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Generator temperature control

Abstract

A transportation refrigeration system (**100**) including: a transportation refrigeration unit; an energy storage device (**350**) configured to provide electrical power to the transportation refrigeration unit; an electric generation device (**340**) operably connected to at least one of a wheel (**364**) or axle (**365**) of the transport refrigeration system, the electric generation device being configured to generate electrical power from at least one of the wheel and the wheel axle to charge the energy storage device when the electric generation device is activated; a power management module (**310**) in electrical communication with the energy storage device and the electric generation device, the power management module being configured to determine a current temperature of the electric generation device (**340**), wherein the power management module is configured to adjust a torque limit of the electric generation device in response to a current temperature of the electric generation device.

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Background/Summary

BACKGROUND

(1) The embodiments herein generally relate to transport refrigeration systems and more specifically, the energy management of such transport refrigeration systems.

(2) Typically, cold chain distribution systems are used to transport and distribute cargo, or more specifically perishable goods and environmentally sensitive goods (herein referred to as perishable goods) that may be susceptible to temperature, humidity, and other environmental factors. Perishable goods may include but are not limited to fruits, vegetables, grains, beans, nuts, eggs, dairy, seed, flowers, meat, poultry, fish, ice, and pharmaceuticals. Advantageously, cold chain distribution systems allow perishable goods to be effectively transported and distributed without damage or other undesirable effects.

(3) Refrigerated vehicles and trailers are commonly used to transport perishable goods in a cold chain distribution system. A transport refrigeration system is mounted to the vehicles or to the trailer in operative association with a cargo space defined within the vehicles or trailer for maintaining a controlled temperature environment within the cargo space.

(4) Conventionally, transport refrigeration systems used in connection with refrigerated vehicles and refrigerated trailers include a transportation refrigeration unit having a refrigerant compressor, a condenser with one or more associated condenser fans, an expansion device, and an evaporator with one or more associated evaporator fans, which are connected via appropriate refrigerant lines in a closed refrigerant flow circuit. Air or an air/gas mixture is drawn from the interior volume of the cargo space by means of the evaporator fan(s) associated with the evaporator, passed through the airside of the evaporator in heat exchange relationship with refrigerant whereby the refrigerant absorbs heat from the air, thereby cooling the air. The cooled air is then supplied back to the cargo space.

(5) On commercially available transport refrigeration systems used in connection with refrigerated vehicles and refrigerated trailers, the compressor, and typically other components of the transportation refrigeration unit, must be powered during transit by a prime mover. In mechanically driven transport refrigeration systems the compressor is driven by the prime mover, either through a direct mechanical coupling or a belt drive, and other components, such as the condenser and evaporator fans are belt driven.

(6) Transport refrigeration systems may also be electrically driven. In an electrically driven transport refrigeration system, a prime mover carried on and considered part of the transport refrigeration system, drives an AC synchronous generator that generates AC power. The generated AC power is used to power an electric motor for driving the refrigerant compressor of the transportation refrigeration unit and also powering electric AC fan motors for driving the condenser and evaporator motors and electric heaters associated with the evaporator. A more efficient method to power the electric motor is desired to reduce fuel usage.

BRIEF DESCRIPTION

(7) According to one embodiment, a transport refrigeration system is provided. The transportation refrigeration system including: a transportation refrigeration unit; an energy storage device

configured to provide electrical power to the transportation refrigeration unit; an electric generation device operably connected to at least one of a wheel of the transport refrigeration system and a wheel axle of the transport refrigeration system, the electric generation device being configured to generate electrical power from at least one of the wheel and the wheel axle to charge the energy storage device when the electric generation device is activated; a power management module in electrical communication with the energy storage device and the electric generation device, the power management module being configured to determine a current temperature of the electric generation device, wherein the power management module is configured to adjust a torque limit of the electric generation device in response to a current temperature of the electric generation device.
(8) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include a temperature sensor configured to measure a current temperature of the electric generation device and transmit the current temperature to the power management module.
(9) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include an ambient temperature sensor configured to measure an ambient temperature proximate the transport refrigeration system and transmit the ambient temperature to the power management module, wherein the power management module is configured to determine the current temperature of the electric generation device in response to at least the ambient temperature.
(10) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include that the ambient temperature sensor is an ambient temperature sensor of the transportation refrigeration unit.
(11) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include a rotational velocity sensor configured to detect a rotational velocity of the electric generation device, the rotational velocity sensor being in electrical communication with the power management module, wherein the power management module is configured to determine the current temperature of the electric generation device in response to at least the ambient temperature and the rotational velocity of the electric generation device.
(12) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include that the torque limit is decreased when the current temperature of the electric generation device is greater than a selected temperature.
(13) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include that the torque limit is increased when the current temperature of the electric generation device is below a selected temperature.
(14) According to another embodiment, a method of operating a transport refrigeration system including a vehicle integrally connected to a transport container is provided. The method including: powering a transportation refrigeration unit using an energy storage device, the transportation refrigeration unit being configured to provide conditioned air to refrigerated cargo space enclosed within the transport container; charging the energy storage device using an electric generation device operably connected to at least one of a wheel of the transport refrigeration system and a wheel axle of the transport refrigeration system, the electric generation device being configured to generate electrical power from at least one of the wheel and the wheel axle to charge the energy storage device when the electric generation device is activated; determining a current temperature of the electric generation device; and adjusting, using a power management module, a torque limit of the electric generation device in response to the current temperature of the electric generation device, the power management module being in electrical communication with the energy storage device and the electric generation device.
(15) In addition to one or more of the features described above, or as an alternative, further

embodiments of the transport refrigeration system may include that determining a current temperature of the electric generation device further includes: measuring a current temperature of the electric generation device using a temperature sensor; and transmitting the current temperature to the power management module.
(16) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include that determining a current temperature of the electric generation device further includes: measuring an ambient temperature proximate the transport refrigeration system; transmitting the ambient temperature to the power management module; and determining the current temperature of the electric generation device in response to at least the ambient temperature.
(17) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include that the ambient temperature sensor is an ambient temperature sensor of the transportation refrigeration unit.
(18) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include: detecting a rotational velocity of the electric generation device using a rotational velocity sensor, the rotational velocity sensor being in electrical communication with the power management module; and determining the current temperature of the electric generation device in response to at least the ambient temperature and the rotational velocity of the electric generation device.
(19) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include: decreasing the torque limit of the electric generation device when the current temperature of the electric generation device is greater than a selected temperature.
(20) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include: increasing the torque limit of the electric generation device when the current temperature of the electric generation device is less than a selected temperature.
(21) According to another embodiment, a computer program product tangibly embodied on a computer readable medium is provided. The computer program product including instructions that, when executed by a processor, cause the processor to perform operations including: powering a transportation refrigeration unit using an energy storage device, the transportation refrigeration unit being configured to provide conditioned air to refrigerated cargo space enclosed within the transport container; charging the energy storage device using an electric generation device operably connected to at least one of a wheel of the transport refrigeration system and a wheel axle of the transport refrigeration system, the electric generation device being configured to generate electrical power from at least one of the wheel and the wheel axle to charge the energy storage device when the electric generation device is activated; determining a current temperature of the electric generation device; and adjusting, using a power management module, a torque limit of the electric generation device in response to the current temperature of the electric generation device, the power management module being in electrical communication with the energy storage device and the electric generation device.
(22) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include that determining a current temperature of the electric generation device further includes: measuring a current temperature of the electric generation device using a temperature sensor; and transmitting the current temperature to the power management module.
(23) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include that determining a current temperature of the electric generation device further includes: measuring an ambient temperature proximate the transport refrigeration system; transmitting the ambient temperature to the power

management module; and determining the current temperature of the electric generation device in response to at least the ambient temperature.
(24) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include that the ambient temperature sensor is an ambient temperature sensor of the transportation refrigeration unit.
(25) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include that the operations further include: detecting a rotational velocity of the electric generation device using a rotational velocity sensor, the rotational velocity sensor being in electrical communication with the power management module; and determining the current temperature of the electric generation device in response to at least the ambient temperature and the rotational velocity of the electric generation device.
(26) In addition to one or more of the features described above, or as an alternative, further embodiments of the transport refrigeration system may include that the operations further include: decreasing the torque limit of the electric generation device when the current temperature of the electric generation device is greater than a selected temperature.
(27) Technical effects of embodiments of the present disclosure include preventing the overheat of an electrical generation devices of a transportation refrigeration unit by monitoring at least one of temperature of the electrical generation unit and ambient temperature.
(28) The foregoing features and elements may be combined in various combinations without exclusivity, unless expressly indicated otherwise. These features and elements as well as the operation thereof will become more apparent in light of the following description and the accompanying drawings. It should be understood, however, that the following description and drawings are intended to be illustrative and explanatory in nature and non-limiting.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:
(2) FIG. **1** is a schematic illustration of a transport refrigeration system, according to an embodiment of the present disclosure;
(3) FIG. **2** is an enlarged schematic illustration of a transportation refrigeration unit of the transport refrigeration system of FIG. **1**, according to an embodiment of the present disclosure; and
(4) FIG. **3** is a flow process illustrating a method of operating the transport refrigeration system of FIGS. **1** and **2**, according to an embodiment of the present disclosure.
DETAILED DESCRIPTION
(5) A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.
(6) Referring to FIGS. **1** and **2**, various embodiments of the present disclosure are illustrated. FIG. **1** shows a schematic illustration of a transport refrigeration system **200**, according to an embodiment of the present disclosure. FIG. **2** shows an enlarged schematic illustration of the transport refrigeration system **200** of FIG. **1**, according to an embodiment of the present disclosure.
(7) The transport refrigeration system **200** is being illustrated as a trailer system **100**, as seen in FIG. **1**. The trailer system **100** includes a vehicle **102** integrally connected to a transport container **106**. The vehicle **102** includes an operator's compartment or cab **104** and a propulsion motor **320** which acts as the drive system of the trailer system **100**. The propulsion motor **320** is configured to power the vehicle **102**. The energy source that powers the propulsion motor **320** may be at least one of compressed natural gas, liquefied natural gas, gasoline, electricity, diesel, or a combination thereof. The propulsion motor **320** may be an electric motor or a hybrid motor (e.g., a combustion

engine and an electric motor). The transport container **106** is coupled to the vehicle **102**. The transport container **106** may be removably coupled to the vehicle **102**. The transport container **106** is a refrigerated trailer and includes a top wall **108**, a directly opposed bottom wall **110**, opposed side walls **112**, and a front wall **114**, with the front wall **114** being closest to the vehicle **102**. The transport container **106** further includes a door or doors **117** at a rear wall **116**, opposite the front wall **114**. The walls of the transport container **106** define a refrigerated cargo space **119**. It is appreciated by those of skill in the art that embodiments described herein may be applied to a tractor-trailer refrigerated system or non-trailer refrigeration such as, for example a rigid truck, a truck having refrigerated compartment.
(8) Typically, transport refrigeration systems **200** are used to transport and distribute perishable goods and environmentally sensitive goods (herein referred to as perishable goods **118**). The perishable goods **118** may include but are not limited to fruits, vegetables, grains, beans, nuts, eggs, dairy, seed, flowers, meat, poultry, fish, ice, blood, pharmaceuticals, or any other suitable cargo requiring temperature controlled transport. The transport refrigeration system **200** includes a transportation refrigeration unit **22**, a refrigerant compression device **32**, an electric motor **26** for driving the refrigerant compression device **32**, and a controller **30**. The transportation refrigeration unit **22** is in operative association with the refrigerated cargo space **112** and is configured to provide conditioned air to the transport container **106**. The transportation refrigeration unit **22** functions, under the control of the controller **30**, to establish and regulate a desired environmental parameters, such as, for example temperature, pressure, humidity, carbon dioxide, ethylene, ozone, light exposure, vibration exposure, and other conditions in the interior compartment **119**, as known to one of ordinary skill in the art. In an embodiment, the transportation refrigeration unit **22** is capable of providing a desired temperature and humidity range.
(9) The transportation refrigeration unit **22** includes a refrigerant compression device **32**, a refrigerant heat rejection heat exchanger **34**, an expansion device **36**, and a refrigerant heat absorption heat exchanger **38** connected in refrigerant flow communication in a closed loop refrigerant circuit and arranged in a conventional refrigeration cycle. The transportation refrigeration unit **22** also includes one or more fans **40** associated with the refrigerant heat rejection heat exchanger **34** and driven by fan motor(s) **42** and one or more fans **44** associated with the refrigerant heat absorption heat exchanger **38** and driven by fan motor(s) **46**. The transportation refrigeration unit **22** may also include a heater **48** associated with the refrigerant heat absorption heat exchanger **38**. In an embodiment, the heater **48** may be an electric resistance heater. It is to be understood that other components (not shown) may be incorporated into the refrigerant circuit as desired, including for example, but not limited to, a suction modulation valve, a receiver, a filter/dryer, an economizer circuit.
(10) The refrigerant heat rejection heat exchanger **34** may, for example, comprise one or more refrigerant conveying coiled tubes or one or more tube banks formed of a plurality of refrigerant conveying tubes across flow path to the heat outlet **142**. The fan(s) **40** are operative to pass air, typically ambient air, across the tubes of the refrigerant heat rejection heat exchanger **34** to cool refrigerant vapor passing through the tubes. The refrigerant heat rejection heat exchanger **34** may operate either as a refrigerant condenser, such as if the transportation refrigeration unit **22** is operating in a subcritical refrigerant cycle or as a refrigerant gas cooler, such as if the transportation refrigeration unit **22** is operating in a transcritical cycle.
(11) The refrigerant heat absorption heat exchanger **38** may, for example, also comprise one or more refrigerant conveying coiled tubes or one or more tube banks formed of a plurality of refrigerant conveying tubes extending across flow path from a return air inlet **136**. The fan(s) **44** are operative to pass air drawn from the refrigerated cargo space **119** across the tubes of the refrigerant heat absorption heat exchanger **38** to heat and evaporate refrigerant liquid passing through the tubes and cool the air. The air cooled in traversing the refrigerant heat rejection heat exchanger **38** is supplied back to the refrigerated cargo space **119** through a refrigeration unit outlet

140. It is to be understood that the term “air” when used herein with reference to the atmosphere within the cargo box includes mixtures of air with other gases, such as for example, but not limited to, nitrogen or carbon dioxide, sometimes introduced into a refrigerated cargo box for transport of perishable produce.

(12) Airflow is circulated into and through the refrigerate cargo space **119** of the transport container **106** by means of the transportation refrigeration unit **22**. A return airflow **134** flows into the transportation refrigeration unit **22** from the refrigerated cargo space **119** through the refrigeration unit return air intake **136**, and across the refrigerant heat absorption heat exchanger **38** via the fan **44**, thus conditioning the return airflow **134** to a selected or predetermined temperature. The conditioned return airflow **134**, now referred to as supply airflow **138**, is supplied into the refrigerated cargo space **119** of the transport container **106** through the refrigeration unit outlet **140**. Heat **135** is removed from the refrigerant heat rejection heat exchanger **34** through the heat outlet **142**. The transportation refrigeration unit **22** may contain an external air inlet **144**, as shown in FIG. **2**, to aid in the removal of heat **135** from the refrigerant heat rejection heat exchanger **34** by pulling in external air **137**. The supply airflow **138** may cool the perishable goods **118** in the refrigerated cargo space **119** of the transport container **106**. It is to be appreciated that the transportation refrigeration unit **22** can further be operated in reverse to warm the container system **106** when, for example, the outside temperature is very low. In the illustrated embodiment, the return air intake **136**, the refrigeration unit outlet **140**, the heat outlet **142**, and the external air inlet **144** are configured as grilles to help prevent foreign objects from entering the transportation refrigeration unit **22**.

(13) The transport refrigeration system **200** also includes a controller **30** configured for controlling the operation of the transport refrigeration system **200** including, but not limited to, the operation of various components of the refrigerant unit **22** to provide and maintain a desired thermal environment within the refrigerated cargo space **119**. The controller **30** may also be able to selectively operate the electric motor **26**. The controller **30** may be an electronic controller including a processor and an associated memory comprising computer-executable instructions that, when executed by the processor, cause the processor to perform various operations. The processor may be but is not limited to a single-processor or multi-processor system of any of a wide array of possible architectures, including field programmable gate array (FPGA), central processing unit (CPU), application specific integrated circuits (ASIC), digital signal processor (DSP) or graphics processing unit (GPU) hardware arranged homogenously or heterogeneously. The memory may be a storage device such as, for example, a random access memory (RAM), read only memory (ROM), or other electronic, optical, magnetic or any other computer readable medium.

(14) The transportation refrigeration unit **22** is powered by the energy storage device **350**, which provides electrical power to the transportation refrigeration unit **22** and will be discussed further below. Examples of the energy storage device **350** may include a battery system (e.g., a battery or bank of batteries), fuel cells, flow battery, and others devices capable of storing and outputting electric energy that may be DC. The energy storage device **350** may include a battery system, which may employ multiple batteries organized into battery banks.

(15) The battery **350** may be charged by a stationary charging station **386** such as, for example a wall 48V power outlet. The charging station **386** may provide single phase (e.g., level 2 charging capability) or three phase AC power to the energy storage device **350**. It is understood that the charging station **386** may have any phase charging and embodiments disclosed herein are not limited to single phase or three phase AC power. In an embodiment, the single phase AC power may be a high voltage DC power, such as, for example, 500VDC.

(16) In one embodiment, the energy storage device **350** is located outside of the transportation refrigeration unit **22**, as shown in FIG. **1**. In another embodiment, the energy storage device **350** is located within the transportation refrigeration unit **22**. The transportation refrigeration unit **22** has a plurality of electrical power demand loads on the energy storage device **350**, including, but not

limited to, the drive motor **42** for the fan **40** associated with the refrigerant heat rejection heat exchanger **34**, and the drive motor **46** for the fan **44** associated with the refrigerant heat absorption heat exchanger **38**. As each of the fan motors **42**, **46** and the electric motor **26** may be an AC motor or a DC motor, it is to be understood that various power converters **52**, such as AC to DC rectifiers, DC to AC inverters, AC to AC voltage/frequency converters, and DC to DC voltage converters, may be employed in connection with the energy storage device **150** as appropriate. In the depicted embodiment, the heater **48** also constitutes an electrical power demand load. The electric resistance heater **48** may be selectively operated by the controller **30** whenever a control temperature within the temperature controlled cargo box drops below a preset lower temperature limit, which may occur in a cold ambient environment. In such an event the controller **30** would activate the heater **48** to heat air circulated over the heater **48** by the fan(s) **44** associated with the refrigerant heat absorption heat exchanger **38**. The heater **48** may also be used to de-ice the return air intake **136**. Additionally, the electric motor **26** being used to power the refrigerant compression device **32** also constitutes a demand load. The refrigerant compression device **32** may comprise a single-stage or multiple-stage compressor such as, for example, a reciprocating compressor or a scroll compressor. The transport refrigeration system **200** may also include a voltage sensor **28** to sense the voltage from the energy storage device **350**.

(17) As described above the energy storage device **350** is used to electrical power the transportation refrigeration unit **22**. The energy storage device **350** is integrated within an energy management system **300**. The energy management system **300** comprises an electric generation device **340**, the energy storage device **350** configured to provide electrical power to electric motor **26**, the electric motor **26** configured to power the transportation refrigeration unit **22**, a power management module **310**, and an inertial sensor **360**.

(18) The electric generation device **340** is configured to harvest electrical power from kinetic energy of the trailer system **100**. The electric generation device **340** can be at least one of an axle generator and a hub generator mounted configured to recover rotational energy when the transport refrigeration system **20** is in motion and convert that rotational energy to electrical energy, such as, for example, when the axle **365** of the trailer system **100** is rotating due to acceleration, cruising, or braking. The electric generation device **340** may be mounted on or operably connected to a wheel axle **365** of the trailer system **100** and the hub generator may be mounted on a wheel **364** of the trailer system **100**. It is understood that the electric generation device **340** may be mounted on any wheel **364** or axle **365** of the trailer system **100** and the mounting location of the electric generation device **340** illustrated in FIG. **1** is one example of a mounting location.

(19) The electric generation device **340** will then use the generated electrical power to charge the energy storage device **350**. In an alternate embodiment, the electric generation device **340** may be operably connected to the wheel axle **365** or wheel **364** through at least one mechanical linkage, such as, for example a drive shaft, belt system, or gear system. The mechanical linkage configured to rotate the electric generation device **340** as the wheels **364** or wheel axle **365** rotates when the electric generation device **340** is activated. The electric generation device **340** may comprise a single on-board, engine driven AC generator configured to generate alternating current (AC) power including at least one AC voltage at one or more frequencies. In an embodiment, the electric generation device **340** may, for example, be a permanent magnet AC generator, asynchronous, or a synchronous AC generator. In another embodiment, the electric generation device **340** may comprise a single on-board, engine driven DC generator configured to generate direct current (DC) power at least one voltage.

(20) The inertial sensor **360** is configured to detect at least one of a deceleration of the vehicle **102** and a downward pitch of the vehicle **102** (e.g., indicating the vehicle **102** is moving downhill). The inertial sensor **360** may be a 5-axis sensor. The inertial sensor **360** may be configured to detect three linear accelerations and two rotational accelerations. The three linear acceleration may be along an X-axis, a Y-axis, and a Z-axis of a three-dimensional Cartesian coordinate system. The

rotational accelerations may be around two of the three axis of the three-dimensional Cartesian coordinate system, such as, for example, the X-axis and the Z-axis. The inertial sensor **360** may accomplish this detection utilizing a plurality of connected sensors or a single sensor. In an embodiment, the inertial sensor **360** is a single sensor in electronic communication with the power management module **310**. The power management module **310** is configured to activate the electric generation device **340** when the inertial sensor **360** detects at least one of the deceleration of the vehicle **102** and the downward pitch of the vehicle **102**. The inertial sensor **360** may also include a GPS device in order to predict in advance at least one of the deceleration of the vehicle **102** and the downward pitch of the vehicle **102**. The power management module **310** is in electrical communication with at least one of the energy storage device **350**, the electric generation device **340**, and the inertial sensor **360**.

(21) The power management module **310** may be an electronic controller including a processor and an associated memory comprising computer-executable instructions that, when executed by the processor, cause the processor to perform various operations. The processor may be but is not limited to a single-processor or multi-processor system of any of a wide array of possible architectures, including field programmable gate array (FPGA), central processing unit (CPU), application specific integrated circuits (ASIC), digital signal processor (DSP) or graphics processing unit (GPU) hardware arranged homogenously or heterogeneously. The memory may be a storage device such as, for example, a random access memory (RAM), read only memory (ROM), or other electronic, optical, magnetic or any other computer readable medium.

(22) The inertial sensor **360** is configured to detect a deceleration of the vehicle **102**. The inertial sensor **360** is in operative association with the vehicle **102** and may detect when a brake **103** of the vehicle **102** is being applied to slow the vehicle **102** and/or the vehicle **102** is decelerating without the brakes **103** being applied (i.e., driver lets foot off accelerator pedal). The inertial sensor **360** is in operative communication with the power management module **310** and the power management module **310** controls the operation of the inertial sensor **360**. The power management module **310** is configured to activate the electric generation device **340** when the deceleration is greater than a selected deceleration, which may indicate that some propulsion motor **320** rotation is no longer needed to drive the vehicle **102** and it is a good time to bleed off some rotational energy of the wheels **364** or axle **365** of the trailer system **100** using the electric generation device **340**. Bleeding off rotational energy of the wheels **364** or axle **365** when the vehicle **102** is decelerating helps reduce any performance impact to the ability of the propulsion motor **320** to power the vehicle **102**.

(23) The inertial pitch sensor **360** is also configured to detect a pitch angle of the vehicle **102**. The power management module **310** is configured to activate the electric generation device **340** when the when the pitch angle is less than a selected pitch angle, which may indicate that some propulsion motor **320** rotation is no longer needed to drive the vehicle **102** and it is a good time to bleed off some rotational energy of the wheels **364** or axle **365** of the trailer system **100** using the electric generation device **340**. For example, when the vehicle **102** is descending downhill with a negative pitch angle, gravity assists in driving the vehicle downhill and the full capacity of the e rotational energy of the wheels **364** and axle **365** may no longer be needed to drive the vehicle **102**. Bleeding off rotational energy of the wheels **364** or axle **365** when the vehicle **102** is descending downhill helps reduce any performance impact to the ability of the propulsion motor **320** to power the vehicle **102**.

(24) The electric generation device **340** may also include a rotational velocity sensor **360***a* configured to measure the rotational velocity of the electric generation device **340** (e.g., rotations per minute (RPM)). The rotational velocity sensor **360***a* of the electric generation device is in operative communication with the power management module **310** and the power management module **310** may control the operation of the rotational velocity sensor **360***a*. The power management module **310** is configured to determine when the vehicle **102** is decelerating utilizing the inertial sensor **360** and/or the rotational velocity sensor **360***a*, which may indicate that some

propulsion motor **320** rotation is no longer needed to drive the vehicle **102** (i.e., the vehicle is going downhill or decelerating) and it is a good time to bleed off some rotational energy of the wheels **364** or axle **365** of the trailer system **100** using the electric generation device **340**. Bleeding off rotational energy of the wheels **364** or axle **365** when the vehicle **102** is decelerating or going downhill helps reduce any performance impact to the ability of the propulsion motor **320** to power the vehicle **102**.

(25) The power management module **310** may detect a state of charge of the energy storage device **350** and determine whether the energy storage device **350** may take additional charge (i.e., electrical power). For example, the power management module **310** may detect that the state of charge of the energy storage device **350** is less than a selected state of charge (e.g., 50% charged). If the power management module **310** detects that the state of charge of the energy storage device **350** is less than a selected state of charge then the power management module **310** may increase the torque limit of the electric generation device **340** for a selected period of time if the transport refrigeration system **200** is also detected to be decelerating and/or going downhill (i.e., free energy). The selected period of time may be short enough, such that the electric generation device **340** does not overheat. Advantageously, temporarily raising the torque limit of the electric generation device **340** for a selected period of time allows the electric generation device **340** to generate as much electric power as possibly when the energy is “free” and there is space in the energy storage device **350**. As discussed above, energy may be considered “free” when the vehicle **102** is moving downhill or decelerating.

(26) Additionally, the power management module **310** is configured to monitor the rotational velocity of the electric generation device **340** to detect wheel **364** slippage using the rotational velocity sensor **360***a*. In one embodiment, the rotational velocity sensor **360***a* may be a sensor mechanically connected to the electric generation device **340** to detect rotational velocity of the electric generation device **340**. In another embodiment, the rotational velocity sensor **360***a* may be an electronic sensor electrically connected to the electric generation device **340** to detect rotational velocity of the electric generation device **340** by measuring the electrical frequency output of the electric generation device **340**. In yet another embodiment, the rotational velocity sensor **360***a* may be a wireless sensor capable of detecting rotational velocity of the electric generation device **340** wirelessly, such as, for example, RFID tracking, wireless capacitive sensor, wireless electromagnetic induction sensor, or any other wireless detection method known to one of skill in the art.

(27) The power management module **310** is configured to detect and monitor the deceleration of the electric generation device **340** in order to detect wheel **364** slippage. Sudden or rapid deceleration of the electric generation device **340** may indicate that the wheel **364** of the trailer system **100** has loss grip with the road surface below and the wheel **364** (e.g., tire) has started slipping. The power management module **310** is configured to decrease the torque limit of the electric generation device **340** when the rotational velocity of the electric generation device **340** decelerates greater than a selected deceleration. If the electric generation device **340-**decelerates too fast, this may be indicative of wheel **364** slippage, thus the torque limit of the electric generation devices **340** may be temporarily lowered to help the wheel regain traction with the road until the wheel regains traction with the road surface. Decreasing the torque limit of the electric generation device **340** will cap the rotational velocity of the wheel **364**, thus allowing the wheel **364** to slow in regain traction.

(28) In one embodiment, the rotational velocity sensor **360***a* may be a sensor mechanically connected to the electric generation device **340** to detect rotational velocity of the electric generation device **340**. In another embodiment, the rotational velocity sensor **360***a* may be an electronic sensor electrically connected to the electric generation device **340** to detect rotational velocity of the electric generation device **340** by measuring the electrical frequency output of the electric generation device **340**. In another embodiment, the rotational velocity sensor **360***a* may be

an inverter connected to the electric generation device **340** to detect rotational velocity of the electric generation device **340** by measuring the electrical frequency output of the electric generation device **340**. In yet another embodiment, the rotational velocity sensor **360***a* may be a wireless sensor capable of detecting rotational velocity of the electric generation device **340** wirelessly, such as, for example, RFID tracking, wireless capacitive sensor, wireless electromagnetic induction sensor, or any other wireless detection method known to one of skill in the art.

(29) The power management module **310** is configured to detect and monitor the acceleration and deceleration of the electric generation device **340** in order to detect wheel **364** slippage. Sudden or rapid deceleration of the electric generation device **340** may indicate that the wheel **364** of the trailer system **100** has loss grip with the road surface below and the wheel **364** (e.g., tire) has started slipping. The power management module **310** is configured to decrease the torque limit of the electric generation device **340** when the rotational velocity of the electric generation device **340** decelerates greater than a selected acceleration. If the electric generation device **340** decelerates too fast, this may be indicative of wheel **364** slippage, thus the torque limit of the electric generation devices **340** may be temporarily lowered to help the wheel regain traction with the road until the wheel regains traction with the road surface. Decreasing the torque limit of the electric generation device **340** will cap the rotational velocity of the wheel **364**, thus allowing the wheel **364** to slow and regain traction.

(30) Additionally, the power management module **310** is configured to monitor a temperature of the electric generation device **340** to prevent overheating of the electric generation device **340**. In order to monitor the temperature of the electric generation device **340**, the power management module **310** may be in electronic communication with a temperature sensor **370***a* located at the electric generation device **340** and/or an ambient temperature sensor **370***b* configured to measure the ambient temperature proximate the transport refrigeration system **200**. The temperature sensor **370***a* located at the electric generation device **340** is configured to measure the temperature of the electric generation device **340** directly using a thermocouple located on, within, or proximate the electric generation device **340**. In an embodiment, the temperature sensor **370***a* is physically attached to the electric generation device **340** to directly measure the temperature of the electric generation device **340**. The ambient temperature sensor **370***b* may be located proximate the transportation refrigeration unit **22** or within the transportation refrigeration unit **22**. In an embodiment, the ambient temperature sensor **370***b* is an ambient temperature sensor of the transportation refrigeration unit **22**. Alternatively, the ambient temperature sensor **370***b* may be a remote sensor in electronic communication with the power management module **310** through a cloud computing network (e.g., a weather website on the internet) to provide the power management module **310** with the current local temperature proximate the transport refrigeration system **200**.

(31) The power management module **310** may utilize the ambient temperature from ambient temperature sensor **370***b* to determine (e.g., calculate from preload algorithms, lookup table, and/or test data) a current temperature of the electric generation device **340**. The power management module **310** may also utilize the current rotational velocity of the electric generation device **340**, as measured by the rotational velocity sensor **360***a*, to determine the current temperature of the electric generation device **340**. Alternately, the power management module **310** may directly measure the current temperature of the electric generation device **340** using the temperature sensor **370***a*. The power management module **310** may also utilize the current rotational velocity to determine (e.g., calculate from preload algorithms, lookup table, and/or test data) a torque limit of the electric generation device **340**.

(32) The power management module **310** is configured to adjust the torque limit of the electric generation device **340** in response to the current temperature of the electric generation device **340**. In one example, if the current temperature of the electric generation device **340** indicates that the

electric generation device **340** is hot (i.e., greater than a selected temperature) then the power management module **310** will reduce the torque limit. In another example, if the current temperature of the electric generation device **340** indicates that the electric generation device **340** is cold (i.e., less than a selected temperature) then the power management module **310** will increase the torque limit. Advantageously, by adjusting the torque limit of the electric generation device **340** based upon the ambient temperature and/or current temperature of the electric generation device **340**, the electric generation device **340** is protected from overheating at elevated ambient temperatures. Also, advantageously, by adjusting the torque limit of the electric generation device **340** based upon the ambient temperature, the electric generation device **340** may be worked harder at lower ambient temperatures due to a lower risk of overheating the electric generation device **340** in lower ambient temperatures.

(33) Referring now to FIG. **3**, with continued reference to FIGS. **1** and **2**. FIG. **3** shows a flow process illustrating a method **400** of operating a transport refrigeration system **200** comprising a vehicle **102** integrally connected to a transport container **106**, according to an embodiment of the present disclosure.

(34) At block **404**, a transportation refrigeration unit **22** is powered using an energy storage device **350**. As discussed above, the transportation refrigeration unit **22** is configured to provide conditioned air to refrigerated cargo space **112** enclosed within the transport container **106**.

(35) At block **406**, the energy storage device **350** is charged using an electric generation device **340** operably connected to at least one of the wheel **364** of the transport refrigeration system **200** and the wheel axle **365** of the transport refrigeration system **200**. The electric generation device **340** being configured to generate electrical power from at least one of a wheel **364** and a wheel axle **365** to charge the energy storage device **350** when the electric generation device **340** is activated.

(36) At block **408**, a current temperature of the electric generation device **340** is determined. In one embodiment, the current temperature of the electric generation device **340** may be measured using a temperature sensor **370***a* and the temperature sensor **370***a* may then transmit the current temperature of the electric generation device **340** to the power management module **310**.

(37) In another embodiment, an ambient temperature proximate the transport refrigeration system **200** may be measured using an ambient temperature sensor **370***b* and the ambient temperature sensor **370***b* may then transmit the ambient temperature of the electric generation device **340** to the power management module **310**. Thus, the method **400** may further comprise: measuring an ambient temperature proximate the transport refrigeration system **200**; transmitting the ambient temperature to the power management module **310**; and determining the current temperature of the electric generation device **340** in response to at least the ambient temperature. The method **400** may further comprise: detecting a rotational velocity of the electric generation device **340** using a rotational velocity sensor **360***a*; and determining the current temperature of the electric generation device **340** in response to at least the ambient temperature and the rotational velocity of the electric generation device **340**. The rotational velocity sensor **360***a* is in electrical communication with the power management module **310**, as discussed above.

(38) At block **410**, the torque limit of the electric generation device **340** is determined in response to the current temperature and rotational velocity of the electric generation device **340**. As discuses above, the power management module **310** is in electrical communication with the energy storage device **350** and the electric generation device **340**. The torque limit may be adjusted by decreasing the torque limit of the electric generation device **340** when the current temperature of the electric generation device **340** is greater than a selected temperature. The torque limit may be adjusted by increasing the torque limit of the electric generation device **340** when the current temperature of the electric generation device **340** is less than a selected temperature. The torque limit will be adjusted (calculate from preload algorithms) depending on the rotational velocity of the electric generation device **340**.

(39) While the above description has described the flow process of FIG. **3** in a particular order, it

should be appreciated that unless otherwise specifically required in the attached claims that the ordering of the steps may be varied.

(40) As described above, embodiments can be in the form of processor-implemented processes and devices for practicing those processes, such as processor. Embodiments can also be in the form of computer program code containing instructions embodied in tangible media, such as floppy diskettes, CD ROMs, hard drives, or any other computer-readable storage medium, wherein, when the computer program code is loaded into and executed by a computer, the computer becomes a device for practicing the embodiments. Embodiments can also be in the form of computer program code, for example, whether stored in a storage medium, loaded into and/or executed by a computer, or transmitted over some transmission medium, loaded into and/or executed by a computer, or transmitted over some transmission medium, such as over electrical wiring or cabling, through fiber optics, or via electromagnetic radiation, wherein, when the computer program code is loaded into an executed by a computer, the computer becomes an device for practicing the exemplary embodiments. When implemented on a general-purpose microprocessor, the computer program code segments configure the microprocessor to create specific logic circuits.

(41) The term “about” is intended to include the degree of error associated with measurement of the particular quantity based upon the equipment available at the time of filing the application. For example, “about” can include a range of ±8% or 5%, or 2% of a given value.

(42) The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present disclosure. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, element components, and/or groups thereof.

(43) While the present disclosure has been described with reference to an exemplary embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the present disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the present disclosure without departing from the essential scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this present disclosure, but that the present disclosure will include all embodiments falling within the scope of the claims.

Claims

1. A transport refrigeration system comprising: a transportation refrigeration unit including a refrigerant compression device, a refrigerant heat rejection heat exchanger, an expansion device, and a refrigerant heat absorption heat exchanger connected in refrigerant flow communication, the transportation refrigeration unit mounted to a transport container to cool an interior of the transport container; an energy storage device configured to provide electrical power to the transportation refrigeration unit; an electric generation device operably connected to at least one of a wheel of the transport refrigeration system and a wheel axle of the transport refrigeration system, the electric generation device being configured to generate electrical power from at least one of the wheel and the wheel axle to charge the energy storage device when the electric generation device is activated; a power management module in electrical communication with the energy storage device and the electric generation device, the power management module being configured to determine a current temperature of the electric generation device, wherein the power management module is configured to adjust a torque limit of the electric generation device in response to a current temperature of the electric generation device; an ambient temperature sensor configured to measure an ambient

temperature proximate the transport refrigeration system and transmit the ambient temperature to the power management module, wherein the power management module is configured to determine the current temperature of the electric generation device in response to at least the ambient temperature; wherein the ambient temperature sensor is positioned within the transportation refrigeration unit.
2. The transport refrigeration system of claim 1, further comprising: a temperature sensor configured to measure a current temperature of the electric generation device and transmit the current temperature to the power management module.
3. The transport refrigeration system of claim 1, wherein the ambient temperature sensor is an ambient temperature sensor of the transportation refrigeration unit.
4. The transport refrigeration system of claim 1, further comprising: a rotational velocity sensor configured to detect a rotational velocity of the electric generation device, the rotational velocity sensor being in electrical communication with the power management module, wherein the power management module is configured to determine the current temperature of the electric generation device in response to at least the ambient temperature and the rotational velocity of the electric generation device.
5. The transport refrigeration system of claim 1, wherein the torque limit is decreased when the current temperature of the electric generation device is greater than a selected temperature.
6. The transport refrigeration system of claim 1, wherein the torque limit is increased when the current temperature of the electric generation device is below a selected temperature.
7. A method of operating a transport refrigeration system comprising a vehicle integrally connected to a transport container, the method comprising: powering a transportation refrigeration unit using an energy storage device, the transportation refrigeration unit including a refrigerant compression device, a refrigerant heat rejection heat exchanger, an expansion device, and a refrigerant heat absorption heat exchanger connected in refrigerant flow communication, the transportation refrigeration unit mounted to the transport container, the transportation refrigeration unit being configured to provide conditioned air to refrigerated cargo space enclosed within the transport container; charging the energy storage device using an electric generation device operably connected to at least one of a wheel of the transport refrigeration system and a wheel axle of the transport refrigeration system, the electric generation device being configured to generate electrical power from at least one of the wheel and the wheel axle to charge the energy storage device when the electric generation device is activated; determining a current temperature of the electric generation device; and adjusting, using a power management module, a torque limit of the electric generation device in response to the current temperature of the electric generation device, the power management module being in electrical communication with the energy storage device and the electric generation device; wherein determining the current temperature of the electric generation device further comprises: measuring an ambient temperature proximate the transport refrigeration system; transmitting the ambient temperature to the power management module; and determining the current temperature of the electric generation device in response to at least the ambient temperature; wherein the ambient temperature sensor is positioned within the transportation refrigeration unit.
8. The method of claim 7, wherein determining a current temperature of the electric generation device further comprises: measuring a current temperature of the electric generation device using a temperature sensor; and transmitting the current temperature to the power management module.
9. The method of claim 7, wherein the ambient temperature sensor is an ambient temperature sensor of the transportation refrigeration unit.
10. The method of claim 7, further comprising: detecting a rotational velocity of the electric generation device using a rotational velocity sensor, the rotational velocity sensor being in electrical communication with the power management module; and determining the current temperature of the electric generation device in response to at least the ambient temperature and the

rotational velocity of the electric generation device.

11. The method of claim 7, further comprising: decreasing the torque limit of the electric generation device when the current temperature of the electric generation device is greater than a selected temperature.

12. The method of claim 7, further comprising: increasing the torque limit of the electric generation device when the current temperature of the electric generation device is less than a selected temperature.

13. A non-transitory computer program product tangibly embodied on a computer readable medium, the non-transitory computer program product including instructions that, when executed by a processor, cause the processor to perform operations comprising: powering a transportation refrigeration unit using an energy storage device, the transportation refrigeration unit including a refrigerant compression device, a refrigerant heat rejection heat exchanger, an expansion device, and a refrigerant heat absorption heat exchanger connected in refrigerant flow communication, the transportation refrigeration unit mounted to a transport container, the transportation refrigeration unit being configured to provide conditioned air to refrigerated cargo space enclosed within the transport container; charging the energy storage device using an electric generation device operably connected to at least one of a wheel of the transport refrigeration system and a wheel axle of the transport refrigeration system, the electric generation device being configured to generate electrical power from at least one of the wheel and the wheel axle to charge the energy storage device when the electric generation device is activated; determining a current temperature of the electric generation device; and adjusting, using a power management module, a torque limit of the electric generation device in response to the current temperature of the electric generation device, the power management module being in electrical communication with the energy storage device and the electric generation device; wherein determining the current temperature of the electric generation device further comprises: measuring an ambient temperature proximate the transport refrigeration system; transmitting the ambient temperature to the power management module; and determining the current temperature of the electric generation device in response to at least the ambient temperature; wherein the ambient temperature sensor is positioned within the transportation refrigeration unit.

14. The non-transitory computer program product of claim 13, wherein determining a current temperature of the electric generation device further comprises: measuring a current temperature of the electric generation device using a temperature sensor; and transmitting the current temperature to the power management module.

15. The non-transitory computer program product of claim 13, wherein the ambient temperature sensor is an ambient temperature sensor of the transportation refrigeration unit.

16. The non-transitory computer program product of claim 13, wherein the operations further comprise: detecting a rotational velocity of the electric generation device using a rotational velocity sensor, the rotational velocity sensor being in electrical communication with the power management module; and determining the current temperature of the electric generation device in response to at least the ambient temperature and the rotational velocity of the electric generation device.

17. The non-transitory computer program product of claim 13, wherein the operations further comprise: decreasing the torque limit of the electric generation device when the current temperature of the electric generation device is greater than a selected temperature.