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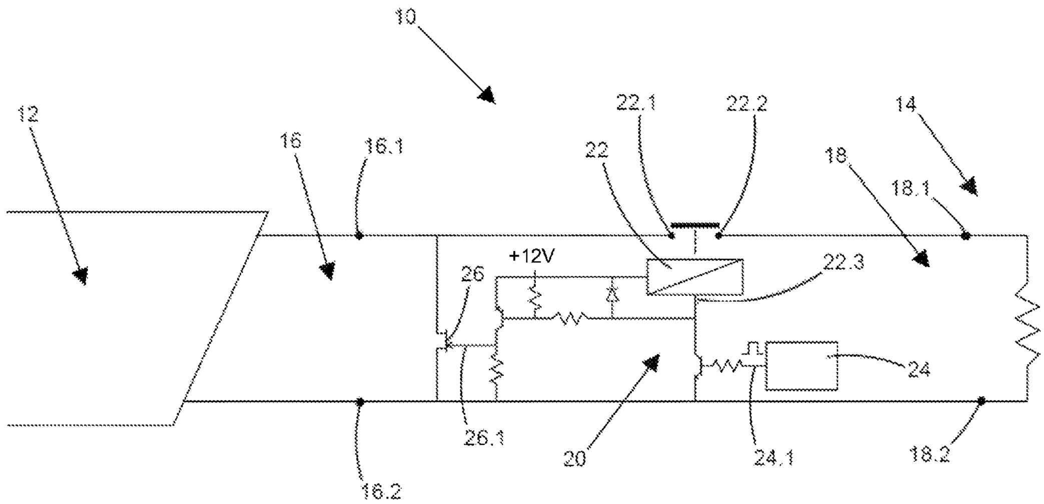

Fig 1

(57) Abstract: A photovoltaic switch apparatus, which includes an input port having two input terminals connectable in circuit across an electrical supply output of a photovoltaic cell arrangement, an output port having two output terminals connectable in circuit across an electrical load, a switching arrangement disposed between the input port and the output port, comprising: a latching relay; a switching pulse circuit; and a semiconductor switch connected across the input port terminals operable, when activated, to connect the two input terminals in circuit to each other, in use to short the electrical supply from the photovoltaic arrangement, the semiconductor switch having a switching input connected in circuit to the switching pulse circuit.

WO 2018/104765 A1

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PHOTOVOLTAIC SWITCHING

FIELD OF THE INVENTION

This invention relates to photovoltaic switching. In particular, the invention relates to a photovoltaic switch apparatus, to a photovoltaic arc-over detection and switching apparatus, a method of determining resistance of a heating element, a resistance calculation apparatus, a method of measuring power consumption of a water heater, and a method of determining instantaneous power output of a photovoltaic array.

BACKGROUND OF THE INVENTION

The inventor is aware of prior art in the field of photovoltaic (PV) power generation. However, most solutions offered to the market are sophisticated systems that often employ inverters, mains power grid chargers and batteries.

The inventor identified a low cost and low complexity market for photovoltaic systems where a photovoltaic cell is directly connected to a load without any power conditioning circuitry between the photovoltaic cell and the load. These types of systems are not commonplace in the market and raise their own unique technical difficulties.

In a low cost/low complexity solution, a photovoltaic cell, or arrangement of cells are connected directly to a load, such as an electric water heater. However, one technical problem to be solved is to switch elevated direct current voltages (exceeding 15V) and at currents exceeding 5A from the photovoltaic cell to the load without causing arc-over, whilst minimising losses between the photovoltaic cell and the load.

The best method to minimise losses is to use an electro-mechanical relay as switching component. Solid state relays are prone to losses, generates a lot of heat, are bulky and are therefore less desirable than electromechanical relays. However, electro-mechanical relays are prone to arc-over when a direct current at an elevated voltage is switched off. One solution is to use relays with a high direct current switching rating, but this increases the cost of the system.

Another problem is that standard thermostats with which alternating current water heaters are normally fitted, are not specified to switch large direct currents and, if used in a direct current photovoltaic arrangement, the standard thermostats are prone to failure due to excessive arc-over.

A solution is offered in US 8,350,414, by Richard T West. The simplest solution offered by West employs two sets of relays C1/C2, a transistor Q1, a controller 11 (see Figure 1). The controller is programmed with switching sequences to switch a load 30 on and off as described in column 3 lines 4 to 40. However, the complexity of controller 11 and the dual relay configuration C1/C2 introduces unnecessary complexity and adds unnecessary cost. The complexity is apparent from the description in the patent specification. The inventor was seeking an analogue solution that does not require a digital controller and without a dual relay configuration.

The present invention presents a low cost and low complexity solution to be used in combination with a standard thermostat and resistive heater combination where arc-over of the thermostat switch would normally reduce the thermostat's mean time between failures.

SUMMARY OF THE INVENTION

According to one aspect of the invention, there is provided a photovoltaic switch apparatus, which includes

an input port having two input terminals connectable in circuit across an electrical supply output of a photovoltaic cell arrangement;

an output port having two output terminals connectable in circuit across an electrical load;

a switching arrangement disposed between the input port and the output port, the switching arrangement comprising:

- a latching relay with switching contacts connected respectively between at least one terminal of the input port and one terminal of the output port;

- a switching pulse circuit, operable to generate a switching pulse with a pulse width sufficient to switch the latching relay, an output of the switching pulse circuit connected in circuit to a switching input of the latching relay; and

- a semiconductor switch connected across the input port terminals operable, when activated, to connect the two input terminals in circuit to each other, in use to short the electrical supply from the photovoltaic arrangement, the semiconductor switch having a switching input connected in circuit to the switching pulse circuit.

In this specification the term latching relay is meant to refer to a latching relay component, or to a relay and latching circuit combination.

The latching relay component may be any type of electromechanical relay, with a latching output.

The switching pulse circuit may be an analogue circuit operable to generate an output pulse with a pulse width of at least 8ms.

In operation, the switching pulse circuit, being connected to both the latching relay and the semiconductor switch will cause the semiconductor switch to operate within less than 1ms, while the latching relay will only switch after about 5 to 50 ms. The effect of the switching pulse will thus be to cause a short circuit across the input port terminals of the photovoltaic switch apparatus within the switching time of the semiconductor switch and, when the latching relay switches, to switch the latching relay with no current flow through its switching contacts.

According to another aspect of the invention, there is provided a photovoltaic arc-over detection and switching apparatus, which includes

an input port having two input terminals connectable in circuit across an electrical supply output of a photovoltaic cell arrangement;

an output port having two output terminals connectable in circuit across an electrical load comprising a resistive heating element and an electromechanical thermostat;

a semiconductor switch connected across the input port terminals, operable, when activated to connect the two input terminals in circuit to each other, thereby to short the electrical supply from the photovoltaic arrangement, the semiconductor switch having a switching input connected in circuit to the switching pulse circuit; and

an arc-over detection circuit operable to detect arc-over of the electromechanical thermostat, the arc-over detection circuit having a switching pulse circuit, operable to generate a switching pulse when arcing is detected from the electromechanical thermostat, the switching pulse connected to the switching input of the semiconductor switch.

Preferably, the arc-over detection circuit may be an analogue circuit.

The arc-over detection circuit may include an alternating current detection circuit, operable to detect any alternating current components across the output terminals of the output port.

The alternating current detection circuit may include an alternating current filter, operable to pass any alternating current components detected at the output port.

The alternating current detection circuit may include an alternating current amplification stage connected to an output of the alternating current filter.

The alternating current detection circuit may include a rectifier connected to an output of the alternating current amplification stage.

The alternating current detection circuit may include an integrating timer connected to an output of the rectifier.

The alternating current detection circuit may include a one-shot monostable multivibrator connected to an output of the integrating timer, the one-shot monostable multivibrator having an output connected to the switching input of the semiconductor switch.

In operation, the arc-over detection circuit, being connected across a standard thermostat and resistive heating element combination of a water heater detects alternating current (AC) components on the direct current (DC) supply line to the water heater. Upon detection of AC components exceeding a predefined threshold, the arc-over detection circuit is activated to cause the semiconductor switch to operate within less than 1ms. The effect of the switching pulse will thus be to cause a short circuit across the input port terminals of the photovoltaic switch apparatus within the switching time of the semiconductor switch and thus permitting the standard thermostat to switch whilst minimising arc-over across the thermostat terminals.

The photovoltaic cell arrangement may include one or more photovoltaic cells connected in a series- or parallel circuit with each other. Importantly, the photovoltaic cells are to be connected directly to the input port of the photovoltaic switch apparatus.

The semiconductor switch may be in the form of a transistor, a field effect transistor (FET), an Insulated Gate Bipolar Transistor (IGBT), a TRIAC, a Silicon Controlled Rectifier (SCR), or the like.

The invention extends to a method of determining resistance of a heating element of an electric water heater connected to a photovoltaic cell arrangement in a photovoltaic power generation arrangement, the method including

momentarily disconnecting the photovoltaic cell arrangement from the heating element and measuring the open circuit voltage (V_{OC}) of the photovoltaic cell arrangement;

momentarily connecting a known resistance (R_K) across the photovoltaic cell arrangement and then measuring the voltage drop (V_K) across the known resistance (R_K);

calculating the current (I_K) through the known resistance (R_K) by dividing the voltage drop across the known resistance (V_K) by the known resistance (R_K);

calculating the instantaneous output resistance (R_S) of the photovoltaic cell arrangement by dividing the difference between the open circuit voltage (V_{OC}) and the voltage drop across the known resistance (V_K) with the current (I_K);

disconnecting the known resistance (R_K) from the photovoltaic cell arrangement;

connecting the photovoltaic cell arrangement to the heating element with unknown resistance (R_E);

measuring the voltage drop (V_E) across the heating element with unknown resistance (R_E);

approximating the unknown resistance (R_E) of the heating element by multiplying the voltage drop (V_E) across the heating element with the output resistance (R_S) of the photovoltaic cell arrangement and dividing the answer with the difference between the open circuit voltage (V_{OC}) of the photovoltaic cell arrangement and the voltage drop (V_E) across the heating element.

For good accuracy, the known resistance (R_K) value should be within approximately 30% of the unknown resistance (R_E). Typically, the value of the unknown resistance (R_E), being the resistance of the heating element, falls within a specific range of values and the known resistance (R_E) can therefore be chosen to fall within the same range of values.

In order to improve the accuracy of R_E, the method of determining resistance of a heating element of an electric water heater may be repeated to determine a running average of R_E.

According to another aspect of the invention, there is provided a resistance calculation apparatus, which includes

an input port having two input terminals connectable in circuit across an electrical supply output of a photovoltaic cell arrangement;

an output port having two output terminals connectable in circuit across an electrical load;

a measurement arrangement disposed between the input port and the output port, the measurement arrangement having:

- a relay with switching contacts connected respectively between at least one terminal of the input port and one terminal of the output port;

- a semiconductor switch connected in series with a known resistance across the input port terminals, the semiconductor switch operable, when activated, to connect the two input terminals in circuit with the known resistance across the photovoltaic cell arrangement; and

- a voltage measurement input connectable across the input terminal;

- a control circuit, operable, selectively

- to generate a switching pulse, thereby to activate the semiconductor switch;

- to operate the relay;

- to measure the voltage across the input terminal.

The control circuit may be operable

momentarily to disconnect the photovoltaic cell arrangement from the heating element and to measure the open circuit voltage (V_{OC}) of the photovoltaic cell arrangement;

momentarily to connect a known resistance (R_K) across the photovoltaic cell arrangement and then to measure the voltage drop (V_K) across the known resistance (R_K);

to calculate the current (I_K) through the known resistance (R_K) by dividing the voltage drop across the known resistance (V_K) by the known resistance (R_K);

to calculate the instantaneous output resistance (R_S) of the photovoltaic cell arrangement by dividing the difference between the open circuit voltage (V_{OC}) and the voltage drop across the known resistance (V_K) with the current (I_K);

to disconnect the known resistance (R_K) from the photovoltaic cell arrangement;

to connect the photovoltaic cell arrangement to the heating element with unknown resistance (R_E);

to measure the voltage drop (V_E) across the heating element with unknown resistance (R_E);

to approximate the unknown resistance (R_E) of the heating element by multiplying the voltage drop (V_E) across the heating element with the output resistance (R_S) of the photovoltaic cell arrangement and dividing the answer with the difference between the open circuit voltage (V_{OC}) of the photovoltaic cell arrangement and the voltage drop (V_E) across the heating element.

In accordance with another aspect of the invention, there is provided a method of measuring power output of a photovoltaic array, which includes

determining the resistance of a heating element of an electric water heater connected to a photovoltaic cell arrangement as described above;

measuring the voltage over the heating element, over a period of time; and

calculating the instantaneous power dissipated by the heating element by use of the voltage drop over the heating element and the resistance of the heating element and multiplying the instantaneous power with the period of time.

In accordance with another aspect of the invention, there is provided a method of determining instantaneous power output of a photovoltaic array, which includes

momentarily disconnecting the photovoltaic cell arrangement from the heating element and measuring the open circuit voltage (V_{OC}) of the photovoltaic cell arrangement;

momentarily connecting a known resistance (R_K) across the photovoltaic cell arrangement and then measuring the voltage drop (V_K) across the known resistance (R_K);

calculating the current (I_K) through the known resistance (R_K) by dividing the voltage drop across the known resistance (V_K) by the known resistance (R_K);

calculating the instantaneous output resistance (R_S) of the photovoltaic cell arrangement by dividing the difference between the open circuit voltage (V_{OC}) and the voltage drop across the known resistance (V_K) with the current (I_K); and

determining instantaneous power output of a photovoltaic array by multiplying the calculated current (I_K) with the voltage drop across the known resistance (V_K) of the photovoltaic cell arrangement.

The invention will now be described by way of a non-limiting example, with reference to the following drawing(s).

DRAWINGS

In the drawing(s):

Figure 1 shows a circuit diagram of a photovoltaic switch apparatus in accordance with one aspect of the invention connected in circuit with a photovoltaic cell arrangement and an electrical load in the form of a domestic water heater;

Figure 2 shows a circuit diagram of an arc-over detection- and switching circuit in accordance with another aspect of the invention connected in circuit with a photovoltaic cell arrangement and an electrical load in the form of a domestic water heater;

Figure 3 shows the arc detection circuit of Figure 2 in more detail; and

Figure 4 shows a photovoltaic measurement apparatus in accordance with one aspect of the invention connected in circuit with a photovoltaic cell arrangement and an electrical load in the form of a domestic water heater.

EMBODIMENT OF THE INVENTION

In Figure 1 a photovoltaic switch apparatus 10 is shown connected in circuit with a photovoltaic cell arrangement 12 and an electrical load in the form of a domestic water heater 14.

The photovoltaic switch apparatus 10 is provided with an input port 16 comprising two input terminals 16.1 and 16.2 connected in circuit across an electrical supply output of the photovoltaic cell arrangement 12.

The photovoltaic switch apparatus 10 is provided with an output port 18 comprising two output terminals 18.1 and 18.2 connected in circuit across the domestic water heater 14.

The photovoltaic switch apparatus 10 includes a switching arrangement 20 disposed between the input port 16 and the output port 18, the switching arrangement 20 comprising a latching relay 22, a switching pulse circuit 24 and a semiconductor switch in the form of a Field Effect Transistor (FET) 26.

The latching relay 22 has switching contacts 22.1, 22.2 connected respectively between terminal 16.1 of the input port 16 and terminal 18.1 of the output port 18. The latching relay 22 is an electromechanical relay, with a latching output.

The switching pulse circuit 24 has a switching pulse output 24.1 connected in circuit to a switching input 22.3 of the latching relay 22, the switching pulse output arranged to generate a pulse with a pulse width sufficient to switch the latching relay. The switching pulse circuit 24 is an analogue circuit operable to generate an output pulse with a pulse width of at least 8ms.

It is to be appreciated that the switching pulse circuit 24 can be provided with a control input (not shown) which can be used to activate the switching pulse circuit 24 when switching of the photovoltaic switch apparatus 10 is desired.

The FET 26 which is connected across the input port terminals 16.1 and 16.2 is operable, when activated, to connect the two input terminals 16.1, 16.2 in circuit to each other to short the electrical supply from the photovoltaic arrangement 12, the FET 26 has a switching input 26.1 connected in circuit to the switching pulse output 24.1 of the switching pulse circuit 24.

In use the switching pulse circuit 24, being connected to both the latching relay 22 and the FET 26, will cause the FET 26 to operate within less than 1ms, while the latching relay 22 will only switch in about 5 to 50 ms. The effect of a switching pulse on the switching pulse output 24.1 will thus be to cause a short circuit across the input port terminals 16.1, 16.2 of the photovoltaic switch apparatus 10 within the switching time of the FET 26 and, when the latching relay 22 switches, to switch the latching relay with no current flow through its switching contacts 22.1, 22.1.

Figure 2 shows an arc-over detection- and switching apparatus 50 connected in circuit with a photovoltaic cell arrangement 52 and an electrical load in the form of a domestic water heater 54.1 and thermostat combination 54.2.

The arc-over detection- and switching apparatus 50 has an input port 56 comprising two input terminals 56.1 and 56.2 connected in circuit across an electrical supply output of the photovoltaic cell arrangement 52.

The arc-over detection- and switching apparatus 50 has an output port 58 comprising two output terminals 58.1 and 58.2 connected in circuit across the domestic water heater 54.2 and electromechanical thermostat 54.1 combination.

The arc-over detection- and switching apparatus 50 includes a switching arrangement 60 disposed between the input port 56 and the output port 58, the switching arrangement 60 comprising an arc-over detection circuit 62 and a semiconductor switch in the form of a Field Effect Transistor (FET) 66. The FET 66 is connected across the input port terminals 56.1 and 56.2 operable, when activated, to connect the two input terminals 56.1, 56.2 in circuit to each other, thereby to short the electrical supply from the photovoltaic arrangement 52, the FET has a switching input 66.1 connected in circuit to the arc-over detection circuit 62.

The arc-over detection circuit 62 is operable to detect arc-over of the electromechanical thermostat 54.1, the arc-over detection circuit has a switching pulse circuit (see Figure 3), operable to generate a switching pulse output when arc-over is detected from the electromechanical thermostat 54.1, the switching pulse output 62.1 is connected to the switching input 66.1 of the semiconductor switch 66.

The arc-over detection circuit 62 is described in more detail in Figure 3. The same components as shown in Figure 2 have been numbered with like numerals. Capacitor 68 directs any alternating current components on the output terminal 58.1 to amplifier 70 through resistor 72. A rectified output of the amplifier 70 together with the rectified output of a unity gain inverting amplifier 74 are presented to an integrating timer 76. Timer 76 activates a one-shot monostable multivibrator 78. The one-shot multivibrator 78 has an output connected to FET 66 and switches the FET 66 for a predefined period of time.

Gain for amplifier 70 is determined by the ratio of resistors 80 and 72 while gain for amplifier 74 is set by the ratio of 82 and 84. The operating bias is controlled by resistors 86 and 88. Transient-voltage-suppression diode 90 protects the input of amplifier 70. Diodes 92 and 94 provide active full wave rectification to the integrating timer 76, while resistor 96 couples the one-shot monostable multivibrator 78 to FET 66. Diode 98 absorbs stray inductive reverse voltages across the input terminals 56.1, 56.2.

As can be seen in Figure 3, the arc-over detection circuit is a fully analogue circuit, which contribute to the affordability and simplicity of the invention.

In operation, the arc-over detection circuit 50, being connected across a standard thermostat 54.1 and resistive heating element 54.2 combination of a water heater detects alternating current (AC) components on the direct current (DC) supply line to the water heater 54.2. Upon detection of AC components exceeding a predefined threshold, the arc-over detection circuit is activated to cause the semiconductor switch to operate within less than 1ms. The effect of the switching pulse will thus be to cause a short circuit across the input port terminals of the photovoltaic switch apparatus within the switching time of the semiconductor switch and thus permitting the standard thermostat to switch whilst minimising arc-over across the thermostat terminals.

In Figure 4 a photovoltaic resistance calculation apparatus 100 is shown. The photovoltaic resistance calculation apparatus 100 has an input port 102 comprising two input terminals 102.1, 102.2 connected in circuit across an electrical supply output of a photovoltaic cell arrangement 104. The photovoltaic resistance calculation apparatus 100 further has an output port 106 comprising two output terminals 106.1, 106.2 connected in circuit across an electrical load 108.

The photovoltaic resistance calculation apparatus 100 further has a measurement arrangement 110 disposed between the input port 102 and the output port 106. The measurement arrangement comprises a relay 112 with switching contacts connected respectively between terminal 102.1 of the input port 102 and terminal 106.1 of the output port 106; a semiconductor switch in the form of a field effect transistor (FET) 114 connected in series with a known resistance 116 across the input port terminals 102.1, 102.2, the FET operable, when activated, to connect the two input terminals 102.1, 102.2 in circuit with the known resistance across the a photovoltaic cell arrangement 104; a voltage measurement input 118 connectable across the input terminal 102.1, 102.2.

The measurement arrangement comprises a control circuit 120, operable, selectively:
- to generate a switching pulse, thereby to switch on the FET;
- to operate the relay; and
- to measure the voltage across the input terminal.

In use, the control circuit 120 is operable:

- momentarily to disconnect the photovoltaic cell arrangement 104 from the heating element 108 and to measure the open circuit voltage (V_{OC}) at 118 of the photovoltaic cell arrangement 104;

- momentarily to connect the known resistance (R_K) 116 across the photovoltaic cell arrangement 104 and then to measure the voltage drop (V_K) at 118 across the known resistance (R_K) 116;

- to calculate the current (I_K) through the known resistance (R_K) by dividing the voltage drop (V_K) across the known resistance (V_K) by the known resistance (R_K);

- to calculate the instantaneous output resistance (R_S) of the photovoltaic cell arrangement 104 by dividing the difference between the open circuit voltage (V_{OC}) and the voltage drop across the known resistance (V_K) with the current (I_K);

- to disconnect the known resistance (R_K) from the photovoltaic cell arrangement by switching the FET 114 off;

- to connect the photovoltaic cell arrangement 104 to the heating element 108 with unknown resistance (R_E) by switching relay 112 on;

- to measure the voltage drop (V_E) at 118 across the heating element 108 with unknown resistance (R_E);

- to approximate the unknown resistance (R_E) of the heating element by multiplying the voltage drop (V_E) across the heating element with the output resistance (R_S) of the photovoltaic cell arrangement and dividing the answer with the difference between the open circuit voltage (V_{OC}) of the photovoltaic cell arrangement and the voltage drop (V_E) across the heating element.

The resistance calculation apparatus provides a method of measuring power output of a photovoltaic array, which includes the steps of

measuring the voltage over a heating element 108 of an electric water heater connected to a photovoltaic cell arrangement 104 as described above;

determining the current flowing through the heating element 108 over a period of time by use of the voltage and resistance information; and

calculating the instantaneous power dissipated by the heating element 108 by use of the voltage drop over the heating element and the resistance of the heating element 108 and multiplying the instantaneous power with the period of time.

The inventor is of the opinion that the photovoltaic switch apparatus and the photovoltaic arc-over detection and switching apparatus comprising only analogue components provides novel, low complexity, cost efficient solutions to the problem of switching direct current loads connected to a photovoltaic arrangement.

Furthermore, the photovoltaic resistance calculation apparatus provides a novel method of determining the resistance of a heating element of an electric water heater connected to a photovoltaic cell arrangement in a photovoltaic power generation arrangement. With the resistance of the heating element known, the invention further provides a novel method of measuring power consumption of a water heater.

The invention further provides a novel method of determining the instantaneous power output of a photovoltaic cell arrangement without the need for any separate light sensor such as a light dependent resistor (LDR).

The methods described above are novel and are implemented by means of a simple analogue circuit arrangement. This brings substantial benefit in terms of cost and reliability.

CLAIMS:

1. A photovoltaic switch apparatus, which includes

an input port having two input terminals connectable in circuit across an electrical supply output of a photovoltaic cell arrangement;

an output port having two output terminals connectable in circuit across an electrical load;

a switching arrangement disposed between the input port and the output port, the switching arrangement comprising:

- a latching relay with switching contacts connected respectively between at least one terminal of the input port and one terminal of the output port;

- a switching pulse circuit, operable to generate a switching pulse with a pulse width sufficient to switch the latching relay, an output of the switching pulse circuit connected in circuit to a switching input of the latching relay; and

- a semiconductor switch connected across the input port terminals operable, when activated, to connect the two input terminals in circuit to each other, in use to short the electrical supply from the photovoltaic arrangement, the semiconductor switch having a switching input connected in circuit to the switching pulse circuit.

2. A photovoltaic switch apparatus as claimed in claim 1, in which the latching relay is an electromechanical relay with a latching output.

3. A photovoltaic switch apparatus as claimed in claim 1, in which the switching pulse circuit is an analogue circuit operable to generate an output pulse with a pulse width of at least 8ms.

4. A photovoltaic switch apparatus as claimed in claim 1, in which the semiconductor switch is selected from any one of a transistor, a field effect transistor, an Insulated Gate Bipolar Transistor (IGBT), a TRIAC and a Silicon Controlled Rectifier (SCR).

5. A photovoltaic arc-over detection and switching apparatus, which includes

an input port having two input terminals connectable in circuit across an electrical supply output of a photovoltaic cell arrangement;

an output port having two output terminals connectable in circuit across an electrical load comprising a resistive heating element and an electromechanical thermostat;

a semiconductor switch connected across the input port terminals operable, when activated, to connect the two input terminals in circuit to each other, in use to create a short circuit across the electrical supply from the photovoltaic arrangement, the semiconductor switch having a switching input; and

an arc-over detection circuit operable to detect arc-over of the electromechanical thermostat to which the output port is connectable, the arc-over detection circuit having a switching pulse circuit, operable to generate a switching pulse when arc-over is detected from the electromechanical thermostat, an ouput from the switching pulse circuit connected to the switching input of the semiconductor switch.

6. A photovoltaic arc-over detection and switching apparatus as claimed in claim 5, which comprises solely of analogue components.

7. A photovoltaic arc-over detection and switching apparatus as claimed in claim 5, which includes an alternating current detection circuit, operable to detect any alternating current components across the output terminals of the output port.

8. A photovoltaic arc-over detection and switching apparatus as claimed in claim 7, in which the alternating current detection circuit includes an alternating current filter, operable to pass any alternating current components detected at the output port.

9. A photovoltaic arc-over detection and switching apparatus as claimed in claim 8, in which the alternating current detection circuit includes an alternating current amplification stage connected to an output of the alternating current filter.

10. A photovoltaic arc-over detection and switching apparatus as claimed in claim 9, in which the alternating current detection circuit includes a rectifier connected to an output of the alternating current amplification stage.

11. A photovoltaic arc-over detection and switching apparatus as claimed in claim 10, in which the alternating current detection circuit includes an integrating timer connected to an output of the rectifier.

12. A photovoltaic arc-over detection and switching apparatus as claimed in claim 11, in which the alternating current detection circuit includes a one-shot monostable multivibrator connected to an output of the integrating timer, the one-shot monostable multivibrator having an output connected to the switching input of the semiconductor switch.

13. A photovoltaic arc-over detection and switching apparatus as claimed in claim 5, in which the semiconductor switch is selected from any one of a transistor, a field effect transistor an Insulated Gate Bipolar Transistor (IGBT), a TRIAC, a Silicon Controlled Rectifier (SCR).

14. A method of determining resistance of a heating element of an electric water heater connected to a photovoltaic cell arrangement in a photovoltaic power generation arrangement, the method including

momentarily disconnecting the photovoltaic cell arrangement from the heating element and measuring the open circuit voltage (V_{OC}) of the photovoltaic cell arrangement;

momentarily connecting a known resistance (R_K) across the photovoltaic cell arrangement and then measuring the voltage drop (V_K) across the known resistance (R_K);

calculating the current (I_K) through the known resistance (R_K) by dividing the voltage drop across the known resistance (V_K) by the known resistance (R_K);

calculating the instantaneous output resistance (R_S) of the photovoltaic cell arrangement by dividing the difference between the open circuit voltage (V_{OC}) and the voltage drop across the known resistance (V_K) with the current (I_K);

disconnecting the known resistance (R_K) from the photovoltaic cell arrangement and connecting the heating element to the photovoltaic cell arrangement;

connecting the photovoltaic cell arrangement to the heating element with unknown resistance (R_E);

measuring the voltage drop (V_E) across the heating element with unknown resistance (R_E); and

approximating the unknown resistance (R_E) of the heating element by multiplying the voltage drop (V_E) across the heating element with the output resistance (R_S) of the photovoltaic cell arrangement and dividing the answer with the difference between the open circuit voltage (V_{OC}) of the photovoltaic cell arrangement and the voltage drop (V_E) across the heating element.

15. A resistance calculation apparatus, which includes

an input port having two input terminals connectable in circuit across an electrical supply output of a photovoltaic cell arrangement;

an output port having two output terminals connectable in circuit across an electrical load;

a measurement arrangement disposed between the input port and the output port, the measurement arrangement having:

- a relay with switching contacts connected respectively between at least one terminal of the input port and one terminal of the output port;

- a semiconductor switch connected in series with a known resistance across the input port terminals, the semiconductor switch operable, when activated, to connect the two input terminals in circuit with the known resistance across the a photovoltaic cell arrangement; and

- a voltage measurement input connectable across the input terminal;

- a control circuit, operable, selectively

  - to generate a switching pulse, to activate the semiconductor switch;
  - to operate the relay;
  - to measure the voltage across the input terminal.

16. A photovoltaic resistance calculation apparatus as claimed in claim 15, in which the control circuit may be operable

momentarily to disconnect the photovoltaic cell arrangement from the heating element and to measure the open circuit voltage (V_{OC}) of the photovoltaic cell arrangement;

momentarily to connect a known resistance (R_K) across the photovoltaic cell arrangement and then to measure the voltage drop (V_K) across the known resistance (R_K);

to calculate the current (I_K) through the known resistance (R_K) by dividing the voltage drop across the known resistance (V_K) by the known resistance (R_K);

to calculate the instantaneous output resistance (R_S) of the photovoltaic cell arrangement by dividing the difference between the open circuit voltage (V_{OC}) and the voltage drop across the known resistance (V_K) with the current (I_K);

to disconnect the known resistance (R_K) from the photovoltaic cell arrangement;

to connect the photovoltaic cell arrangement to the heating element with unknown resistance (R_E);

to measure the voltage drop (V_E) across the heating element with unknown resistance (R_E);

to approximate the unknown resistance (R_E) of the heating element by multiplying the voltage drop (V_E) across the heating element with the output resistance (R_S) of the photovoltaic cell arrangement and dividing the answer with the difference between the open circuit voltage (V_{OC}) of the photovoltaic cell arrangement and the voltage drop (V_E) across the heating element.

17. A method of measuring power output of a photovoltaic array, which includes

determining the resistance of a heating element of an electric water heater connected to a photovoltaic cell arrangement as claimed in claim 16;

determining the current flowing through the heating element over a period of time; and

calculating the instantaneous power dissipated by the heating element by use of the current and the resistance of the heating element and multiplying the instantaneous power with the period of time.

18. A method of determining instantaneous power output of a photovoltaic array, which includes

momentarily disconnecting the photovoltaic cell arrangement from the heating element and measuring the open circuit voltage (V_{OC}) of the photovoltaic cell arrangement;

momentarily connecting a known resistance (R_K) across the photovoltaic cell arrangement and then measuring the voltage drop (V_K) across the known resistance (R_K);

calculating the current (I_K) through the known resistance (R_K) by dividing the voltage drop across the known resistance (V_K) by the known resistance (R_K);

calculating the instantaneous output resistance (R_S) of the photovoltaic cell arrangement by dividing the difference between the open circuit voltage (V_{OC}) and the voltage drop across the known resistance (V_K) with the current (I_K); and

determining instantaneous power output of a photovoltaic array by multiplying the calculated current (I_K) with the voltage drop across the known resistance (V_K) of the photovoltaic cell arrangement.

19. A photovoltaic switch apparatus as claimed in claim 1, substantially as herein described and illustrated.

20. A photovoltaic arc-over detection and switching apparatus as claimed in claim 5, substantially as herein described and illustrated.

21. A method of determining resistance of a heating element of an electric water heater as claimed in claim 14, substantially as herein described and illustrated.

22. A resistance calculation apparatus as claimed in claim 15, substantially as herein described and illustrated.

23. A method of measuring power consumption of a water heater as claimed in claim 17, substantially as herein described and illustrated.

24. A method of determining instantaneous power output of a photovoltaic array as claimed in claim 18, substantially as herein described and illustrated.

25. A new photovoltaic switch apparatus, substantially as herein described.

26. A new photovoltaic arc-over detection and switching apparatus, substantially as herein described.

27. A new method of determining resistance of a heating element of an electric water heater, substantially as herein described.

28. A new resistance calculation apparatus, substantially as herein described.

29. A new method of measuring power consumption of a water heater, substantially as herein described.

30. A new method of determining instantaneous power output of a photovoltaic array, substantially as herein described.

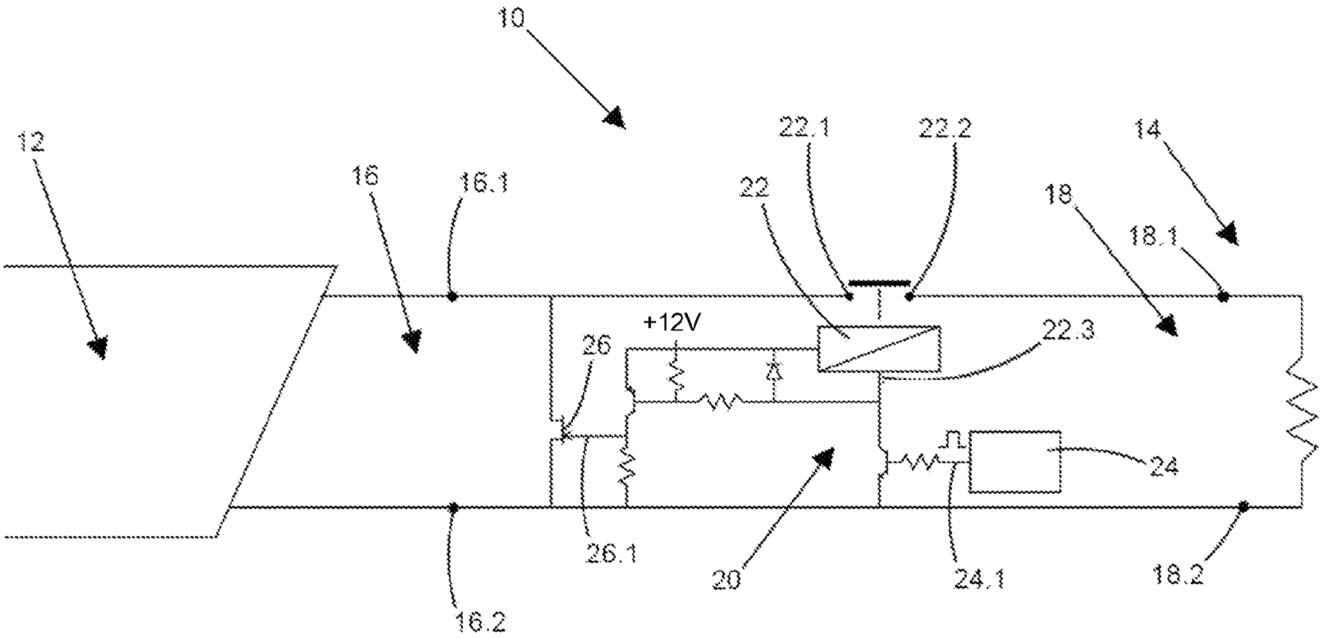
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Fig 1

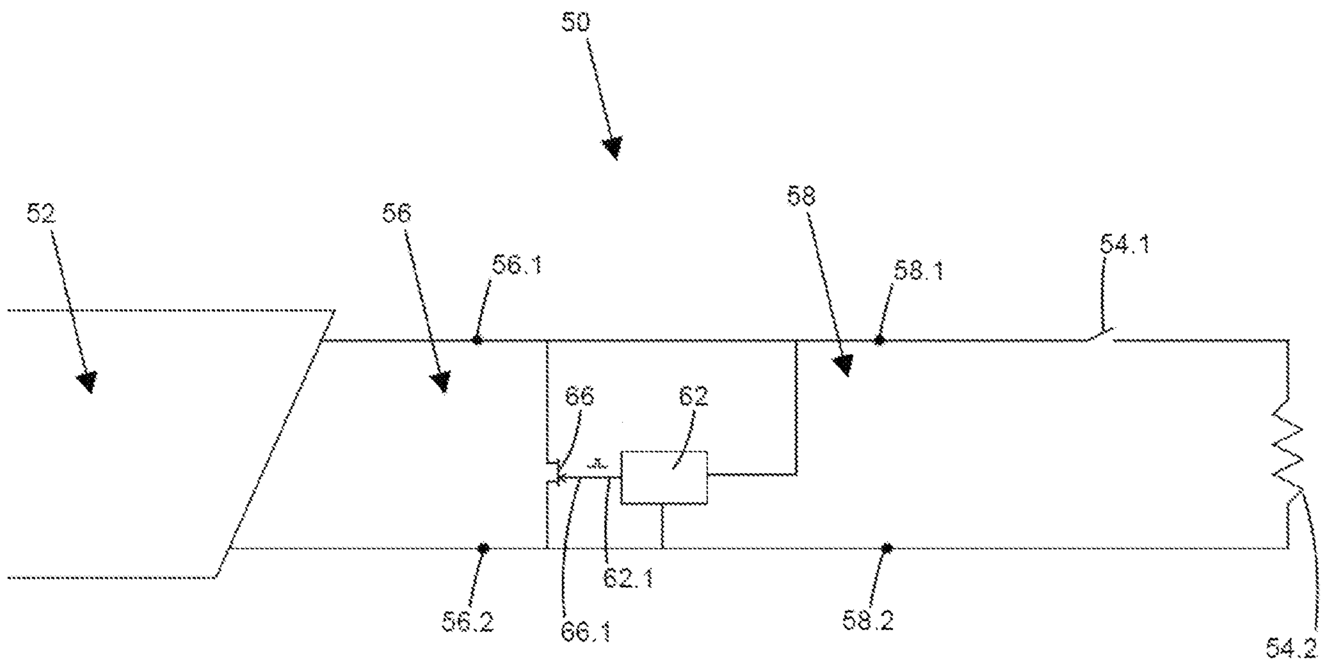
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Fig 2

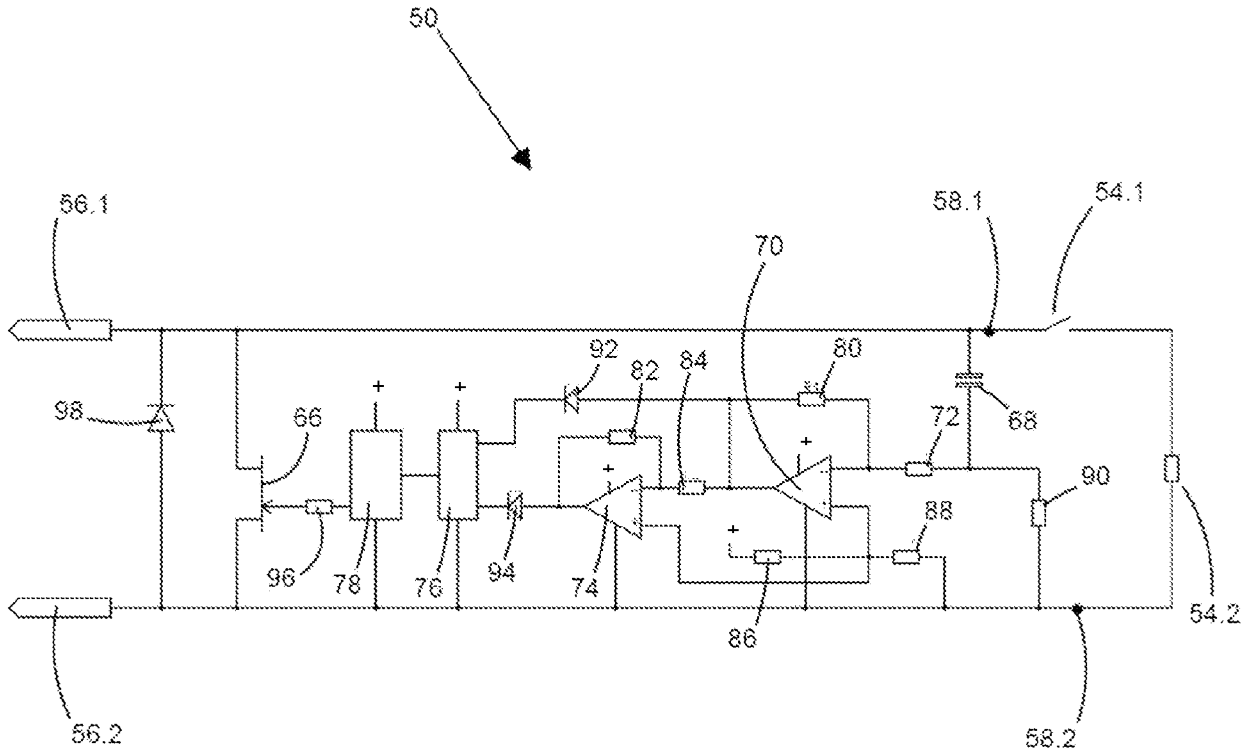
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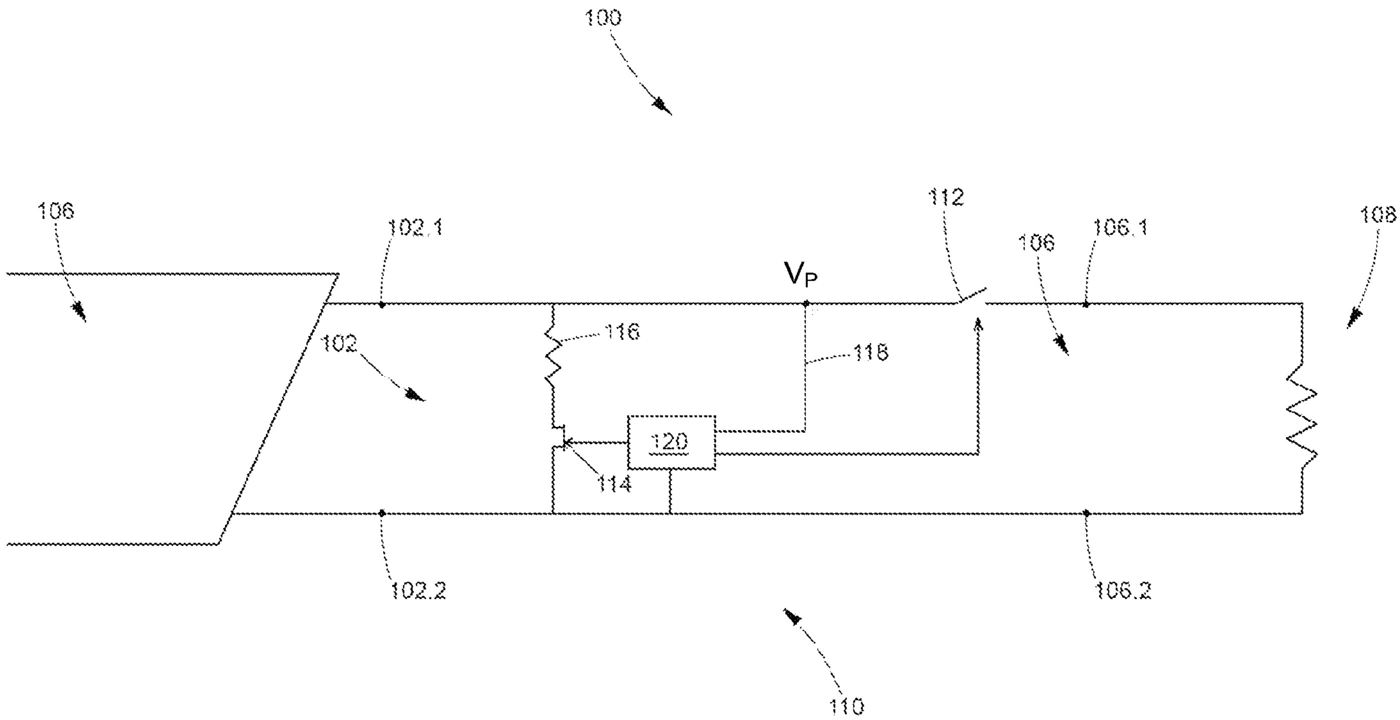
Fig 3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106.1
108
VP
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120
114
102.2
106.2
110

Fig 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 18/57373

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H02M 5/458 (2017.01)
CPC - H02M 5/458; H02M 7/217; H02M 3/335; Y02B 70/12

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)
See Search History Document

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2012/0038227 A1 (WEST) 16 February 2012 (16.02.2012), entire document especially Fig 1; paras [0014], [0017], [0037]	1-4
Y	US 4,175,249 A (GRUBER) 20 November 1979 (20.11.1979), entire document especially col 3, lns 19-25; col 6, lns 43-68	1-4
A	US 4,618,908 A (PAICE et al.) 21 October 1986 (21.10.1986), entire document especially Fig 1; col 2, lns 21-45	1-4

☐ 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
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"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
08 November 2017	11 DEC 2017

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 16/57373

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 19-30
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
they are omnibus claims not in conformance with Rule 6.2(a).

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I: claims 1-4: drawn to a photovoltaic switch.

Group II: claim 5-13: drawn to a photovoltaic arc-over detection and switching apparatus.

Group III: claims 14, 18: drawn to a method of determining resistance of a heating element and instantaneous power output of a photovoltaic array.

Group IV: claims 15-17: drawn to a resistance calculation apparatus.

-- Please See Continuation Sheet --

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-4

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Continuation of Box No. III -- Observations where unity of invention is lacking

Note: Claims 19-30 are determined to be unsearchable because they are omnibus claims not in conformance with Rule 6.2(a).

The inventions listed as Groups I-IV do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Special technical features:
Group I requires a switching pulse circuit, operable to generate a switching pulse with a pulse width sufficient to switch the latching relay, an output of the switching pulse circuit connected in circuit to a switching input of the latching relay, not found in the other groups.

Group II requires an arc-over detection circuit operable to detect arc-over of the electromechanical thermostat to which the output port is connectable, the arc-over detection circuit having a switching pulse circuit, operable to generate a switching pulse when arc-over is detected from the electromechanical thermostat, an ouput from the switching pulse circuit connected to the switching input of the semiconductor switch, not found in the other groups.

Group III requires momentarily disconnecting the photovoltaic cell arrangement from the heating element and measuring the open circuit voltage (Voe) of the photovoltaic cell arrangement, momentarily connecting a known resistance (RK) across the photovoltaic cell arrangement and then measuring the voltage drop (VK) across the known resistance (RK); calculating the current (IK) through the known resistance (RK) by dividing the 30 voltage drop across the known resistance (VK) by the known resistance (RK); calculating the instantaneous output resistance (Re) of the photovoltaic cell arrangement by dividing the difference between the open circuit voltage (Voe) and the voltage drop across the known resistance (VK) with the current (IK); disconnecting the known resistance (RK) from the photovoltaic cell arrangement and connecting the heating element to the photovoltaic cell arrangement; connecting the photovoltaic cell arrangement to the heating element with unknown resistance (RE); measuring the voltage drop (VE) across the heating element with unknown resistance (RE); and approximating the unknown resistance (RE) of the heating element by multiplying the voltage drop (VE) across the heating element with the output resistance (Re) of the photovoltaic cell arrangement and dividing the answer with the difference between the 10 open circuit voltage (Voe) of the photovoltaic cell arrangement and the voltage drop (VE) across the heating element, not found in the other groups.

Group IV requires a voltage measurement input connectable across the input terminal; a control circuit, operable, selectively to generate a switching pulse, to activate the semiconductor switch; to operate the relay; to measure the voltage across the input terminal, not found in the other groups.

Shared Features:
The only technical features shared by Groups I-IV that would otherwise unify the groups are a photovoltaic cell arrangement.

The only additional technical features shared by Groups I, II and IV that would otherwise unify the groups are a photovoltaic switch apparatus, which includes an input port having two input terminals connectable in circuit across an electrical supply output of a photovoltaic cell arrangement; an output port having two output terminals connectable in circuit across an electrical load; a switching arrangement disposed between the input port and the output port, the switching arrangement comprising - a semiconductor switch connected across the input port terminals operable, when activated, to connect the two input terminals in circuit to each other, in use to short the electrical supply from the photovoltaic arrangement, the semiconductor switch having a switching input connected in circuit to the switching pulse circuit.

Further, the only additional technical features shared by Groups I and IV that would otherwise unify the groups are a relay with switching contacts connected respectively between at least one terminal of the input port and one terminal of the output port.

However, these shared technical features do not represent a contribution over prior art, because the shared technical features are disclosed by US 2015/0270731 A1 to Adelmann et al. (hereinafter 'Adelmann') 24 September 2015 (24.09.2015), which discloses a photovoltaic cell arrangmenet which includes photovoltaic switch apparatus, which includes an input port having two input terminals connectable in circuit across an electrical supply output of a photovoltaic cell arrangement (para [0078] -Thereby, a surplus of electric energy from the photovoltaic cells 11 is used to charge the lithium battery 8.); an output port having two output terminals connectable in circuit across an electrical load (para para [0056] -The hybrid storage system provides a positive input terminal 40 and a negative input terminal 41, which are connected to corresponding output terminals of the photovoltaic panel (or other energy sources) 11, and a positive output terminal 42 and a negative output terminal 43, which are connected to corresponding input terminals of the load 19.); a switching arrangement disposed between the input port and the output port, the switching arrangement comprising - a semiconductor switch connected across the input port terminals operable, when activated, to connect the two input terminals in circuit to each other, in use to short the electrical supply from the photovoltaic arrangement, the semiconductor switch having a switching input connected in circuit to the switching pulse circuit and a relay with switching contacts connected respectively between at least one terminal of the input port and one terminal of the output port (para [0017], [0029], [0056], [0057] -In particular, the two-way DC/DC converter may comprise at least two semiconductor switches, wherein respective input connections of the transistors are connected to the charge control system via respective control lines. In this way, the two-way DC/DC converter is easy to control via electric signals. -In particular, the voltage may be applied by pulse charging, and especially by pulse-width modulated charging.).

As the shared technical features were known in the art at the time of the invention, they cannot be considered special technical features that would otherwise unify the groups.

Groups I-IV therefore lack unity under PCT Rule 13.