Title of the Invention: Disconnection of a string carrying direct current power

Abstract Title: Disconnection of a string carrying direct current

A device adapted to disconnect a string such as a photovoltaic string 8 carrying direct current (DC) power comprising positive and negative lines comprises a differential current sensor RCD1 that compares respective currents in the lines; parallel connected first switch S1 and second switch Q1 in series with the positive line and a control module. During normal operation when first and second switches are closed if the differential current exceeds a maximum allowed current the control module opens first switch S1 with minimal arcing and subsequently opens second switch Q1. When in normal operation the switches are open and the string begins to produce DC power the second switch is closed first and the first switch S1 is closed subsequently. The negative line can have a similar switch circuit comprising third and fourth switches S3, Q3 that operate in the same way. The first and third switches S1, S3 can be direct or alternating current relays or circuit breakers. Second and fourth switches Q1, Q3 can be an insulated gate bipolar transistor (IGBT), an IGBT with an integral diode, a solid state switch, a metal oxide semiconductor field effect transistor (MOSFET) or a field effect transistor (FET). The first and third switches can carry more current than the second and fourth switches.
Fig. 3
403 Connect relays and IGBTs in parallel to form an isolator.

405 Connect the isolator in series with the power line.

407 Measure a differential current across positive and negative lines.

409 Diff current Higher than a predermined value?

Yes

411 Switch off Relays.

II increases

413 Switch off IGBTs.

415 Relays and IGBTs Off?

Yes

419

No 417 Alarm/notify.

Fig. 4
DISCONNECTION OF A STRING CARRYING DIRECT CURRENT POWER

BACKGROUND

1. Technical Field

The present invention relates to multiple photovoltaic strings which have direct current (DC) outputs which are interconnected at an input of a power combiner junction box and specifically to a system and method to disconnect and or connect a photovoltaic string DC output from the input of the power combiner junction box.

2. Description of Related Art

In Photovoltaic Power Systems and The National Electrical Code, Suggested Practices: Article 690-18 requires that a mechanism be provided to disable portions of the PV array or the entire PV array. Ground-fault detection, interruption, and array disablement devices might, depending on the particular design, accomplish the following actions; sense ground-fault currents exceeding a specified value, interrupt or significantly reduce the fault currents, open the circuit between the array and the load, short the array or sub-array

According to the IEE wiring regulations (BS 7671:2008) a residual current device (RCD) class II device on the direct current (DC) photovoltaic side for disconnection because of ground-fault current is referred to in regulation 712.412.

In US patent application publication, US2006/0237058, a combined box is used to collect direct current from solar panels or other energy sources. The combiner box integrates means necessary for ground fault detection, current monitoring, voltage monitoring, and power monitoring. Each string of DC power has a negative component attached to the negative bus of the combiner box and a positive component attached to the positive bus of the combiner box. At or near either bus, integrated circuitry is used to monitor and report current, current differential and power for each entering string or circuit of DC power. Integrated circuitry may, if necessary, shut off individual strings of DC input, allowing the other inputs to continue power production through the combiner box.
BRIEF SUMMARY

According to an embodiment of the present invention there is provided a device adapted for disconnecting at least one string carrying direct current power in a plurality of interconnected strings. Each string includes a positive and negative line. The device includes a differential current sensor adapted to measure differential current by comparing respective currents in the positive and negative lines. A first switch and a second switch parallel-connected to form a first unit. The first unit is connected in series with the positive line. A control module may be operatively attached to the differential current sensor and the first switch and the second switch. During normal operation, the first switch is closed and the second switch is closed. When the differential current sensor measures the differential current to be greater than a maximum allowed current differential then the control module opens the first switch with minimal arcing and subsequently opens the second switch. During normal operation, the first switch allows through substantially more of a current flowing in the positive line and the second switch allows through substantially less of the current flowing in the positive line. A third switch and a fourth switch may be parallel-connected to form a second unit. The second unit is preferably connected in series with the negative line. During normal operation the third switch is closed and the fourth switch is closed, when the differential current sensor measures the differential current to be greater than a maximum allowed current differential then the control module opens the third switch with minimal arcing and subsequently opens the fourth switch. During normal operation, the third switch allows through substantially more of a current flowing in the negative line and the fourth switch allows through substantially less of the current flowing in the negative line.

Typically prior to normal operation when the string begins to produce DC power, the first switch is open and the second switch is open. The control module closes the second switch and subsequently closes the first switch with minimal arcing. The third switch is open and the fourth switch is open, the control module closes the fourth switch and subsequently closes the third switch with minimal arcing.
The second switch and the fourth switch respectively may be an insulated gate bipolar transistor (IGBT), an IGBT with integral diode, a solid state switch, metal oxide semiconductor field effect transistor (MOSFET) or a field effect transistor (FET). The first switch and the third switch respectively may be a relay or a circuit breaker. The first switch and the third switch are typically operated simultaneously. The second switch and the fourth switch are typically operated simultaneously.

According to an embodiment of the present invention there is provided a method for disconnecting a string supplying direct current (DC) power into a DC power combiner, the string including a positive and negative line. The method connects in parallel a first switch and a second switch to form a first unit, and connect in series the first unit with the positive line. Currents are then compared in the positive and negative line, thereby measuring differentially, a current across the positive line and the negative line. The current may typically between the positive line and ground. The current may typically between the negative line and ground.

Whereupon the differential current measured is found to be greater than a maximum allowed current differential, the first switch is opened and subsequently the second switch is opened, thereby isolating with minimal arcing the positive line from the DC power combiner.

The method further includes a third switch and a fourth switch connected in parallel to form a second unit, and series connecting the second unit with the negative line. When the differential current measured, is found to be greater than a maximum allowed current differential, the third switch is opened and subsequently the fourth switch is opened, thereby isolating with minimal arcing the negative line from the DC power combiner.

Prior to the comparing, when the string begins to produce DC power with the first switch and the second switch both open. The second switch is closed and subsequently the first switch is closed, thereby connecting with minimal arcing the positive line to the DC power combiner. Prior to the comparing when the string begins to produce DC power with the third switch and the fourth switch both open, the fourth switch is closed and
subsequently the third switch is closed, thereby connecting with minimal arcing the negative line to the DC power combiner.

The method preferably notifies of a failure of the string subsequent to the measuring of the differential current. A test of the measuring may also be initiated by injecting a current in the positive line prior to and during the measuring or by injecting a current in the negative line prior to and during the measuring.

The first switch and the third switch are typically operated simultaneously. The second switch and the fourth switch are typically operated simultaneously.

These, additional, and/or other aspects and/or advantages of the present invention are set forth in the detailed description which follows; possibly inferable from the detailed description; and/or learnable by practice of the present invention.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

15 Figure 1 shows a power combiner box, according to an embodiment of the present invention.

Figure 2 shows further details of an isolator and sensing unit, according to an embodiment of the present invention.

Figure 3 shows more details of a digital controller, according to an embodiment of the present invention.

Figure 4 shows a method for disconnecting a string from multiple parallel-connected strings, using an isolation and test unit, according to an embodiment of the present invention.

25 The foregoing and/or other aspects will become apparent from the following detailed description when considered in conjunction with the accompanying drawing figures.
DETAILED DESCRIPTION

Reference will now be made in detail to aspects of the present invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to the like elements throughout. The aspects are described below to explain the present invention by referring to the figures.

Before explaining embodiments of the invention in detail, it is to be understood that the invention is not limited in its application to the details of design and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

By way of introduction, aspects of the present invention are directed to minimization of arcing whilst disconnecting or connecting a direct current (DC) string from multiple interconnected DC strings. Electric arcing can have detrimental effects on electric power distribution systems and electronic equipment. Arcing may occur in switches, circuit breakers, relay contacts, fuses and poor cable terminations. When a circuit is switched off or a bad connection occurs in a connector, an arc discharge may form across the contacts of relay for example. An arc discharge is an electrical breakdown of a gas which produces an ongoing plasma discharge, resulting from a current flowing through a medium such as air which is normally non-conducting. At the beginning of a disconnection, the separation distance between the two contacts is very small. As a result, the voltage across the air gap between the contacts produces a very large electrical field in terms of volts per millimeter. This large electrical field causes the ignition of an electrical arc between the two sides of the disconnection. If a circuit has enough current and voltage to sustain an arc, the arc can cause damage to equipment such as melting of conductors, destruction of insulation, and fire. The zero crossing of alternating current (AC) power systems may cause an arc not to reignite. However, a direct current system which has DC strings may be more prone to arcing than AC systems because of the absence of zero crossing in DC power systems. US
patent application publication, US2006/0237058 does not address the issue of arcing due
to disconnection of DC strings.

Reference is now made to Figure 1 which shows a power combiner box 19, according to
an embodiment of the present invention. Power combiner box 19 includes multiple
combiner circuit boards 12, multiple digital controllers 10, multiple isolation and test
units 4, multiple photovoltaic string inputs 8, multiple bus bars 17 and 13, user interface
16 and power supply unit (PSU) 18.

Each Combiner circuit board 12 has multiple units 4a-4n mechanically mounted to board
12. Unit 4 typically receives a direct current (DC) output from a photovoltaic string 8 or
other DC power sources such as a battery, electric fuel cell or DC generator. Outputs 9 of
units 4a-4n are preferably connected in parallel using bus bar 17. Alternatively, outputs 9
of units 4a-4n may first be connected to an input of a DC to DC converter. An output of
the DC to DC converter may then be connected to bus bar 17. Multiple bus bars 17 are
further connected in parallel using bus bar 13. Bus bar 13, therefore gives the combined
DC power output of power combiner 19. Power combiner 19 is protected by lightning
suppressor 192 (for example a varistor type) and may also isolated using DC disconnect
194. A digital controller 10 is operatively attached to units 4a-4n via communication and
control lines 11. Communication and control lines 11 typically convey control signals to
an unit 4, to switch on or off an unit 4 for example or to receive signals which represent
currents or voltages measured by sensors located in unit 4 for example.

A user interface 16 is operatively attached to digital controllers 10 via b-directional
communication lines 3. Communication lines 3 may typically be a dual RS-485 bus for
example. User interface 16 is supplied with a DC power from a power supply 18 which
converts a mains alternating current (AC) power into the DC power. The DC power may
also be used to supply circuit boards 12, controllers 10 and unit circuits 4. Alternatively
circuit boards 12, controllers 10 and unit circuits 4 may be supplied from DC to DC
converters which get an input from strings 8 or the DC from PSU 18.
Reference is now made to Figure 2 which shows further details of unit 4 according to an embodiment of the present invention. A photovoltaic string 8 has a negative line connected to node X and a positive line connected to one end of a fuse 404. The other end of fuse 404 connects to node A. Across nodes A and X is a lightening suppressor 402. Suppressor 402 is additionally connected to electrical earth.

Connected across nodes A and B is a voltage sensor V1 which provides an output 406. Voltage sensor V1 typically may measure the voltage at node A or node B or the voltage difference between nodes A and B. Output 406 is operatively attached to controller 10 via control and communication line 11 (not shown). A collector of an insulated gate bipolar transistor (IGBT) Q1 connects to node A. The emitter of Q1 connects to an emitter of an IGBT Q2. The collector of Q2 connects to node B. The emitters of Q1 and Q2 also connect to the anodes of two diodes D1 and D2. The cathode of D1 connects to node A and the cathode of D2 connects to node B. The base of Q1 is connected to the base of Q2. One output of a drive circuit 400 connects to the bases of Q1 and Q2 and another output connects to the anodes of diodes D1 and D2. One side of a relay RR1 contact switch S1 connects to node A. The other side of contact switch S1 connects to one side of a contact switch S2 of relay RR2. The other side of contact switch S2 connects to node B.

Connected across nodes X and Y is a voltage sensor V2 which provides an output 408. Voltage sensor V2 typically may measure the voltage at node X or node Y or the voltage difference between nodes X and Y. Output 408 is operatively attached to controller 10 via control and communication line 11. A collector of an insulated gate bipolar transistor (IGBT) Q3 connects to node X. The emitter of Q3 connects to an emitter of an IGBT Q4. The collector of Q4 connects to node Y. The emitters of Q3 and Q4 also connect to the anodes of two diodes D3 and D4. The cathode of D3 connects to node X and the cathode of D4 connects to node Y. The base of Q3 is connected to the base of Q4. One output of a drive circuit 400 connects to the bases of Q3 and Q4 and another output connects to the anodes of diodes D3 and D4. One side of a relay RR3 contact switch S3 connects to node X. The other side of contact switch S3 connects to one side of a contact switch S4 of relay RR4. The other side of contact switch S4 connects to node Y. Relays RR1, RR2, RR3
and RR4 are typically rated with a breakdown DC voltage of 700 volts for switch contacts S1, S2, S3, S4. Relays RR1, RR2, RR3 and RR4 are typically AC relays or DC relays rated at around 1000 volts. During normal operation of strings 8 and combiner box 19, relays RR1, RR2, RR3 and RR4 are on, i.e. switch contacts S1, S2, S3, S4 are closed and IGBTs Q1, Q2, Q3, Q4 are on also. The typical collector emitter voltage (VCE) for an IGBT is around 2 volts compared to the substantially zero voltage across switch contacts S1, S2, S3, S4. Therefore, the bulk of the string current (I_{string}) flows through switch contacts S1 and S2 (in the positive line) and through switch contacts S3 and S4 (in the negative line).

Node B connects to the positive input of residual current device RCD1 and node Y connects to the negative input of residual current device RCD1. Residual current device RCD1 provides a positive line output and a negative line output via a serially connected current sensor R2 in the negative line output. Alternatively residual current device RCD1 may be disposed between the positive and negative outputs of string 8 and nodes A and X. Residual current device RCD1 typically may be hall effect residual current device (RCD). Operatively attached to RCD1 is a test circuit 414 via inductor L2. RCD1 may be operatively attached to test circuit 414 via hall effect. Inductor L2 is connected in series with a battery B1 or a DC power supply from PSU 18, resistor R1 and switch Q5. The gate of switch Q5 is operatively attached to controller 10 via control and communication line 11. Residual current device RCD1 provides a measure of a differential current between the currents in a positive line of DC output 9 and a negative line of DC output 9. The differential current threshold is optionally around 20 milliamperes. Additionally residual current device RCD1 provides a measure of a differential voltage between the negative line and positive line of DC output 9. The differential current and the differential voltage may be used to calculate the power of a string 8. The measure of the differential current is provided to controller 10 via output 410. Output 410 is operatively attached to controller 10 via control and communication line 11. Output 410 is provided from the output of an amplifier A1 which has an inductor L1 across an input of amplifier A1. Inductor L1 operatively attaches amplifier A1 to RCD1. A threshold of the differential current to indicate a current leakage is optionally around a value of 20 milliamperes. The
differential current above a value of 20 milliamperes, typically may indicate a current leakage in a photovoltaic string 8. Typically, both a positive and a negative of string 8 is isolated from electrical earth. The current leakage is either between the negative and electrical earth or between the positive and electrical earth. The differential current also above 20 milliamperes occurs when for example, an additional current is imposed onto positive at node B and/or node Y using test circuit 414.

A measure of string 8 current is also provided from the output 412 of amplifier A2. Output 412 is operatively attached to controller 10 via control and communication line 11. Output 412 along with voltage sensors 408 and 406 may provide a measure of the power generated by a string 8. Current sensor R2 is connected to the input of amplifier A2 via series resistors R3 and R4. Current sensor R2 may be located in the positive power line or the negative power line.

Reference is now made to Figure 3 which shows more details of digital controller 10, according to an embodiment of the present invention. Digital controller 10 includes multiplexors 106a, 106b/108a, 108b, digital signal processors (DSP) 100a/100b, analogue to digital (AD) converters 104a/104b, user interface 16, power supply unit 18 and complex programmable logic device (CPLD) 102. User interface 16 is supplied with direct current (DC) power from PSU 18. User interface 16 is operatively attached to DSP 100a and DSP 100b using bi-directional buses 3, bus 3 is typically a dual RS-485 bus.

Using 16 photovoltaic strings 8 as an example; preferably DSP 100a and multiplexors 106a and 108a are responsible for 8 of the photovoltaic strings 8 and DSP 100b and multiplexors 106b and 108b are responsible for the remaining 8 photovoltaic strings 8. Control line 120a is supplied from DSP 100a to control multiplexor 106a and control line 120b is supplied from DSP 100b to control multiplexor 106b. Using the example, multiplexor 106a receives outputs 406, 408 and 412 for 8 strings 8. Multiplexor 106a is controlled by DSP 100a via control line 120a to select which string 8 of the 8 strings 8, is used to provide outputs 406, 408 and 412 to analogue to digital (AD) converter 104a. Similarly (as multiplexor 106a) multiplexor 106b receives outputs 406, 408 and 412 for the other 8 strings 8. Multiplexor 108a receives output 410 for 8 strings 8. Multiplexor
108a is controlled by DSP 100a via control line 130a to select which string 8 of the 8 strings 8, is used to provide output 410 to analogue to digital (AD) converter 104a. Similarly (as multiplexor 108a) multiplexor 108b receives output 410 for the other 8 strings 8. Synchronization between DSP 100a and DSP 100b is by use of bi-directional synchronization control line 132. Complex programmable logic device (CPLD) 102 provides outputs to control test circuit 414, drive circuit 400 and relays RR1-RR4 in each unit 4 used for each string 8. The working operation of DSP 110b and DSP 100a are also verified by CPLD 102 using watchdog bi-directional control lines WDb and WDa respectively. According to another aspect of the present invention, just one DSP 100 and multiplexors 106 and 108 may be used to implement controller 10 for a number of photovoltaic strings 8.

Reference is now made Figure 4 which shows a method 401 for disconnecting a string 8 from multiple parallel-connected strings 8 using isolation and test unit 4, according to an embodiment of the present invention. Referring again to Figure 2, an isolator may be formed (step 403) between nodes A and B, so as to place the isolator in series with the positive power line (step 405) of string 8. Similarly, a second isolator may be formed between nodes X and Y, so as to place the second isolator in series with the negative power line of string 8. The isolator and the second isolator are identical circuits and are typically activated simultaneously by drive circuits 400. Typically, the negative power line of a string 8 is not connected to electrical earth. Therefore, operation of both the isolator and the second isolator to disconnect string 8 in the event of a current leakage to earth due to a fault in string 8, prevents the current leakage to electrical earth from other parallel-connected strings 8.

Formation of an isolator in step 403 between nodes A and B includes a first switch and a second switch. The isolator connects and disconnects a string 8 from output 9. The first switch is connected in parallel with the second switch to form a parallel connection. The parallel connection is then connected serially between nodes A and B. The first switch is formed by connecting in series switches S1 and S2 of relays RR1 and RR2 respectively. The second switch includes a collector of Q1 connected to node A and a collector of Q2
connected to node B. Emitters of Q1 and Q2 are connected together. Where the emitters of Q1 and Q2 are connected together are also connected the anodes of diodes D1 and D2. The cathode of D1 connects to node A and the cathode of D2 connects to node B. The bases of Q1 and Q2 are connected together and where the bases of Q1 and Q2 are connected together, a connection to drive circuit 400 is made. A second connection to drive circuit 400 is made where the emitters of Q1 and Q2 are connected together.

An input of residual current device RCD1 is connected across nodes B and Y. RCD1 provides a measure (step 407) of a level of differential current between current flowing in the positive line of string 8 and the current flowing in the negative line of string 8. A differential current which is greater than a predetermined value is typically indicative of leakage current to electrical earth owing to fault in a string 8 or power lines connected to string 8. Also, a differential current which is greater than a predetermined value may be provided by test circuit 414 so as to ensure that measurement step 407 is functioning correctly as part of periodic test function. The level of differential current is measured when the isolation between nodes A and B/ X and Y are ON, in a normal mode of operation. During the normal mode of operation, current in the positive line is the sum of current flowing through switch contacts S1, S2 and current flowing through Q1 and D1 and Q2 and D2. During the normal mode of operation, current in the negative line is the sum of current flowing through switch contacts S3, S4 and current flowing through Q3 and D3 and Q4 and D4. The lower ON resistance of switches S1-S4 means that the current going through switches S1-S4 is much greater than the current going through IGBTs Q1-Q2 and diodes D1-D2. During the normal mode of operation the level of differential current between current flowing in the positive line of string 8 and the current flowing in the negative line of string 8 is substantially zero and/ or less than 20 milliamperes. In decision box 409 if the modulus of the level of differential current is substantially zero and/ or less than 20 milliamperes., monitoring of the differential current continues with step 407. In decision box 409 if the modulus of the level of differential current is greater than a predetermined value (typically greater than 20 milliamperes.), relays RR1-RR4 are switched OFF (step 411) thereby opening switches S1-S4. The opening of switches S1-S4 substantially increases the current IGBTs Q1-Q4 and diodes
D1-D4 which are still ON. Substantial increase in the current through through IGBTs Q1-Q4 and diodes D1-D4 means that the opening of switches S1-S4 in step 411 allows for minimized arcing of switches S1-S4. After switches S1-S4 are opened IGBTs Q1-Q4 are turned OFF (step 413).

In decision 415, a check is made to see if IGBTs Q1-Q4 and switches S1-S4 are indeed turned OFF by measuring the voltages across nodes A, B and nodes X,Y. The voltages across nodes A, B and nodes X,Y are measured by voltage sensor V1 and voltage sensor V2 respectively. Voltage sensor V1 provides output 406 and voltage sensor V2 provides output 408. Additionally current and voltage sensing from outputs 410, 412 and RCD1 may be used to see if IGBTs Q1-Q4 and switches S1-S4 are indeed turned OFF. If IGBTs Q1-Q4 and switches S1-S4 are indeed turned OFF a disconnected status for string is initiated (step 419), otherwise an alarm or indication of a fault is made with step 417.

Connection of a string 8, for example when multiple strings 8 begin to generate DC power, has IGBTs Q1-Q4 and switches S1-S4 initially turned OFF. First, IGBTs Q1-Q4 are turned on, followed by switches S1-S4 being closed. Turning on IGBTs Q1-Q4 first before switches S1-S4 being closed prevents arcing of switches S1-S4. During a normal operation of a string 8, the lower ON resistance of switches S1-S4 means that the current going through switches S1-S4 is much greater than the current going through IGBTs Q1-Q2 and diodes D1-D2.

The term “comprising” as used herein, refers to an open group of elements for example, comprising an element A and an element B means including one or more of element A and one or more of element B and other elements other than element A and element B may be included.

The terms “sensing” and “measuring” are used herein interchangeably.
The definite articles "a", "an" is used herein, such as "a string", "a switch" have the meaning of "one or more" that is "one or more strings or "one or more switches".

Examples of various features/aspects/components/operations have been provided to facilitate understanding of the disclosed embodiments of the present invention. In addition, various preferences have been discussed to facilitate understanding of the disclosed embodiments of the present invention. It is to be understood that all examples and preferences disclosed herein are intended to be non-limiting.

Although selected embodiments of the present invention have been shown and described individually, it is to be understood that at least aspects of the described embodiments may be combined. Also although selected embodiments of the present invention have been shown and described, it is to be understood the present invention is not limited to the described embodiments. Instead, it is to be appreciated that changes may be made to these embodiments without departing from the principles and spirit of the invention, the scope of which is defined by the claims and the equivalents thereof.
CLAIMS

We claim:

1. A device adapted for disconnecting at least one string carrying direct current power in a plurality of interconnected strings, each string including a positive and negative line, the device comprising:
   a differential current sensor adapted to measure differential current by comparing respective currents in the positive and negative lines;
   a first switch and a second switch parallel-connected to form a first unit, wherein the first unit is connected in series with the positive line;
   a control module operatively attached to the differential current sensor, the first switch and the second switch;
   wherein during normal operation the first switch is closed and the second switch is closed, when the differential current sensor measures the differential current to be greater than a maximum allowed current differential then the control module opens the first switch with minimal arcing and subsequently opens the second switch.

2. The device of claim 1, wherein during normal operation, the first switch allows through substantially more of a current flowing in the positive line and the second switch allows through substantially less of the current flowing in the positive line.

3. The device of claim 1, further comprising:
   a third switch and a fourth switch parallel-connected to form a second unit, wherein the second unit is connected in series with the negative line; and
   wherein during normal operation the third switch is closed and the fourth switch is closed, when the differential current sensor measures the differential current to be greater than a maximum allowed current differential then the control module opens the third switch with minimal arcing and subsequently opens the fourth switch.
4. The device of claim 3, wherein during normal operation, the third switch allows through substantially more of a current flowing in the negative line and the fourth switch allows through substantially less of the current flowing in the negative line.

5. The device of claim 1, wherein prior to normal operation when the string begins to produce DC power, the first switch is open and the second switch is open, the control module closes the second switch and subsequently closes the first switch with minimal arcing.

6. The device of claim 3, wherein the third switch is open and the fourth switch is open, the control module closes the fourth switch and subsequently closes the third switch with minimal arcing.

7. The device of claims 3 wherein said second switch and said fourth switch respectively are selected from a group comprising of an insulated gate bipolar transistor (IGBT), an IGBT with integral diode, a solid state switch, metal oxide semiconductor field effect transistor (MOSFET), a field effect transistor (FET).

8. The device of claims 3, wherein said first switch and said third switch respectively are selected from a group comprising of a direct current (DC) relay, an alternating current (AC) relay, a DC circuit breaker, an AC circuit breaker.

9. A method for disconnecting a string supplying direct current (DC) power into a DC power combiner, the string including a positive and negative line, the method comprising:
   - parallel connecting a first switch and a second switch to form a first unit, and series connecting the first unit with the positive line;
   - comparing currents in the positive and negative line, thereby measuring differentially, a current across the positive line and the negative line; and
   - upon measuring the differential current to be greater than a maximum allowed current differential, opening the first switch and subsequently opening the second switch, thereby isolating with minimal arcing the positive line from the DC power combiner.
10. The method of claim 9, further comprising:
   parallel connecting a third switch and a fourth switch to form a second unit, and
   series connecting the second unit with the negative line; and
   upon measuring the differential current to be greater than a maximum allowed
   current differential, opening the third switch and subsequently opening the fourth switch,
   thereby isolating with minimal arcing the negative line from the DC power combiner.

11. The method of claim 9, wherein prior to the comparing when the string begins to
    produce DC power with the first switch and the second switch both open, closing the
    second switch and subsequently closing the first switch, thereby connecting with minimal
    arcing the positive line to the DC power combiner.

12. The method of claim 9, wherein prior to the comparing when the string begins to
    produce DC power with the third switch and the fourth switch both open, closing the
    fourth switch and subsequently closing the third switch, thereby connecting with minimal
    arcing the negative line to the DC power combiner.

13. The method of claim 9, wherein the current is between the positive line and ground.

14. The method of claim 9, wherein the current is between the negative line and ground.

15. The method of claim 9, further comprising:
   notifying of a failure of said string subsequent to said measuring.

16. The method of claim 9, further comprising:
   initiating a test of said measuring by injecting a current in said positive line prior
   to and during said measuring.

17. The method of claim 9, further comprising:
   initiating a test of said measuring by injecting a current in said negative line prior
   to and during said measuring.
18. The method of claims 10, wherein said first switch and said third switch are operated simultaneously.

19. The device of claims 10, wherein said second switch and said fourth switch are operated simultaneously.
Amendment to the claims have been filed as follows

1. A direct current (DC) power combiner operable to interconnect a plurality of interconnected photovoltaic strings, the DC power combiner including:
   a device adapted for disconnecting at least one photovoltaic string from the plurality of interconnected photovoltaic strings, each photovoltaic string connectible by a first and second DC power line, the device including:
   a differential current sensor adapted to measure differential current by comparing respective currents in the first and second DC power lines;
   a first switch connected in series with the first DC power line;
   a control module operatively attached to the differential current sensor and the first switch;
   wherein said control module is operable to open the first switch when the differential current sensor measures the differential current to be greater than a maximum allowed current differential, thereby isolating the first DC power line from the DC power combiner and disconnecting the photovoltaic string from the interconnected photovoltaic strings.

2. The DC power combiner of claim 1, further comprising a second switch parallel connected to said first switch to form a first unit, wherein the first unit is connected in series with the first DC power line.

3. The DC power combiner of claim 2, when the first switch is closed, the differential current sensor measures the differential current to be greater than a maximum allowed current differential then the control module opens the first switch and subsequently opens the second switch.

4. The DC power combiner of claim 2, wherein the first switch allows through substantially more of a current flowing in the first DC power line and the second switch allows through substantially less of the current flowing in the first DC power line.

5. The DC power combiner of claim 1, further comprising:
   a third switch and a fourth switch parallel-connected to form a second unit, wherein the second unit is connected in series with the second DC power line; and
   wherein the third switch is closed and the fourth switch is closed, when the differential current sensor measures the differential current to be greater than a maximum allowed current
differential then the control module opens the third switch and subsequently opens the fourth switch.

6. The DC power combiner of claim 5, wherein the third switch allows through substantially more of a current flowing in the second DC power line and the fourth switch allows through substantially less of the current flowing in the second DC power line.

7. The DC power combiner of claim 2, wherein the photovoltaic string begins to produce DC power, the first switch is open and the second switch is open, the control module closes the second switch and subsequently closes the first switch.

8. The DC power combiner of claim 5, wherein the third switch is open and the fourth switch is open, the control module closes the fourth switch and subsequently closes the third switch.

9. The DC power combiner of claims 2 and 5, wherein said second switch and said fourth switch respectively are selected from a group comprising of an insulated gate bipolar transistor (IGBT), an IGBT with integral diode, a solid state switch, metal oxide semiconductor field effect transistor (MOSFET), a field effect transistor (FET).

10. The DC power combiner of claims 1 and 5, wherein said first switch and said third switch respectively are selected from a group comprising of a relay, a circuit breaker.

11. A method for providing ground fault protection, the method performed in a direct current (DC) power combiner operable to interconnect a plurality of photovoltaic strings, wherein each photovoltaic string is connectible by a first and second DC power line, the method including the steps of:

   measuring a differential current by comparing respective currents in the first and second DC power lines; and

   upon a control module measuring the differential current to be greater than a maximum allowed current differential, opening a first switch, thereby isolating the first DC power line from the DC power combiner and disconnecting the photovoltaic string from the interconnected photovoltaic strings.

12. The method of claim 11, further comprising:

   parallel connecting the first switch and a second switch to form a first unit, and series
connecting the first unit with the first DC power line.

13. The method of claim 11, further comprising:
   parallel connecting a third switch and a fourth switch to form a second unit, and series
   connecting the second unit with the second DC power line; and
   upon measuring the differential current to be greater than a maximum allowed current
differential, opening the third switch and subsequently opening the fourth switch, thereby
isolating the second DC power line from the DC power combiner.

14. The method of claim 12, wherein prior to the comparing when the photovoltaic string begins
to produce DC power with the first switch and the second switch both open, closing the second
switch and subsequently closing the first switch, thereby connecting the first DC power line to
the DC power combiner.

15. The method of claim 11, wherein prior to the comparing when the photovoltaic string begins
to produce DC power with the third switch and the fourth switch both open, closing the fourth
switch and subsequently closing the third switch, thereby connecting the second DC power line
to the DC power combiner.

16. The method of claim 11, wherein the differential current is indicative of current between the
first DC power line and ground.

17. The method of claim 11, wherein the differential current is indicative of current between the
second DC power line and ground.

18. The method of claim 11, further comprising:
   notifying of a failure of said photovoltaic string subsequent to said measuring.

19. The method of claim 11, further comprising:
   initiating a test of said measuring by injecting a current in said first DC power line prior
to and during said measuring.

20. The method of claim 11, further comprising:
   initiating a test of said measuring by injecting a current in said second DC power line
prior to and during said measuring.
21. The method of claims 11 or 13, wherein said first switch and said third switch are operated simultaneously.

22. The method of claims 12 or 13, wherein said second switch and said fourth switch are operated simultaneously.
**Application No:** GB1020862.7  
**Examiner:** Robert Barrell  
**Claims searched:** 1 to 19  
**Date of search:** 15 June 2011

### Patents Act 1977: Search Report under Section 17

#### Documents considered to be relevant:

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<td>1 to 15, 18 and 19</td>
<td>US2009/0190275 A1 (GILMORGE et al) See: the abstract; figs 1 to 8 and paragraphs 0018 to 0046</td>
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<td>DE102008057874 A1 (ADENISI) See: the whole document</td>
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### Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC

- **H01H; H01L; H02H; H02J**

Worldwide search of patent documents classified in the following areas of the IPC

The following online and other databases have been used in the preparation of this search report.
### International Classification:

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