $V_{DC}$ is applied to the DC-to-DC converter device 21. Fig. 3 shows that the resulting $V_{BUS}$ reaches a maximum voltage of almost twice the applied 650 $V_{DC}$, about 1.12 $kV_{DC}$, which rapidly decreases over time, and when a time of about 300 $\mu$s has elapsed after applying the voltage step, the voltage $V_{BUS}$ does not exceed a voltage value of 0.70 kV any more.

**[0096]** The bus voltage surge due to the inrush current either requires adding additional protective circuit elements implementing an inrush current limiter or selecting respectively rated electronic components for the converter circuit 24 in order to cope reliably with the overvoltage of $V_{BUS}$ due to the inrush current.

**[0097]** An inrush current limiter is an electronic component used to limit an inrush current to avoid damage or even destruction to electronic components of an electronic circuit, to avoid blowing fuses or tripping circuit breakers.

**[0098]** Contrary to the DC-to-DC converter circuit 24, the electronic circuit 1 includes the surge protection circuit 1, which is capable to suppress the voltage surge of the bus voltage $V_{BUS}$ shown in fig. 3 entirely. Thus, the surge protection circuit 1 does not only provide protection of the optional driver circuit 12 against voltage surges of the DC grid but also provides the extra benefit of addressing the problems arising from the inrush current scenario.

**[0099]** The electronic circuit 10 with the surge protection circuit 1 provides an inrush current limitation due to a smooth starting capability. As fig. 3 illustrates for the known DC-to-DC converter device 21 with a conventional surge protections means 23, e.g. using a VDR or a suppressor diode, the surge protection circuit 1 provides the further benefit of implementing the feature of inrush current limitation without requiring additional circuit elements of an inrush limiter.

**[0100]** The inrush current limiter, e.g. designed around a thermistor, is therefore not required in case of the electronic circuit 10 including the surge protection circuit 1.

**[0101]** Negative temperature coefficient (NTC) thermistors and fixed resistors regularly provide the capability to limit inrush current. NTC thermistors as inrush-current limiting devices in power supply circuits are added in series with the circuit being protected. They present a higher resistance initially, which prevents large currents from flowing at turn-on. As current continues to flow, NTC thermistors heat up, allowing higher current flow during normal operation. NTC thermistors are usually much larger than measurement-type thermistors, and are designed purposely for power applications but come along with the additional cost of additional electronic components.

**[0102]** The surge protection circuit 1 according to the first aspect enables to omit the dedicated inrush current limiter, thereby offering protection for the circuits succeeding to the surge protection circuit 1 in the DC power supply path not only from surge voltages and voltage spikes, but also in inrush current scenarios.

**[0103]** Contrary thereto, the conventional surge protection circuit 23 based on a VDR or a suppressor diode inevitably fails in keeping the voltages $V_{IN}$ resp. $V_{BUS}$ after the EMI filter circuit 22 below the desired voltage limit values determined by the rated voltages of the respectively succeeding electrical components. This failure of the conventional surge protection circuit 23 results from the nominal DC grid voltage of up to 800 V, and the maximum rated voltage of the critical electrical components of, for example, 900 V being close together. As the respective characteristic curve V= f (I) of both the VDR or the suppressor diode only have a limited gradient, the conventional surge protection circuit 23 fails in protecting the critical electrical components of the electric circuits of the DC-to-DC converter device 21 according to prior art.

**[0104]** The surge protection circuit 1 of the electronic circuit 10, however, provides an active attenuation component for the EMI filter circuit 11, 22, which effectively prevents an overshoot of the voltages $V_{IN1}$, $V_{IN2}$, and $V_{BUS}$ after a sudden and fast increase of the current drawn by the electronic circuit 10.

**[0105]** The surge protection circuit 1 provides efficient protection against voltage surges even for high nominal voltage values on the DC grid, while simultaneously enabling using cost-effective electrical components in the protected electronic circuits. The cost-effective electrical components may have rated voltages, which although exceeding the nominal voltages on the DC grid, are nevertheless smaller than the surge voltage values that may occur on the DC grid.

**[0106]** Fig. 4 displays a simplified structure of an industrial DC grid and its key elements.

**[0107]** An industrial energy system for a future manufacturing site according to fig. 4 may comprise a DC-based smart grid for industry.

**[0108]** A bidirectional power supply includes centralised AC-to-DC converters, which supply all electric loads 15 at the manufacturing site with DC power. The bidirectional power supply also enables to feed surplus electric energy from the local DC grid into the AC grid. The DC grid enables integration of renewable energy sources locally at the manufacturing site, e.g. integrating power generation via photovoltaic cells, wind turbines and by other renewable energy sources. Using the DC grid reduces losses in power conversion when compared to integrating renewable energy sources via the AC grid, as, for example, there exists no need for synchronising each renewable energy source with a three-phase AC grid.

**[0109]** The DC grid also enables integrating energy storage devices at the manufacturing site with the benefit of reduced conversion losses. This provides the additional effect of maintaining electric power supply for the manufacturing site in case of an AC grid failure. Thus, a peak power requirement when designing the AC grid over a region with a plurality of manufacturing sites, and the bidirectional power supply for the individual manufacturing site, may be reduced.

**[0110]** A decentralised grid management provides the full potential of power balancing and stability enhancement to the manufacturing site.

**[0111]** The dynamic power demands of robotic manufacturing benefit from expanded distribution of the DC grid capacity. A high ratio of recuperative energy may be used locally at the manufacturing site, or fed to the AC grid.

**[0112]** Decentralised drive applications, for example conveyor systems benefit from reduced component complexity when supplied with DC power instead of AC power.

**[0113]** Multi axis machining centres accelerate huge masses for time-efficient processing of products, product parts and subassemblies. A shared DC grid increases the efficiency of dynamic energy demands and enables an expanded usage of recuperative energy. Lift applications in industrial applications produce a high amount of recuperative energy. The bidirectional power exchange via the DC grid yields additional savings.

**[0114]** The DC grid for a manufacturing site enables seamless and efficient integration of renewable energy, e.g. solar panels installed on factory roofs, and storage devices for balancing power supply and demand in the factory. Fig. 4 shows a direct current supply of an entire manufacturing facility extending a direct current supply of a production cell, which provides the groundwork for the power supply of manufacturing plants via a DC grid. The DC grid enables to implement an energy transition in industrial production achieving a significant reduction of consumed power and a recovery of braking energy. Robotic devices in manufacturing plants may recuperate energy and store recuperated energy into the energy storage devices at the DC voltage level of the DC grid.

**[0115]** Robotic devices use Siliciumcarbid (SiC) transistors, which are able to cope with voltage surges of 1500 V. In case of robotic devices, established conventional overvoltage protection measures are applicable, e.g. including the use of varistors or suppressor diodes, which exhibit a large tolerance with regard to their respective response thresholds.

**[0116]** Contrary thereto, an integration of DC-to-DC converters such as LED drivers poses more problems in order to adapt to the extended DC voltage ranges, in particular due to the overvoltage protection issues. A LED driver uses cheap semiconductors, e.g. 650V-rated MOSFETs. Use of electronic components extending the rated voltages of the electronic components up to 900 V is envisaged, but already comes at the expense of increased cost.

**[0117]** Fig. 5 illustrates the simplified structure of an industrial DC grid stabilizing energy availability in future industrial applications.

**[0118]** The implementation of the DC grid at manufacturing sites has the potential to reduce operating costs and take advantage of renewable energy sources. Conversion from DC to AC is not required to be done by an inverter - the grid infrastructure provided by the DC grid offers the possibility of optimizing the purchase of energy and to stabilize the grid.

**[0119]** In the industrial sector, electric motors account for a significant proportion of electricity consumption and are thus the most relevant electrical load to be supplied with electrical energy. Reducing the energy requirements of these drive systems by increasing their efficiency contributes to an equivalent reduction in $CO_2$ emissions.

**[0120]** The advantage of using a frequency inverter is the continuous adaptation of the motor speed to the actual need, which can very often also lead to energy savings. A frequency inverter is supplied with the alternating current, which is first converted into direct current using a rectifier. The direct current is then converted into alternating current with variable frequency and voltage through a voltage feed inverter in order to electronically change the speed of a three-phase motor. However, if the three-phase motor is operating in the braking mode, e.g. in a crane that is in lowering mode, the energy flow changes. This energy cannot be fed back into the grid by the frequency inverter because the input rectifier only allows the energy to flow in one direction. Therefore, the energy that is fed back must be dissipated via the direct current voltage circuit of the frequency inverter.

**[0121]** The increasing use of frequency inverters to control motor speeds causes effects on mains supply, causing harmonics and distorting the voltage of the mains supply grid. If frequency inverters or other devices with power electronics are increasingly installed, grid effects such as harmonics and voltage surges on a mains supply grid will increase.

**[0122]** A further increase in the use of inverters for the flexible control of electric motors is desirable in order to improve both production processes and energy efficiency. However, line perturbations due to harmonics and equipment costs, e.g. for other systems operating of the mains supply grid at the manufacturing site limit the improvement. The network structure of the mains supply grid at the manufacturing site according to fig. 5 is based on an alternating current (AC) supply, which provides the direct current power supply for the manufacturing site via a central rectifier. Active grid filters may be integrated into the central rectifier to ensure the voltage quality harmonic requirements. The direct supply of the frequency inverter with direct current means that a decentralized energy conversion is no longer needed. Since central energy conversion from AC to DC is significantly more efficient, conversion losses are significantly reduced.

**[0123]** Through the direct supply of all electric motors via a frequency inverter with direct current power supply, all installed motors are connected via the DC grid. The DC grid essentially only causes transmission losses (ohmic losses). Compared to an AC grid, the capacitive and inductive line losses are eliminated.

**[0124]** Through the elimination of the input rectifier and the grid filter with frequency inverters, these can be designed more cost-effectively and more compactly. This simplifies integration into the motor, which can significantly increase the degree of acceptance In addition, the DC grid offers the possibility of integrating photovoltaics directly at the direct current voltage level. In this case, conversion from DC to AC is not required to be done by an inverter. This grid infrastructure offers the possibility of optimizing purchase of energy, and stabilizing the grid.

**[0125]** The electronic circuit 10 with the surge protection circuit 1 enables to integrate building infrastructure systems, e.g. lighting systems, into the DC grid at the manufacturing site.

## Claims

1. An electronic circuit including a surge protection circuit (1) for the power supply interface of a DC-to-DC converter device (10), wherein the electronic circuit comprises a DC grid interface comprising first and second DC input voltage lines (L, N), and

    the surge protection circuit (1) comprises
    a serial circuit element (2) connected between the first and the second DC input voltage lines (L, N) and configured to implement a low-pass filter, and
    a linear regulator circuit element (3) including at least one transistor (Q1, Q2), and
    **characterized in that**
    the surge protection circuit (1) comprises the serial circuit element (2) comprising a R-C element for implementing the low-pass filter including at least one resistor (R7) and a capacitor (C5),
    wherein a first terminal of the at least one resistor (R7) is connected with the first DC voltage input line (L) and a second terminal of the at least one resistor (R7) is connected with a first terminal of the capacitor (C5), and a second terminal of the capacitor (C5) is connected with the second DC voltage input line (N), and
    wherein a base of the at least one transistor (Q1, Q2) is connected with the second terminal of the at least one resistor (R7) and the first terminal of the capacitor (C5), and an emitter of the at least one transistor (Q1, Q2) is

connected with an output connection of the surge protection circuit (1).

2. The electronic circuit including the surge protection circuit (1) for a DC-to-DC converter device according to claim 1, wherein
the surge protection circuit (1) comprises the at least one transistor (Q1, Q2) of the linear regulator circuit element (3) in an emitter-follower circuit topology configuration.

3. The electronic circuit including the surge protection circuit (1) for a DC-to-DC converter device according to any of the preceding claims, wherein
the surge protection circuit (1) further comprises a diode (D7) connected between an emitter of the at least one transistor (Q1, Q2) and a base of the at least one transistor (Q1, Q2).

4. The electronic circuit including the surge protection circuit (1) for a DC-to-DC converter device according to any of the preceding claims, wherein
the surge protection circuit (1) comprises the first transistor (Q1) and at least one second transistor (Q2), wherein the first transistor (Q1) and the at least one second transistor (Q2) are connected in a Darlington configuration.

5. The electronic circuit including the surge protection circuit (1) for a DC-to-DC converter device according to any of the preceding claims, wherein
the surge protection circuit (1) is configured to operate in a voltage range of a DC grid supply.

6. The electronic circuit including the surge protection circuit (1) for a DC-to-DC converter device according to claim 5, wherein
the surge protection circuit (1) is configured to operate in a nominal voltage range of the DC grid supply ranging from 400 $V_{DC}$ to 950 $V_{DC}$.

7. The electronic circuit including the surge protection circuit (1) for a DC-to-DC converter device according to claim 5 or 6, wherein
the nominal voltage of the DC grid supply essentially corresponds to 650 V.

8. A power supply for generating a load current ($I_{LOAD}$) for an electric load (15) from a DC supply voltage, wherein the power supply comprises

    a DC-to-DC converter circuit (15.1) configured to generate the load current ($I_{LOAD}$) and to output the load current ($I_{LOAD}$) via an output interface (LED+, LED-), and
    the electronic circuit including the surge protection circuit (1) according to any one of claims 1 to 7 configured to be connected between the DC grid interface for obtaining the DC supply voltage and the DC-to-DC converter circuit (15.1).

9. The power supply according to claim 8, wherein
the DC-to-DC converter circuit (15.1) includes electric components with a voltage rating that exceeds a nominal voltage of the DC grid supply voltage and is smaller than a maximum peak voltage of the DC grid supply voltage.

10. The power supply according to claim 9, wherein the voltage rating exceeds the nominal voltage of the DC grid supply voltage and is smaller than two times the nominal voltage of the DC grid supply voltage, or
the voltage rating exceeds 800 V and is less or equal 950 V.

11. The power supply according to one of claims 8 to 10, wherein

    the power supply comprises an EMI filter circuit (11), and
    the EMI filter circuit (11) is connected between the DC grid interface and the surge protection circuit (1).

12. The power supply according to any of claims 8 to 11, wherein
the power supply is a light driver configured to provide the load current ($I_{LOAD}$) for supplying at least one lighting module.

## Patentansprüche

1. Elektronische Schaltung einschließlich einer Überspannungsschutzschaltung (1) für die Leistungsversorgungsschnittstelle einer Gleichstromumrichtervorrichtung (10), wobei die elektronische Schaltung eine Gleichstrom-Netzschnittstelle umfasst, umfassend eine erste und eine zweite Gleichstromeingangsspannungsleitung (L, N), und wobei die Überspannungsschutzschaltung (1) umfasst:

   ein serielles Schaltungselement (2), das zwischen die erste und die zweite Gleichstromeingangsspannungsleitung (L, N) geschaltet ist und konfiguriert ist, um einen Tiefpassfilter zu implementieren, und
   ein lineares Reglerschaltungselement (3), einschließlich mindestens eines Transistors (Q1, Q2), und
   **dadurch gekennzeichnet, dass**
   die Überspannungsschutzschaltung (1) das serielle Schaltungselement (2) umfasst, umfassend ein RC-Element zum Implementieren des Tiefpassfilters einschließlich mindestens eines Widerstands (R7) und eines Kondensator (C5),
   wobei ein erster Anschluss des mindestens einen Widerstands (R7) mit der ersten Gleichspannungseingangsleitung (L) geschaltet ist und ein zweiter Anschluss des mindestens einen Widerstands (R7) mit einem ersten Anschluss des Kondensators (C5) geschaltet ist und ein zweiter Anschluss des Kondensators (C5) mit der zweiten Gleichspannungseingangsleitung (N) geschaltet ist, und
   wobei eine Basis des mindestens einen Transistors (Q1, Q2) mit dem zweiten Anschluss des mindestens einen Widerstands (R7) und dem ersten Anschluss des Kondensators (C5) geschaltet ist und ein Emitter des mindestens einen Transistors (Q1, Q2) mit einem Ausgangsanschluss der Überspannungsschutzschaltung (1) geschaltet ist.

2. Elektronische Schaltung einschließlich der Überspannungsschutzschaltung (1) für eine Gleichstromumrichtervorrichtung nach Anspruch 1, wobei
   die Überspannungsschutzschaltung (1) mindestens einen Transistor (Q1, Q2) des linearen Reglerschaltungselements (3) in einer Emitterfolger-Schaltungstopologiekonfiguration umfasst.

3. Elektronische Schaltung einschließlich der Überspannungsschutzschaltung (1) für eine Gleichstromumrichtervorrichtung nach einem der vorstehenden Ansprüche, wobei
   die Überspannungsschutzschaltung (1) ferner eine Diode (D7) umfasst, die zwischen einem Emitter des mindestens einen Transistors (Q1, Q2) und einer Basis des mindestens einen Transistors (Q1, Q2) geschaltet ist.

4. Elektronische Schaltung einschließlich der Überspannungsschutzschaltung (1) für eine Gleichstromumrichtervorrichtung nach einem der vorstehenden Ansprüche, wobei
   die Überspannungsschutzschaltung (1) den ersten Transistor (Q1) und mindestens einen zweiten Transistor (Q2) umfasst, wobei der erste Transistor (Q1) und der mindestens eine zweite Transistor (Q2) in einer Darlington-Konfiguration geschaltet sind.

5. Elektronische Schaltung einschließlich der Überspannungsschutzschaltung (1) für eine Gleichstromumrichtervorrichtung nach einem der vorstehenden Ansprüche, wobei
   die Überspannungsschutzschaltung (1) konfiguriert ist, um in einem Spannungsbereich einer Gleichstromnetzversorgung betrieben zu werden.

6. Elektronische Schaltung einschließlich der Überspannungsschutzschaltung (1) für eine Gleichstromumrichtervorrichtung nach Anspruch 5, wobei
   die Überspannungsschutzschaltung (1) konfiguriert ist, um in einem Nennspannungsbereich der Gleichstromnetzversorgung, die in dem Bereich von 400 $V_{DC}$ bis 950 $V_{DC}$ liegt, betrieben zu werden.

7. Elektronische Schaltung einschließlich der Überspannungsschutzschaltung (1) für eine Gleichstromumrichtervorrichtung nach Anspruch 5 oder 6, wobei
   die Nennspannung der Gleichstromnetzversorgung im Wesentlichen 650 V entspricht.

8. Leistungsversorgung zum Erzeugen eines Laststroms ($I_{LOAD}$) für eine elektrische Last (15) aus einer Gleichstromversorgungsspannung, wobei die Leistungsversorgung umfasst:

   eine Gleichstromumrichterschaltung (15.1), die konfiguriert ist, um den Laststrom ($I_{LOAD}$) zu erzeugen und den Laststrom ($I_{LOAD}$) über eine Ausgangsschnittstelle (LED+, LED-) auszugeben, und wobei die elektronische Schaltung die Überspannungsschutzschaltung (1) nach einem der Ansprüche 1 bis 7 einschließt und konfiguriert ist, um zwischen die Gleichstromnetzschnittstelle zum Erhalten der Gleichstromversorgungsspannung und die Gleichstromumrichterschaltung (15.1) geschaltet zu werden.

**9.** Leistungsversorgung nach Anspruch 8, wobei
die Gleichstromumrichterschaltung (15.1) elektrische Komponenten mit einem Spannungsnennwert einschließt, der eine Nennspannung der Gleichstromnetzversorgungsspannung überschreitet und kleiner als eine maximale Spitzenspannung der Gleichstromnetzversorgungsspannung ist.

**10.** Leistungsversorgung nach Anspruch 9, wobei der Spannungsnennwert die Nennspannung der Gleichstromnetzversorgungsspannung übersteigt und kleiner als das Zweifache der Nennspannung der Gleichstromnetzversorgungsspannung ist, oder
der Spannungsnennwert 800 V überschreitet und kleiner als oder gleich 950 V ist.

**11.** Leistungsversorgung nach einem der Ansprüche 8 bis 10, wobei

die Leistungsversorgung eine EMI-Filterschaltung (11) umfasst, und
die EMI-Filterschaltung (11) zwischen der Gleichstromnetzschnittstelle und der Überspannungsschutzschaltung (1) angeschlossen ist.

**12.** Leistungsversorgung nach einem der Ansprüche 8 bis 11, wobei
die Leistungsversorgung ein Lichttreiber ist, der konfiguriert ist, um den Laststrom ($I_{LOAD}$) zum Versorgen mindestens eines Beleuchtungsmoduls bereitzustellen.

## Revendications

**1.** Circuit électronique comportant un circuit limiteur de surtension (1) pour l'interface d'alimentation en puissance d'un dispositif convertisseur CC vers CC (10), dans lequel le circuit électronique comprend une interface de réseau CC comprenant des première et seconde lignes de tension d'entrée CC (L, N), et

le circuit limiteur de surtension (1) comprend
un élément de circuit en série (2) connecté entre les première et seconde lignes de tension d'entrée CC (L, N) et configuré pour implémenter un filtre passe-bas, et
un élément de circuit régulateur linéaire (3) comportant au moins un transistor (Q1, Q2), et
**caractérisé en ce que**
le circuit limiteur de surtension (1) comprend l'élément de circuit en série (2) comprenant un élément R-C permettant d'implémenter le filtre passe-bas comportant au moins une résistance (R7) et un condensateur (C5), dans lequel une première borne de l'au moins une résistance (R7) est connectée à la première ligne d'entrée de tension CC (L) et une seconde borne de l'au moins une résistance (R7) est connectée à une première borne du condensateur (C5), et une seconde borne du condensateur (C5) est connectée à la seconde ligne d'entrée de tension CC (N), et
dans lequel une base de l'au moins un transistor (Q1, Q2) est connectée à la seconde borne de l'au moins une résistance (R7) et à la première borne du condensateur (C5), et un émetteur de l'au moins un transistor (Q1, Q2) est connecté à une connexion de sortie du circuit limiteur de surtension (1).

**2.** Circuit électronique comportant le circuit limiteur de surtension (1) destiné à un dispositif convertisseur CC vers CC selon la revendication 1, dans lequel
le circuit limiteur de surtension (1) comprend l'au moins un transistor (Q1, Q2) de l'élément de circuit régulateur linéaire (3) dans une configuration de topologie de circuit à émetteur-suiveur.

**3.** Circuit électronique comportant le circuit limiteur de surtension (1) destiné à un dispositif convertisseur CC vers CC selon l'une quelconque des revendications précédentes, dans lequel
le circuit limiteur de surtension (1) comprend en outre une diode (D7) connectée entre un émetteur de l'au moins un transistor (Q1, Q2) et une base de l'au moins un transistor (Q1, Q2).

**4.** Circuit électronique comportant le circuit limiteur de surtension (1) destiné à un dispositif convertisseur CC vers CC selon l'une quelconque des revendications précédentes, dans lequel le circuit limiteur de surtension (1) comprend le premier transistor (Q1) et au moins un second transistor (Q2), dans lequel le premier transistor (Q1) et l'au moins un second transistor (Q2) sont connectés dans une configuration de Darlington.

**5.** Circuit électronique comportant le circuit limiteur de surtension (1) destiné à un dispositif convertisseur CC vers CC selon l'une quelconque des revendications précédentes, dans lequel
le circuit limiteur de surtension (1) est configuré pour fonctionner dans une plage de tension d'une alimentation réseau CC.

**6.** Circuit électronique comportant le circuit limiteur de surtension (1) destiné à un dispositif convertisseur CC vers CC selon la revendication 5, dans lequel
le circuit limiteur de surtension (1) est configuré pour fonctionner dans une plage de tension nominale de l'alimentation réseau CC allant de 400 $V_{CC}$ à 950 $V_{CC}$.

**7.** Circuit électronique comportant le circuit limiteur de surtension (1) destiné à un dispositif convertisseur CC vers CC selon la revendication 5 ou 6, dans lequel
la tension nominale de l'alimentation réseau CC correspond sensiblement à 650 V.

**8.** Alimentation en puissance permettant de générer un courant de charge ($I_{LOAD}$) destiné à une charge électrique (15) à partir d'une tension d'alimentation CC, dans lequel l'alimentation en puissance comprend

un circuit convertisseur CC vers CC (15.1) configuré pour générer le courant de charge ($I_{LOAD}$) et pour délivrer en sortie le courant de charge ($I_{LOAD}$) par l'intermédiaire d'une interface de sortie (LED+, LED-), et
le circuit électronique comportant le circuit limiteur de surtension (1) selon l'une quelconque des revendications 1 à 7 configuré pour être connecté entre l'interface de réseau CC permettant d'obtenir la tension d'alimentation CC et le circuit convertisseur CC vers CC (15.1).

**9.** Alimentation en puissance selon la revendication 8, dans laquelle
le circuit convertisseur CC vers CC (15.1) comporte des composants électriques avec une classe de tension qui dépasse une tension nominale de la tension d'alimentation réseau CC et est plus petite qu'une tension de crête maximale de la tension d'alimentation réseau CC.

**10.** Alimentation en puissance selon la revendication 9, dans laquelle la classe de tension dépasse la tension nominale de la tension d'alimentation réseau CC et est plus petite que deux fois la tension nominale de la tension d'alimentation réseau CC, ou
la classe de tension dépasse 800 V et est inférieure ou égale à 950 V.

**11.** Alimentation en puissance selon l'une des revendications 8 à 10, dans laquelle

l'alimentation en puissance comprend un circuit de filtre EMI (11), et
le circuit de filtre EMI (11) est connecté entre l'interface de réseau CC et le circuit limiteur de surtension (1).

**12.** Alimentation en puissance selon l'une quelconque des revendications 8 à 11, dans laquelle
l'alimentation en puissance est un pilote de lumière configuré pour fournir le courant de charge ($I_{LOAD}$) permettant d'alimenter au moins un module d'éclairage.

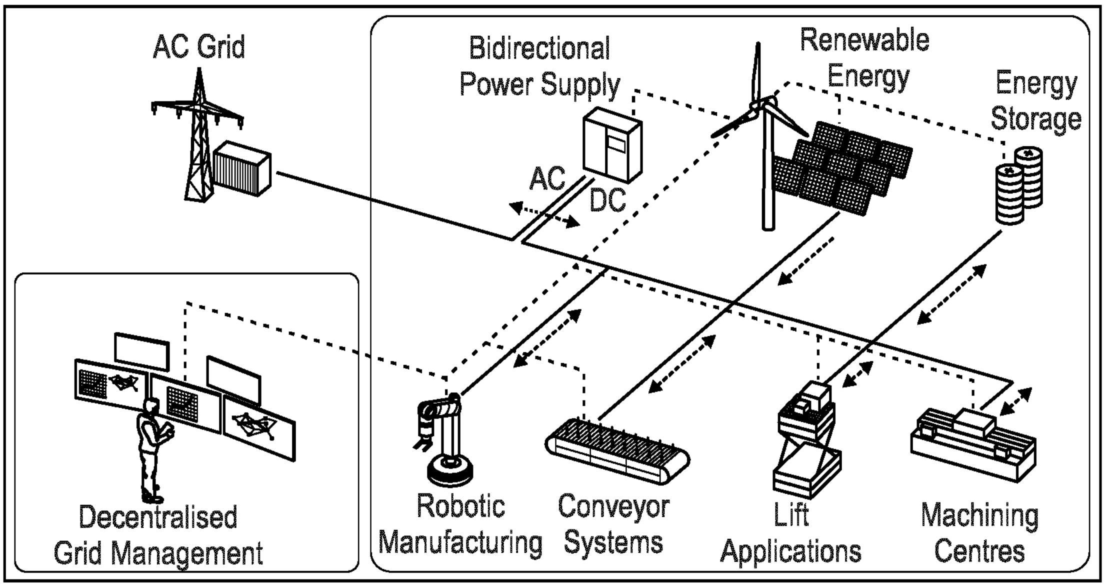

AC Grid
Bidirectional Power Supply
Renewable Energy
Energy Storage
AC
DC
Decentralised Grid Management
Robotic Manufacturing
Conveyor Systems
Lift Applications
Machining Centres

Fig. 4

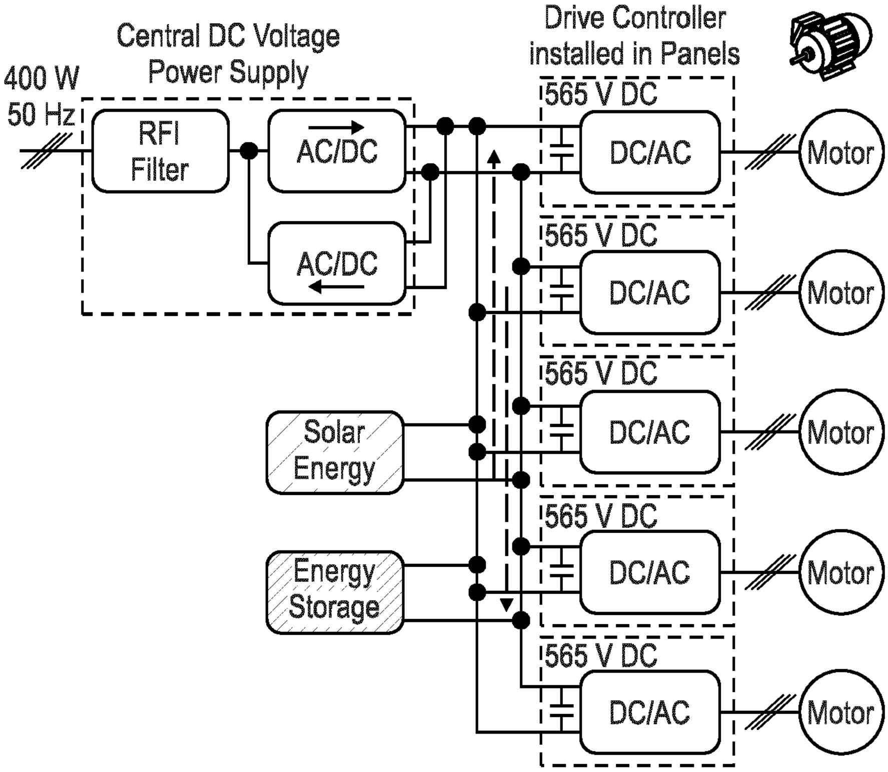

Central DC Voltage Power Supply
Drive Controller installed in Panels
400 W
50 Hz
RFI Filter
AC/DC
AC/DC
565 V DC
DC/AC
Motor
565 V DC
DC/AC
Motor
565 V DC
DC/AC
Motor
565 V DC
DC/AC
Motor
565 V DC
DC/AC
Motor
Solar Energy
Energy Storage

Fig. 5

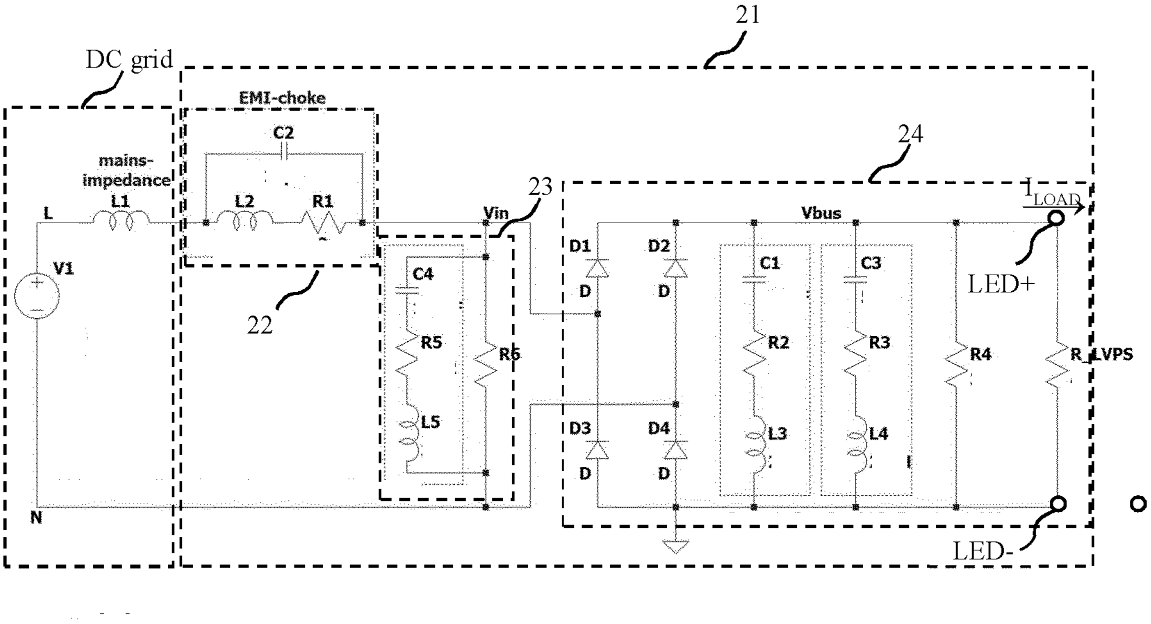


FIG. 2

(Prior Art)

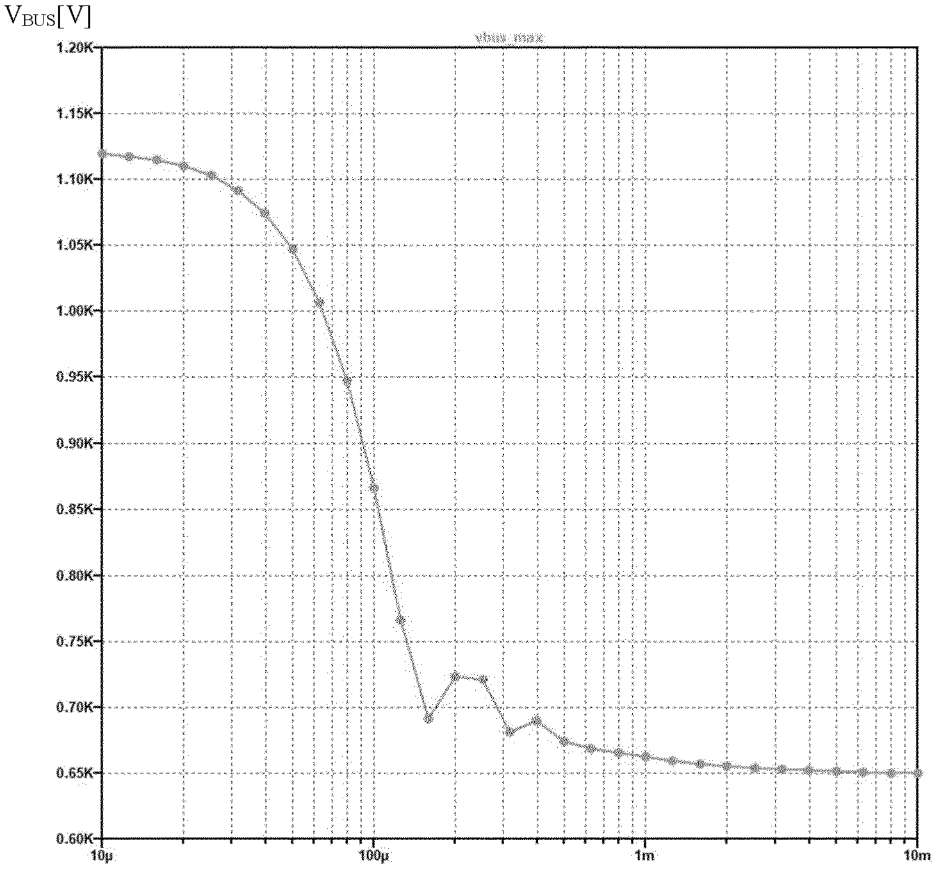
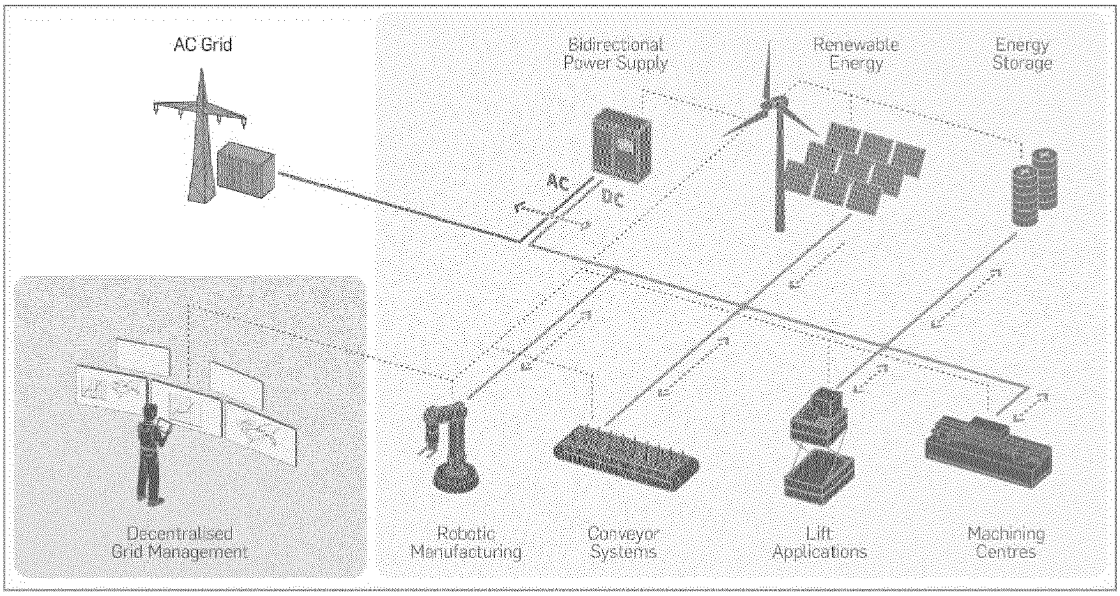


FIG. 3

(Prior Art)



Source: ZVEI

FIG. 4

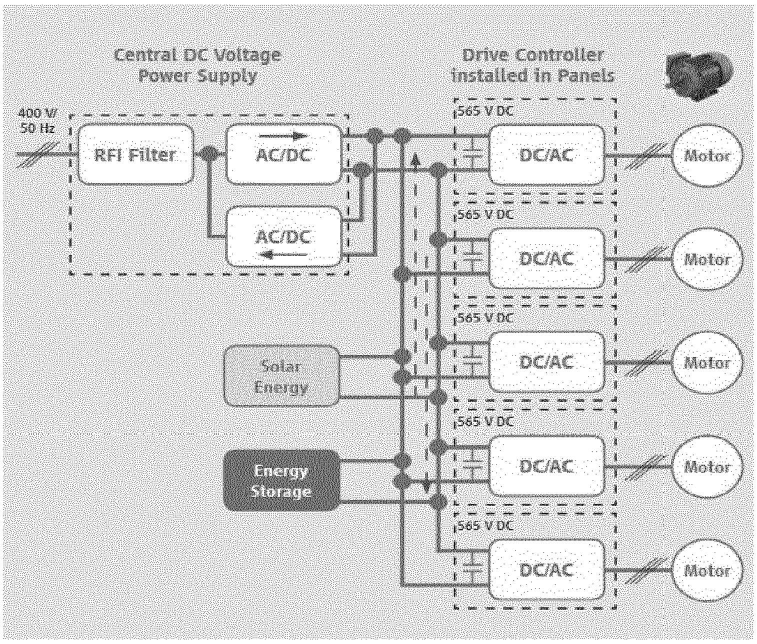


FIG. 5

## REFERENCES CITED IN THE DESCRIPTION

### Patent documents cited in the description

- US 2017311400 A1 **[0005]**
- US 2019335552 A1 **[0005]**