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System and method for identifying a high-temperature condition of an electrical cable for an aircraft propulsion system

Abstract

An assembly for an aircraft propulsion system includes a propulsor, an electric motor, and an electrical distribution system. The electric motor is operably connected to the propulsor and operable to drive rotation of the propulsor. The electrical distribution system includes an electrical power source, an electrical cable, and a temperature protection assembly. The electrical cable electrically connects the electrical power source and the electric motor. The electrical cable extends through at least one thermal zone between the electrical power source and the electric motor. The temperature protection assembly includes a temperature sensor operable to sense a temperature in each thermal zone of the at least one thermal zone. The temperature protection assembly further includes a controller. The controller is configured to determine a zone temperature in the at least one thermal zone.

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Background/Summary

TECHNICAL FIELD

(1) This disclosure relates generally to electrical distribution systems for an aircraft propulsion system and, more particularly, to systems and methods for identifying a high-temperature condition of an electrical cable for an electrical distribution system.

BACKGROUND OF THE ART

(2) Propulsion systems for aircraft may include electrical loads such as electric motors configured to operate in combination with an engine to provide thrust for an associated aircraft. Operation of the electrical loads may contribute significant thermal energy to the electrical cables used to connect the electrical loads to a power source, thereby increasing an operational temperature of the electrical cables. Various systems and methods for facilitating electrical cable resistance to high-temperature conditions are known in the art. While these known systems and methods have various advantages, there is still room in the art for improvement.

SUMMARY

(3) It should be understood that any or all of the features or embodiments described herein can be used or combined in any combination with each and every other feature or embodiment described herein unless expressly noted otherwise.

(4) According to an aspect of the present disclosure, an assembly for an aircraft propulsion system includes a propulsor, an electric motor, and an electrical distribution system. The electric motor is operably connected to the propulsor and operable to drive rotation of the propulsor. The electrical distribution system includes an electrical power source, an electrical cable, and a temperature protection assembly. The electrical cable electrically connects the electrical power source and the electric motor. The electrical cable extends through at least one thermal zone between the electrical power source and the electric motor. The temperature protection assembly includes a temperature sensor operable to sense a temperature in each thermal zone of the at least one thermal zone. The temperature protection assembly further includes a controller. The controller includes a processor in communication with a non-transitory memory storing instructions, which instructions when executed by the processor, cause the processor to determine a zone temperature in the at least one thermal zone using the temperature sensor, determine an electrical current flow through the electrical cable, and estimate a temperature of the electrical cable within the at least one zone using the determined zone temperature of the at least one thermal zone and the determined electrical current flow.

(5) In any of the aspects or embodiments described above and herein, the at least one thermal zone may include a first thermal zone and a second thermal zone. The instructions, when executed by the processor, may further cause the processor to estimate the temperature of the electrical cable within the first thermal zone using the determined zone temperature of the first thermal zone and estimate the temperature of the electrical cable within the second thermal zone using the determined zone temperature of the second thermal zone.

(6) In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to identify a presence or an absence of a high-temperature condition for the electrical cable by comparing the estimated temperature of the electrical cable to a high-temperature threshold. The presence of the high-temperature condition may be identified where the estimated temperature of the electrical cable is greater than or equal to the high-temperature threshold.

(7) In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to generate a warning in response to identifying the presence of the high-temperature condition.

(8) In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to identify a power limit for the electric motor. The warning may include the power limit.

(9) In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to reduce an electrical power consumption of the electric motor in response to identification of the presence of the high-temperature condition.

(10) In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to record an amount of time the estimated temperature of the electrical cable is greater than or equal to the high-temperature threshold.

(11) In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to determine an initial zone temperature of the at least one thermal zone using the temperature sensor of each thermal zone of the at least one thermal zone, energize the electric motor to drive rotation of the propulsor, determine the zone temperature of the at least one thermal zone using the temperature sensor of each thermal zone of

the at least one thermal zone subsequent to energizing the electric motor, and estimate the temperature of the electrical cable within the at least one zone using the determined zone temperature of the at least one thermal zone, the initial zone temperature of the at least one thermal zone, and the determined electrical current flow.

(12) In any of the aspects or embodiments described above and herein, the electrical power source may be a motor controller for the electric motor.

(13) In any of the aspects or embodiments described above and herein, the electrical distribution system may include a cable bundle. The cable bundle may include a plurality of adjoined electrical cables disposed within the at least one thermal zone. The electrical cable may be one of the plurality of electrical cables.

(14) In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to determine a second electrical current flow through a second electrical cable of the plurality of electrical cables of the cable bundle using a second current sensor and estimate a second temperature of the second electrical cable within the at least one zone using the determined zone temperature of the at least one thermal zone and the determined second electrical current flow.

(15) In any of the aspects or embodiments described above and herein, the temperature protection assembly may include one of the temperature sensor disposed within each thermal zone of the at least one thermal zone, and the instructions, when executed by the processor, may further cause the processor to determine the zone temperature of the at least one thermal zone using the temperature sensor of each thermal zone of the at least one thermal zone.

(16) According to another aspect of the present disclosure, a method for identifying a high-temperature condition of an electrical cable of an electrical distribution system for an aircraft propulsion system is provided. The method includes determining an initial zone temperature of at least one thermal zone and energizing an electric motor to drive rotation of a propulsor of the aircraft propulsion system by supplying electrical power to the electric motor with an electrical cable of the electrical distribution system. The electrical cable extends through the at least one thermal zone. The method further includes determining a zone temperature of the at least one thermal zone subsequent to energizing the electric motor and while the electric motor is energized, determining an electrical current flow through the electrical cable, estimating a temperature of the electrical cable within the at least one zone using the determined zone temperature of the at least one thermal zone and the determined electrical current flow, and identifying a presence or an absence of the high-temperature condition for the electrical cable by comparing the estimated temperature of the electrical cable to a high-temperature threshold. The presence of the high-temperature condition is identified where the estimated temperature of the electrical cable is greater than or equal to the high-temperature threshold.

(17) In any of the aspects or embodiments described above and herein, the method may further include controlling the electric motor to reduce a torque or a rotation speed of the electric motor in response to identifying the presence of the high-temperature condition for the electrical cable.

(18) In any of the aspects or embodiments described above and herein, the method may further include operating an engine to drive rotation of the propulsor with an engine output shaft of the engine in combination with the electric motor and controlling the engine to increase a torque or a rotation speed of the engine output shaft in response to identifying the presence of the high-temperature condition of the electrical cable.

(19) According to another aspect of the present disclosure, an assembly for an aircraft propulsion system includes an electrical load and an electrical distribution system. The electrical distribution system includes an electrical power source, an electrical cable, and a temperature protection assembly. The electrical cable electrically connects the electrical power source and the electrical load. The electrical cable extends through at least one thermal zone between the electrical power source and the electrical load. The temperature protection assembly includes a temperature sensor

disposed within each thermal zone of the at least one thermal zone. The temperature protection assembly further includes a controller. The controller includes a processor in communication with a non-transitory memory storing instructions, which instructions when executed by the processor, cause the processor to determine an initial zone temperature of the at least one thermal zone using a temperature sensor of each thermal zone of the at least one thermal zone, energize the electrical load, determine a zone temperature of the at least one thermal zone using the temperature sensor of each thermal zone of the at least one thermal zone subsequent to energizing the electrical load, determine an electrical current flow through the electrical cable using a current sensor, and estimate a temperature of the electrical cable within the at least one zone using the determined zone temperature of the at least one thermal zone and the determined electrical current flow.

(20) In any of the aspects or embodiments described above and herein, the instructions, when executed by the processor, may further cause the processor to identify a presence or an absence of a high-temperature condition for the electrical cable by comparing the estimated temperature of the electrical cable to a high-temperature threshold. The presence of the high-temperature condition may be identified where the estimated temperature of the electrical cable is greater than or equal to the high-temperature threshold.

(21) In any of the aspects or embodiments described above and herein, the at least one thermal zone may include a first thermal zone and a second thermal zone. The instructions, when executed by the processor, may further cause the processor to estimate the temperature of the electrical cable within the first thermal zone using the determined zone temperature of the first thermal zone and estimate the temperature of the electrical cable within the second thermal zone using the determined zone temperature of the second thermal zone.

(22) In any of the aspects or embodiments described above and herein, the electrical power source may be a battery.

(23) In any of the aspects or embodiments described above and herein, the electrical power source may be a generator.

(24) The present disclosure, and all its aspects, embodiments and advantages associated therewith will become more readily apparent in view of the detailed description provided below, including the accompanying drawings.

Description

DESCRIPTION OF THE DRAWINGS

(1) FIG. 1 illustrates a perspective view of a portion of an aircraft including a propulsion system, in accordance with one or more embodiments of the present disclosure.

(2) FIG. 2 schematically illustrates a side view of an aircraft propulsion system including a gas turbine engine, in accordance with one or more embodiments of the present disclosure.

(3) FIG. 3 illustrates a cutaway view of an electrical cable bundle for an electrical distribution system for an aircraft propulsion system, in accordance with one or more embodiments of the present disclosure.

(4) FIG. 4 schematically illustrates an electrical distribution system for an aircraft propulsion system, in accordance with one or more embodiments of the present disclosure.

(5) FIG. 5 schematically illustrates another electrical distribution system for an aircraft propulsion system including an electric motor, in accordance with one or more embodiments of the present disclosure.

(6) FIG. 6 illustrates a block diagram depicting a method for identifying a high-temperature condition for an electrical cable of an electrical distribution system for an aircraft propulsion system, in accordance with one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

(7) FIGS. 1 and 2 illustrate a propulsion system **20** configured for an aircraft, such as the aircraft **1000** of FIG. 1. Briefly, the aircraft may be a fixed-wing aircraft (e.g., an airplane), a rotary-wing aircraft (e.g., a helicopter), a tilt-rotor aircraft, a tilt-wing aircraft, or any other aerial vehicle. Moreover, the aircraft may be a manned aerial vehicle or an unmanned aerial vehicle (UAV, e.g., a drone). The propulsion system **20** of FIG. 2 includes an engine **22**. The present disclosure, however, is not limited to propulsion systems which include an engine, and may also be applicable to propulsion systems driven solely by electrical power (e.g., battery-electric propulsion systems). The propulsion system **20** further includes at least a portion of an electrical distribution system **24**. The electrical distribution system **24** may be shared by the aircraft **1000** and/or one or more additional propulsion systems for the aircraft **1000**.

(8) FIG. 2 illustrates a side, cutaway view of the engine **22**. The engine **22** of FIG. 2 is configured as a hybrid-electric, turboprop gas turbine engine. However, the present disclosure may be equally applicable to other configurations of gas turbine engines such as, but not limited to, a turboshaft gas turbine engine, a turboprop gas turbine engine, a turbojet gas turbine engine, a propfan gas turbine engine, an open rotor gas turbine engine, an auxiliary power unit (APU), or the like. The present disclosure is also applicable to engines other than gas turbine engines such as, but not limited to, intermittent combustion engines (e.g., rotary engines, piston engines, etc.). Moreover, the present disclosure is not limited to use with hybrid-electric propulsion systems.

(9) The engine **22** of FIG. 2 includes an air inlet **26**, a compressor **28**, a combustor **30**, a high-pressure turbine **32**, a power turbine **34**, an exhaust **36**, an engine static structure **38**, and an electric motor **40**. The engine **22** may additionally include an electric generator **42**. The engine static structure **38** may include, for example, one or more engine cases for the engine **22**. The engine static structure **38** may additionally include cowlings, bearing assemblies, and/or other structural components of the engine **22**. The one or more engine cases form, house, and/or structurally support one or more of the air inlet **26**, the compressor **28**, the combustor **30**, the high-pressure turbine **32**, the power turbine **34**, the exhaust **36**, the electric motor **40**, and the electric generator **42**.

(10) Components of the engine **22**, such as components of the compressor **28**, the high-pressure turbine **32**, and the power turbine **34**, are arranged as a first rotational assembly **44** (e.g., a high-pressure spool) and a second rotational assembly **46** (e.g., a power spool). The first rotational assembly **44** and the second rotational assembly **46** are mounted for rotation about an axial centerline **48** (e.g., a rotational axis) of the engine **22** relative to the engine static structure **38**.

(11) The first rotational assembly **44** includes a first shaft **50**, a bladed compressor rotor **52** for the compressor **28**, and a bladed first turbine rotor **54** for the high-pressure turbine **32**. The first shaft **50** interconnects the bladed compressor rotor **52** and the bladed first turbine rotor **54**.

(12) The second rotational assembly **46** includes a second shaft **56** and a bladed second turbine rotor **58** for the power turbine **34**. The second shaft **56** (e.g., an engine output shaft) is connected to the bladed second turbine rotor **58**. The second shaft **56** operably connects the bladed second turbine rotor **58** with a propulsor or other rotational load of the propulsion system **20**. For example, the second shaft **56** of FIG. 2 operably connects the bladed second turbine rotor **58** with a propeller **60** of the propulsion system **20**. The second shaft **56** may be directly or indirectly connected to the propeller **60**. For example, the second shaft **56** may be interconnected with the propeller **60** by a reduction gear box (RGB) **62** configured to drive rotation of the propeller **60** at a reduced rotational speed relative to the second shaft **56**.

(13) During operation of the engine **22** of FIG. 2, ambient air enters the engine **22** through the air inlet **26** and is directed into the compressor **28**. The ambient air is compressed by the bladed compressor rotor **52** and directed into a combustion chamber of the combustor **30**. Fuel is injected into the combustion chamber and mixed with the compressed air to provide a fuel-air mixture. This fuel-air mixture is ignited, and combustion products thereof flow through and sequentially cause the bladed first turbine rotor **54** and the bladed second turbine rotor **58** to rotate. The rotation of the

bladed first turbine rotor **54** and the bladed second turbine rotor **58** respectively drive rotation of the first rotational assembly **44** and the second rotational assembly **46**. Rotation of the second rotational assembly **46** further drives rotation of the propeller **60** to provide propulsion for the propulsion system **20** and the aircraft **1000** (see FIG. 1). Combustion exhaust gas flowing past the bladed second turbine rotor **58** along is directed out of the engine **22** through the exhaust **36**.

(14) The electric motor **40** is electrically connected to the electrical distribution system **24** and configured to receive electrical power from the electrical distribution system **24** for operation of the electric motor **40**. The electric motor **40** is configured to apply a rotational force to the second rotational assembly **46**. The electric motor **40** may be directly or indirectly coupled to the second shaft **56** to drive the second shaft **56**, at least in part, by applying a rotational force to the second shaft **56**. For example, the electric motor **40** in combination with the bladed second turbine rotor **58** may provide the rotational force for driving the propeller **60**. The electric motor **40** of FIG. 2 is illustrated in direct contact with the second shaft **56**, however, the present disclosure is not limited to the exemplary configuration of the electric motor **40** of FIG. 2. For example, the electric motor **40** may be indirectly connected to the second shaft **56** by a gear box, a clutch assembly, or the like. The electric motor **40** may include or otherwise be electrically connected to a motor controller (e.g., an inverter), which motor controller may control electrical power (e.g., frequency, voltage, and/or current of the electrical power) supplied to the electric motor **40** from the electrical distribution system **24** to energize or deenergize the electric motor **40** and/or to control a rotation speed and/or torque of the electric motor **40**.

(15) As previously discussed, the engine **22** may additionally include the electric generator **42**. The electric generator **42** of FIG. 2 is configured to generate and supply electrical power to the electrical distribution system **24**. The electric generator **42** of FIG. 2, for example, is operably coupled to the first shaft **50**. For example, the electric generator **42** may be directly connected to the first shaft **50**. The electric generator **42** may alternatively be operably coupled to the first shaft **50** by an accessory gear box (not shown) or other speed-reducing gear assembly. The present disclosure is not limited to any particular operable connection between the first shaft **50** and the electric generator **42**. The first shaft **50** drives rotation of the electric generator **42** to generate electrical power for the electrical distribution system **24**. The electric generator **42** is electrically connected to the electrical distribution system **24** to supply electrical power for electrical loads of the propulsion system **20** and/or the aircraft **1000** (see FIG. 1). Electrical power for the electrical distribution system **24** may additionally or alternatively be provided by other electrical power sources which are independent of the propulsion system **20** such as, but not limited to, a generator of another propulsion system (e.g., for multi-propulsion-system aircraft), an auxiliary power unit (APU), a fuel cell (e.g., hydrogen fuel cell) assembly, or another power source disposed on the aircraft **1000** or otherwise outside of the propulsion system **20**, and/or a ground-based power supply (e.g., an airport electrical distribution system, generator, or other electrical power supply or battery charging device) external to the aircraft **1000**.

(16) The electrical distribution system **24** is configured to supply electrical power for electrical loads of the propulsion system **20** and/or the aircraft **1000** (see FIG. 1). For example, the electrical distribution system **24** of FIG. 2 supplies electrical power to the electric motor **40** for operation of the electric motor **40**. Examples of electrical loads for the aircraft **1000** include, but are not limited to, electronic control systems, environmental control systems, electric motors, lighting systems, communication systems, and the like. The electrical distribution system **24** of FIG. 2 includes a battery **64** and a temperature protection assembly **66**. The electrical distribution system **24** may include additional electrical components such as, but not limited to, breakers, contactors, transformers, alternating current (AC) to direct current (DC) conversion components, DC to AC conversion components, and the like to effect operation of the electrical distribution system **24** to supply electrical power to the electrical loads of the propulsion system **20** and/or the aircraft **1000**.

(17) The battery **64** is configured to selectively supply electrical power to electrical loads of the

electrical distribution system **24** independently or in combination with the electric generator **42** and/or other electrical power sources (e.g., an APU). The battery **64** may be disposed, for example, in the aircraft **1000** and/or its propulsion systems **20**. The battery **64** may include a plurality of battery modules (e.g., battery packs), battery cells, and/or the like electrically connected together in series and/or parallel as necessary to configure the battery **64** with the desired electrical characteristics (e.g., voltage output, current output, storage capacity, etc.). The battery **64** (e.g., and its battery cells) may be configured as a rechargeable battery having a battery chemistry such as, but not limited to, lead acid, nickel cadmium (NiCd), nickel-metal hydride (Ni-MH), lithium-ion (Li-ion), lithium-polymer (Li-poly), lithium metal, and the like. The present disclosure, however, is not limited to any particular configuration of the battery **64**.

(18) Referring to FIGS. **2** and **3**, electrical components of the propulsion system **20** (e.g., the electric motor **40**, the electric generator **42**, etc.), the electrical distribution system **24**, and the aircraft **1000** (see FIG. **1**) may be electrically interconnected by a plurality of electrically-conductive cables, wires, and the like (collectively referred to herein as “cables” or electrical cables”). FIG. **3** illustrates a cutaway view of a plurality of cables **68**. The cables **68** of FIG. **3** are arranged as a bundle **70** in which the plurality of cables **68** are adjoined with each of the cables **68** disposed at (e.g., on, adjacent, or proximate) at least another of the cables **68** for at least a portion of their respective lengths. The present disclosure, however, is not limited to the arrangement of cables **68** arranged in bundles **70**. Each of the cables **68** of FIG. **3** includes a conductor **72** and an insulation **74**. The conductor **72** is an electrically conductive material such as, but not limited to, metal (e.g., copper) wire. The insulation **74** is an electrical insulating material such as, but not limited to, a plastic material (e.g., a thermoplastic or thermoset material). The insulation surrounds the conductor **72**.

(19) The insulation for an electrical cable may be rated based on an intended voltage for the conductor of the electrical cable. For example, higher conductor voltages may require increasingly thick insulation. Degradation of the insulation can lead to unintended electrical discharges and other electrical hazards such as, but not limited to, electrical arcing, fires, electrocution, electrical component failure, and the like. Maintaining the quality of the insulation, therefore, facilitates a reduction in likelihood of the aforementioned unintended electrical discharges and other electrical hazards.

(20) One of the factors that may impact the quality and longevity of electrical cable insulation is the operating temperature of the insulation. The operating temperature of the insulation may be influenced, at least in part, by the operating temperature of the electrical cable conductor as well as the temperature of the environment surrounding the electrical cable. For example, the operating temperature to which the insulation may be exposed may be a function of electrical current flow through the conductor, the frequency of the electrical current (e.g., the “skin effect” for AC current), the proximity of the electrical cable conductor to an electrical cable conductor of another cable (e.g., the “proximity effect”), the quantity, proximity, and current flow of cables bundled cables, and the ambient temperature of the environment (e.g., based on cooling capability, altitude, proximity to an engine or other high-temperature system, etc.). Electrical cable insulation may additionally include a temperature rating based on the material or materials forming the insulation. As an example, some high-temperature insulation may support operating temperatures up to approximately 260 degrees Celsius (° C.). The present disclosure, however, is not limited to any particular electrical cable insulation temperature rating. Operating at or above the temperature rating of the insulation can degrade or otherwise negatively impact the insulation integrity and performance.

(21) FIG. **4** schematically illustrates an exemplary configuration of a portion of the electrical distribution system **24** and its temperature protection assembly **66**. The electrical distribution system **24** of FIG. **4** includes an electrical power source **76** electrically connected with an electrical power load **78** by one of the electrical cables **68** of the electrical distribution system **24**. As will be

discussed in further detail, the cable **68** may extend through a plurality of thermal zones **80** along its length between the electrical power source **76** and the electrical power load **78**. The cable **68** of FIG. **4** passes through five thermal zones **80** (e.g., Zones A-E) from the electrical power source **76** to the electrical power load **78**, however, the present disclosure is not limited to any particular number of thermal zones **80**. The different thermal zones **80** may represent different compartments, components, regions, or other portions of the aircraft **1000** (see FIG. **1**) and/or the propulsion system **20** (see FIG. **2**) which may have similar or different ambient temperatures or other thermal conditions. Examples of the thermal zones **80** include, but are not limited to, an aircraft fuselage, an aircraft wing, a propulsion system nacelle, an engine, and the like. The temperature protection assembly **66** includes a controller **82** and at least one temperature sensor **84**. The temperature protection assembly **66** may additionally include one or more electrical current flow sensors **86**.

(22) The controller **82** includes a processor **88** and memory **90**. The memory **90** is connected in signal communication with the processor **88**. The processor **88** may include any type of computing device, computational circuit, or any type of process or processing circuit capable of executing a series of instructions that are stored in memory **90**, thereby causing the processor **88** to perform or control one or more steps or other processes. The processor **88** may include multiple processors and/or multicore CPUs and may include any type of processor, such as a microprocessor, digital signal processor, co-processors, a micro-controller, a microcomputer, a central processing unit, a field programmable gate array, a programmable logic device, a state machine, logic circuitry, analog circuitry, digital circuitry, etc., and any combination thereof. The instructions stored in memory **90** may represent one or more algorithms for controlling aspects of the propulsion system **20**, the electrical distribution system **24**, and/or the temperature protection assembly **66**, and the stored instructions are not limited to any particular form (e.g., program files, system data, buffers, drivers, utilities, system programs, etc.) provided they can be executed by the processor **88**. The memory **90** may be a non-transitory computer readable storage medium configured to store instructions that when executed by one or more processors, cause the one or more processors to perform or cause the performance of certain functions. The memory **90** may be a single memory device or a plurality of memory devices. A memory device may include a storage area network, network attached storage, as well a disk drive, a read-only memory, random access memory, volatile memory, non-volatile memory, static memory, dynamic memory, flash memory, cache memory, and/or any device that stores digital information. One skilled in the art will appreciate, based on a review of this disclosure, that the implementation of the controller **82** may be achieved via the use of hardware, software, firmware, or any combination thereof. The controller **82** may also include input and output devices (e.g., keyboards, buttons, switches, touch screens, video monitors, sensor readouts, data ports, etc.) that enable the operator to input instructions, receive data, etc. The controller **82** may be located within the propulsion system **20**. Alternatively, the controller **82** may be located outside of the propulsion system **20** (e.g., on the aircraft **1000**; see FIG. **1**).

(23) The controller **82** may form or otherwise be part of an electronic engine controller (EEC) for the propulsion system **10**. The EEC may control operating parameters of the engine **22** including, but not limited to, fuel flow, stator vane position (e.g., variable compressor inlet guide vane (IGV) position), compressor air bleed valve position, propeller rotation speed, propeller blade pitch, etc. so as to control an engine power and/or thrust of the engine **22**. The EEC may modulate fuel flow to the combustor **30** to obtain a desired output power of the engine **22**. For example, the EEC may modulate the fuel flow using a closed-loop process in which an output power or other operating parameter of the engine **22** is measured and fuel flow is increased or decreased as a function of the measured output power or operational parameter. In some embodiments, the EEC may be part of a full authority digital engine control (FADEC) system for the propulsion system **20**.

(24) The temperature sensors **84** are connected in signal communication with the controller **82**. The temperature sensors **84** are configured, for example, to generate an output signal (e.g., a digital

signal, an electrical signal, etc.) representative of a temperature of the surrounding environment. The temperature sensors **84** may be configured, for example, as resistance temperature detectors (RTDs), thermocouples, thermal imagers, or the like, and the present disclosure is not limited to any particular configuration of the temperature sensors **84**. The temperature sensors **84** are configured to sense a temperature of the thermal zones **80**. As shown in FIG. 4, at least one of the temperature sensors **84** may be disposed within each thermal zone **80** (e.g., Zones A-E) through which the cable **68** extends. The temperature sensors **84** may be disposed at (e.g., on, adjacent, or proximate) the cable **68** or spaced from the cable **68** within the respective thermal zone **80**. Alternatively, the temperature sensors **84** may be disposed outside the thermal zones **80** with each of the temperature sensors **84** configured to sense a temperature in one or more of the thermal zones **80**. As previously discussed, the temperature protection assembly **66** may additionally include one or more of the electrical current flow sensors **86**. The electrical current flow sensors **86** may be configured to measure a current flow through the conductor **72** of the cable **68**. Alternatively, the controller **82** may be configured to receive a measured value of the current flow through the conductor **72** from another component of the electrical distribution system **24** or the electrical power load **78**. For example, the controller **82** may receive a measured value of the current flow from a motor controller, an inverter, a battery monitoring system (BMS), which is representative of the electrical current flow through the conductor **72**.

(25) FIG. 5 schematically illustrates another exemplary configuration of the electrical distribution system **24** and its temperature protection assembly **66**. The electrical distribution system **24** of FIG. 5 includes the battery **64** configured to supply electrical power to the electric motor **40** through a motor controller **92** of the electrical distribution system **24**. The motor controller **92** is configured to control electrical power (e.g., DC to AC conversion, frequency, voltage, and/or current of the electrical power) supplied to the electric motor **40** from the battery **64** to energize or deenergize the electric motor **40** and/or to control a rotation speed and/or torque of the electric motor **40**. The motor controller **92** of FIG. 5 is connected in signal communication with the controller **82**. The motor controller **92** may measure an electrical current flow supplied to the electric motor **40** and provide the measured electrical current flow to the controller **82**. The controller **82** may additionally control operation of the motor controller **92** to control a rotation speed and/or torque of the electric motor **40**. The battery **64** of FIG. 5 may be electrically connected to the motor controller **92** by a first cable **68A**, **68** and the motor controller **92** of FIG. 5 may be electrically connected to the electric motor **40** by a second cable **68B**, **68**. The temperature protection assembly **66** of FIG. 5 may include at least one first temperature sensor **84A**, **84** for the first cable **68A**, **68** (e.g., within one or more thermal zones **80** through which the first cable **68A**, **68** extends; see FIG. 4). The temperature protection assembly **66** of FIG. 5 may include at least one second temperature sensor **84B**, **84** for the second cable **68B**, **68** (e.g., within one or more thermal zones **80** through which the second cable **68B**, **68** extends; see FIG. 4). The present disclosure, however, is not limited to the foregoing exemplary configuration of the electrical distribution system **24** and the temperature protection assembly **66** of FIG. 5.

(26) Referring to FIGS. 4-6, a Method **600** for identifying a high-temperature condition of an electrical cable of an electrical distribution system for an aircraft propulsion system is provided. FIG. 6 illustrates a flowchart for the Method **600**. The Method **600** will be described herein, for example, with respect to the engine **22**, the electrical distribution system **24**, and the temperature protection assembly **66**. The processor **88** may execute instructions stored in memory **90**, thereby causing the controller **82** and/or its processor **88** to execute or otherwise control one or more steps of the Method **600**. However, it should be understood that the Method **600** is not limited to use with the engine **22**, the electrical distribution system **24**, and the temperature protection assembly **66**. Unless otherwise noted herein, it should be understood that the steps of Method **600** are not required to be performed in the specific sequence in which they are discussed below and, in some embodiments, the steps of Method **600** may be performed separately or simultaneously.

(27) Step **602** includes, optionally, measuring an initial temperature of one or more of the thermal zones **80** for the cable **68** using the temperature sensors **84**. The initial temperatures may be measured, for example, prior to (e.g., immediately prior to), concurrent with, or after (e.g., immediate after) initiating electrical current flow through the cable **68**, for example, by supplying electrical power to the electrical power load **78** (e.g., the electric motor **40**, the battery **64**, etc.) from the electrical power source **76** (e.g., the battery **64**, the electric generator **42** (see FIG. 2), the motor controller **92**, an APU of the aircraft **1000** (see FIG. 1), a ground-based electrical power system, etc.). For example, the initial temperatures may be measured after a command has been received (e.g., by the controller **82**) to energize the electrical power load **78** but while the electrical power load **78** is deenergized. Alternatively, the controller **82** may use a predetermined initial temperature of one or more of the thermal zones **80** for the cable **68**, for example, stored in memory **90**. A value of the predetermined initial temperature may be representative of an assumed or otherwise estimated temperature of the respective thermal zones **80** for the cable **68** (e.g., with the electrical power load **78** deenergized). The controller **82** may select one of a plurality of predetermined initial temperatures for each of the thermal zones **80** for the cable **68** based on one or more operating conditions of the aircraft **1000** and/or the propulsion system **20** (see FIGS. 1 and 2) such as, but not limited to, altitude, engine power, outside air temperature (OAT), or the like.

(28) Step **604** includes, optionally, energizing the electrical power load **78** by directing electrical current through the cable **68** to the electrical power load **78** (e.g., from the electrical power source **76**). For example, the controller **82** may control the motor controller **92** to apply electrical power to the electric motor **40** to cause the electric motor **40** to drive, at least in part, rotation of the propeller **60** (see FIG. 2). It should be understood, however, that aspects of the present disclosure Method **600** may also be performed for cables **68** and associated electrical power loads **78** which are deenergized to identify a high-temperature condition of the cables **68**.

(29) Step **606** includes measuring a temperature of one or more of the thermal zones **80** for the cable **68** using the temperature sensors **84**. Step **606** may further include measuring an electrical current flow through the cable **68**, for example, using the electrical current flow sensor **86** or another current flow measuring component of the electrical distribution system **24** or the electrical power load **78**. Alternatively, a value of the electrical current flow may be assumed, for example, based on a known electrical power consumption of the electrical power load **78**.

(30) Step **608** includes estimating a temperature of the cable **68** (e.g., the insulation **74**). Step **608** may first include estimating a temperature increase of the cable **68** relative to an initial temperature of the cable **68**. For example, the cable **68** may be assumed to have an initial temperature (e.g., a cable **68** temperature prior to supplying electrical power to the electrical power load **78**) which is the same as or substantially the same as the measured initial temperature or predetermined initial temperature of the one or more of the thermal zones **80** for the cable **68** (see Step **602**). The temperature increase of the cable **68** subsequent to energization may be estimated, for example, using the following equation [1]:

$$(31) \Delta T = \frac{I^2 R_{COND} t}{mC} + \Delta T_{ENV} + \Delta T_{INS}$$

where I is electrical current flow through the cable **68** (e.g., measured electrical current flow through the conductor **72**), R_{COND} is the electrical resistance of the conductor **72**, t is an amount of time (e.g., seconds) for which electrical current has been flowing through the cable **68** (e.g., to the electrical power load **78**), m is the mass of the conductor **72**, C is the specific heat capacity of the conductor **72**, ΔT_{ENV} is an estimated value of the temperature increase due to the ambient temperature of the thermal zone **80**, and ΔT_{INS} is an estimated value of the temperature increase due to the insulation **74**. The ΔT_{ENV} may be estimated, for example, using the measured temperature of the thermal zones **80** and a heat transfer coefficient h_{ENV} between the cable **68** and the surrounding environment (e.g., air, other cables **68** of a cable bundle **70** of the thermal zones **80**, structural components, etc.). The ΔT_{INS} may be estimated, for example, using the electrical resistance R_{INS} of the insulation **74** and a heat transfer

coefficient $h_{\text{sub.CABLE}}$ between the conductor **72** and the insulation **74**. Values of the electrical resistance $R_{\text{sub.COND}}$, the electrical resistance $R_{\text{sub.INS}}$, the mass m , the specific heat capacity C , and the heat transfer coefficients $h_{\text{sub.ENV}}$, $h_{\text{sub.CABLE}}$ may be known values or otherwise experimentally determined values. For example, routine experimentation and/or analysis may be performed by a person of ordinary skill in the art to determine suitable values of the electrical resistance $R_{\text{sub.COND}}$, the electrical resistance $R_{\text{sub.INS}}$, the mass m , the specific heat capacity C , and the heat transfer coefficients $h_{\text{sub.ENV}}$, $h_{\text{sub.CABLE}}$ for a particular aircraft **1000**, propulsion system **20**, electrical distribution system **24**, and cable **68**, in accordance with and as informed by one or more aspects of the present disclosure. Values of the electrical resistance $R_{\text{sub.COND}}$ may be corrected based on a measured frequency of the electrical current flow I through the cable **68** (e.g., for AC electrical systems). The electrical resistance $R_{\text{sub.COND}}$ may increase as the electrical current flow I increases, for example, due to the skin effect. The controller **82** may estimate the temperature of the cable **68** for each thermal zone **80** by adding the estimated temperature increase ΔT of the cable **68** for each thermal zone **80** to the measured or predetermined initial temperature for each thermal zone **80**. The estimated temperature of the cable **68** may be provided to a pilot or other operator of the aircraft **1000** (see FIG. 1). For example, the estimated temperature of the cable **68** for the electric motor **40** may facilitate control by the pilot or other operator to maximize a propulsion power of the propulsion system **20** without exceeding a temperature limit of the cable **68**.

(32) Step **610** includes identifying a presence or an absence of a high-temperature condition for the cable **68**. The controller **82** may compare the estimated temperature of the cable **68** (see Step **608**) to a high-temperature threshold value. The controller **82** may identify the presence of the high-temperature condition for the cable **68**, for example, where the estimated temperature of the cable **68** is greater than or equal to the high-temperature threshold value. The controller **82** may identify the absence of the high-temperature condition for the cable **68**, for example, where the estimated temperature of the cable **68** is less than the high-temperature threshold value. The controller **82** may identify the presence or the absence of a high-temperature condition for one, more than one, or each thermal zone **80** that the cable **68** passes through. The high-temperature threshold value may be selected based on a temperature rating for the cable **68**. For example, the high-temperature threshold value may be selected with a margin between the high-temperature threshold value and the temperature rating for the cable **68** to prevent exceeding the temperature rating.

(33) Step **612** includes one or more corrective actions in response to identification of the presence of the high-temperature condition for the cable **68**. The controller **82** may generate a warning (e.g., an audible alarm, a warning light, etc.) for a pilot or other operator of the aircraft **1000** (see FIG. 1). The controller **82** may identify a power limit for the electrical power load **78** (e.g., the electric motor **40**), which power limit may be selected to facilitate a reduction of the cable **68** temperature below the high-temperature threshold value. The controller **82** may provide the power limit to the pilot or other operator of the aircraft **1000** with the warning.

(34) The controller **82** may control a power output of the electric motor **40** and/or the engine **22** in response to identification of the presence of the high-temperature condition of the cable **68** for the electric motor **40**. The controller **82** may control the electric motor **40** (e.g., using the motor controller **92**) to reduce a power output (e.g., a torque or rotational speed) of the electric motor **40**. Additionally, the controller **82** may increase a power output of the engine **22** (e.g., by increasing fuel flow to the combustor **30**; see FIG. 2), in combination with reducing the power output of the electric motor **40**, to maintain a constant or substantially constant rotational speed of the second shaft **56** (see FIG. 2).

(35) The controller **82** may measure and record an amount of time that the presence of the high-temperature condition is identified for the cable **68**. The controller **82** may additionally or alternatively measure and record the estimated temperature values of the cable **68** in excess of the high-temperature threshold value. The times and/or estimated temperatures of the cable **68** for the

high-temperature condition may be used by the controller 82 or maintenance personnel to identify a material condition of the cable 68, estimated an amount of cable 68 operational life remaining, and/or to determine that an inspection or replacement of the cable 68 should be performed.

(36) While the principles of the disclosure have been described above in connection with specific apparatuses and methods, it is to be clearly understood that this description is made only by way of example and not as limitation on the scope of the disclosure. Specific details are given in the above description to provide a thorough understanding of the embodiments. However, it is understood that the embodiments may be practiced without these specific details.

(37) It is noted that the embodiments may be described as a process which is depicted as a flowchart, a flow diagram, a block diagram, etc. Although any one of these structures may describe the operations as a sequential process, many of the operations can be performed in parallel or concurrently. In addition, the order of the operations may be rearranged. A process may correspond to a method, a function, a procedure, a subroutine, a subprogram, etc.

(38) The singular forms “a,” “an,” and “the” refer to one or more than one, unless the context clearly dictates otherwise. For example, the term “comprising a specimen” includes single or plural specimens and is considered equivalent to the phrase “comprising at least one specimen.” The term “or” refers to a single element of stated alternative elements or a combination of two or more elements unless the context clearly indicates otherwise. As used herein, “comprises” means “includes.” Thus, “comprising A or B,” means “including A or B, or A and B,” without excluding additional elements.

(39) It is noted that various connections are set forth between elements in the present description and drawings (the contents of which are included in this disclosure by way of reference). It is noted that these connections are general and, unless specified otherwise, may be direct or indirect and that this specification is not intended to be limiting in this respect. Any reference to attached, fixed, connected, or the like may include permanent, removable, temporary, partial, full and/or any other possible attachment option.

(40) No element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. No claim element herein is to be construed under the provisions of 35 U.S.C. 112 (f) unless the element is expressly recited using the phrase “means for.” As used herein, the terms “comprise”, “comprising”, or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.

(41) While various inventive aspects, concepts and features of the disclosures may be described and illustrated herein as embodied in combination in the exemplary embodiments, these various aspects, concepts, and features may be used in many alternative embodiments, either individually or in various combinations and sub-combinations thereof. Unless expressly excluded herein all such combinations and sub-combinations are intended to be within the scope of the present application. Still further, while various alternative embodiments as to the various aspects, concepts, and features of the disclosures—such as alternative materials, structures, configurations, methods, devices, and components, and so on—may be described herein, such descriptions are not intended to be a complete or exhaustive list of available alternative embodiments, whether presently known or later developed. Those skilled in the art may readily adopt one or more of the inventive aspects, concepts, or features into additional embodiments and uses within the scope of the present application even if such embodiments are not expressly disclosed herein. For example, in the exemplary embodiments described above within the Detailed Description portion of the present specification, elements may be described as individual units and shown as independent of one another to facilitate the description. In alternative embodiments, such elements may be configured as combined elements.

Claims

1. An assembly for an aircraft propulsion system, the assembly comprising: a propulsor; an electric motor operably connected to the propulsor and operable to drive rotation of the propulsor; and an electrical distribution system including an electrical power source, an electrical cable, and a temperature protection assembly, the electrical cable electrically connects the electrical power source and the electric motor, and the electrical cable extends through at least one thermal zone between the electrical power source and the electric motor, and the temperature protection assembly includes a temperature sensor operable to sense a temperature in each thermal zone of the at least one thermal zone, and the temperature protection assembly further includes a controller, the controller includes a processor in communication with a non-transitory memory storing instructions, which instructions when executed by the processor, cause the processor to: determine a zone temperature in the at least one thermal zone using the temperature sensor; determine an electrical current flow through the electrical cable; and estimate a temperature of the electrical cable within the at least one zone using the determined zone temperature of the at least one thermal zone and the determined electrical current flow.
2. The assembly of claim 1, wherein the at least one thermal zone includes a first thermal zone and a second thermal zone, and the instructions, when executed by the processor, further cause the processor to: estimate the temperature of the electrical cable within the first thermal zone using the determined zone temperature of the first thermal zone; and estimate the temperature of the electrical cable within the second thermal zone using the determined zone temperature of the second thermal zone.
3. The assembly of claim 1, wherein the instructions, when executed by the processor, further cause the processor to identify a presence or an absence of a high-temperature condition for the electrical cable by comparing the estimated temperature of the electrical cable to a high-temperature threshold, and wherein the presence of the high-temperature condition is identified where the estimated temperature of the electrical cable is greater than or equal to the high-temperature threshold.
4. The assembly of claim 3, wherein the instructions, when executed by the processor, further cause the processor to generate a warning in response to identifying the presence of the high-temperature condition.
5. The assembly of claim 4, wherein the instructions, when executed by the processor, further cause the processor to identify a power limit for the electric motor, and the warning includes the power limit.
6. The assembly of claim 3, wherein the instructions, when executed by the processor, further cause the processor to reduce an electrical power consumption of the electric motor in response to identification of the presence of the high-temperature condition.
7. The assembly of claim 3, wherein the instructions, when executed by the processor, further cause the processor to record an amount of time the estimated temperature of the electrical cable is greater than or equal to the high-temperature threshold.
8. The assembly of claim 1, wherein the instructions, when executed by the processor, further cause the processor to: determine an initial zone temperature of the at least one thermal zone using the temperature sensor of each thermal zone of the at least one thermal zone; energize the electric motor to drive rotation of the propulsor; determine the zone temperature of the at least one thermal zone using the temperature sensor of each thermal zone of the at least one thermal zone subsequent to energizing the electric motor; and estimate the temperature of the electrical cable within the at least one zone using the determined zone temperature of the at least one thermal zone, the initial zone temperature of the at least one thermal zone, and the determined electrical current flow.
9. The assembly of claim 1, wherein the electrical power source is a motor controller for the

electric motor.

10. The assembly of claim 1, wherein the electrical distribution system includes a cable bundle, the cable bundle includes a plurality of adjoined electrical cables disposed within the at least one thermal zone, and the electrical cable is one of the plurality of electrical cables.

11. The assembly of claim 10, wherein the instructions, when executed by the processor, further cause the processor to: determine a second electrical current flow through a second electrical cable of the plurality of electrical cables of the cable bundle using a second current sensor; and estimate a second temperature of the second electrical cable within the at least one zone using the determined zone temperature of the at least one thermal zone and the determined second electrical current flow.

12. The assembly of claim 1, wherein the temperature protection assembly includes one of the temperature sensor disposed within each thermal zone of the at least one thermal zone, and the instructions, when executed by the processor, further cause the processor to determine the zone temperature of the at least one thermal zone using the temperature sensor of each thermal zone of the at least one thermal zone.

13. A method for identifying a high-temperature condition of an electrical cable of an electrical distribution system for an aircraft propulsion system, the method comprising: determining an initial zone temperature of at least one thermal zone; energizing an electric motor to drive rotation of a propulsor of the aircraft propulsion system by supplying electrical power to the electric motor with an electrical cable of the electrical distribution system, and the electrical cable extends through the at least one thermal zone; determining a zone temperature of the at least one thermal zone subsequent to energizing the electric motor and while the electric motor is energized; determining an electrical current flow through the electrical cable; estimating a temperature of the electrical cable within the at least one zone using the determined zone temperature of the at least one thermal zone and the determined electrical current flow; and identifying a presence or an absence of the high-temperature condition for the electrical cable by comparing the estimated temperature of the electrical cable to a high-temperature threshold, and wherein the presence of the high-temperature condition is identified where the estimated temperature of the electrical cable is greater than or equal to the high-temperature threshold.

14. The method of claim 13, further comprising controlling the electric motor to reduce a torque or a rotation speed of the electric motor in response to identifying the presence of the high-temperature condition for the electrical cable.

15. The method of claim 14, further comprising: operating an engine to drive rotation of the propulsor with an engine output shaft of the engine in combination with the electric motor; and controlling the engine to increase a torque or a rotation speed of the engine output shaft in response to identifying the presence of the high-temperature condition of the electrical cable.

16. An assembly for an aircraft propulsion system, the assembly comprising: an electrical load; and an electrical distribution system including an electrical power source, an electrical cable, and a temperature protection assembly, the electrical cable electrically connects the electrical power source and the electrical load, and the electrical cable extends through at least one thermal zone between the electrical power source and the electrical load, and the temperature protection assembly includes a temperature sensor disposed within each thermal zone of the at least one thermal zone, and the temperature protection assembly further includes a controller, the controller includes a processor in communication with a non-transitory memory storing instructions, which instructions when executed by the processor, cause the processor to: determine an initial zone temperature of the at least one thermal zone using a temperature sensor of each thermal zone of the at least one thermal zone; energize the electrical load; determine a zone temperature of the at least one thermal zone using the temperature sensor of each thermal zone of the at least one thermal zone subsequent to energizing the electrical load; determine an electrical current flow through the electrical cable using a current sensor; and estimate a temperature of the electrical cable within the at least one zone using the determined zone temperature of the at least one thermal zone and the

determined electrical current flow.

17. The assembly of claim 16, wherein the instructions, when executed by the processor, further cause the processor to identify a presence or an absence of a high-temperature condition for the electrical cable by comparing the estimated temperature of the electrical cable to a high-temperature threshold, and wherein the presence of the high-temperature condition is identified where the estimated temperature of the electrical cable is greater than or equal to the high-temperature threshold.

18. The assembly of claim 16, wherein the at least one thermal zone includes a first thermal zone and a second thermal zone, and the instructions, when executed by the processor, further cause the processor to: estimate the temperature of the electrical cable within the first thermal zone using the determined zone temperature of the first thermal zone; and estimate the temperature of the electrical cable within the second thermal zone using the determined zone temperature of the second thermal zone.

19. The assembly of claim 16, wherein the electrical power source is a battery.

20. The assembly of claim 16, wherein the electrical power source is a generator.
