United States Patent Application Publication	20250257927
Kind Code	A1
Publication Date	August 14, 2025
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METHODS OF CONTROLLING A SUPPLY OF ELECTRICAL POWER AND ELECTRICAL SYSTEMS

Abstract

The present disclosure relates to a method of controlling a supply of electrical power from a DC link to a load using a switching system including a switchable current path between the DC link and the load. The switchable current path includes a controllable switch. The method includes performing a transition procedure including: transitioning the switchable current path between a non-conducting state and a conducting state by progressively varying a duty cycle of a control signal for the switch between 0% and a value equal to or less than 100% inclusive.

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Family ID: **1000008229699**

Appl. No.: **18/921941**

Filed: **October 21, 2024**

Foreign Application Priority Data

EP	24157309.6	Feb. 13, 2024

Publication Classification

Int. Cl.: **F25D21/00** (20060101); **F25D11/00** (20060101); **F25D21/08** (20060101); **H03K3/017** (20060101)

U.S. Cl.:

CPC **F25D21/006** (20130101); **F25D11/003** (20130101); **F25D21/08** (20130101); **H03K3/017** (20130101);

Background/Summary

FIELD

[0001] The present disclosure relates to methods of controlling a supply of electrical power from a DC source (e.g., a DC link) to a load. The present disclosure also relates to electrical systems comprising means adapted to carry out such methods.

BACKGROUND

[0002] It is known that coupling of relatively large loads (e.g., a heater) to a power supply can lead to relatively high transient current flows, which may be referred to as inrush currents. Such inrush currents may stress electrical components through which they pass and thus reduce a longer-term reliability of an electrical system of which the electrical components form a part.

SUMMARY

[0003] According to a first aspect there is provided a method of controlling a supply of electrical power from a DC link to a load using a switching system including a switchable current path between the DC link and the load, the switchable current path comprising a controllable switch, the method comprising performing a transition procedure including: transitioning the switchable current path between a non-conducting state and a conducting state by progressively varying a duty cycle of a control signal for the switch between 0% and a value equal to or less than 100% inclusive.

[0004] It may be that the transition procedure includes: transitioning the switchable current path between the non-conducting state and the conducting state by progressively varying the duty cycle of the control signal for the switch between 0% and 100% inclusive. It may be that progressively varying a duty cycle of a control signal for the controllable switch between 0% and 100% inclusive includes progressively varying the duty cycle of the control signal for the switch through a range extending from 1% to 99%. It may be that the control signal comprises a pulse-width modulated signal. It may be that the switch is a semiconductor-based switch. The switch may be an insulated-gate bipolar transistor.

[0005] The switching system may further comprise a snubber coupled in parallel with the switchable current path between the DC link and the load. The snubber may comprise (e.g., be) a capacitor.

[0006] It may be that the method includes: transitioning the switchable current path from the non-conducting state to the conducting state by progressively increasing the duty cycle of the control signal for the switch from 0% to 100% inclusive.

[0007] It may be that progressively increasing the duty cycle of the control signal for the controllable switch from 0% to 100% inclusive includes progressively increasing the duty cycle of the control signal for the switch through a range extending from 1% to 99%.

[0008] It may be that the method includes: transitioning the primary switchable current path from the conducting state to the non-conducting state by progressively decreasing the duty cycle of the control signal for the switch from 100% to 0% inclusive.

[0009] It may be that progressively decreasing the duty cycle of the control signal for the controllable switch from 100% to 0% inclusive includes progressively decreasing the duty cycle of the control signal for the switch through a range extending from 1% to 99%.

[0010] The switchable current path may be a primary switchable current path. The switching system may comprise a secondary switchable current path coupled in parallel with the primary switchable current path. The transition procedure may include: maintaining the primary switchable current path in a conducting state while transitioning the secondary switchable current path between a non-conducting state and a conducting state.

[0011] The method may comprise performing a switch-on transition procedure including: maintaining the primary switchable current path in the conducting state while transitioning the secondary switchable current path from the non-conducting state to the conducting state; and subsequently maintaining the secondary switchable current path in the conducting state while transitioning the primary switchable current path from the conducting state to a non-conducting state.

[0012] The method may comprise performing a switch-off transition procedure including: maintaining the primary switchable current path in the conducting state while transitioning the secondary switchable current path from the conducting state to the non-conducting state; and subsequently maintaining the secondary switchable current path in the non-conducting state while transitioning the primary switchable current path from the conducting state to a non-conducting state.

[0013] The secondary switchable current path may comprise a contactor. The method may comprise transitioning the secondary switchable current path between the non-conducting state and the conducting state by closing or opening the contactor.

[0014] The method may comprise receiving, at the switching system from the DC link, an input voltage of at least 600 VDC. The method may comprise receiving, at the switching system from the DC link, an input voltage of at least 700 VDC.

[0015] The method may comprise performing the transition procedure in response to a demand to vary a power consumption of the load.

[0016] The method may comprise performing the or each transition procedure in response to a demand to vary the power consumption of the load from a first non-zero value to a second non-zero value.

[0017] According to a second aspect there is provided an electrical system comprising a DC link, a load, a controller and a switching system including a switchable current path between the DC link and the load, wherein the controller is configured to perform a method in accordance with the first aspect.

[0018] It may be that the switchable current path is a primary switchable current path and the switching system includes and a secondary switchable current path coupled in parallel with the primary switchable current path. The load may be a heating arrangement comprising one or more heating elements.

[0019] According to a third aspect there is provided a computer program comprising instructions to cause an electrical system in accordance with the first aspect to execute a method in accordance with the first aspect.

[0020] According to a fourth aspect there is provided a computer-readable medium having stored thereon a computer program in accordance with the third aspect.

[0021] According to a fifth aspect there is provided a transport refrigeration system comprising an electrical system in accordance with the second aspect.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIG. **1** shows a vehicle comprising a transport refrigeration system;

[0023] FIG. **2** is a schematic diagram of example transport refrigeration unit suitable for use with the vehicle of FIG. **1**, the example transport refrigeration unit comprising an electrical system and a vapour-compression refrigeration circuit;

[0024] FIG. **3** is a circuit diagram which shows an example electrical system suitable for use with the transport refrigeration unit of FIG. **2**;

[0025] FIG. **4** is a flowchart which shows an example method of controlling a supply of electrical power from a DC link to a load; and

[0026] FIG. **5** is a flowchart which shows a switch-on transition procedure of the method shown by FIG. **4**;

[0027] FIG. **6** is a flowchart which shows a switch-off transition procedure of the method shown by FIG. **4**;

[0028] FIG. **7** is a highly schematic diagram of a machine-readable medium.

DETAILED DESCRIPTION

[0029] FIG. **1** shows a vehicle **10** comprising a transport refrigeration system **20**. In the example of FIG. **1**, the transport refrigeration system **20** forms a part of an over-the-road refrigerated semi-trailer having a structure **22** supporting (or forming) at least one climate-controlled compartment **24** which is configured to be cooled and/or heated by a TRU **110**. The climate-controlled compartment **24** can take the form of multiple compartments or have multiple zones. The structure **22** includes a chassis. The structure **22** supports the TRU **110**. The vehicle **10** further comprises a tractor unit **14** removably couplable to the trailer.

[0030] FIG. **2** schematically shows a diagram of an example TRU **110** suitable for use within the vehicle **10** and the transport refrigeration system **20** of FIG. **1**. The TRU **110** comprises a vapour-compression refrigeration circuit **400** and an electrical system **200**.

[0031] The vapour-compression refrigeration circuit **400** includes an evaporator **408** which is configured to receive heat from the climate-controlled compartment **24** of the transport refrigeration system **20** and a condenser **404** which is configured to reject heat to a thermal sink **44** (e.g., ambient air outside of the climate-controlled compartment **24**). For these purposes, the vapour-compression refrigeration circuit **400** also includes a compressor **402** and an expansion valve **406**. Accordingly, the vapour-compression refrigeration circuit **400** may be controlled to cause heat to be removed from the climate-controlled compartment **24**.

[0032] The electrical system **200** comprises a DC link **210** configured to receive electrical power from a DC power supply **220**, and a heating arrangement **260** (e.g., a heater **260**). This disclosure envisages that the DC power supply **210** may not form part of the electrical system **200** as such, and that the DC link **210** may instead be couplable to, and hence configured to receive electrical power from, a DC power supply **220**. It will be appreciated that the term “DC link” is a term of the art, and the DC link may comprise, for instance, an energy storage device such as a DC link capacitor. The DC power supply **220** may be derived from, for instance, a feed-in converter such as an on-board charger (OBC) of the TRU **11** or the vehicle **10**.

[0033] In the example of FIG. **2**, the heating arrangement **260** is provided proximal to the evaporator **408**. Accordingly, in use, the heating arrangement **260** may be operated to provide heating to the evaporator **408** (e.g., for defrosting the evaporator **408**). However, this disclosure envisages that the heating arrangement **260** may be provided elsewhere within the TRU **110**. In general terms, the heating arrangement **260** is configured to provide electrical heating to the TRU **110**. The electrical system **200** is configured to control a supply of electrical power from the DC link **210** to the heating arrangement **260** and thereby cause the heating arrangement **260** to generate heat for heating the TRU **110**. The heating arrangement **260** generates heat by means of resistive (e.g., Ohmic) heating when electrical power is supplied thereto.

[0034] FIG. **3** is a circuit diagram showing an example electrical system **200** suitable for use as the electrical system **200** of the TRU **110** described above with reference to FIG. **2**, with like reference signs denoting similar or common features.

[0035] The electrical system **200** comprises a switching system **250**. In turn, the switching system **250** includes a half-bridge **252**, a snubber **254** and a contactor **256**. The switching system **250** is configured to receive electrical power from the DC link **210** through input terminals **232**, **234** and to provide electrical power from output terminals **242**, **244**. The heating arrangement **260** is configured to receive electrical power from the switching system **250** through input terminals **246**, **248**. In use, the input terminals **232**, **234** of the switching system **250** may receive an input voltage of at least 600 VDC, and optionally between 600 VDC and 800 VDC (e.g., 700 VDC) from the DC link **210**.

[0036] A first input connection rail **231** extends between the DC link **210** and the first input terminal **232** of the switching system **250**. Similarly, a second input connection rail **233** extends between the DC link **210** and the second input terminal **234** of the switching system **250**. The input connection rails **231**, **233** provide an electrical connection between DC link **210** and the heating arrangement **260** via the switching system **250**. In use, the first input connection rail **231** is connected to a positive terminal of the DC power supply **220** via the DC link **210** whereas the second input connection rail **233** is connected to a reference voltage (e.g. ground or negative) terminal of the DC power supply **220** via the DC link **210**. As a result, an electric potential of the first input connection rail **231** is higher than an electric potential of the second input connection rail **233** during use. Therefore, the first connection rail **231** may be referred to as a positive input connection rail **231** and the second input connection rail **233** may be referred to as a negative input connection rail **233**.

[0037] Similarly, a first output connection rail **241** extends between the first output terminal **242** of the switching system **250** and the first input terminal **246** of the heating arrangement **260**. Similarly, a second output connection rail **243** extends between the second output terminal **244** of the switching system **250** and the second input terminal **248** of the heating arrangement **260**. The output connection rails **241**, **243** provide an electrical connection between the switching system **250** and the heating arrangement **260**. In use, the first output connection rail **241** is connected to the positive terminal of the DC power supply **220** via the DC link **210** and the switching system **250** whereas the second input connection rail **243** is connected to a reference voltage (e.g., ground or negative) terminal of the DC power supply **220** via the DC link **210** and the switching system **250**. As a result, an electric potential of the first output connection rail **241** is higher than an electric potential of the second output connection rail **243** during use. Therefore, the first output connection rail **241** may be referred to as a positive output connection rail **241** and the second output connection rail **243** may be referred to as a negative output connection rail **243**.

[0038] The half-bridge **252** comprises a semiconductor switch T**1** (e.g., a controllable semiconductor based switch such as an insulated-gate bipolar transistor) and a diode D**1**. The semiconductor switch T**1** and the diode D**1** are coupled in series between the input connection rails **231**, **234**. A cathode of the diode D**1** is coupled to the positive output connection rail **241** via the first output terminal **242** while an anode of the diode is coupled to a half-bridge junction J**1** at a node between the diode D**1** and the semiconductor switch T**1**. The semiconductor switch T**1** is coupled between the half-bridge junction J**1** and the negative input connection rail **233** via the second input terminal **234**. Those skilled in the art will appreciate that the diode D**1** of the half-bridge **252** may be replaced with a switch (e.g., a further semiconductor switch) as in a conventional half-bridge topology. The half-bridge junction J**1** is, in turn, coupled to the negative output connection rail **243** via the second output terminal **244**. Therefore, the semiconductor switch T**1** forms part of (e.g., functionally provides) a switchable current path **201** between the second input terminal **234** and the second output terminal **244** via the half-bridge junction J**1**.

[0039] The contactor **256** is also coupled between the second input terminal **234** and the second output terminal **244**, but not via the half-bridge junction J**1**. That is, the contactor **256** forms part of (e.g., functionally provides) a switchable current path **202** between the second input terminal **234** and the second output terminal **244** that bypasses the half-bridge junction J**1**. The switchable current path **202** functionally provided by the semiconductor switch T**1** may be referred to as a primary switchable current path **201** herein, whereas the switchable current path **202** functionally provided by the contactor **256** may be referred to as a secondary switchable current path **202** herein.

[0040] Therefore, each switchable current path **201**, **202** (partially) extends between the DC link **210** and the heating arrangement **260**. The primary switchable current path **201** is in parallel with the secondary switchable current path **202**.

[0041] The snubber **254** comprises a capacitor C**1** coupled in series between the positive input connection terminal **232** and the negative input terminal **234**. A first terminal of the capacitor C**1** is coupled to the positive input connection rail **231** via the first input terminal **232** while a second terminal of the capacitor C**2** is coupled to the negative input connection rail **233** via the second input terminal **234**. The snubber **254** is thus coupled in parallel between the DC link **210** and the heating arrangement **260**. Those skilled in the art will appreciate that a snubber may typically comprise a component having a resistance (e.g., a dedicated resistor). However, in electrical systems in accordance with the present disclosure, the snubber **254** need not necessarily comprise a dedicated resistor. Instead, a resistance of the heating arrangement **260** may serve a corresponding purpose.

[0042] An inductance of the input connection rails **231**, **233** is represented in FIG. **3** by a first inductor L**1**, while an inductance of the output connection rails **241**, **243** is represented in FIG. **3** by a second inductor L**2**. The snubber **254** is advantageously able to suppress voltage fluctuations (e.g., overvoltages) which may arise due to the inductance(s) L**1**, L**2** during performance of the transition procedure(s) described below with reference to FIGS. **4** to **6** (e.g., the method **300** described below). In addition, the action of the snubber **254** in use during performance of said transition procedure(s) may reduce an amount of electromagnetic compatibility (EMC) shielding necessary or desirable to allow the electrical system **200** to be readily incorporated within, for example, a transport refrigeration system **20**.

[0043] Those skilled in the art will also recognise that, by varying a duty cycle of a control signal for the semiconductor switch T**1** when the contactor **256** is open, an output voltage supplied to the input terminals **246**, **248** of the heating arrangement **260** may be varied between a value which is substantially the same as the input voltage supplied to the input terminals **232**, **234** of the switching system **250** from the DC link **210** (i.e., when the duty cycle of the control signal for the switch T**1** is 100%) and a value which is approximately/close to zero (i.e., when the duty cycle of the control signal for the switch T**1** approximately/close to 0%). For example, when the duty cycle of the control signal for the switch T**1** is 50%, the output voltage supplied to the input terminals **246**, **248** of the heating arrangement **260** will be approximately half the input voltage supplied to the input terminals **232**, **234** of the switching system **250** from the DC link **210**. In this way, the half-bridge **252** functions as a buck converter (a step-down converter) in cooperation with the other features of the electrical system **200**.

[0044] The heating arrangement **260** comprises a first heating element H**1** and a second heating element H**2**. Each heating element has a resistance (for the purpose of providing resistive heating), but may also have a capacitance and/or an inductance. The heating arrangement **260** further comprises a first switch S**1**, a second switch S**2**, and a third switch S**3**. The heating arrangement **260** as a whole may be considered to be a load and/or the individual heating elements H**1**, H**2** may be considered to be loads. In this example, each heating element has substantially the same resistance, which may be, for example, 98 Ohms. Each heating element H**1**, H**2** may have a positive temperature coefficient (PTC) type resistance.

[0045] The switches S**1**, S**2**, S**3** are controllable to change a mode of operation of the heating arrangement **260** and thereby vary a power consumption of the heating arrangement **260**. That is, in a low-power mode of the heating arrangement **260**, switch S**3** is in a closed state (i.e., a conducting state) while both switches S**1** and S**2** are in an open state (i.e., a non-conducting state). As a result, the heating elements H**1**, H**2** are coupled in series with one another between the input terminals **246**, **248** of the heating arrangement **260**. Accordingly, an effective overall resistance of the heating arrangement **260** may be 196 Ohms. In an intermediate-power mode of the heating arrangement **260**, both switches S**1** and S**3** are in the open state while switch S**2** is in the closed state. Hence only the first heating element H**1** is coupled between the input terminals **246**, **248** of the heating arrangement **260**. Thus the effective overall resistance of the heating arrangement is 98 Ohms. In a high-power mode of the heating arrangement **260**, both switches S**1** and S**2** are in the closed state while switch S**3** is in the open state. Therefore, the heating elements H**1**, H**2** are coupled in parallel with one another between the input terminals **246**, **248** of the heating arrangement **260**. It follows that the effective overall resistance of the heating arrangement is 49 Ohms. Without wishing to be bound by theory, those skilled in the art will appreciate that with a lower effective overall resistance of the heating arrangement **260**, an amount of energy lost as heat due to resistive heating in the heating arrangement **260** increases in accordance with Ohm's law and the definition of electric power. Specifically, if the potential difference between the input terminals **246**, **248** of the heating arrangement is 700 VDC, then the power consumption, P, of the heating arrangement **260** is as follows: in the low-power mode, P=V.sup.2/R=700.sup.2/196=2.5 KW; in the intermediate-power mode, P=700.sup.2/98=5 KW; and in the high-power mode, P=700.sup.2/49=10 KW.

[0046] The electrical system **200** further comprises a controller **290** configured to control both the secondary switchable current path **202** (e.g., by controlling the contactor **256**) and the primary switchable current path **201** (e.g., by controlling the semiconductor switch T**1**). The controller **290** may also be configured to vary the power consumption of the heating arrangement **260** (e.g., move between the low-power mode, the intermediate-power mode and the high-power mode thereof).

[0047] FIG. **4** is a flowchart showing an example method **300** of controlling a supply of electrical power from a DC link to a load (e.g., using the electrical system **200**, and in particular the switching system **250**, described above with reference to FIGS. **2** and **3**) in accordance with the present disclosure. The method(s) described herein may be carried out by a suitable data processing apparatus, such as the controller **290** described above with respect to FIG. **3**. In other words, the controller **290** may be configured to carry out the method(s) described herein (e.g., the method **300**). Although description of the method **300** continues with direct reference to the specific example electrical system **200** described above with reference to FIG. **3**, it will be appreciated that the method **300** is more broadly applicable for use with switching systems including a primary switchable current path between a DC link (e.g., the DC link **210**) and a load (e.g., the heating arrangement **260**) and a secondary switchable current path coupled in parallel with the primary switchable current path.

[0048] The method **300** includes determining, at block **302**, whether the heating arrangement **260** is on (i.e., is generating heat) or off (i.e., is not generating heat). In other words, the heating arrangement **260** is on when electrical power is being supplied to it from the DC link **210** and is off when electrical power is not being supplied to it from the DC link **210**. More specifically, the heating arrangement **260** is off when both the secondary switchable current path **202** and the primary switchable current path **201** are in a non-conducting state (e.g., a fully deactivated state/is fully deactivated). Hence if both the secondary switchable current path **202** and the primary switchable current path **201** are in the non-conducting state, a determination may be made, at block **302**, that the heating arrangement **260** is off. On the other hand, if the secondary switchable current path **202** is in a conducting state (e.g., a fully activated state/is fully activated), a determination may be made, at block **302**, that the heating arrangement **260** is on. The determination at block **302** may also be based on additional considerations, such as whether the DC link **210** is supplying electrical power to the input terminals **232**, **234** of the switching system **250**. If so, the electrical system **200** may be provided with appropriate sensor apparatus (e.g., transducers) communicatively coupled to the controller **290** for determining whether electrical power is being supplied to the input terminals **232**, **234**.

[0049] If a determination is made, at block **302**, that the heating arrangement **260** is currently off, the method **300** proceeds to determining, at block **304**, whether there is a demand to turn the heating arrangement **260** on. The determination at block **304** may include determining whether a demand to turn the heating arrangement **260** on has been received from, for instance, a human-machine interface (HMI) such as a graphical user interface (GUI), or an external data processing apparatus (such as a controller of the TRU **110**) via an application-program interface (API). Otherwise, the controller **290** carrying out the method **300** may otherwise determine whether there is a demand to turn the heating arrangement on (e.g., due to frost build-up on the evaporator **408**).

[0050] If a determination is made, at block **304**, that there is a demand to turn the heating arrangement **260** on, the method continues to performing, at block **310**, a switch-on transition procedure using the switching arrangement **250**. The switch-on transition procedure is described in further detail below with reference to FIG. **5**. However, after the switch-on transition procedure has been performed at block **310**, the heating arrangement **260** is switched on and the method **300** returns to the determining, at block **302**, whether the heating arrangement **260** is on or off and continues thereafter as described herein. Conversely, if a determination is made, at block **304**, that there is not a demand to turn the heating arrangement **260** on, the method **300** directly returns to determining, at block **302**, whether the heating arrangement **260** is on or off and continues thereafter.

[0051] In the alternative, if a determination is made, at block **302**, that the heating arrangement **260** is currently on, the method **300** proceeds to determining, at block **306**, whether there is a demand to turn the heating arrangement **260** off. In a similar way to the determination at block **304**, the determination at block **306** may include determining whether a demand to turn the heating arrangement **260** off has been received from, for instance, a human-machine interface (HMI) such as a graphical user interface (GUI), or an external data processing apparatus (such as a controller of the TRU **110**) via an application-program interface (API). Otherwise, the controller **290** carrying out the method **300** may otherwise determine whether there is a demand to turn the heating arrangement off (e.g., due to clearance of frost from the evaporator **408**).

[0052] If a determination is made, at block **306**, that there is a demand to turn the heating arrangement **260** off, the method continues to performing, at block **320**, a switch-off transition procedure using the switching arrangement **250**. The switch-off transition procedure is described in further detail below with reference to FIG. **6**. However, after the switch-off transition procedure has been performed at block **320**, the heating arrangement **260** is switched off and the method **300** returns to determining, at block **302**, whether the heating arrangement **260** is on or off and continues thereafter as described herein.

[0053] Contrastingly, if a determination is made, at block **306**, that there is not a demand to turn the heating arrangement **260** off, the method **300** continues to determining, at block **308**, there is a demand to change a mode (e.g., vary a power consumption) of the heating arrangement **260**. The determination at block **308** may include determining whether a demand to change the mode of heating arrangement **260** off has been received from, for instance, a human-machine interface (HMI) such as a graphical user interface (GUI), or an external data processing apparatus (such as a controller of the TRU **110**) via an application-program interface (API). Otherwise, the controller **290** carrying out the method **300** may otherwise determine whether there is a demand to change the mode of the heating arrangement **260** (e.g., due to excessive heat generation or insufficient heat generation by the heating arrangement **260**).

[0054] If it is determined, at block **308**, that there is not a demand to change the mode of the heating arrangement **260**, the method **300** directly returns to determining, at block **302**, whether the heating arrangement **260** is on or off and continues thereafter as described herein. If it determined, at block **308**, that there is a demand to change the mode of the heating arrangement **260**, the method **300** proceeds to: performing, at block **320**′, a switch-off transition procedure; changing, at block **330**, the mode of the heating arrangement **260**; and then performing, at block **310**′, a switch-on transition procedure. The switch-off transition procedure represented by block **320**′ is generally similar (e.g., identical to) to the switch-off procedure represented by block **320**, and the switch-on transition procedure represented by block **310**′ is generally similar (e.g., identical to) to the switch-off procedure represented by block **310**. Changing the mode of the heating arrangement **260**, as represented by block **300**, may include operating the switches S**1**, S**2**, S**3** of the heating arrangement **260** in order to move the heating arrangement **260** between the low-power mode, the intermediate-power mode and the high-power mode as described above.

[0055] FIG. **5** is a flowchart showing the switch-on transition procedure as represented by block **310** in FIG. **4**. When the switch-on transition procedure is commenced, both the secondary switchable current path **202** and the primary switchable current path **201** are in the non-conducting state. The switch-on transition procedure includes transitioning, at block **312**, the primary switchable current path **201** from the non-conducting state to the conducting state. This is achieved by progressively increasing a duty cycle of a pulse-width modulated control signal for the semiconductor switch T**1** from 0% to 100% inclusive. As a result, the output voltage supplied to the input terminals **246**, **248** of the heating arrangement **260** is progressively increased from approximately zero to the input voltage from the DC link **210**. The progressive increase of the duty cycle for the control signal for the semiconductor switch T**1** may be determined based on/adapted to the characteristics of the heating arrangement **260** (e.g., if the heating elements H**1**, H**2** have PTC type resistances, the progressive increase of the heating arrangement **260** may be adapted to account for the resistance of the heating elements H**1**, H**2** generally increasing with time).

[0056] After the primary switchable current path **201** has been transitioned to the conducting state as described above, the switch-on transition procedure includes maintaining, at block **314**, the primary switchable current path **201** in the conducting state while simultaneously transitioning the secondary switchable current path **202** from the non-conducting state into the conducting state. This is achieved by maintaining the duty cycle of the pulse-width modulated control signal for the semiconductor switch T**1** at 100% while simultaneously closing the contactor **256**.

[0057] Once the primary switchable path **201** has been transitioned into the conducting state at block **314**, the switch-on transition procedure includes maintaining, at block **316**, the secondary switchable current path **202** in the conducting state while transitioning the primary switchable current path **201** from the conducting state into the non-conducting state This is achieved by keeping the contactor **256** closed while decreasing (e.g., progressively decreasing) the duty cycle of the pulse-width modulated control signal for the semiconductor switch T**1** from 100% to 0% inclusive.

[0058] Following block **316**, the switch-on transition procedure is complete and the method **300** continues as described above with reference to FIG. **4**. At this stage, the heating arrangement **260** may receive electrical power from the DC link **210** via the secondary switchable current path **202** but not via the primary switchable current path **201**.

[0059] The switch-on transition procedure, as represented by block **310**, provides that the contactor **256** of the secondary switchable current path **202** does not conduct all of the current associated with coupling the heating arrangement **260** to the DC link **210**. Instead, the primary switchable current path **201** is operated so as to progressively increase the voltage applied to the heating arrangement **260** before the contactor **256** is closed and begins to conduct current. This limits a magnitude of an inrush current associated with the application of a voltage to the heating elements H**1**, H**2** of the heating arrangement **260** during coupling to the DC link **210**. Because inrush currents are associated with stress (e.g., thermal stress) on components such as the heating elements H**1**, H**2**, the switch-on transition procedure reduces electrical stress on the heating arrangement **260** and thereby increases a robustness of the electrical system **200** as a whole. Further, because the primary switchable current path **201** conducts some of the current supplied from the DC link **210** as the contactor **256** is closed, a risk to the contactor arising from electrical arcing and/or transient effects as it is closed is mitigated by performance of the switch-on transition procedure, thereby extending a lifetime of the contactor **256**. In other words, the contactor **256** does not bear a significant electrical load as it is closed.

[0060] FIG. **6** is a flowchart showing the switch-off transition procedure as represented by block **320** in FIG. **4**. When the switch-off transition procedure is commenced, the secondary switchable current path **202** is in the conducting state whereas the primary switchable current path **201** is in the non-conducting state. The switch-off transition procedure includes transitioning, at block **322**, the primary switchable current path **201** from the non-conducting state to the conducting state. In a similar way to the switch-on transition procedure, this is achieved by increasing (e.g., progressively increasing) a duty cycle of a pulse-width modulated control signal for the semiconductor switch T**1** from 0% to 100%. However, unlike in the switch-on transition procedure, this does not result in the output voltage supplied to the input terminals **246**, **248** of the heating arrangement **260** being varied.

[0061] After the primary switchable current path **201** has been transitioned to the conducting state as described above, the switch-off transition procedure includes maintaining, at block **324**, the primary switchable current path **201** in the conducting state while simultaneously transitioning the secondary switchable current path **202** from the conducting state into the non-conducting state. This is achieved by maintaining the duty cycle of the pulse-width modulated control signal for the semiconductor switch T**1** at 100% while simultaneously opening the contactor **256**.

[0062] Once the primary switchable path **201** has been transitioned into the non-conducting state at block **324**, the switch-off transition procedure includes maintaining, at block **326**, the secondary switchable current path **202** in the non-conducting state while transitioning the primary switchable current path **201** from the conducting state into the non-conducting state. This is achieved by keeping the contactor **256** open while progressively decreasing the duty cycle of the pulse-width modulated control signal for the semiconductor switch T**1** from 0% to 100%.

[0063] Following block **326**, the switch-off transition procedure is complete and the method **300** continues as described above with reference to FIG. **4**. At this stage, the heating arrangement **260** may not receive electrical power from the DC link **210** via the secondary switchable current path **202** or the primary switchable current path **201**.

[0064] The switch-off transition procedure, as represented by block **320**, enables a lifetime of the contactor **256** to be relatively extended as a consequence of the primary switchable current path **201** conducting some of the current supplied from the DC link **210** as the contactor **256** is opened. Therefore, a risk to the contactor **256** arising from electrical arcing and/or transient effects as it is opened is mitigated by performance of the switch-off transition procedure. That is to say that the contactor **256** does not bear a significant electrical load as it is opened.

[0065] The transition procedures described herein (i.e., the switch-on transition procedure and the switch-off transition procedure) provide effect and simple means for coupling of relatively large loads to a power supply. In addition, the transition procedures provide that the semiconductor switch T**1** of the primary switchable current path **201** need not be continually switched between states while the heating arrangement **260** is on, thereby increasing a mean time between failures (MTBF) of the semiconductor switch T**1**. This is also associated with an increased efficiency of the conduction of electrical power from the DC link **210** to the heating arrangement **260**. Further, this is associated with a relatively reduced peak temperature of the semiconductor switch T**1** in use. Consequently, a level of cooling (e.g., a size of a heat sink) provided to the semiconductor switch T**1** may be relatively reduced. This facilitates a simpler and/or less complex electrical system **200**. Yet further, this is associated with an increased electromagnetic compatibility (EMC) of the electrical system **200**.

[0066] Moreover, the use of two parallel switchable current paths (i.e., the secondary switchable current path **202** and the primary switchable current path **201**) results in a layer of redundancy for the electrical system **200**. Namely, if the semiconductor switch T**1** fails, the heating arrangement **260** may still be switched on and off by simply opening and closing of the contactor **256** (even though this is generally undesirable for the reasons given above).

[0067] Although it has been described, with reference to FIGS. **3** to **6**, that the electrical system **200** comprises both a primary switchable current path **201** and a secondary switchable current path **202** and that the method **300** includes taking actions in respect of both switchable current paths **201**, **202**, this need not necessarily be the case. In particular, it may be that the electrical system **200** only comprises the primary switchable current path **201** comprising the controllable switch T**1** (which may then be more simply referred to as the switchable current path **201**) and that the method **300** only includes taking actions in respect of said switchable current path **201**. If so, it may be that the switch-on transition procedure only comprises transitioning the primary switchable current path **201** from the non-conducting state to the conducting state and subsequently maintaining the primary switchable current path **201** in the conducting state. Conversely, it may be that the switch-on transition procedure only comprises includes transitioning the primary switchable current path **201** from the conducting state to the non-conducting state and subsequently maintaining the primary switchable current path **201** in the non-conducting state.

[0068] Further, although it has been described that the method **300** comprises an action of determining, at block **302**, whether the heating arrangement **260** is on (i.e., is generating heat) or off (i.e., is not generating heat), this need not necessarily be the case. If so, it may be that if a determination is made, at block **304**, that there is not a demand to turn the heating arrangement **260** on, the method **300** proceeds to determining, at block **306**, whether there is a demand to turn the heating arrangement **260** off and continues thereafter as described herein. Further, if it is determined, at block **308**, that there is not a demand to change the mode of the heating arrangement **260**, the method **300** directly returns to determining, at block **304**, whether there is a demand to turn the heating arrangement **260** on. Similarly, after the transition procedure(s) has/have been performed at block(s) **310**, **310′**, **320**, the method **300** may return to determining at block **304**, whether there is a demand to turn the heating arrangement **260** on.

[0069] FIG. **7** shows, highly schematically, a machine-readable medium **600** having stored thereon a computer program **60** comprising instructions which, when executed by the controller **290** provided to a switching system **250** in accordance with the present disclosure (e.g., the switching system **250** of the electrical system **200** described above with reference to FIG. **3**), cause the controller **290** to execute the method **300** described above with reference to FIGS. **4-7**.

[0070] Except where mutually exclusive, a feature described in relation to any one of the above aspects may be applied mutatis mutandis to any other aspect. Furthermore, except where mutually exclusive, any feature described herein may be applied to any aspect and/or combined with any other feature described herein. Moreover, while the present disclosure is made with in the context of transport refrigeration systems and/or vapour-compression circuits, it will be appreciated that the present disclosure has other possible applications in other technical areas.

Claims

1. A method of controlling a supply of electrical power from a DC link to a load using a switching system including a switchable current path between the DC link and the load, the switchable current path comprising a controllable switch, the method comprising performing a transition procedure including: transitioning the switchable current path between a non-conducting state and a conducting state by progressively varying a duty cycle of a control signal for the switch between 0% and a value equal to or less than 100% inclusive.

2. The method of claim 1, wherein the switching system further comprises a snubber coupled in parallel between the DC link and the load.

3. The method of any claim 1, including: transitioning the switchable current path between the non-conducting state and the conducting state by progressively varying the duty cycle of the control signal for the switch between 0% and 100% inclusive.
4. The method of any claim 1, including: transitioning the switchable current path from the non-conducting state to the conducting state by progressively increasing the duty cycle of the control signal for the switch from 0% to 100% inclusive.
5. The method of claim 1, including: transitioning the switchable current path from the conducting state to the non-conducting state by progressively decreasing the duty cycle of the control signal for the switch from 100% to 0% inclusive.
6. The method of claim 1, wherein the switchable current path is a primary switchable current path and the switching system comprises a secondary switchable current path coupled in parallel with the primary switchable current path, and wherein the transition procedure includes: maintaining the primary switchable current path in a conducting state while transitioning the secondary switchable current path between a non-conducting state and a conducting state.
7. The method of claim 6, comprising performing a switch-on transition procedure including: maintaining the primary switchable current path in the conducting state while transitioning the secondary switchable current path from the non-conducting state to the conducting state; and subsequently maintaining the secondary switchable current path in the conducting state while transitioning the primary switchable current path from the conducting state to a non-conducting state.
8. The method of claim 6, comprising performing a switch-off transition procedure including: maintaining the primary switchable current path in the conducting state while transitioning the secondary switchable current path from the conducting state to the non-conducting state; and subsequently maintaining the secondary switchable current path in the non-conducting state while transitioning the primary switchable current path from the conducting state to a non-conducting state.
9. The method of claim 6, wherein the secondary switchable current path comprises a contactor, and wherein the method comprises transitioning the secondary switchable current path between the non-conducting state and the conducting state by closing or opening the contactor.
10. The method of claim 1, wherein the method comprises performing the transition procedure in response to a demand to vary a power consumption of the load.
11. The method claim 1, wherein the load is a heating arrangement comprising one or more heating elements.
12. An electrical system comprising a DC link, a load, a controller and a switching system including a switchable current path between the DC link and the load, wherein the controller is configured to perform the method of claim 1.
13. A computer program comprising instructions to cause a controller of an electrical system comprising a DC link, a load, the controller and a switching system including a switchable current path between the DC link and the load to execute the method of claim 1.
14. A computer-readable medium having stored thereon the computer program of claim 13.
15. A transport refrigeration system comprising the electrical system of claim 12.