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(71) Applicant: **SMA SOLAR TECHNOLOGY AG** [DE/DE]; Sonnenallee 1, 34266 Niestetal (DE).

(72) Inventors: **SCHNABEL, Fabian**; Herkulesstraße 28, 34119 Kassel (DE). **ALTHOF, Carsten**; Luisenstraße 10, 32105 Bad Salzuflen (DE).

(74) Agent: **REHBERG HÜPPE + PARTNER**; Nikolausberger Weg 62, 37073 Göttingen (DE).

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(54) Title: GENERATOR GROUNDING WITH POWER LIMITATION

(57) Abstract: A circuitry arrangement (5) for grounding a connector (PV-) of a photovoltaic generator (1) includes a grounding path (6) extending from the connector (PV-) towards earth potential (PE) and a limiting circuit (7) in the grounding path (6). The limiting circuit (7) limits an amperage (I) of an earth current (12) flowing through the grounding path (6) increasingly with increasing thermal load to the limiting circuit (7) due to the earth current (12)in such a way that a thermal overload of the limiting circuit (7) due to the earth current (12) is avoided, even with an earth fault of any other connector (PV+) of the photovoltaic generator (1).

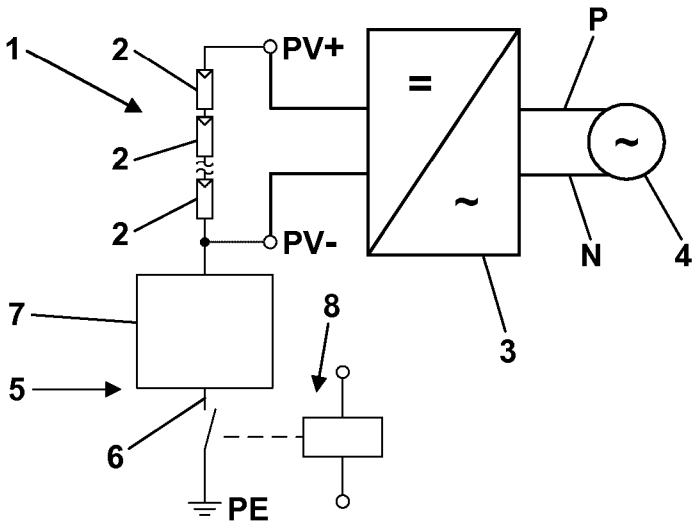


Fig. 1

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GENERATOR GROUNDING WITH POWER LIMITATION

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority to German Patent Application No. DE 10 2011 055 371.1 entitled "Leistungsbegrenzte Generatorerdung" and filed on November 15, 2011.

PRIOR ART

From European patent application publication EP 2 107 589 A1 it is known to ground a connector of a photovoltaic generator via a fuse. A circuitry arrangement is provided for surveying the fuse both with regard to an earth current flowing through the fuse and with regard to fusing of the fuse due to a fault current. A permanent grounding of a connector of a photovoltaic generator via a fuse is only possible if the photovoltaic generator is connected to an inverter which provides a galvanic isolation, like for example by means of a transformer. Further, a permanent grounding via a fuse does not allow the operation of the photovoltaic generator in an isolé terre (IT) grid which is generally isolated with regard to electric earth so that any earth fault occurring does only result in a punctual grounding and does not directly require a shutdown due to flowing earth currents.

The circuitry arrangement of EP 2 107 589 A1 used for surveying the fuse includes a measurement arrangement for determining the isolation resistance of connectors of a

photovoltaic generator with regard to electric earth, which is known from German patent application publication DE 10 2006 022 686 A1. In this measurement arrangement, the connectors of the photovoltaic generator are individually connected to electric earth via a shunt resistor, and the voltages with regard to electric earth which are then present at the connectors of the photovoltaic generator due to the output voltage of the photovoltaic generator are evaluated with regard to the isolation resistance of interest.

When a photovoltaic generator, via a transformerless inverter, is connected to an alternating current (AC) power grid with earth reference, a virtual grounding of a connector of the photovoltaic generator may be achieved by means of suitably operating the inverter. As long as the inverter is not yet operating, like for example during the night or in the early morning or in the late evening hours, when the output voltage of the photovoltaic generator is only low, this virtual grounding, however, is not yet present, and thin film modules of the photovoltaic generator may be damaged during these periods. This also applies to a special variant of virtual grounding which is known from EP 2 136 449 B1 and in which a transformer is provided between an output side AC power grid and the inverter. The potential centre point of the AC power grid present at the primary side of the transformer, by means of an offset voltage, is shifted with regard to earth potential to such an extent that the photovoltaic generator at the input side of the inverter is entirely on a desired (positive or negative) electric potential with regard to earth potential.

US patent application publication US 2010/0085670 A1 discloses a photovoltaic module monitoring system. A so-called string combiner comprises a ground fault test switch connected in series with a ground fault current limiter between DC negative of several strings and inverter ground.

German patent application publication DE 199 31 055 A1 discloses a protection circuitry for avoiding overloading capacitors with voltages of a high frequency. The capacitor to be protected is connected in series with a PTC thermistor. If a current flows through the PTC

thermistor, the PTC thermistor gets hot and its resistance increases. Thus, the faulty voltage which would otherwise be applied to the capacitor drops across the hot thermistor.

Current-limiting circuitries consisting of a series connection of a transistor and a current-limiting resistor, and of a limiting circuit for controlling the gate of the transistor are generally known. Here, the limiting circuit consists of a second resistor and a diode connected in parallel to the transistor and the current-limiting resistor. The gate of the transistor is connected to the centre point of the limiting circuit between the second resistor and the diode. Such a current-limiting circuitry could in principle be provided in series with a relay in a grounding path for a connector of a photovoltaic generator to, for example, ground this connector as long as it is not yet virtually grounded by a transformerless inverter to which the photovoltaic generator is connected. In such a case, however, either the relay would have to be of a very large dimension or the ohmic resistance of the current-limiting resistor would have to be high to enable such a circuitry arrangement to handle the potentially high powers which may occur in a photovoltaic generator due to the high voltages and due to the high amperages of compensation currents via earth which may flow in the circuitry due to the high capacitance of the photovoltaic generator with regard to earth. The first option means a big and expensive relay. The second option means that, even after closing the relay, a current-limiting resistor with a high ohmic resistance is arranged in the grounding path. This has the effect that even with an only small persistent earth current which may not be avoided in practice, a significant voltage drops across the current-limiting resistor. As a result, the connector to which the grounding path is connected is not hard grounded, but it is on an electric potential shifted with regard to earth potential by this voltage dropping across the current-limiting resistor. Such a circuitry arrangement would thus be unsuitable for a complete protection of thin film modules of a photovoltaic generator.

European patent application publication EP 2 091 123 A2 discloses a circuitry arrangement for grounding a connector of a DC current system. Here, a current-limiting diode is provided in a grounding path extending from the connector to earth potential. The grounding

path with the current-limiting diode normally provides for hard grounding of the connector to which the grounding path is connected. In case of an earth fault, the current-limiting diode limits the amperage of an earth current flowing through the grounding path. The disclosure of EP 2 091 123 A2 does not relate to photovoltaic power plants with photovoltaic generators. Further, it is not directly applicable to photovoltaic generators as the output voltages of present photovoltaic generators of some hundred up to more than thousand Volts are quite high and as, in case of an earth fault current even of limited amperages, high electric powers flow through the grounding path and may easily damage electronic parts, like the current-limiting diode, arranged in the grounding path.

There still is a need for a circuitry arrangement by which a connector of a photovoltaic generator may be hard grounded even if an inverter via which the photovoltaic generator is connected to an AC power grid with earth reference is not operating, and which is not damaged if an earth fault occurs. Further, the circuitry arrangement should allow for a switchable grounding of the connector of the photovoltaic generator.

SUMMARY OF THE INVENTION

The present invention relates to a circuitry arrangement for grounding a connector of a photovoltaic generator. The circuitry arrangement comprises a grounding path extending from the connector towards earth potential and a limiting circuit in the grounding path. The limiting circuit limits an amperage of an earth current flowing through the grounding path increasingly with increasing thermal load to the limiting circuit due to the earth current in such a way that a thermal overload of the limiting circuit due to the earth current is avoided, even with an earth fault of any other connector of the photovoltaic generator.

Further the present invention relates to a photovoltaic inverter comprising connectors for at least one photovoltaic generator, and a circuitry arrangement according to the present invention for one connector for the at least one photovoltaic generator.

Other features and advantages of the present invention will become apparent to one with skill in the art upon examination of the following drawings and the detailed description. It is intended that all such additional features and advantages be included herein within the scope of the present invention, as defined by the claims.

SHORT DESCRIPTION OF THE DRAWINGS

The invention can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present invention. In the drawings, like reference numerals designate corresponding parts throughout the several views.

Fig. 1 is circuit diagram showing the principle of the circuitry arrangement of the present invention.

Fig. 2 shows an embodiment of a limiting circuit of the circuitry arrangement of the present invention.

Fig. 3 shows a further embodiment of the limiting circuit.

Fig. 4 shows current and voltage courses in the limiting circuit according to Fig. 3.

Fig. 5 shows another embodiment of the limiting circuit.

Fig. 6 shows current and voltage courses in the limiting circuit according to Fig. 5.

DETAILED DESCRIPTION

The circuitry arrangement of the present invention for grounding a connector of a photovoltaic generator comprises a grounding path extending from the connector to earth potential. In the grounding path a limiting circuit is arranged which limits the amperage of an earth current flowing via the ground path increasingly with increasing thermal load to the limiting circuit due to the earth current in such a way that it avoids a thermal overload of the limiting circuit by the earth current even with an earth fault of any other connector of the photovoltaic generator. This means that the limitation of the earth current flowing via the grounding path increases with increasing thermal load to the limiting circuit caused by the earth current not only somehow but at least so strongly that a thermal overload of the limiting circuit is securely avoided even with an earth fault of the connector of the photovoltaic generator which has the maximum difference in potential with regard to the connector to which the grounding path is connected. Furthermore, the limitation of the amperage of the earth current may stay small at just a small thermal load to the limiting circuit due to the earth current. This means that the electric resistance of the limiting circuit, as long as no earth fault occurs, is only very small, and that the grounding by means of the limiting circuit is so hard that it does not result in any undesired shift with regard to earth potential of the potential of the connector of the photovoltaic generator to which the grounding path is connected.

The limiting circuit may limit the amperage of the earth current indirectly or directly depending on the course of a voltage dropping across the grounding path or the limiting circuit. The voltage and the earth current caused by the voltage determine the electric power transformed into heat in the limiting circuit. The course of the voltage - together with the basically fixed values of the thermal capacitance and the thermal coupling of the limiting circuit to a heat sink - determines how much of this heat is accumulated in the limiting circuit and thus thermally loads the limiting circuit.

The limiting circuit may also limit the amperage of the earth current flowing via the grounding path to a maximum instantaneous value such that an instantaneous power loss

dissipated in the limiting circuit is limited. The limiting circuit then, for example, additionally limits a temporal average of the amperage of the earth current to a maximum average which is reduced with regard to the maximum instantaneous value to further limit a temporal average of the dissipated power loss. For example, the maximum average may be reduced by at least 50 % as compared to the maximum instantaneous value. Preferable, it is reduced by at least 75 %.

In any case, the design of the limiting circuit according to the present invention provides fora less strong limitation of the amperage of the earth currents flowing via the grounding path if the earth currents prevail for a short time only, which may occur in regular operation and only cause short term power losses, in contrast to longer lasting power losses which indicate a failure, particularly an earth fault.

The limitation of the amperage of the earth current according to the present invention, which is directly or, via the causative power loss, at least indirectly depending on the thermal load to the limiting circuit, has the important advantage, as compared to a simple limitation of the amperage of the earth current to a fixed maximum value, that even with the high voltages, which potentially occur at the connector of the photovoltaic generator to be grounded, damages to the limiting circuit due to thermal overload are avoided. Thus, its function is ensured even with any ground faults in the photovoltaic generator.

Although the limitation of the amperage of the earth current, with just a small thermal load to the limiting circuit, remains small according to the present invention, i.e. although even higher earth currents may flow for a short term, the limiting circuit provides the basis for being able to activate the grounding via the grounding path without the necessity of an expensive relay. As the amperage of any compensation currents which may flow when activating or connecting the grounding via closing the grounding path are limited by the limiting circuit, a relay which is connected in series with the limitation circuit in the grounding path as a switch for activating the grounding is not loaded with such a high power that it could not be kept inexpensive. If the heat which is caused by dissipation of high lost power during a compensation of high voltages via the

grounding path is buffered by the thermal capacitance of the limiting circuit and thus does not result in a short term power limitation, such a compensation process may be kept short. This means that the adjustment of the electric potential of the connector of the photovoltaic generator, to which the grounding path is connected, to earth which is to be achieved by means of grounding may be achieved quickly.

The amperage of a persistent earth current flowing through the grounding path as a result of an earth fault in the photovoltaic generator, however, is particularly strongly limited by the limiting circuit according to the present invention. If in this case - depending on the location of the earth fault - a voltage up to the output voltage of the photovoltaic generator drops across the grounding path, a comparatively high electric power is dissipated into heat in the limiting circuit even with a comparatively low earth current. The accompanying thermal load to the limiting circuit results in a particularly strong limitation of the amperage of the earth current.

Particularly, the limiting circuit of the circuitry arrangement of the present invention may comprise a transistor arranged in the grounding path. This transistor may primarily be controlled for limiting the amperage of the earth current flowing through the grounding path. Particularly, the current limiting circuitry may include a first series connection of a transistor and a first resistor, and a second series connection of a Zener diode and a second resistor, which is connected in parallel to the first series connection and whose centre point is connected to the gate of the transistor. The additional limitation of the earth current according to the present invention may then be achieved in that the additionally current-limiting first resistor connected in series with the transistor is a temperature-depending resistor thermally coupled to the transistor. At a normal working temperature, the entire ohmic resistance of such a circuitry arrangement may be so small that it effects a hard grounding of the connector of the photovoltaic generator to which the grounding path is connected. With a current beginning to flow through the transistor, the transistor heats up, and due to the thermal coupling, the temperature-depending resistor (PTC resistor) also heats up. As a result, the operation point of the transistor is shifted and its ohmic resistance increases.

Correspondingly, the ohmic resistance of the entire circuitry arrangement increases much stronger than the ohmic resistance of the PTC resistor. This increase strongly depends on the voltage dropping across the grounding path and on the earth current resulting from this voltage at the present ohmic resistance of the circuitry. As a result, the heat accumulated in the limiting circuit which is generated in the limiting circuit by dissipation of electric power of the earth current flowing through the grounding path is effectively limited.

As an alternative to its linear operation described above, the transistor which is operated for limiting the amperage of the earth current flowing through the grounding path may be controlled for completely blocking the current at intervals which depend on the voltage dropping across the limiting circuit. This means that time distance between these intervals become infinite, i.e. the current is never blocked at a voltage dropping across the grounding path close to zero. Vice versa, the time distance between the intervals get shorter and shorter, i.e. the transistor is more often blocking the current when the voltage dropping across the grounding path increases. The periods for which the transistor is blocking the currents may also be prolonged. In this way, the heat generated in the limitation circuitry by dissipation of power of the earth current flowing through the grounding path and accumulated in the limiting circuit is also limited to a harmless level.

It is a big advantage of the circuitry arrangement of the present invention that it does without an external power supply. It is supplying itself out of the voltage present at the connector of the photovoltaic generator to which it is connected. This, of course, does not apply to a relay connected in series with the limiting circuit of the circuitry arrangement of the present invention. Such a relay has to be controlled externally. However, such a relay and the transistor of the current-limiting circuit in the grounding path are preferably closed or "on", i.e. conductive, in their uncontrolled state. This ensures that the circuitry arrangement of the present invention hard grounds the connector of the photovoltaic generator to which the grounding path is connected even during the night and in the early morning hours and the late evening hours during which no active control is provided.

The circuitry arrangement of the present invention may also be used for permanently grounding a connector of the photovoltaic generator, i.e. not only during times in which an inverter to which the photovoltaic generator is connected is not operating. In such cases, no additional relay in the grounding path is necessary, by which the grounding via the circuitry arrangement according to the present invention may be shut off as soon as the respective inverter is operating.

The circuitry arrangement of the present invention is non-sensitive to any earth faults occurring. It limits any earth currents occurring. When the earth currents become small again, e.g. because an earth fault has been eliminated, the grounding by means of the circuitry arrangement of the present invention automatically becomes of low ohmic resistance again, i.e. it hard grounds again. Without additional measures, the circuitry arrangement of the present invention is, however, not suited for indicating an occurring earth fault externally in order to, for example, call for its elimination.

For additional protection, the circuitry arrangement in the grounding path may comprise a fuse which fuses when the limiting circuit, for any reason, is no longer able to limit the earth current flowing through the grounding path to an acceptable level.

The circuitry arrangement according to the present invention is preferably integrated in a photovoltaic inverter. Here, the grounding path may be directly connected to an input side connector of the photovoltaic inverter, which is provided for a photovoltaic generator. It is also possible to connect the grounding path to an input side DC voltage link of the photovoltaic inverter.

Referring now in greater detail to the drawings, **Fig. 1** indicates a photovoltaic generator 1 as a series connection or a string of a plurality of photovoltaic modules 2. The photovoltaic generator 1 is connected to a photovoltaic inverter 3 which feeds electric energy from the photovoltaic generator 1 into an AC power grid 4. The AC power grid 4 comprises an earth reference in that its neutral conductor comprises an electric potential with regard to earth potential (PE) of zero. In operation of the inverter 3, the photovoltaic generator 1 is virtually grounded such

that a negative connector PV- also comprises the electric potential of zero with regard to PE. In this way, the photovoltaic modules 2 which are made as thin film modules are entirely kept at a positive electrical potential with regard to PE. This virtual grounding, however, is not present if the inverter 3 is not operating. This particularly applies during the night but also in the early morning and late evening hours or due to a faulty state or during maintenance of the inverter. A circuitry arrangement 5 is provided for keeping the photovoltaic modules 2 of the photovoltaic generator 1 at a positive electrical potential with regard to PE also during these periods. The circuitry arrangement 5 comprises a grounding path 6 in which a limiting circuit 7 is connected in series with a relay 8. The relay 8 comprises a closed or conductive basic state and is controlled for interrupting or disconnecting the grounding path 6 when the inverter 3 starts operating and provides for a virtual grounding of the connector PV-. As long as the relay is closed, the circuitry arrangement 5 provides for hard grounding the connector PV-, i.e. for a grounding with a low ohmic resistance. The limiting circuit 7 does not only limit an earth current flowing through the grounding path 6 with regard to its amperage but also with regard to its electric power loss which is dissipated into heat in the limiting circuit 7. This heat accumulates in the limiting circuit 7 and thermally loads the limiting circuit 7. By means of the limiting circuit 7, high earth currents occurring in case of earth faults are always avoided. Further, compensation currents via earth which flow when closing the relay 8 due to a voltage dropping across the grounding path are limited. Primarily, the integrity of the circuitry arrangement 5 is ensured in that it is protected against an overload of its components.

In Fig. 1, the circuitry arrangement 5 is depicted separately besides the photovoltaic inverter 3. Preferably, however, it is a part of the photovoltaic inverter 3. i.e. arranged in a same housing as the other components of the photovoltaic inverter 3.

Fig. 2 shows a preferred basic concept for the limiting circuit 7 of the circuitry arrangement 5 according to Fig. 1 in the grounding path 6. In this limiting circuit, a current-limiting resistor R_1 is connected in series with a transistor T_1 in the grounding path 6. The gate of the transistor T_1 is

controlled by a partial circuit 9 of the limiting circuit 7. Together with the current-limiting resistor R_1, the partial circuit 9 provides the power limitation according to the present invention.

How this may be realized in detail may be seen from **Fig. 3**. Here, the partial circuit 9 is a series connection of a second resistor R_2 and a Zener diode Z_1. In so far, it is a usual current-limiting circuit. The current-limiting resistor R_1, however, is made as a temperature-dependent resistor, and it is thermally coupled to the transistor T_1. The thermal coupling is indicated by a double-headed arrow 10 in Fig. 3. When an earth current flows through the grounding path 6, whose amperage is limited by the transistor, a voltage drops across the transistor T_1, and, correspondingly, a power loss occurs which heats up the transistor T_1. Due to the thermal coupling the resistor R_1 is also heated up. As a result, the ohmic resistance of the resistor R_1 increases. At the beginning, i.e. as long as only a minimal earth current flows which is not limited by the transistor T_1, the ohmic resistance of the resistor R_1 only has a very low value and thus does not cause a relevant shift of the electric potential of the connector PV- according to Fig. 1 with regard to PE. Due to the increased ohmic resistance and its relation to the second resistor R_2, the amperage of the earth current is increasingly limited. In this way, there is an increasing limitation of the electric power of the earth current which further heats the transistor T_1. This limitation is somewhat delayed with regard to the voltage dropping across the limiting circuit 7, because the transistor T_1 and thus the thermally coupled temperature-dependent resistor T_1 are not heated up instantaneously. This, however, is no drawback as it allows for quickly grounding the connector PV- upon connecting the circuitry arrangement 5 by means of the relay 8 according to Fig. 1. An earth current occurring in case of an earth fault, however, is nevertheless securely limited without endangering the integrity of the limiting circuit 7 by thermally overloading it.

Fig. 4 shows the course 11 of the voltage U dropping across the grounding path 6 and the limiting circuit 7 and the course 12 of the amperage I of the earth current through the grounding path 6 according to Fig. 1 under various conditions, when the limiting circuit 7 is constructed according to Fig. 3. From a point in time t_0 up to a point in time t_1, the relay 8 is opened. A voltage

U_0 is present at the connector PV- of the photovoltaic generator 1 with regard to PE which typically corresponds to half the output voltage of the photovoltaic generator 1 and which is negative. No current flows through the grounding path 6. At the point in time t_1, the grounding by means of the circuitry arrangement 5 according to the present invention is activated by closing the relay 8. A compensation current via earth flows through the limiting circuit 7 which limits the amperage of this earth current to a value of I_1. The voltage between the connector PV- and earth potential (PE) decreases to a value close to zero. Due to the relative short term of this normal compensation process, there is no significant heating-up of the transistor T_1 and correspondingly also no heating-up of the temperature-dependent resistor R_1. Thus, between t_1 and t_2, the limiting circuit 7 only limits the amperage I but not the electric power of the compensation current. After the point in time t_2, the voltage dropping across the ground path 6 is comparatively small, i.e. the connector PV- is grounded at a low ohmic resistance. A static earth current flows through the grounding path 6 whose amperage I_2 is determined by the isolation resistance of the photovoltaic generator 1.

In case of an earth fault occurring in the area of the photovoltaic generator at a point in time t_3, the voltage dropping across the limiting circuit 7 strongly increases, and the amperage I is at first limited to the amperage I_1 again. As the voltage dropping across the circuit does not decrease as in the compensation process between t_1 and t_2, however, a power loss occurs which is dissipated into heat in the transistor T_1. This heat particularly increases the temperature of the transistor T_1 if it is accumulated therein over a longer period of time. Due to the thermal coupling 10, the temperature and the ohmic resistance of the temperature-dependent resistor R_1 also increase. As a result, the amperage I of the earth current is further limited both directly by the increased ohmic resistance of the temperature-dependent resistor R_1 and by the dependency of the maximum amperage determined by the partial circuit 9 on the ohmic resistance of the temperature-dependent resistor R_1, until the limiting circuit 7 achieves a thermal balance and the current remains on a constant low level which depends on the voltage U dropping across the limiting circuit 7.

If the earth or isolation fault is eliminated at a point in time t_6, the voltage U dropping across the limiting circuit 7 due to the still flowing earth current decreases. This reduces the power loss supplied to the transistor T_1, and as a consequence - due to coupling of the transistor T_1 to a heat sink not depicted here - the temperature of the transistor T_1 and the temperature of the resistor R_1 thermally coupled to the transistor T_1 decrease. Thus, the amperage of the current flowing through the limiting circuit 7, with decreasing voltage U, increases again up to I_1 at maximum. When the hard grounding corresponding to the compensation process between t_1 and t_2 is provided again, the amperage decreases again to its static final value I_2, and at a point in time t_7 there is a situation corresponding to the period from t_1 to t_3.

Fig. 5 shows a further embodiment of the limiting circuit 7 in the grounding path 6 of the circuitry arrangement 5 according to the present invention. Additionally, the relay 8 according to Fig. 1 is depicted, and a generator capacitance C_{GE} is indicated. The generator capacitance C_{GE} represents the intrinsic capacitance of the photovoltaic generator 1 of Fig. 1 with regard to earth which is high due to the large surface area of its photovoltaic modules 2. According to Fig. 5, the partial circuit 9 for controlling the gate of the transistor T_1, besides the resistor R_2 and the Zener diode Z_1 connected in series with the resistor R_2, is made of further components including resistors R_3 to R_6, transistors M_1 and M_2, a further diode Z_2, and a capacitor C. These components form a "status observer" which estimates the temperature of the transistor T_1 based on the temporal course of the voltage dropping across the limiting circuit 7, and which controls the transistor T_1 depending on this temperature for blocking the current through the grounding path 6 at intervals. The dimensions of the resistors R_5 and R_6 in combination with the capacitance of the capacitor C determine the on and off times of the transistor T_1 and thus the power loss dissipated in the transistor T_1 with regard to its temporal average. In this context, the electric capacitance of the capacitor C may be regarded as a counterpart of the heat capacitance of the transistor T_1. The resistors R_3 and R_4 in combination with the resistors R_1 and R_2 adjust the power loss limit, below of which no control of the transistor T_1 for blocking the earth current through the grounding path 6

takes place. Generally, controlling the transistor T_1 for temporarily blocking the earth current may also be realized in another way than by means of the limiting circuit 7 depicted here. For example, a direct measurement of the power may be made and evaluated by an evaluation unit, like for example a microcontroller, in such a way that a short term high power for the duration of compensation processes is allowed in that the transistor is not blocked, on the one hand, and a permanent average power is limited by a pulsed control of the transistor to a low value, on the other hand. In contrast, the embodiment of the limiting circuit 7 depicted in Fig. 5 is, however, preferred in so far as it does without any direct measurement and without a digital evaluation unit and may thus be realized essentially more easily.

Fig. 6 shows the course 11 of the voltage U dropping across the grounding path 6 and the limiting circuit 7 and the course 12 of the amperage I of the earth current flowing through the grounding path 6 according to Fig. 5 under various conditions. Here, the courses of voltage U and amperage I in the periods of time t_0 to t_1, t_1 to t_2 and t_2 to t_3 are similar to the corresponding periods of Fig. 4.

If an earth fault occurs at the point in time t_3, which results in an increase of the voltage U dropping across the grounding path 6 up to U_0, the amperage of the earth current is limited to the maximum value I_1. As the voltage U_0, however, does not decrease, the partial circuit 9, due to the voltage U_C dropping across the capacitor C, acknowledges an imminent thermal overload and thus interrupts the current flow at the point in time t_4 by blocking the transistor T_1. After a period of time adjustable by dimensioning the capacitor C and the resistors R_4 and R_5 appropriately, due to the reduced voltage U_C dropping across the capacitor C, it is tried to provide a grounding again by unblocking the transistor T_1 at a point in time t_5. With a still existing earth fault, the earth current through the grounding path 6 quickly reaches the maximum value I_1 of the amperage again. If this does not reduce the voltage, i.e. does not provide for a grounding, the current is stopped after a short time again by blocking the transistor T_1. This pulsed operation of the transistor T_1 takes place until the earth fault is eliminated. Thus, only such an earth current may flow with regard to its

temporal average, whose amperage corresponds to f times the maximum value I_1 of the amperage, f being the duty cycle of the pulsed operation of the transistor T_1, i.e. the proportion of the on times of the transistor T_1. The earth current limited in this binary way, with otherwise comparable conditions, may correspond in its magnitude to the earth current which flows through the limiting circuit 7 operating in an analogue way according to Fig. 3 at the point in time t_6 (see Fig. 4). By means of the controlled pulsed operation of the transistor T_1, there is a limitation of the heat generated and accumulated in the limiting circuit 7, particularly in the transistor T_1, and thus of the thermal load to the transistor T_1. When the earth fault is eliminated at the point in time t_6, and the transistor T_1 is thus unblocked again, the voltage U dropping across the grounding path 6 decreases, and the earth current may flow at the amperage I_1 until the low ohmic grounding is provided again. With unblocked transistor T_1, the static final value I_2 of the amperage of the earth current is permanently flowing from the point in time t_7. Here too, the status at the point in time t_7 corresponds to the status of the limiting circuit 7 in the period between t_2 and t_3.

Many variations and modifications may be made to the preferred embodiments of the invention without departing substantially from the spirit and principles of the invention. All such modifications and variations are intended to be included herein within the scope of the present invention, as defined by the following claims.

LIST OF REFERENCE NUMERALS

1	photovoltaic generator
2	photovoltaic module
3	inverter
4	AC power grid
5	circuitry arrangement
6	grounding path
7	limiting circuit
8	relay
9	partial circuit
10	thermal coupling
11	course of the voltage U
12	course of the amperage I of the earth current
N	neutral conductor
P	phase conductor
PV-	negative connector
PV+	positive connector
PE	earth potential
R_1	resistor
R_2	resistor
R_3	resistor
R_4	resistor
R_5	resistor
Z_1	diode
Z_2	diode
M_1	transistor
M_2	transistor
C	capacitor
C_{GE}	generator capacitance
U_C	voltage dropping across the capacitor C
t	point in time
U	voltage
I	amperage

CLAIMS

1. A circuitry arrangement (5) for grounding a connector (PV-) of a photovoltaic generator (1), the circuitry arrangement comprising

- a grounding path (6) extending from the connector (PV-) to earth potential (PE) and
- a limiting circuit (7) in the grounding path (6), the limiting circuit (7) being configured to limit an amperage (I) of an earth current (12) flowing through the grounding path (6),

characterized in that the limiting circuit (7) is configured to limit the amperage (I) of the earth current (12) increasingly with increasing thermal load to the limiting circuit (7) due to the earth current (12) in such a way that a thermal overload of the limiting circuit (7) due to the earth current (12) is avoided, even with an earth fault of any other connector (PV+) of the photovoltaic generator (1).

2. The circuitry arrangement (5) according to claim 1, **characterized** in that the limiting circuit (7) is configured to limit the amperage (I) of the earth current (12) depending on the course (11) of a voltage (U) dropping across the limiting circuit (7).

3. The circuitry arrangement (5) of claim 1 or 2, **characterized** in that the limiting circuit (7) in the grounding path (6) is connected in series with a switch for activating the grounding.

4. The circuitry arrangement (5) of claim 3, **characterized** in that the switch is a relay (8).

5. The circuitry arrangement (5) of any of the preceding claims, **characterized** in that the limiting circuit (7) comprises a transistor (T_1) arranged in the grounding path (6).

6. The circuitry arrangement (5) of claim 5, **characterized** in that the transistor (T_1) is controlled for limiting the amperage (I) of the earth current (12).

7. The circuitry arrangement (5) of claim 6, **characterized** in that the transistor (T_1) is connected in series with and thermally coupled to a temperature-dependent resistor (R_1).

8. The circuitry arrangement (5) of claim 6, **characterized** in that the transistor (T_1) is controlled depending on a voltage (U) dropping across the limiting circuit (7) for blocking the earth current at intervals.

9. The circuitry arrangement (5) of any of the preceding claims, **characterized** in that the limiting circuit (7) is supplied with electric energy out of the voltage (U) dropping across the grounding path (6).

10. The circuitry arrangement (5) of any of the preceding claims, **characterized** in that a fuse is arranged in the grounding path (6).

11. A photovoltaic inverter (3) comprising:

- connectors (PV-, PV+) for at least one photovoltaic generator (1), and
- a circuitry arrangement (5) of any of the preceding claims for one connector (PV-) of the connectors (PV-, PV+) for the at least one photovoltaic generator (1).

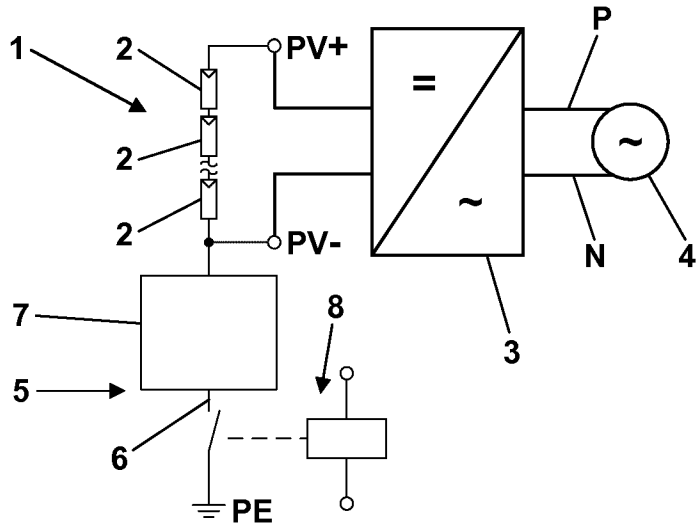


Fig. 1

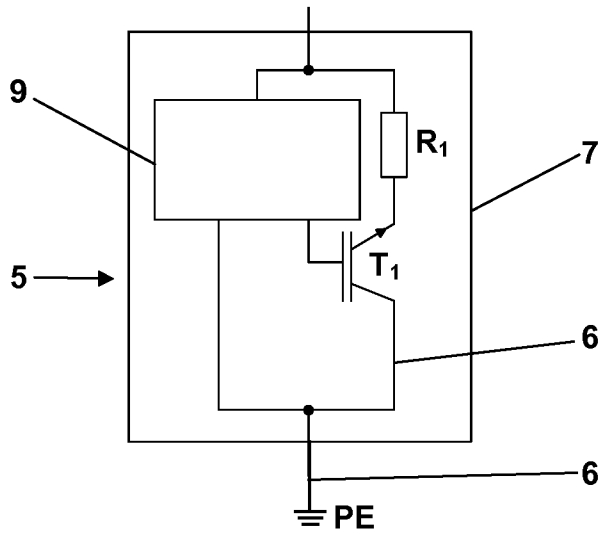


Fig. 2

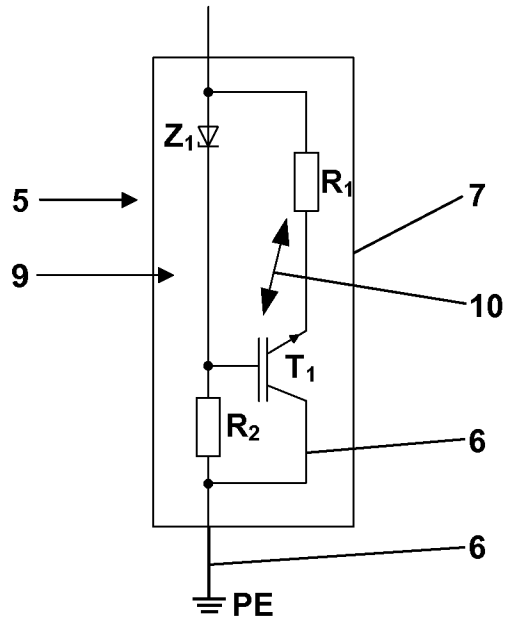


Fig. 3

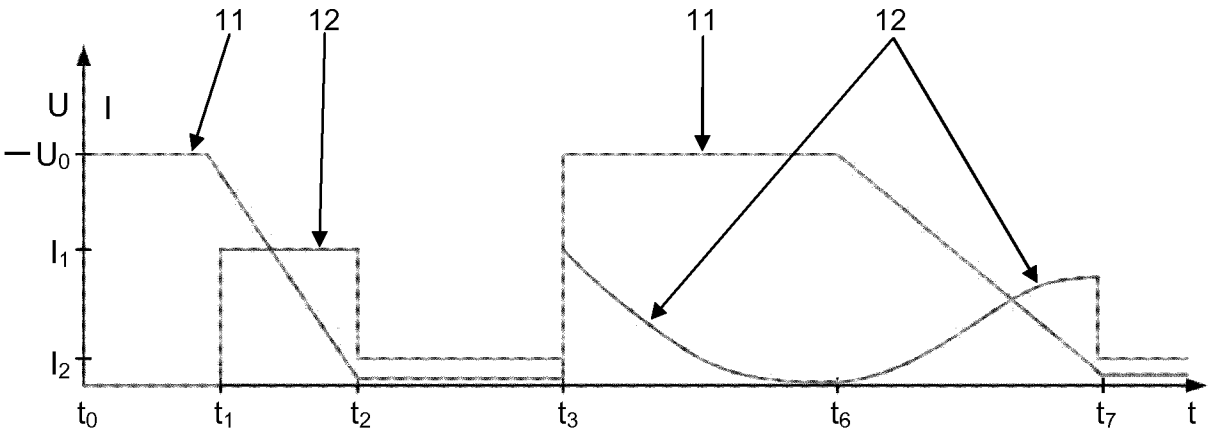


Fig. 4

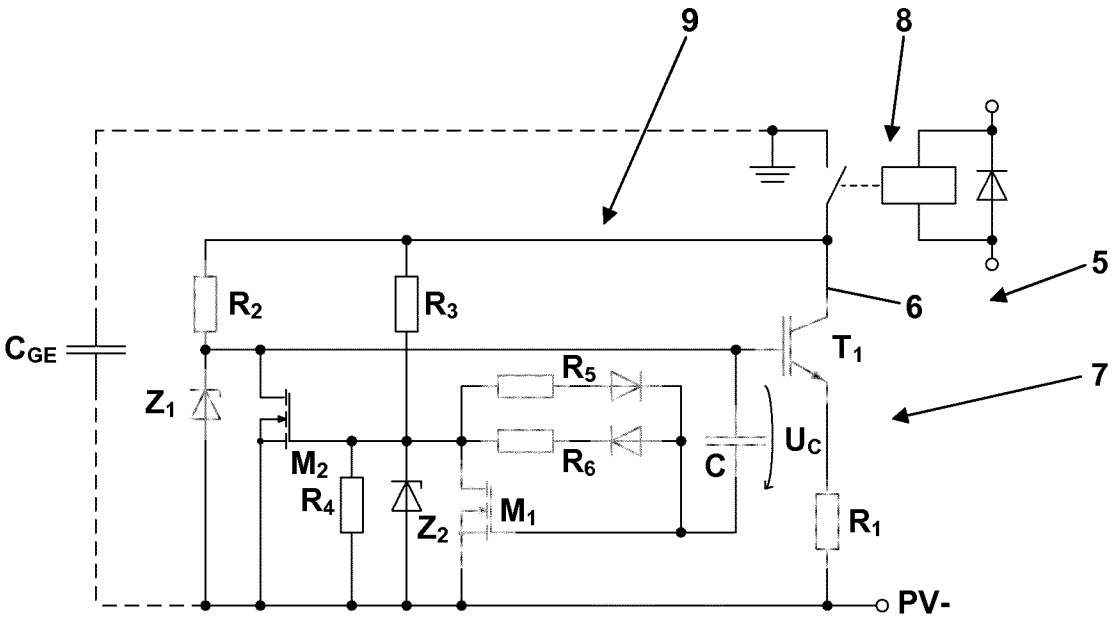

9
8
5
6
7
C_{GE}
R_2
R_3
T_1
Z_1
R_5
R_6
M_2
R_4
Z_2
M_1
C
U_C
R_1
PV-

Fig. 5

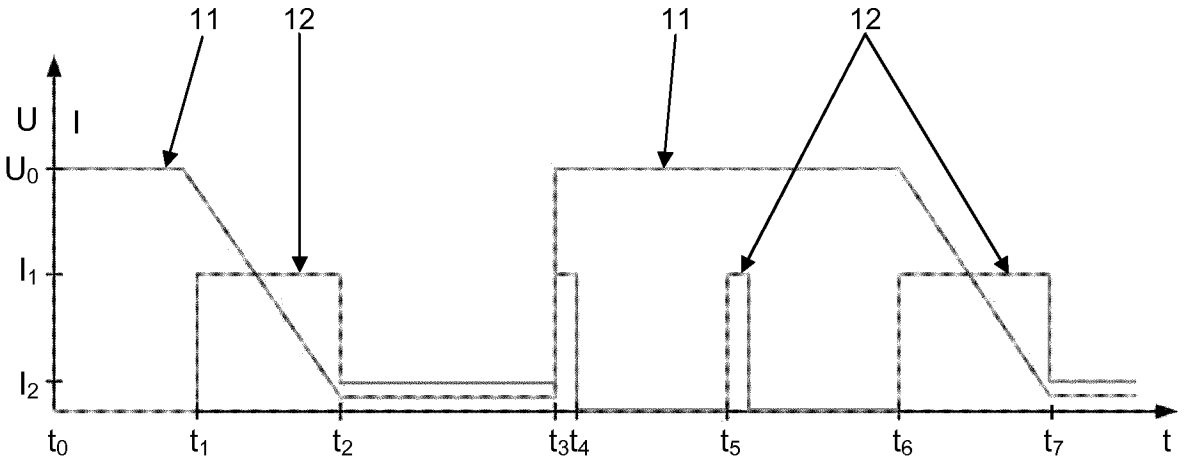

11
12
11
12
U
I
U_0
I_1
I_2
t_0
t_1
t_2
t_3
t_4
t_5
t_6
t_7
t

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/072342

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02H7/20 H02H9/08 H01L31/02
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H02H H01L H02J

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2011/012583 A1 (HYDE RODERICK A [US] ET AL) 20 January 2011 (2011-01-20) paragraphs [0101], [0123] - [0131]; figures 12,13a,13b	1-11
A	US 2010/045259 A1 (MULLER BURKHARD [DE] MUELLER BURKHARD [DE]) 25 February 2010 (2010-02-25) paragraphs [0053] - [0059]	1-11

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
4 March 2013	13/03/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Trifonov, Antoniy

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2012/072342

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2011012583 A1	20-01-2011	US 2011012583 A1	20-01-2011
		WO 2011008301 A1	20-01-2011
US 2010045259 A1	25-02-2010	EP 2157437 A1	24-02-2010
		KR 20100022432 A	02-03-2010
		US 2010045259 A1	25-02-2010