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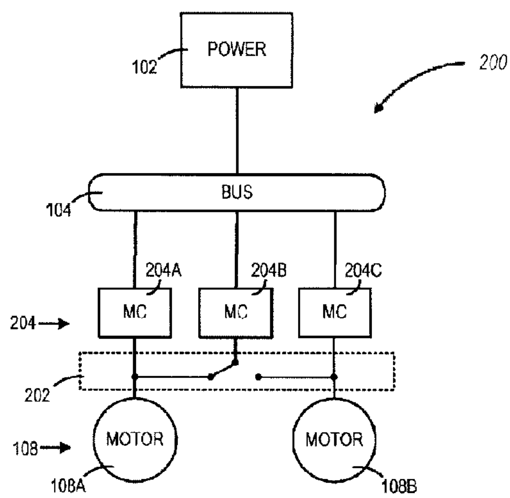
(54) Title: SYSTEMS AND METHODS FOR THE CONTROL AND OPERATION OF A PARALLEL MOTOR CONTROLLER ARCHITECTURE



(57) Abrégé/Abstract:
In a system of electric motors and motor controllers that supply power to the motors load shedding involves defining a plurality of operational modes, each associated with operation of a respective combination of motors, a respective power requirement and a respective relative priority level. When sufficient power to supply the power requirement associated with the mode is not available, power is supplied to the motors according to the relative priority level of the requested mode. When the requested mode has a priority level lower than the priority level of all other modes currently in operation, power less than the power requirement associated with the requested mode is supplied to the motors associated with the requested mode. When the requested mode has a priority level higher than at least one other mode certain motors associated with the modes having lower priority levels are shut off or operated at reduced power and power is redirected to the motors associated with the requested mode.

ABSTRACT

In a system of electric motors and motor controllers that supply power to the motors load shedding involves defining a plurality of operational modes, each associated with operation of a respective combination of motors, a respective power requirement and a respective relative priority level. When sufficient power to supply the power requirement associated with the mode is not available, power is supplied to the motors according to the relative priority level of the requested mode. When the requested mode has a priority level lower than the priority level of all other modes currently in operation, power less than the power requirement associated with the requested mode is supplied to the motors associated with the requested mode. When the requested mode has a priority level higher than at least one other mode certain motors associated with the modes having lower priority levels are shut off or operated at reduced power and power is redirected to the motors associated with the requested mode.

SYSTEMS AND METHODS FOR THE CONTROL AND OPERATION OF A PARALLEL MOTOR CONTROLLER ARCHITECTURE

TECHNICAL FIELD

[0001] Electrical power conversion systems, motor control and distribution systems.

BACKGROUND

[0002] Motors are used in a large variety of applications. In many applications, a motor is connected to a motor controller that performs a particular function for managing the operations of the motor. For example, motors in aircraft are used to drive control surfaces, environmental systems, and many other systems. These motors typically each receive electrical power from a dedicated motor controller connected in-line between the motor and a power source. The motor controller may include any combination of rectifiers, inverters, and filters that condition the electrical signal received from the power source for use by the motor.

[0003] In aircraft and other vehicle platforms, there is typically one dedicated motor controller installed within the vehicle for every motor. Each motor controller is sized according to the peak power load demand of the motor that is serviced by the motor controller. For example, a **100** kilowatt (kW) motor would require a **100** kW motor controller, which is a motor controller that is capable of conditioning and providing **100** kW to the motor.

[0004] Motor controllers can be relatively heavy equipment. Various components of the motor controllers, such as input and output filters, significantly increase the overall weight of each controller. Because the weight of the motor controllers is substantially proportional to the power rating of the controller, the higher the power rating of the motor controller, the heavier the motor controller will be.

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[0005] It is with respect to these considerations and others that the disclosure made herein is presented.

SUMMARY

[0006] In one embodiment, there is provided a method of load shedding in a system of electric motors and motor controllers that supply power to the motors. The method involves defining a plurality of operational modes, each mode associated with operation of a respective group of motors, each mode associated with a respective power requirement and each mode associated with a respective relative priority level relative to each other. The method further involves, in response to a request to operate the group of motors in a particular mode, when sufficient power is available to supply the power requirement associated with the requested mode, causing one or more of the motor controllers to supply the power requirement of the requested mode to the group of motors associated with the requested mode. The method further involves, in response to a request to operate the group of motors in a particular mode, when sufficient power to supply the power requirement associated with the requested mode is not available, causing the controllers to supply power to the group of motors according to the relative priority level of the requested mode, such that: when the requested mode has a priority level lower than the priority level of all other modes currently in operation, the controllers supply less than the power requirement associated with the requested mode to the group of motors associated with the requested mode; when the requested mode has a priority level higher than at least one other mode, determining which of the motors associated with the modes having priority levels lower than the requested mode can be shut off or operated at reduced power to enable power to be redirected from at least some of the motors associated with the modes having a lower priority level than the requested mode to the group of motors associated with the requested mode; and causing the controllers to re-direct power from at least some of the motors associated with the

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modes having lower priority levels than the requested mode to the group of motors associated with the requested mode.

[0006a] In another embodiment, there is provided a computer readable medium storing instructions that when executed by a processor cause the processor to execute the method described above or any of its variants.

[0006b] In another embodiment, there is provided a system including a processor and the computer readable medium described above. The processor and the computer readable medium are configured to execute the method described above or any of its variants.

[0006c] In another embodiment, there is provided a motor control apparatus for controlling load shedding in a system of electric motors and motor controllers that supply power to the motors. The apparatus includes means for defining a plurality of operational modes, each mode associated with operation of a respective group of motors, each mode associated with a respective power requirement and each mode associated with a respective relative priority level relative to each other. The apparatus further includes means for receiving a request to operate the group of motors in a particular mode and means for causing one or more of the motor controllers to supply the power requirement of the requested mode to the group of motors associated with the requested mode, when sufficient power is available to supply the power requirement associated with the requested mode. The apparatus further includes means for causing the controllers to supply power to the group of motors according to the relative priority level of the requested mode when sufficient power to supply the power requirement associated with the requested mode is not available, such that: when the requested mode has a priority level lower than the priority level of all other modes currently in operation, a signal is sent to the controllers to cause the controllers to supply less than the power requirement associated with the requested mode to the group of motors associated with the requested mode; and when the requested mode has a priority level higher than at least one other mode, a determination is made to determine which of the motors associated with the modes having priority levels lower than the requested mode can be shut off or operated at reduced power to enable power to be redirected from at least some of the motors associated with the modes having a lower priority level than the requested mode to the group of motors associated with the requested mode. The apparatus further includes means for causing the controllers to re-direct power from at least some of the motors associated with the modes having lower priority levels than the requested mode to the group of motors associated with the requested mode.

[0006d] In another embodiment, there is provided a method for controlling a plurality of motors in a motor control system including a plurality of motor controllers, a power switching network electrically connecting the motors to the plurality of motor controllers, and a computer for controlling the power switching network and the motor controllers to simultaneously operate the motors in a plurality of different modes of operation. The method involves: causing the computer to receive a communication including an identification of a requested mode of operation and an identification of a requested mode power amount; causing the computer to calculate a maximum power capacity based at least in part on a total number of motor controllers in the motor control system and a power amount associated with each motor controller; and causing the computer to calculate a current power usage based at least in part on current modes of operation in which the motors are currently operating and a total power consumption resulting from operating the motors in the current modes. The method further involves: causing the computer to determine a current power capacity that is currently available to operate the motors in additional modes of operation by finding a difference between a maximum power capacity of the motor control system and the current power usage; and causing the computer to cause at least one motor of the motors to operate in the requested mode in addition to the other ones of the motors operating in the current modes. If the current power capacity is not less than an additional power consumed as result of operating the at least one motor in the requested mode, then the method further involves causing the computer to reduce the current power capacity to account for

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power consumed as result of operating the at least one motors in the requested mode. If the current power capacity is less than the additional power consumed as result of operating the at least one motor in the requested mode, then the method further involves causing the computer to determine a priority of the requested mode relative to a priority of all other current modes currently in operation. If the priority of the requested mode is less than or equal to the priority of all the other current modes, then the method further involves causing the computer to cause the at least one motor to operate in the requested mode at only the current power capacity and reduce the current power capacity to account for the additional power consumed as result of operating the at least one motor in the requested mode. If the priority of the requested mode is not less than or equal to the priority of all the other current modes, then the method further involves causing the computer to determine if any of the current modes are lower priority modes having a priority lower than the priority of the requested mode. If there are any such lower priority modes, then the method further involves causing the computer to determine if any of the lower priority modes are first least priority modes having a priority only a single level lower than the priority of the requested mode. If there are any such first least priority modes, then the method further involves causing the computer to determine a total power that is consumed as result of the motors operating in those first least priority modes; and determine if it is possible to partially reduce the total power consumed as result of the motors operating in the first least priority modes. If it is possible to make a partial reduction of the total power consumed as result of the motors operating in the first least priority modes, then the method further involves causing the computer to: partially reduce the total power consumed as result of the motors operating in the first least priority modes; direct power to the at least one motor operating in the requested mode, in an amount based on the partial reduction in the total power consumed as result of the motors operating in the first least priority modes; and set the current power capacity to zero. If it is not possible to make the partial reduction of the total power consumed as result of the motors operating in the first least priority modes, then the method further involves causing the computer to:

completely reduce the total power consumed as result of the motors operating in the first least priority modes; direct power to the at least one motor operating in the requested mode, in an amount based on a complete reduction of the total power consumed as result of the motors operating in the first least priority modes; and set the current power capacity to zero. The method further involves causing the computer to determine if any of the current modes are also second least priority modes having a priority between the first least priority modes and the priority of the requested mode. If there are any such second least priority modes, then the method further involves causing the computer to determine if it is possible to partially reduce the total power consumed as result of the motors operating in the first least priority modes. If it is possible to make a partial reduction of the power consumed as result of the motors operating in the first least priority modes, then the method further involves causing the computer to: partially reduce the total power consumed as result of the motors operating in the first least priority modes; and direct power to the at least one motor operating in the requested mode, in an amount based on the partial reduction of the total power consumed as result of the motors operating in the first least priority modes. If it is not possible to make a partial reduction of the total power consumed as result of the motors operating in the first least priority modes, then the method further involves causing the computer to: completely reduce the total power consumed as result of the motors operating in the first least priority modes; determine a total power consumed as result of the motors operating in the second least priority modes; and determine if it is possible to partially reduce the total power consumed as result of the motors operating in the second least priority modes. If it is possible to make a partial reduction of the total power consumed as result of the motors operating in the second least priority modes, then the method further involves causing the computer to: partially reduce the total power consumed as result of the motors operating in the second least priority modes; and direct power to the at least one motor operating in the requested mode, in an amount based on a complete reduction of the total power consumed as result of the motors operating in the first least priority modes and partial reduction of the total power consumed as result of operating the motors in the second least priority modes. If it is not possible to make the partial reduction of the total power consumed as result of operating the motors in the second least priority modes, then the method further involves causing the computer to: completely reduce the total power consumed as result of the motors operating in the second least priority modes; direct power to the at least one motor operating in the requested mode, in an amount based on the complete reduction of the total power consumed as result of the motors operating in the first least priority modes and a complete reduction of the total power consumed as result of the motors operating in the second least priority modes; and set the current power capacity to zero.

[0006e] In another embodiment, there is provided a computer-readable medium storing instructions that, when executed by a computer in a motor control system including a plurality of motor controllers, a power switching network electrically connecting a plurality of motors to the plurality of motor controllers, cause the computer to execute the method described above or any of its variants.

[0006f] In another embodiment, there is provided a motor control system for controlling a plurality of motors. The motor control system includes: a plurality of motor controllers; a power switching network electrically connecting the motors to the plurality of motor controllers; a computer for controlling the power switching network and the motor controllers to simultaneously operate the motors in a plurality of different modes of operation; and the computer-readable medium described above. The computer and the computer-readable medium described above are configured, when executed by the computer, to cause the computer to execute the method described above or any of its variants.

[0007] The features, functions, and advantages that have been discussed can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments, further details of which can be seen with reference to the following description, the accompanying drawings and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1** is a block diagram showing a conventional motor controller architecture;

[0009] FIG. **2** is a block diagram showing a parallel motor controller architecture according to various embodiments presented herein;

[0010] FIG. **3** is a power load chart showing an graph of a power load requirement of a cabin air compressor versus a hydraulic motor pump during different phases of aircraft flight according to various embodiments presented herein;

[0011] FIGS. **4**A-**4**E are block diagrams showing examples of motor controller switching architectures according to various embodiments presented herein;

[0012] FIGS. **5**A-**5**C are block diagrams showing implementations utilizing alternative placements of output filter within a motor controller system according to various embodiments presented herein;

[0013] FIG. **6** is a flow diagram illustrating a prior art method for controlling a group of motors;

[0014] FIG. **7** is a flow diagram illustrating an embodiment elaborating on the control and operation of the prior art method for controlling a group of motors;

[0015] FIG. **8** is a flow diagram illustrating an embodiment elaborating on the control and operation of the prior art method for controlling a group of motors, specifically directed to a novel main engine electric start operating logic;

[0016] FIG. **9** is a flow diagram illustrating an embodiment elaborating on the control and operation of the prior art method for controlling a group of motors, specifically directed to a novel Auxiliary Power Unit engine electric start operating logic;

[0017] FIG. **10** is a flow diagram illustrating an embodiment elaborating on the control and operation of the prior art method for controlling a group of motors, specifically directed to a novel battery sourced Auxiliary Power Unit engine electric start operating logic;

[0018] FIG. **11** is a flow diagram illustrating an embodiment elaborating on the control and operation of the prior art method for controlling a group of motors, specifically directed to a novel electric taxiing operating logic;

[0019] FIG. **12** is a flow diagram illustrating an embodiment elaborating on the control and operation of the prior art method for controlling a group of motors, specifically directed to a novel cabin air compressor operating logic;

[0020] FIG. **13** is a flow diagram illustrating an embodiment elaborating on the control and operation of the prior art method for controlling a group of motors, specifically directed to a novel hydraulic pump operating logic;

[0021] FIG. **14** is a flow diagram illustrating an embodiment elaborating on the control and operation of the prior art method for controlling a group of motors, specifically directed to a novel nitrogen generation system operating logic;

[0022] FIG. **15** is a flow diagram illustrating an embodiment elaborating on the control and operation of the prior art method for controlling a group of motors, specifically directed to a novel environmental control system fan operating logic;

[0023] FIG. **16** is a flow diagram illustrating an embodiment elaborating on the control and operation of the prior art method for controlling a group of motors, specifically directed to a novel cargo refrigeration system operating logic;

[0024] FIG. **17** is a flow diagram illustrating an embodiment elaborating on the control and operation of the prior art method for controlling a group of motors, specifically directed to a novel load shed and reconfiguration operating logic; and

[0025] FIG. **18** is a computer architecture diagram showing an illustrative computer hardware and software architecture for a computing system capable of implementing aspects of the embodiments presented herein.

DETAILED DESCRIPTION

[0026] Motors typically include a motor controller for configuring and providing power to the motor. In a system that includes a group of motors, there are typically an identical number of motors and motor controllers. The motor controllers are most often rated to provide a peak power load that is equivalent to or greater than the peak load of the corresponding motor.

[0027] Utilizing the concepts and technologies described herein, a system of motors includes a number of motor controllers connected in parallel to a power switching network. By utilizing this architecture as described below, the number of motor controllers and/or the power rating, or power output capability, of each motor controller may be reduced in such a manner as to reduce the overall weight of the motor system. Throughout this disclosure, embodiments are described with respect to motors and motor controllers utilized within an aircraft. An aircraft environment provides a useful example for embodiments described herein since reducing weight of an aircraft is a universal objective. However, it should be understood that the concepts presented herein are equally applicable to motor systems within any platform, including ships, vehicles, or any other platform in which size and/or weight reduction is a consideration.

[0028] In the following detailed description, reference is made to the accompanying drawings that form a part hereof, and which are shown by way of illustration, specific embodiments, or examples. Referring now to the drawings, in which like numerals represent like elements through the several figures, a parallel motor controller architecture will be described. FIG. **1** shows a conventional architecture **100** of motor controllers for providing power to motors **108**. According to the conventional

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architecture **100**, a power source **102** provides power to a bus **104**, which directs power to any number of conventional motor controllers **106**.

[0029] It should be appreciated that for clarity, only two conventional motor controllers **106**A and **106**B and corresponding motors **108**A and **108**B are shown. Each conventional motor controller **106** conditions the received power signal for use by a single connected motor **108**. In the example shown, the conventional motor controller **106**A provides power to the motor **108**A, while the conventional motor controller **106**B provides power to the motor **108**B.

[0030] For illustrative purposes, the conventional architecture **100** may be implemented within an aircraft. According to this implementation, the power source **102** provides an alternating current (AC) or a direct current (DC) signal to the conventional motor controllers **106**. Example conventional motor controllers **106**A and **106**B include, but are not limited to, a cabin air compressor motor controller, a hydraulic electric motor pump motor controller, a generator engine starting motor controller, a nitrogen generation system compressor motor controller, a fan motor controller, and a flight controls actuator motor controller. It should be appreciated that any type of motor controllers **106** and motors **108** may be utilized within any type of vehicle or other platform without departing from the scope of this disclosure.

[0031] Looking now at FIG. **2**, a parallel motor controller architecture **200** will be described according to various embodiments. Similar to the example conventional architecture **100** shown in FIG. **1**, the parallel motor controller architecture **200** includes the power source **102**, the bus **104**, and the motors **108**. However, in the parallel motor controller architecture **200**, there are multiple parallel motor controllers **204** that are connected in parallel to a power switching network **202**. The power switching network **202** provides power from the parallel motor controllers **204** to the motors **108**. The power switching network **202** includes an electrical circuit that electrically connects the parallel motor controllers **204** to the motors **108** via a series of electrical switches that enable any number of parallel motor controllers **204** to be connected to any given motor **108**. The power switching network **202** may

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include or be connected to a computing device that controls the electronic switches to couple parallel motor controllers **204** as necessary to provide adequate power to the motors **108** according to the present power load requirements of the motors **108** as they change at any given instant in time. The operations of the power switching network **202** will be described in greater detail below.

[0032] In the example shown in FIG. **2**, the three parallel motor controllers **204** each have a power output capability that is lower than that of the conventional motor controllers **106** shown in FIG. **1**. For example, the parallel motor controllers **204**A, **204**B, and **204**C may each be capable of providing **50** kW of power such that the combined power output capability of the motor controllers **204** is **150** kW. In contrast, the conventional architecture **100** of FIG. **1** utilizes two conventional motor controllers **106**A and **106**B, each having a power output capability of **100** kW for a combined power output capability of **200** kW. Because the weight of the motor controllers is typically proportional to the power output capability, the parallel motor controller architecture **200** shown in FIG. **2** may weigh less than the conventional architecture **100** shown in FIG. **1**, even though three parallel motor controllers **204** are utilized in the parallel motor controller architecture **200** as opposed to two conventional parallel motor controllers **106** utilized in the conventional architecture **100**.

[0033] The concepts and technologies described herein take advantage of the operational characteristics of the motors **108** in vehicle and other implementations in which the peak power loads, or the maximum power requirements, of the motors **108** do not occur simultaneously. In these implementations having complementary power loads on the motors, multiple smaller parallel motor controllers **204** can be utilized instead of the dedicated, larger conventional motor controllers **106** and be dynamically reconfigured as described herein to shift power delivery between motors **108** as the power demands of the motors **108** dictate.

[0034] It should be appreciated that the example shown in FIG. **2** is simplified for clarity. Although only three parallel motor controllers, **204**A, **204**B, and **204**C, are shown as being connected to two motors, **108**A and **108**B, any number of parallel motor controllers **204** may be utilized to provide power to any number of motors **108** according to various embodiments. Similarly, the power switching network **202** is shown as including a single, simple electronic switch for clarity purposes. However, any number and type of switching mechanisms may be utilized within the power switching network **202** to combine the power outputs of the parallel motor controllers **204** for delivery to the motors **108**.

[0035] Turning now to FIG. **3**, an illustrative power load chart **302** will be described. The power load chart **302** shows how the embodiments described herein take advantage of the complimentary power load requirements **304** of two different motors on an aircraft during different phases of flight to utilize parallel motor controllers **204** in providing power to the motors **108**. In this example, the top graph shows the power load requirement **304** of a cabin air compressor during eight flight phases **306**, including ground operations, engine start, taxi, take off, climb, cruise, descent, and landing. The vertical axis represents the present power load requirement **304** of the cabin air compressor.

[0036] The bottom graph shows the power load requirement **304** of a hydraulic electric motor pump during the same eight flight phases **306**. Following the two graphs from left to right through the various flight phases **306**, it can be seen that the available power, which is the power output capability of all of the parallel motor controllers **204** together for providing power to each of the two motors **108** shown in Figure **2**, remains at **150** kW. This available power could be provided utilizing the parallel motor controller architecture **200** shown in FIG. **2** in which each of the three parallel motor controllers **204** are rated at **50** kW. The combined **150** kW of the three parallel motor controllers **204** is dynamically redistributed between the cabin air compressor and the hydraulic electric motor pump as the current operational demands of the two motors **108** changes during the various flight phases **306**.

[0037] As an example referring to Figures **2** and **3**, it can be seen that during ground operations, **100** kW of power is provided to the cabin air compressor and **50**

kW of power is provided to the hydraulic electric motor pump. To do so, two parallel motor controllers **204** are connected to the cabin air compressor and one motor controller **204** is connected to the hydraulic electric motor pump. During engine start, the motor controllers **204** may be connected to a generator so that the entire **150** kW of available power is directed to the generator for engine start.

[0038] During taxi and takeoff the operational demands of the motors **108** leads to a reconfiguration of the power switching network **202** such that the power output to the cabin air compressor is reduced to **50** kW, while the power output from two of the parallel motor controllers **204** is redirected to the hydraulic electric motor pump. During climb, cruise, and descent, **100** kW of power is directed to the cabin air compressor and **50** kW of power is directed to the hydraulic electric motor pump. Finally, during landing when there is a higher demand on the hydraulic electric motor pump due to the lowering of landing gear and certain flight control surfaces, power is shifted to provide **100** kW of power to the hydraulic electric motor pump and **50** kW of power to the cabin air compressor.

[0039] It should be understood that the values of the power load requirements **304** of the cabin air compressor and hydraulic electric motor pump are given for illustrative purposes to show the complimentary nature of the power demands of the two motors **108** and the dynamic reconfiguration of the power switching network **202** to redistribute power as required by the power load requirements of the motors **108**. It should further be appreciated that while only example data for the cabin air compressor and hydraulic electric motor pump are shown, any number and type of motors **108** may be utilized and the available power from all of the parallel motor controllers **204** is dynamically distributed between all of the motors **108**.

[0040] FIG. **4**A shows an example power distribution system **400** that will be used throughout FIGS. **4**B-**4**E to illustrate the dynamic reconfiguring of the electrical connections within the power switching network **202** to redirect power from one or more parallel motor controllers **204** to one or more motors **108** as the current operational demands of the motors changes during different phases of flight.

Throughout these examples shown in FIGS. **4**A-**4**E, six parallel motor controllers **204**A-**204**F provide power to four motors **108**, including a generator **108**A, a cabin air compressor **108**B, a pump **108**C, and a fan **108**D.

[0041] FIG. **4**B shows an engine start power distribution system **402** that represents the electrical connections within the power switching network **202** during an engine start operation of an aircraft using the generator **108**A. In this scenario, the generator **108**A demands a very large power load. As a result, all of the parallel motor controllers **204**A-**204**E are electrically connected to the generator **108**A, leaving the motor controller **204**F to provide some power to the fan **108**D for cooling aircraft equipment.

[0042] FIG. **4**C shows a takeoff power distribution system **404** that represents the electrical connections within the power switching network **202** during aircraft takeoff. Because the generator **108**A no longer requires power from the parallel motor controllers **204** after engine start, the generator **108**A is shown to be providing power to a bus **450**. The parallel motor controllers **204** that supplied power to the generator **108**A during engine start have been reconfigured to supply power to the cabin air compressor **108**B and the pump **108**C. During takeoff, the power load requirement (**304** in Figure **3**) of the pump **108**C is larger than that of the cabin air compressor **108**B. As a result, in this example, two parallel motor controllers **204**A and **204**B are connected to the cabin air compressor **108**B and three parallel motor controllers **204**C-**204**E are connected to the pump **108**C.

[0043] FIG. **4**D depicts a cruise power distribution system **406** in which the power switching network **202** is reconfigured during cruise conditions. Because the power load requirements (**304** in Figure **3**) of the cabin air compressor **108**B and the pump **108**C are complimentary (as shown in FIG. **3**), the connection of the parallel motor controller **204**C is switched from the pump **108**C to the cabin air compressor **108**B during cruise to satisfy the higher power load demands of the cabin air compressor **108**B.

[0044] FIG. **4**E shows a hydraulic demand power distribution system **408** in which the power switching network **202** is reconfigured during temporary hydraulic conditions such as raising or lowering the landing gear and reversing the thrust of the engines. As can be seen, four of the six parallel motor controllers **204** are electrically connected to the pump **108**C. As is the case in all of the scenarios presented, as soon as the high power load requirement **304** of the pump **108**C subsides, the power switching network **202** is again reconfigured according to the present power load requirements (**304** in Figure **3**) of all of the motors **108**.

[0045] FIGS. **5**A-**5**C show alternative configurations **500**, **520**, and **540**, respectively, of a motor controller system to illustrate various placements of an output filter **510** according to various embodiments. Conventional motor controllers utilize filters to aid in conditioning electronic signals for use by a motor **108**. FIG. **5**A shows one embodiment in which parallel motor controllers **204**A and **204**B are connected to the power switching network **202** for providing power to the motor **108**. In this example, the power source **102** provides an AC signal to the parallel motor controllers **204**A and **204**B.

[0046] Each motor controller **204**A, **204**B includes an input filter **502**, output filter **510**, and intermediate filter **506** that is positioned between a rectifier **504** and an inverter **508**. It should be appreciated that the components of the parallel motor controllers **204** are not limited to those shown in FIGS. **5**A-**5**C and that the components of any given parallel motor controller **204** may vary from those shown. For example, the power source **102** may provide DC power to the parallel motor controllers **204**A, **204**B, and the parallel motor controllers **204** may include an input filter **502**, an inverter **508**, and an output filter **510**, without requiring a rectifier **504** or any additional filters.

[0047] FIG. **5**B shows an alternative motor controller configuration **520** in which the parallel motor controllers **204**A, **204**B share a single output filter **510**. In this embodiment, the output filter **510** may be connected to the motor **108** so that power received from the power switching network **202** is input into the output filter **510** prior to receipt by the motor **108**. Doing so allows for the removal of the output filters **510** from the parallel motor controllers **204**A, **204**B shown in Figure **5**A. Sharing an output filter **510** rather than including an output filter **510** within every parallel motor controller **204**A, **204**B saves overall system weight since filters can be relatively heavy components.

[0048] To further save weight, the embodiment shown in FIG. **5**C shows an alternative motor controller configuration **540** in which one or more parallel motor controllers **204**A, **204**B do not utilize an output filter. Typically, the output filters such as the type shown at **510** in Figures **5**A and **5**B are used due to the length of the power feeders from the parallel motor controllers **204**A, **204**B in an equipment bay of an aircraft or other vehicle to the motors **108**. The electrical signal from the parallel motor controllers **204**A, **204**B may have a pulse-width modulated or switched (square) waveform that includes significant harmonic content that can be amplified by the impedance of the power feeders by the time that the signals are received by the motors **108**. Output filters **510** within the parallel motor controllers **204**A, **204**B smooth out the waveforms and prevent damage to the motors **108** caused by the amplified harmonics of the unfiltered square waveforms. However, in embodiments in which the parallel motor controllers **204**A, **204**B are located close to the motors **108**, or if radiated emissions from the power feeders are not a consideration, then the alternative motor controller configuration **540** shown in FIG. **5**C that does not include any output filters may be used to further minimize the weight of the motor controller system.

[0049] It should be appreciated that the logical operations described in FIGs. **6** through **17** are implemented (**1**) as a sequence of computer implemented acts or program modules running on a computing system and/or (**2**) as interconnected machine logic circuits or circuit modules within the computing system. The computing system may be a part of or connected to the power switching network **202** shown in Figures **2**, **4**A, **4**B and **5**A-**5**C and will be described below with respect to FIG. **18**. The implementation of the logical operations described herein is a matter

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of choice dependent on the performance and other requirements of the computing system. Accordingly, the logical operations described herein are referred to variously as states operations, structural devices, acts, or modules. These operations, structural devices, acts and modules may be implemented in software, in firmware, in special purpose digital logic, or any combination thereof. It should also be appreciated that more or fewer operations may be performed than shown in the figures and described herein. These operations may also be performed in a different order than those described herein.

[0050] Turning now to FIG. **6**, an illustrative routine **600** from the prior art for controlling a group of motors such as motor **108** shown in Figures **2**, **4**A, **4**B and **5**A-**5**Cwill now be described. The routine **600** begins at operation **602**, where the present power load requirements **304** of each motor **108** are determined. This operation and others may be performed by a motor controller reconfiguration application executing on the computer system, either as part of the power switching network **202** shown in Figure **2**, **4**A, **4**B and **5**A-**5**C or in communication with the power switching network **202**. As described above, the present power load requirement shown at **304** in Figure **3** of a motor **108** represents the operational power demand at that instance in time. As illustrated in FIG. **3**, the present power load requirement **304** of a motor **108** within an aircraft or other vehicle or platform may change according to an operational phase, such as various flight phases **306**. The present power load requirements **304** of different motors **108** may be complimentary such that an increase in a power requirement for one motor **108** coincides with a corresponding decrease in a power requirement for another motor **108**, which allows for the dynamic reconfiguration of the electrical connections within the power switching network **202** as described herein.

[0051] From operation **602**, the routine **600** continues to operation **604**, where the number of parallel motor controllers **204** to be connected to each motor **108** is determined. As described above, the number of parallel motor controllers **204** to be connected to any given motor **108** may include the least number of parallel motor

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controllers **204** that are capable of supplying the present power load requirement **304** of the particular motor **108**. For example, if a motor **108** is utilizing **100** kW of power, then two parallel motor controllers **204** capable of each providing **50** kW of power are connected to the motor **108**. At operation **606**, the power switching network **202** is configured to connect the parallel motor controllers **204** to the motors **108** according to the present power load requirements of the motors as determined at operation **604**. It should be appreciated that the power switching network **202** is configured by activation of any number of electronic switches within a circuit connecting the parallel motor controllers **204** to each of the motors **108**.

[0052] From operation **606**, the routine **600** continues to operation **608**, where the motor controller system is monitored for motor action requests. According to one embodiment, a motor action request may be any activation or motion of a switch, lever, control device, or other apparatus used to control a system that utilizes one or more motors **108**. For example, in an aircraft environment, a motor action request may include, but is not limited to, the lowering or raising of landing gear, the activation or motion of a control for moving a flight control surface, and the activation of a pump. It should be appreciated that the motor action request may be the result of an action taken by a person or may be the result of a computer-controlled action. It should also be understood that the monitoring operation may include active monitoring or polling of any number of systems, or may be passive monitoring such as the receipt of a request.

[0053] At operation **610**, if a motor action request is not received, then the routine **600** returns to operation **608** and the monitoring continues. However, if at operation **610**, it is determined that a motor action request has been made or received, then the routine **600** returns to operation **602**, where the present power load requirements **304** of the motors **108** is reassessed and the routine **600** continues as described above. In this manner, the power switching network **202** may be dynamically reconfigured so as to respond to changes in the power load requirements **304** of the motors **108** by redirecting power from the parallel motor controllers **204** to the applicable motors **108**.

[0054] Turning now to FIG. **7**, an illustrative routine **7000** for controlling a group of motors **108** through load shedding and reconfiguration will now be described. The routine **7000** begins at operation **7010**, by determining an Initial Power Load Demand based on a First Power Load Demand for a First Motor and a Second Power Load Demand for a second motor. The next step, at operation **7020**, includes determining the Maximum Power Output from a first motor controller's power capacity, a second motor controller's power capacity, and a third motor controller's capacity. The next step, at operation **7030**, includes determining that the first motor controller's power capacity is sufficient to match the First Power Load Demand and that the second motor controller's power capacity is sufficient to match the Second Power Load Demand. The next step, at operation **7040**, includes assigning a first set of system-wide priorities based at least in part on the Maximum Power Output, the First Power Load Demand, and the Second Power Load Demand. The next step, at operation **7050**, includes configuring a Power Switching Network to couple together the first motor controller to the First Motor and the second motor controller to the Second Motor. The next step, at operation **7070**, includes determining an Updated Power Load Demand based on the Initial Power Load Demand and the Third Power Load Demand. The next step, at operation **7060**, includes receiving a power request from a control unit for provision of a Third Power Load Demand for a Third Motor. The next step, at operation **7070**, includes determining an Updated Power Load Demand based on the Initial Power Load Demand and the Third Power Load Demand

[0055] Continuing with FIG. **7**, following the determination of the Updated Power Load Demand, the next step, at operation **7080**, includes determining that the Updated Power Load Demand is greater than the Maximum Power Output. The next step, at operation **7090**, includes assigning a second set of system-wide priorities that designates the Third Motor with a higher priority level than the Second Motor, and is based at least in part on the Maximum Power Output, the First Power Load Demand, the Second Power Load Demand, and the Third Power Load Demand. The 'OR' split, at step **7100**, represents the two alternative embodiments, wherein starting at step **7111**, the parallel motor controller architecture reconfigures its resources by completely diverting power away from one motor and towards another, whereas starting at step **7121**, the parallel motor controller architecture adapts to requests for power by higher priority motors by only diverting the amount of power needed, while it is needed.

[0056] The reconfiguration embodiment, at step **7111**, includes determining that the third motor controller's power capacity, in combination with the second motor controller's power capacity, are required to match the Third Power Load Demand. The next step, at operation **7112**, includes configuring the Power Switching Network to decouple the second motor controller from the Second Motor, and then couple the second motor controller and the third motor controller to the Third Motor. The next step, at operation **7113**, includes identifying that the power request is no longer valid. The next step, at operation **7114**, includes reassigning the first set of system-wide priorities. The final step of this embodiment, at operation **7115**, includes configuring the Power Switching Network to decouple the second motor controller from the Third Motor, and then recouple the second motor controller to the Second Motor.

[0057] The load shedding embodiment, at step **7121**, includes determining that the third motor controller's power capacity, in combination with a first portion of the second motor controller's power capacity is sufficient to match the Third Power Load Demand. The next step, at operation **7122**, includes configuring the Power Switching Network to couple the second motor controller to the Third Motor, to direct the second motor controller to deliver the first portion of the second motor controller's power capacity to the Third Motor, and to couple the third motor controller to the Third Motor. The next step, at operation **7123**, includes identifying that the power request is no longer valid. The next step, at operation **7124**, includes

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reassigning the first set of system-wide priorities. The final step of this embodiment, at operation **7125**, includes configuring the Power Switching Network to decouple the second motor controller from the Third Motor, and then recouple the second motor controller to the Second Motor thereby fully matching the Second Power Load Demand.

[0058] Turning now to FIG. **8**, an illustrative routine **800** specifically directed to a novel main engine electric start operating logic will now be described. The routine **800** begins at operation **810**, where a Bus Power Control Unit determines how much power is available for a Parallel Modular Converter that controls the Power Switching Network (**202**). The Bus Power Control Unit sends a power command to the Parallel Modular Converter and sends a main engine electric start mode request to a Generator Control Unit to cause it to open the Generator Circuit Breaker and apply excitation to the starter/generator as shown at **812**.

[0058a] At operation **820** the Parallel Modular Converter receives a torque command **118** from an Electronic Engine Controller and receives and configures the Power Switching Network **204** for an engine start mode.

[0058b] At operation **830** the Parallel Modular Converter selects an appropriate motor control algorithm based on the information it has available to it.

[0058c] At operation **840** the Parallel Modular Converter applies power to the motor starter/generator, and speed feedback information is shared between the Parallel Modular Converter and the Electronic Engine Controller that monitors motor speed as shown at **841**.

[0058d] At operation **850** if a starter cutoff speed is not achieved, operation **840** begins again. However, if the starter cutoff speed is achieved, then the Parallel Modular Converter will initiate a soft shutdown and exit the starter/generator motoring mode as shown at **860**.

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[0058e] At operation **880** the Bus Power Control Unit will release the power budget to other systems, and will communicate to the Electronic Engine Controller and Generator Control Unit to indicate that the mode is no longer the Main Engine Electric Start mode. At operation **881** the Electronic Engine Controller engine is running, while at operation **882** the Generator Control Unit will remove excitation and start a transition to a generate mode.

[0059] Turning now to FIG. **9**, an illustrative routine **900** specifically directed to a novel auxiliary power unit engine electric start operating logic will now be described. The routine **900** begins at operation **910**, where the Bus Power Control Unit determines how much power is available for the Parallel Modular Converter. The Bus Power Control Unit sends a power command to the Parallel Modular Converter and sends an Auxiliary Engine Electric Start (AEES) mode command to an auxiliary generator control unit as shown at **912** to cause the Auxiliary Generator Control Unit to open the Auxiliary Starter Generator Circuit Breaker and apply excitation to the starter/generator.

[0059a] At operation **920** the Parallel Modular Converter configures the Power Switching Network **202** for engine start.

[0059b] At operation **930** the Parallel Modular Converter selects the appropriate motor control algorithm based on the information it has available to it.

[0059c] At operation **940** the Parallel Modular Converter applies power to the motor starter/generator and speed feedback information is shared between the Parallel Modular Converter and the Auxiliary Power Unit Controller that monitors motor speed as shown at **941**.

[0059d] At operation **950** if the starter cutoff speed is not achieved then operation **940** begins again. However, if the starter cutoff speed is achieved, then the Parallel Modular Converter will initiate a soft shutdown and exit the starter/generator motoring mode as shown at **960**.

[0059e] At operation **980** the Bus Power Control Unit will release the power budget to other systems, and will communicate to the Auxiliary Power Unit Controller and the Auxiliary Generator Control Unit to indicate that the mode is no longer the Auxiliary Engine Electric Start mode. At operation **981** the auxiliary engine is running, while at operation **982** the Auxiliary Generator Control Unit will remove excitation and start transition to a generate mode.

[0060] Turning now to FIG. **10**, an illustrative routine **1000** specifically directed to a novel battery sourced Auxiliary Power Unit engine electric start operating logic will now be described. The routine **1000** begins at operation **1010**, where the Bus Power Control Unit will determine how much power is available for the Parallel Modular Converter. The Bus Power Control Unit sends a power command to the Parallel Modular Converter and sends a Battery Auxiliary Engine Electric start mode command to a Battery Voltage Boost Unit. An Auxiliary Power Unit Controller sends a torque command to the Parallel Modular Converter at **1011**.

[0060a] At operation **1012** the Battery Voltage Boost Unit initiates power conversion to provide excitation power for an auxiliary starter generator and high voltage for the Parallel Modular Converter.

[0060b] At **1013** the Auxiliary Generator Control Unit opens the Auxiliary Starter Generator Circuit Breaker and applies excitation to the starter/generator.

[0060c] At operation **1020** the Parallel Modular Converter configures the Power Switching Network for battery auxiliary power unit start.

[0060d] At operation **1030** the Parallel Modular Converter selects the appropriate motor control algorithm based on the information it has available to it.

[0060e] At operation **1040** the Parallel Modular Converter applies power to the motor starter/generator and speed feedback information is shared between the Parallel Modular Converter and the Auxiliary Power Unit Controller that monitors motor speed **1041**.

[0060f] At operation **1050** if the starter cutoff speed is not achieved, operation **1040** begins again.However, if the starter cutoff speed is achieved, then the Parallel Modular Converter will initiate a soft shutdown and exit the starter/generator motoring mode as shown at **1060**.

[0060g] At operation **1080** the Bus Power Control Unit will release the power budget to other systems, and will communicate to the Auxiliary Power Unit Controller and the Auxiliary Generator Control Unit that the Battery Auxiliary Engine Electric Start mode is no longer set.

[0060h] At operation **1081** the auxiliary engine is running, while at operation **1083** the Auxiliary Generator Control Unit removes excitation and starts transition to a generate mode, and at operation **1082** the Battery Voltage Boost Unit stops power conversion for the Auxiliary Starter Generator excitation and the Parallel Modular Converter.

[0061] Turning now to FIG. **11**, an illustrative routine **1100** specifically directed to a novel electric taxiing operating logic will now be described. The routine **1100** begins at operation **1110**, where the Bus Power Control Unit will determine how much power is available for the Parallel Modular Converter. The Bus Power Control Unit sends a power command to the Parallel Modular Converter and sends an electric taxi mode request to an Electric Taxi Controller as shown at **1111**. The Electric Taxi Controller sends a brake status request to an Electric Brake Controller and receives brake status signals from the Electric Brake Controller, as shown at **1112**. The Electric Taxi Controller sends torque, speed and acceleration commands to the Parallel Modular Converter.

[0061a] At operation **1120** the Parallel Modular Converter configures the Power Switching Network for Electric Taxi mode in response to the power command from the Bus Power Control Unit and the torque, speed and acceleration/deceleration status from the Electric Taxi Controller Parallel Modular Converter, and the status of the brakes provided by the Electric Taxi Controller.

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[0061b] At operation **1130** the Parallel Modular Converter selects the appropriate motor control algorithm based on the information it has available to it.

[0061c] At operation **1140** the Parallel Modular Converter applies power to the Electric Taxi motor and speed, acceleration, and deceleration feedback information is shared between the Parallel Modular Converter and the Electric Taxi Controller that monitors motor speed, acceleration, and deceleration rates as shown at **1141**.

[0061d] At operation **1150** the Parallel Modular Converter monitors the Bus Power Control Unit and the Electric Taxi Controller, and if a stop command has not been received then operation **1140** begins again. However, if a stop command has been received, then the Parallel Modular Converter will initiate a soft shutdown and exit the Electric Taxi motor mode as shown at **1160**.

[0061e] At operation **1180** the Bus Power Control Unit will release the power budget to other systems, and will communicate to the Electric Taxi Controller that the Electric Taxiing mode is ended. At operation **1181** the airplane is not taxiing, and at operation **1182** the Electric Brakes Controller provides the status of the electric brakes.

[0062] Turning now to FIG. **12**, an illustrative routine **1200** specifically directed to a novel cabin air compressor operating logic will now be described. The routine **1200** begins at operation **1201**, where an Air Conditioning Pack Control Unit sends a Cabin Air Compressor mode request to the Bus Power Control Unit. The Air Conditioning Pack Control Unit also sends a speed command to the Parallel Modular Converter. At operation **1210** the Bus Power Control Unit will determine how much power is available for the Parallel Modular Converter.

[0062a] At operation **1220** the Parallel Modular Converter configures the Power Switching Network for Cabin Air Compressor mode.

[0062b] At operation **1230** the Parallel Modular Converter selects the appropriate motor control algorithm based on the information it has available to it.

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[0062c] At operation **1240** the Parallel Modular Converter applies power to the Cabin Air Compressor motor and speed feedback information is shared between the Parallel Modular Converter and the Air Conditioning Pack Control Unit that monitors motor speed **1241**.

[0062d] At operation **1250** the Parallel Modular Converter monitors the Bus Power Control Unit and the Air Conditioning Pack Control Unit Controller, and if a stop command has not been received, operation **1240** begins again. However, if a stop command has been received, then the Parallel Modular Converter will initiate a soft shutdown and exit the Cabin Air Compressor motor mode as shown at **1260**. At operation **1280** the Bus Power Control Unit will release the power budget to other systems, and will communicate to the Air Conditioning Pack Control Unit that the Cabin Air Compressor mode is no longer set. At operation **1281** the Cabin Air Compressor is shut down.

[0063] Turning now to FIG. **13**, an illustrative routine **1300** specifically directed to a novel hydraulic pump operating logic will now be described. The routine **1300** begins at operation **1301**, where a Hydraulic Pump Controller sends a Hydraulic Pump mode request to the Bus Power Control Unit and a speed command to the Parallel Modular Converter.

[0063a] At operation **1310** the Bus Power Control Unit will determine how much power is available for the Parallel Modular Converter. At operation **1320** the Parallel Modular Converter configures the Power Switching Network for the Hydraulic Pump mode and that operation is informed by the Hydraulic Pump Controller's speed command.

[0063b] At operation **1330** the Parallel Modular Converter selects the appropriate motor control algorithm based on the information it has available to it.

[0063c] At operation **1340** the Parallel Modular Converter applies power to the Hydraulic Pump motor and speed feedback information is shared between the

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Parallel Modular Converter and the Hydraulic Pump Controller that monitors motor speed as shown at **1341**.

[0063d] At operation **1350** the Parallel Modular Converter monitors the Bus Power Control Unit and the Hydraulic Pump Controller, and if a stop command has not been received, operation **1340** begins again. However, if a stop command has been received, then the Parallel Modular Converter will initiate a soft shutdown and exit the Hydraulic Pump motor mode is shown at **1360**.

[0063e] At operation **1380** the Bus Power Control Unit will release the power budget to other systems, and will communicate to the Hydraulic Pump Controller that the Hydraulic Pump mode is no longer in effect.

[0063f] At operation **1390** the Hydraulic Pump is shut down.

[0064] Turning now to FIG. **14**, an illustrative routine **1400** specifically directed to a novel nitrogen generation system operating logic will now be described. The routine **1400** begins at operation **1401**, where a Nitrogen Generation System Controller sends a Nitrogen Generation System mode request to the Bus Power Control Unit and sends a speed command to the Parallel Modular Converter.

[0064a] At operation **1410** the Bus Power Control Unit will determine how much power is available for the Parallel Modular Converter.

[0064b] At operation **1420** the Parallel Modular Converter configures the Power Switching Network for the Nitrogen Generation System mode and that operation is informed by the Nitrogen Generation System Controller's speed command.

[0064c] At operation **1430** the Parallel Modular Converter selects the appropriate motor control algorithm based on the information it has available to it.

[0064d] At operation **1440** the Parallel Modular Converter applies power to the Nitrogen Generation System motor and speed feedback information is shared between the Parallel Modular Converter and the Nitrogen Generation System Controller that monitors motor speed **1441**.

[0064e] At operation **1450** the Parallel Modular Converter monitors the Bus Power Control Unit and the Nitrogen Generation System Controller, and if a stop command has not been received, operation **1440** begins again. However, if a stop command has been received, then the Parallel Modular Converter will initiate a soft shutdown and exit the Nitrogen Generation System motor mode **1460**.

[0064f] At operation **1480** the Bus Power Control Unit will release the power budget to other systems, and will communicate to the Nitrogen Generation System Controller that the Nitrogen Generation System mode is no longer in effect. At operation **1481** the Nitrogen Generation System compressor is shut down.

[0065] Turning now to FIG. **15**, an illustrative routine **1500** specifically directed to a novel environmental control system fan operating logic will now be described. The routine **1500** begins at operation **1501**, where an Environmental Control System Fan Controller sends an Environmental Control System Fan mode request to the Bus Power Control Unit and sends a speed command to the Parallel Modular Converter.

[0065a] At operation **1510** the Bus Power Control Unit will determine how much power is available for the Parallel Modular Converter.

[0065b] At operation **1520** the Parallel Modular Converter configures the Power Switching Network for the Environmental Control System Fan mode and that operation is informed by the Environmental Control System Fan Controller's speed command.

[0065c] At operation **1530** the Parallel Modular Converter selects the appropriate motor control algorithm based on the information it has available to it.

[0065d] At operation **1540** the Parallel Modular Converter applies power to the Environmental Control System Fan motor and speed feedback information is shared between the Parallel Modular Converter and the Environmental Control System Fan Controller that monitors motor speed as shown at **1541**.

[0065e] At operation **1550** the Parallel Modular Converter monitors the Bus Power Control Unit and the Environmental Control System Fan Controller, and if a stop command has not been received, operation **1540** begins again. However, if a stop command has been received, then the Parallel Modular Converter will initiate a soft shutdown and exit the Environmental Control System Fan motor mode as shown at **1560**.

[0065f] At operation **1580** the Bus Power Control Unit will release the power budget to other systems, and will communicate to the Environmental Control System Fan Controller that the Environmental Control System Fan is no longer in effect. At operation **1581** the Environmental Control System Fan is shut down.

[0066] Turning now to FIG. **16**, an illustrative routine **1600** specifically directed to a novel cargo refrigeration system operating logic will now be described. The routine **1600** begins at operation **1601**, where a Cargo Chilling System Controller sends a Cargo Chilling System mode request to the Bus Power Control Unit and sends a speed command to the Parallel Modular Converter. At operation **1610** the Bus Power Control Unit will determine how much power is available for the Parallel Modular Converter. At operation **1620** the Parallel Modular Converter configures the Power Switching Network for the Cargo Chilling System mode and that operation is informed by the Cargo Chilling System Controller's speed command.

[0066a] At operation **1630** the Parallel Modular Converter selects the appropriate motor control algorithm based on the information it has available to it.

[0066b] At operation **1640** the Parallel Modular Converter applies power to the Cargo Chilling System motor and speed feedback information is shared between the Parallel Modular Converter and the Cargo Chilling System Controller that monitors motor speed as shown at **1641**.

[0066c] At operation **1650** the Parallel Modular Converter monitors the Bus Power Control Unit and the Cargo Chilling System Controller, and if a stop command has not been received, operation **1640** begins again. However, if a stop command has been received, then the Parallel Modular Converter will initiate a soft shutdown and exit the Cargo Chilling System motor mode **1660**.

[0066d] At operation **1680** the Bus Power Control Unit will release the power budget to other systems, and will communicate to the Cargo Chilling System Controller that the Cargo Chilling System mode is no longer in effect.

[0066e] At operation **1681** the Cargo Chilling System compressor is shut down.

[0067] Turning now to FIG. **17**, an illustrative routine **1700** specifically directed to a novel load shed and reconfiguration operating logic will now be described. The routine **1700** begins at operation **1710**, wherein the Parallel Modular Converter receives a signal from the Bus Power Control Unit **1711**, communicating a particular mode request and the power associated with that mode to the Parallel Modular Converter. The Parallel Modular Converter then establishes its configuration including the total number of motor controllers (or modules), the power of each, and if any have failed.

[0067a] At operation **1720**, a determination is made as to what modes are currently running and what power is being consumed as a result of those running modes.

[0067b] At operation **1730**, a determination is made as to the current power capacity that is still available for use in other modes.

[0067c] At step **1740**, if the current power capacity is not less than the power needed for the mode requested by the Bus Power Control Unit, then the Parallel Modular Converter runs the motors in the requested mode at the power associated with the requested mode. The Parallel Modular Converter system then determines its remaining power capacity to account for the running of this new mode, as shown at **1741**, and the Bus Power Control Unit is informed about this at step **1742**.

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[0067d] If the current power capacity is less than the power needed for the requested mode, then a determination of priority of the requested mode is made relative to other running modes as shown at **1750**. If the priority of the requested mode is less than or equal to all other currently running modes, then the Parallel Modular Converter runs the motors in the requested mode at only the currently available capacity, the Parallel Modular Converter sets the remaining power capacity to zero as shown at **1760** and at **1761** the Bus Power Control Unit is informed that the requested mode is operational at reduced power and that the Parallel Modular Converter available power capacity is zero.

[0068] At step **1770**, if the priority of the requested mode is greater than at least one other currently running mode, and if it is possible to reduce the power delivered to that at least one other currently running mode **1771**, then the total power for any such modes with lower priority will be reduced so as to provide the balance of power needed to match the power requested for the requested mode, and the Parallel Modular Converter will run the motors associated with the requested mode and set the remaining power capacity to zero as shown at **1772** while informing the Bus Power Control Unit as shown at **1773** that a lower priority mode is running at a power lower than requested and that the total remaining Parallel Modular Converter power capacity is zero.

[0068a] At step **1776**, if an incremental reduction in the power delivery for the lower priority modes is not possible, then a determination of the maximum possible reduction is calculated assuming the motors associated with all lower priority modes are shut down. At **1777** the motors associated with the requested mode are provided with the power formerly directed to the lower priority modes.

[0069] At step **1780**, if the priority of the requested mode is greater than at least two other currently running modes, one of which has a greater priority than at least one other currently running mode, and if it is possible to reduce the power delivered to that at least one other lower priority modes **1781**, then the total power for any such lowest priority modes will be reduced as shown at **1782** so as to provide the balance of power needed to match the power requested for the motors associated with the requested mode, and the Parallel Modular Converter will run the motors associated with the requested mode and as shown at **1783** will inform the Bus Power Control Unit which lower priority modes are run at lower power and that the remaining Parallel Modular Converter power capacity is zero. At **1781**, if it is not possible to incrementally reduce the power for the lowest priority modes, then at **1786**, a determination of the maximum possible reduction is calculated as a result of completely shutting down all lowest priority modes and partially shutting down all modes with a priority lower than the requested mode but greater than the lowest priority modes, the motors associated with the requested mode are provided with the power formerly directed to those lower priority modes, and the Bus Power Control Unit is informed accordingly as shown at **1788**. At step **1787**, if the reduction in the power delivery described at step **1786** is not possible, then at **1790**, a determination of the maximum possible power reduction is calculated assuming the motors associated with all lower priority modes are shut down, the motors associated with the requested mode are provided with the power formerly directed to the motors associated with those lower priority modes and the Bus Power Control Unit is informed accordingly as shown at **1788**. This process may be repeated until it is executed for all lower priority modes and/or the motors associated with the requested mode receive all of the power associated with the requested mode or the request to operate in the requested mode is no longer valid. One way in which incremental reductions may not be possible is that the requested mode is not operable with only the added amount of power provided by the incremental reductions.

[0070] FIG. **18** shows an illustrative computer architecture for a computer **1800**, housed within an aircraft **1801**, capable of executing the software components described herein for providing power and to a group of motors such as shown at **108** in Figure **2** in the manner presented above. The computer architecture shown in FIG. **18** illustrates a conventional desktop, laptop, or server computer and may be utilized to execute any aspects of the methods presented herein. As described

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above, the computer **1800** may be a part of the power switching network shown at **202** in Figure **2** or may be communicatively linked to the power switching network **202**. While the embodiment may be housed within an aircraft, alternative embodiments within the scope of the present disclosure may be implemented on systems contained within a jet aircraft, a propeller aircraft, a helicopter, a hovercraft, a land vehicle, a sea vehicle, or any other system independently controlling a series of motor controllers and motors.

[0071] The computer architecture shown in FIG. **18** includes a central processing unit **1802** (CPU), a system memory **1808**, including a random access memory **1814** (RAM) and a read-only memory (ROM) **1816**, and a system bus **1804** that couples the memory to the CPU **1802**. A basic input/output system containing the basic routines that help to transfer information between elements within the computer **1800**, such as during startup, is stored in the ROM **1816**. The computer **1800** further includes a mass storage device **1810** for storing an operating system **1818**, application programs, and other program modules, which are described in greater detail herein.

[0072] The mass storage device **1810** is connected to the CPU **1802** through a mass storage controller (not shown) connected to the bus **1804**. The mass storage device **1810** and its associated computer-readable media provide non-volatile storage for the computer **1800**. Although the description of computer-readable media contained herein refers to a mass storage device, such as a hard disk or CD-ROM drive, it should be appreciated by those skilled in the art that computer-readable media can be any available computer storage media that can be accessed by the computer **1800**.

[0073] By way of example, and not limitation, computer-storage media may include volatile and non-volatile, removable and non-removable media implemented in any method or technology for storage of information such as computer-readable instructions, data structures, program modules or other data. For example, computer-storage media includes, but is not limited to, RAM, ROM, EPROM,

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EEPROM, flash memory or other solid state memory technology, CD-ROM, digital versatile disks (DVD), HD-DVD, BLU-RAY, or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by the computer **1800**.

[0074] According to various embodiments, the computer **1800** may operate in a networked environment using logical connections to remote computers through a network such as the network **1822**. The computer **1800** may connect to the network **1822** through a network interface unit **1806** connected to the bus **1804**. It should be appreciated that the network interface unit **1806** may also be utilized to connect to other types of networks and remote computer systems. The computer **1800** may also include an input/output controller **1812** for receiving and processing input from a number of other devices, including a keyboard, mouse, or electronic stylus (not shown in FIG. **18**). Similarly, an input/output controller may provide output to a display screen, a printer, or other type of output device (also not shown in FIG. **18**).

[0075] As mentioned briefly above, a number of program modules and data files may be stored in the mass storage device **1810** and RAM **1814** of the computer **1800**, including an operating system **1818** suitable for controlling the operation of a networked desktop, laptop, or server computer. The mass storage device **1810** and RAM **1814** may also store one or more program modules. In particular, the mass storage device **1810** and the RAM **1814** may store the motor controller reconfiguration application **1820** that is operative to perform the operations described above. The mass storage device **1810** and the RAM **1814** may also store other types of program modules.

[0076] Based on the foregoing referring to Figures **2** and **3**, it should be appreciated that technologies for reconfiguring a power switching network **202** to redirect power from any number of parallel motor controllers **204** to one or more motors **108** as the present power load requirements **304** of the motors **108** change are provided herein. Utilizing the embodiments described herein, the number of parallel motor controllers

204 that service a group of motors **108** within an aircraft, vehicle, or other platform may increase or remain the same as with conventional systems. However, because the dynamic reconfiguration of the electrical connections within the power switching network **202** connecting the parallel motor controllers **204** to the motors **108** as described herein allows for power output capability of the parallel motor controllers **204** to be reduced, the overall weight of a motor controller system may be reduced.

[0077] From the foregoing, it will be appreciated that specific embodiments have been described herein for purposes of illustration on an aircraft, but that various modifications may be made without deviating from the principles described herein. For example, the motor controllers may have more or fewer than the number of fixed modes described in certain embodiments above. The modes may correspond to different flight regimes than those discussed above. Certain embodiments were described in the context of particular systems (e.g., hydraulic pump motors, ECS systems, and nitrogen generation systems), but may be applied to other systems and/or combinations of systems in other embodiments. Aspects of the concepts described herein in the context of particular embodiments may be combined or eliminated in other embodiments. For example, aspects of the backup motor controller functions may be provided in combination with motor controllers operating with a fixed number of predetermined modes. Further, while advantages associated with certain embodiments have been described in the context of those embodiments, other embodiments may also exhibit such advantages, and not all embodiments need necessarily exhibit all such advantages.

EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method of load shedding in a system of electric motors and motor controllers that supply power to the motors, the method comprising:

   defining a plurality of operational modes, each mode associated with operation of a respective group of motors, each mode associated with a respective power requirement and each mode associated with a respective relative priority level relative to each other;

   in response to a request to operate the group of motors in a particular mode:

      when sufficient power is available to supply the power requirement associated with the requested mode, causing one or more of the motor controllers to supply the power requirement of the requested mode to the group of motors associated with the requested mode;

      when sufficient power to supply the power requirement associated with the requested mode is not available, causing the controllers to supply power to the group of motors according to the relative priority level of the requested mode, such that:

         when the requested mode has a priority level lower than the priority level of all other modes currently in operation, the controllers supply less than the power requirement associated with the requested mode to the group of motors associated with the requested mode; and

         when the requested mode has a priority level higher than at least one other mode, determining which of the motors associated with the modes having priority levels lower than the requested mode can be shut off or operated at reduced power to enable power to be redirected from at least some of the motors associated with the modes having a lower priority level than the requested mode to the group of motors associated with the requested mode; and

causing the controllers to re-direct power from at least some of the motors associated with the modes having lower priority levels than the requested mode to the group of motors associated with the requested mode.

2. The method of claim **1** wherein the group of motors comprises one or more motors.

3. The method of claim **1** or **2** further comprising receiving the request to operate the motors in a particular mode from a Bus Power Controller.

4. The method of any one of claims **1**-**3** further comprising determining which motors that are currently operating are associated with modes other than the requested mode.

5. The method of claim **4** further comprising determining whether or not sufficient power is available to supply the power requirement associated with the requested mode.

6. The method of claim **4** or **5** wherein causing one or more of the motor controllers to supply the power requirement of the requested mode to the group of motors associated with the requested mode comprises communicating with at least one of the motor controllers to configure it to supply power to at least one motor in the group.

7. The method of any one of claims **4-6** further comprising determining whether or not sufficient power is not available to supply the power requirement associated with the requested mode.

8. The method of any one of claims **4-7** further comprising determining the priority levels of the modes other than the requested mode that are currently in operation and comparing the priority levels of the modes currently in operation to the priority level of the requested mode to determine the modes in operation that have priority levels higher than the priority level of the requested mode.

9. The method of claim **8** further comprising, when the requested mode has a priority level less than the priority levels of all other modes currently in operation, determining the total power consumed by operating the motors in the modes that are currently in operation and subtracting that total power consumed from a total available power to determine a power available to operate the motors in the group associated with the requested mode.

10. The method of any one of claims **4-7** further comprising determining the priority levels of the modes other than the requested mode that are currently in operation and comparing the priority levels of the modes currently in operation to the priority level of the requested mode to determine the modes in operation that have priority levels less than the priority level of the requested mode.

11. The method of claim **10** wherein determining which of the motors associated with the modes having priority levels lower than the requested mode can be shut off or operated at reduced power, comprises, on a mode by mode basis and starting with the modes having the lowest priority levels, calculating the sum of the power consumed by the motors associated with each mode having a priority level lower than the priority of the requested mode until the sum is equal to or greater than the power requirement of the requested mode or until the power associated with all modes having a priority lower than the requested mode has been included in the sum.

12. The method of claim **11** wherein when the sum is equal to or greater than the power requirement of the requested mode, the causing the controllers to redirect power from at least some of the motors associated with the modes having lower priority to the group of motors associated with the requested mode comprises shutting down all of the motors associated with the modes contributing to the sum that is equal to or greater than the power requirement of the requested mode and causing the controllers to redirect power to the motors associated with the requested mode.

13. The method of claim **11** wherein when the sum is not equal to or greater than the power requirement of the requested mode, the causing the controllers to redirect power from at least some of the motors associated with the modes having lower priority to the group of motors associated with the requested mode comprises shutting down all of the motors associated with the modes whose power contributes to the sum and causing the controllers to redirect that power to the motors associated with the requested mode.

14. The method of any one of claims **1-13** wherein a processor executes each of the recited steps.

15. A computer readable medium storing instructions that when executed by a processor cause the processor to execute the method of any one of claims **1-14**.

16. A system comprising a processor and the computer readable medium of claim **15**, wherein the processor and the computer readable medium are configured to execute the method of any one of claims **1-14**.

17. A motor control apparatus for controlling load shedding in a system of electric motors and motor controllers that supply power to the motors, the apparatus comprising:

means for defining a plurality of operational modes, each mode associated with operation of a respective group of motors, each mode associated with a respective power requirement and each mode associated with a respective relative priority level relative to each other;

means for receiving a request to operate the group of motors in a particular mode;

means for causing one or more of the motor controllers to supply the power requirement of the requested mode to the group of motors associated with the requested mode, when sufficient power is available to supply the power requirement associated with the requested mode;

means for causing the controllers to supply power to the group of motors according to the relative priority level of the requested mode when sufficient power to supply the power requirement associated with the requested mode is not available, such that:

when the requested mode has a priority level lower than the priority level of all other modes currently in operation, a signal is sent to the controllers to cause the controllers to supply less than the power requirement associated with the requested mode to the group of motors associated with the requested mode; and

when the requested mode has a priority level higher than at least one other mode, a determination is made to determine which of the motors associated with the modes having priority levels lower than the requested mode can be shut off or operated at reduced power to enable power to be redirected from at least some of the motors associated with the modes having a lower priority level than the requested mode to the group of motors associated with the requested mode; and

means for causing the controllers to re-direct power from at least some of the motors associated with the modes having lower priority levels than the requested mode to the group of motors associated with the requested mode.

18. The apparatus of claim **17** wherein the group of motors comprises one or more motors.

19. The apparatus of claim **17** or **18** further comprising means for receiving the request to operate the motors in a particular mode from a Bus Power Controller.

20. The apparatus of any one of claims **17-19** further comprising means for determining which motors that are currently operating are associated with modes other than the requested mode.

21. The apparatus of claim **20** further comprising means for determining whether or not sufficient power is available to supply the power requirement associated with the requested mode.

22. The apparatus of claim **20** or **21** the means for wherein causing one or more of the motor controllers to supply the power requirement of the requested mode to the group of motors associated with the requested mode comprises means for communicating with at least one of the motor controllers to configure it to supply power to at least one motor in the group.

23. The apparatus of any one of claims **20-22** further comprising means for determining whether or not sufficient power is not available to supply the power requirement associated with the requested mode.

24. The apparatus of any one of claims **20-23** further comprising means for determining the priority levels of the modes other than the requested mode that are currently in operation and means for comparing the priority levels of the modes currently in operation to the priority level of the requested mode to determine the modes in operation that have priority levels higher than the priority level of the requested mode.

25. The apparatus of claim **24** further comprising means for determining the total power consumed by operating the motors in the modes that are currently in operation and subtracting that total power consumed from a total available power to determine a power available to operate the motors in the group associated with the requested mode, when the requested mode has a priority level less than the priority levels of all other modes currently in operation.

26. The apparatus of any one of claims **20-23** further comprising means for determining the priority levels of the modes other than the requested mode that are currently in operation and means for comparing the priority levels of the modes currently in operation to the priority level of the requested mode to determine the modes in operation that have priority levels less than the priority level of the requested mode.

27. The apparatus of claim **26** wherein the means for determining which of the motors associated with the modes having priority levels lower than the requested mode can be shut off or operated at reduced power, comprises means for calculating, on a mode by mode basis and starting with the modes having the lowest priority levels, a sum of the power consumed by the motors associated with each mode having a priority level lower than the priority of the requested mode until the sum is equal to or greater than the power requirement of the requested mode or until the power associated with all modes having a priority lower than the requested mode has been included in the sum.

28. The apparatus of claim **27** wherein the means for causing the controllers to redirect power from at least some of the motors associated with the modes having lower priority to the group of motors associated with the requested mode comprises means for shutting down all of the motors associated with the modes contributing to the sum that is equal to or greater than the power requirement of the requested mode, when the sum is equal to or greater than the power requirement of the requested mode and means causing the controllers to redirect power to the motors associated with the requested mode.

29. The apparatus of claim **27** wherein the means for causing the controllers to redirect power from at least some of the motors associated with the modes having lower priority to the group of motors associated with the requested mode comprises means for shutting down all of the motors associated with the modes whose power contributes to the sum wherein when the sum is not equal to or greater than the power requirement of the requested mode and means for causing the controllers to redirect that power to the motors associated with the requested mode.

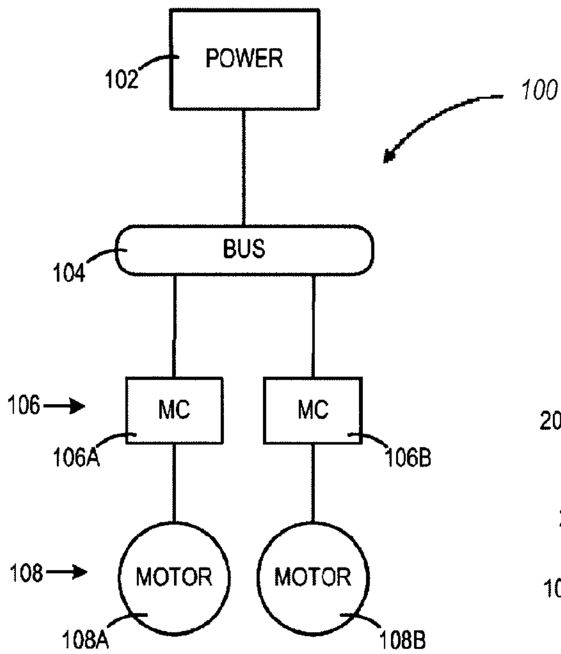


Fig. 1

(PRIOR ART)

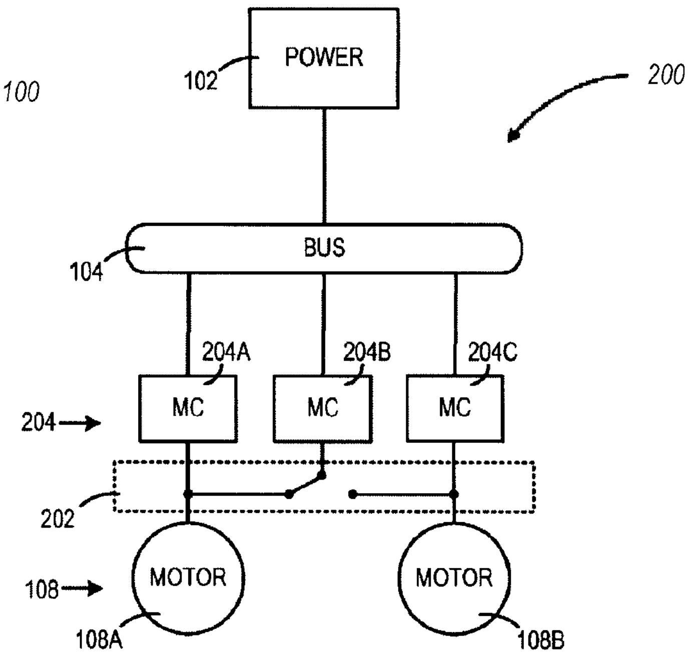


Fig. 2

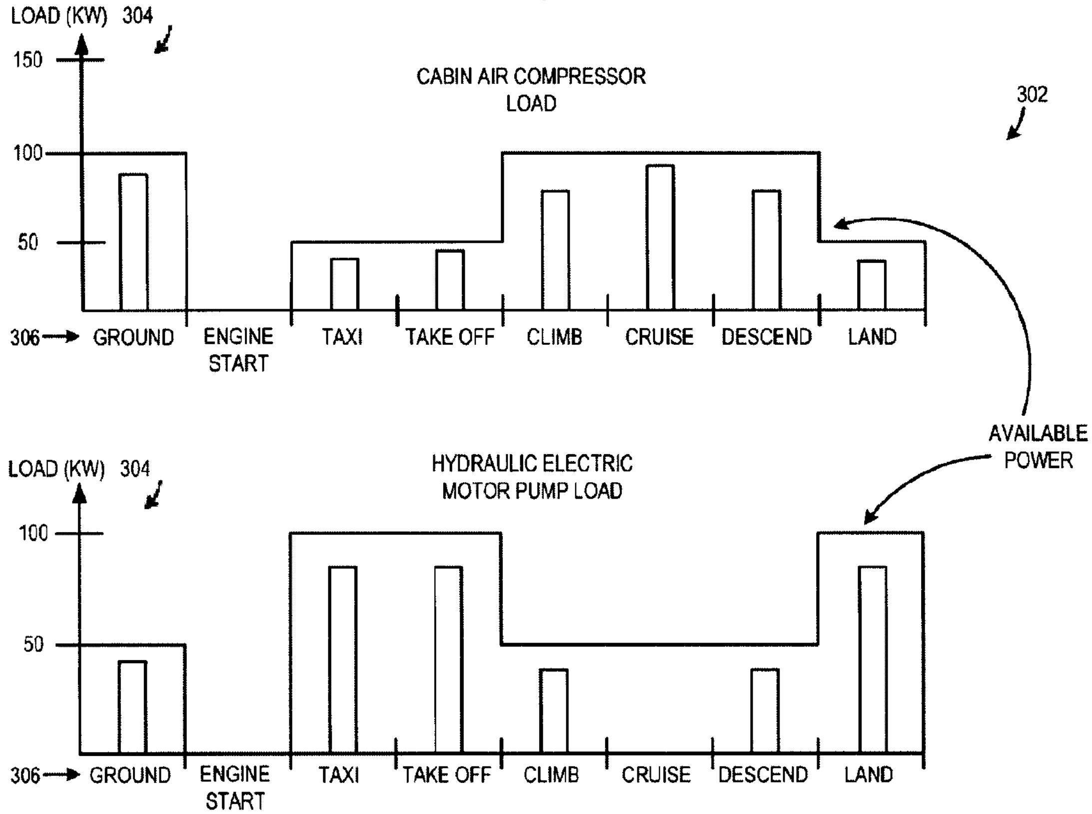

LOAD (KW)
304
150
100
50
CABIN AIR COMPRESSOR LOAD
302
306
GROUND
ENGINE START
TAXI
TAKE OFF
CLIMB
CRUISE
DESCEND
LAND
AVAILABLE POWER
LOAD (KW)
304
HYDRAULIC ELECTRIC MOTOR PUMP LOAD
100
50
306
GROUND
ENGINE START
TAXI
TAKE OFF
CLIMB
CRUISE
DESCEND
LAND

Fig. 3

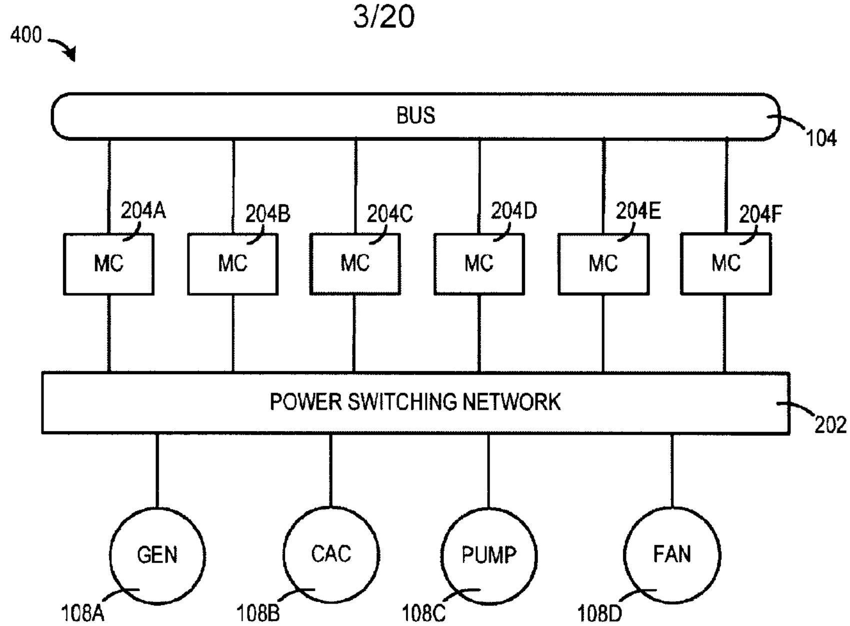

400
BUS
104
204A
204B
204C
204D
204E
204F
MC
MC
MC
MC
MC
MC
POWER SWITCHING NETWORK
202
GEN
CAC
PUMP
FAN
108A
108B
108C
108D

Fig. 4A

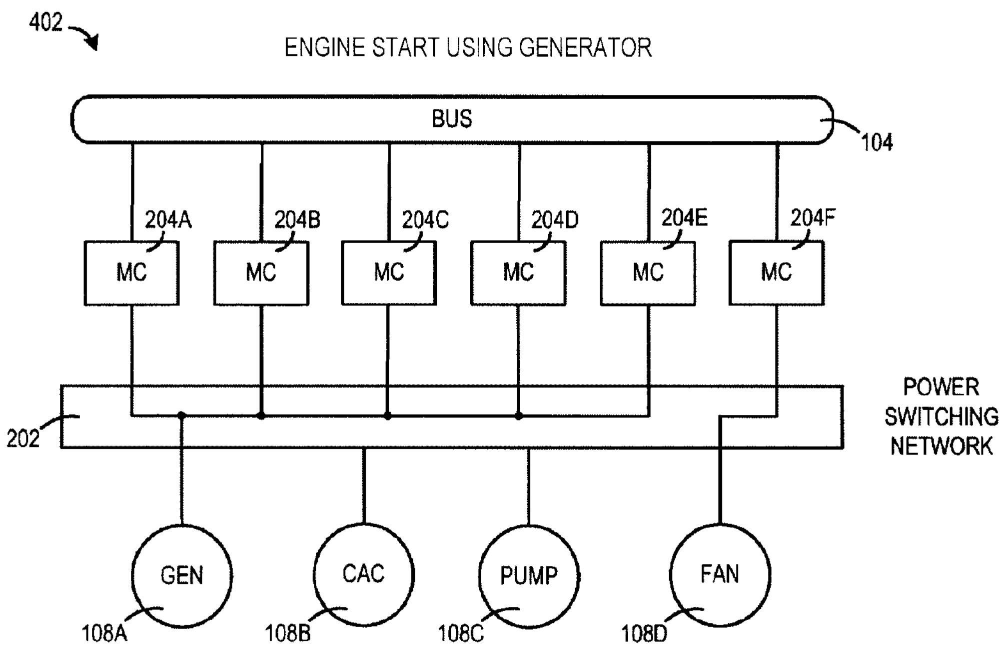

402
ENGINE START USING GENERATOR
BUS
104
204A
204B
204C
204D
204E
204F
MC
MC
MC
MC
MC
MC
202
POWER SWITCHING NETWORK
GEN
CAC
PUMP
FAN
108A
108B
108C
108D

Fig. 4B

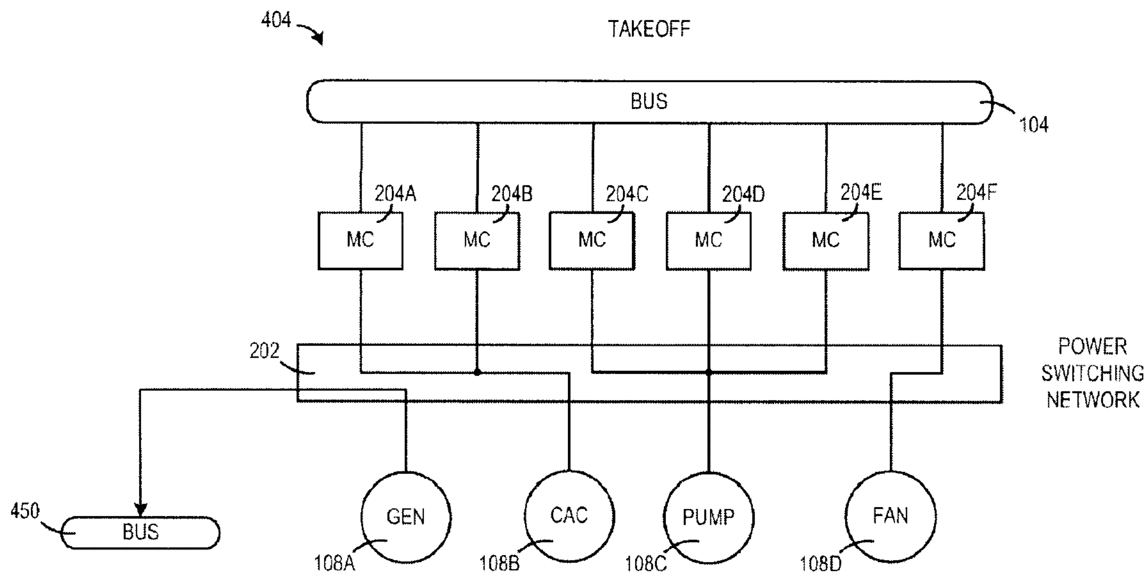

404
TAKEOFF
BUS
104
204A
204B
204C
204D
204E
204F
MC
MC
MC
MC
MC
MC
202
POWER SWITCHING NETWORK
450
BUS
GEN
CAC
PUMP
FAN
108A
108B
108C
108D

Fig. 4C

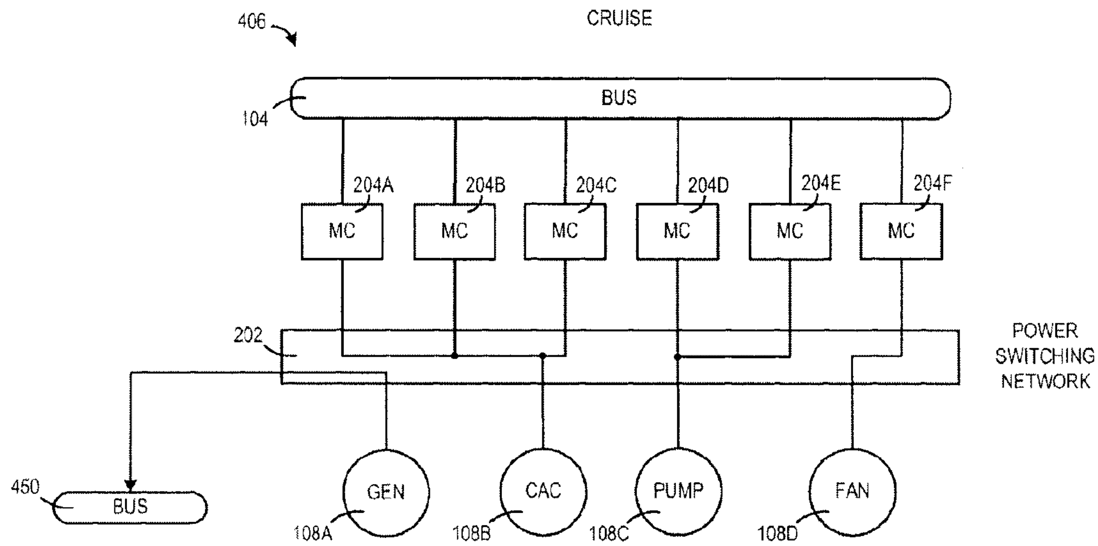

406
CRUISE
BUS
104
204A
204B
204C
204D
204E
204F
MC
MC
MC
MC
MC
MC
202
POWER SWITCHING NETWORK
450
BUS
GEN
CAC
PUMP
FAN
108A
108B
108C
108D

Fig. 4D

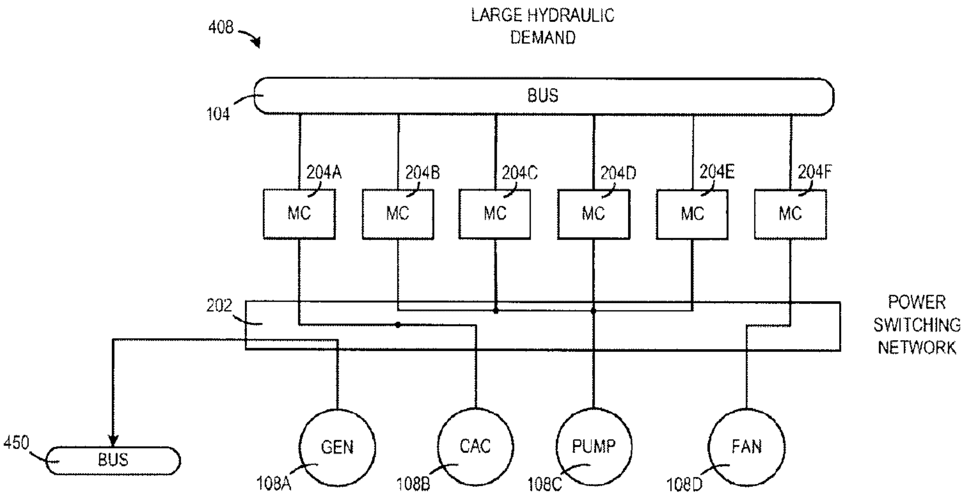

408
LARGE HYDRAULIC DEMAND
BUS
104
204A
204B
204C
204D
204E
204F
MC
MC
MC
MC
MC
MC
202
POWER SWITCHING NETWORK
450
BUS
GEN
CAC
PUMP
FAN
108A
108B
108C
108D

Fig. 4E

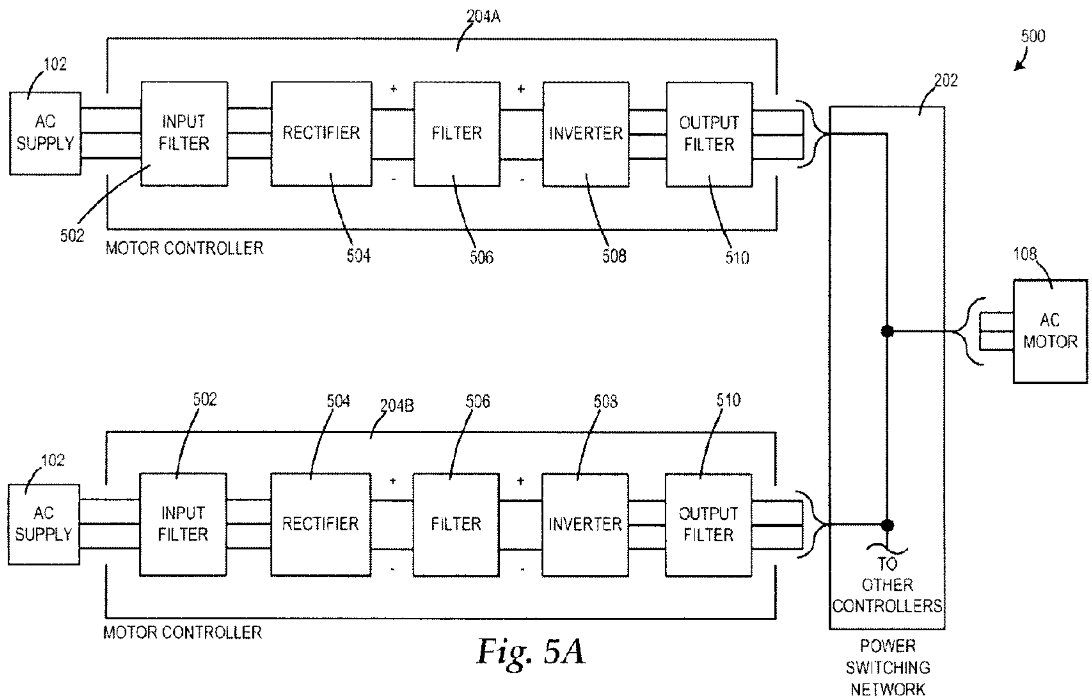

204A
500
102
AC SUPPLY
INPUT FILTER
RECTIFIER
FILTER
INVERTER
OUTPUT FILTER
202
502
MOTOR CONTROLLER
504
506
508
510
108
AC MOTOR
502
504
204B
506
508
510
102
AC SUPPLY
INPUT FILTER
RECTIFIER
FILTER
INVERTER
OUTPUT FILTER
TO OTHER CONTROLLERS
MOTOR CONTROLLER
POWER SWITCHING NETWORK

Fig. 5A

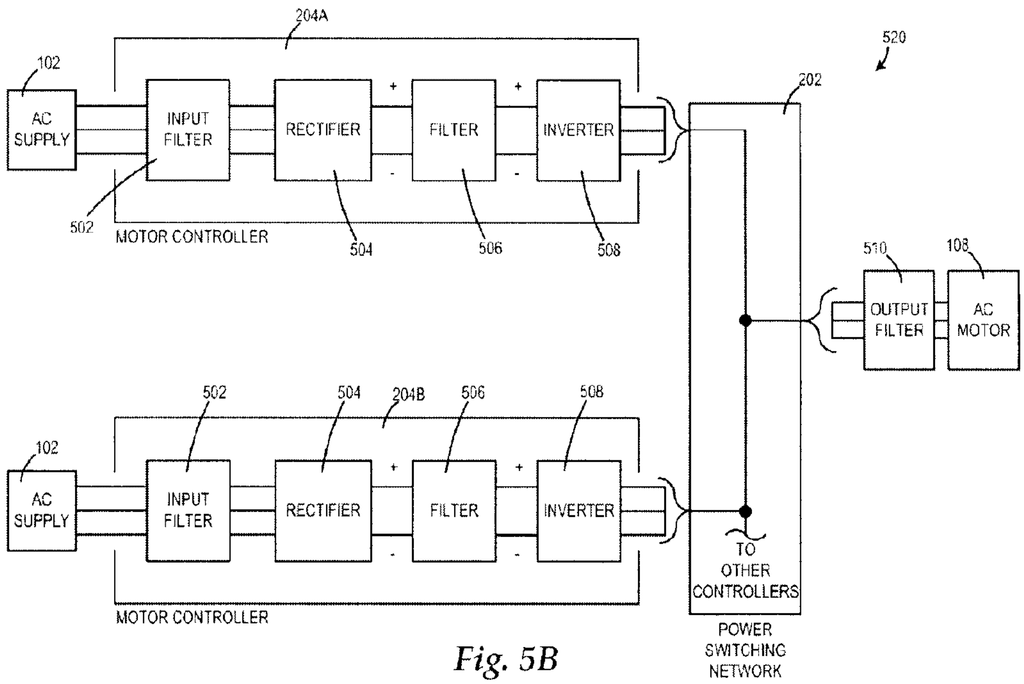

204A
102
AC SUPPLY
INPUT FILTER
RECTIFIER
FILTER
INVERTER
502
MOTOR CONTROLLER
504
506
508
520
202
510
108
OUTPUT FILTER
AC MOTOR
502
504
204B
506
508
102
AC SUPPLY
INPUT FILTER
RECTIFIER
FILTER
INVERTER
TO OTHER CONTROLLERS
MOTOR CONTROLLER
POWER SWITCHING NETWORK

Fig. 5B

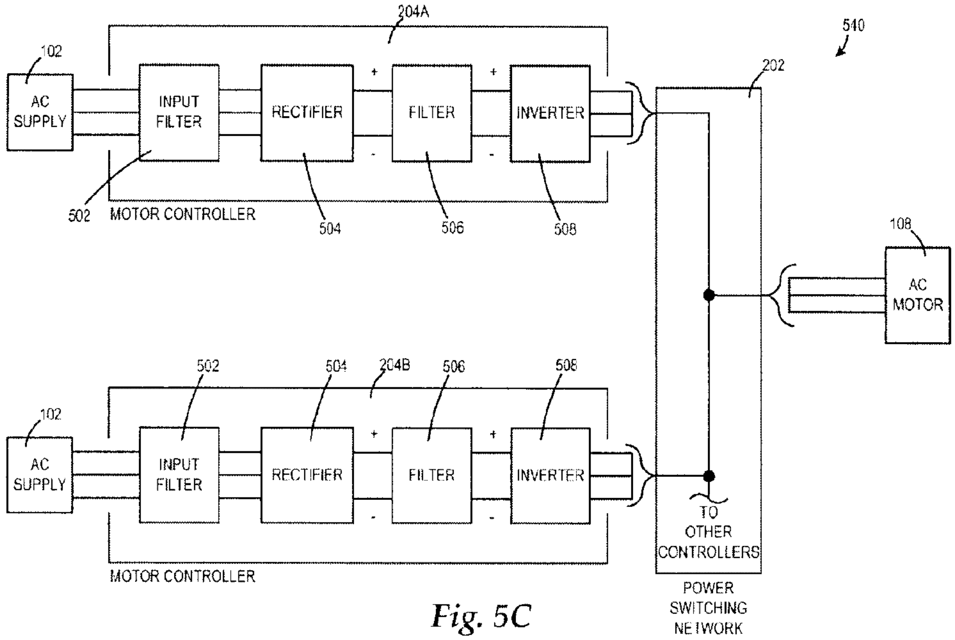

540
204A
102
AC SUPPLY
INPUT FILTER
RECTIFIER
FILTER
INVERTER
502
MOTOR CONTROLLER
504
506
508
202
108
AC MOTOR
502
504
204B
506
508
102
AC SUPPLY
INPUT FILTER
RECTIFIER
FILTER
INVERTER
TO OTHER CONTROLLERS
MOTOR CONTROLLER
POWER SWITCHING NETWORK

Fig. 5C

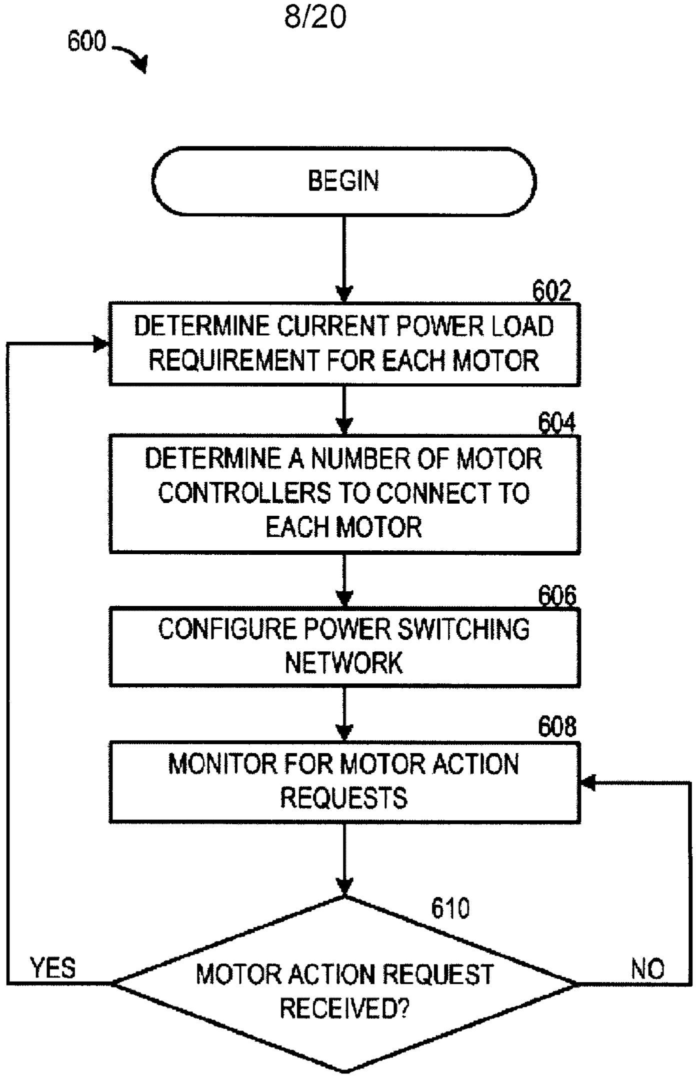


Fig. 6

(PRIOR ART)

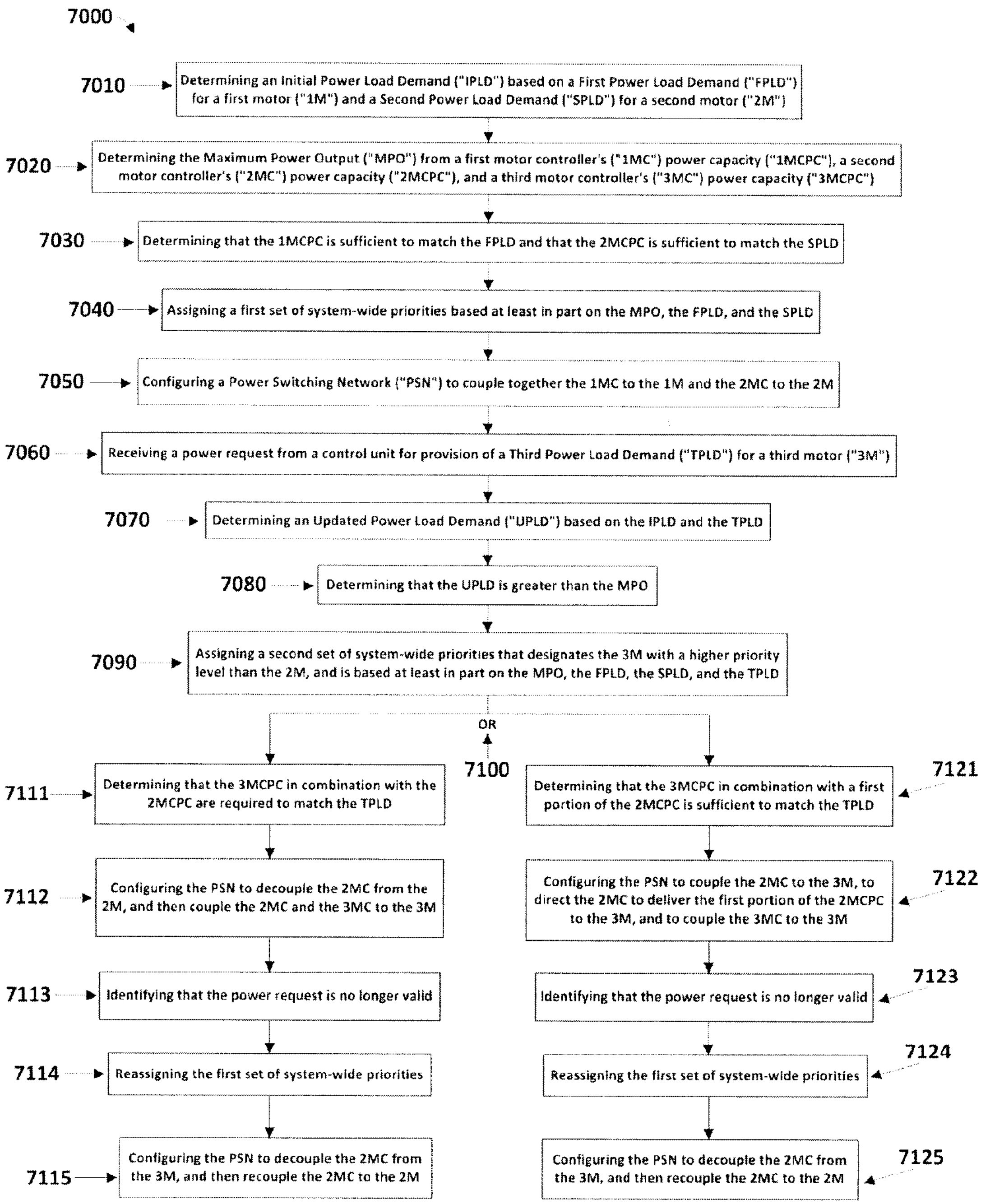

7000
7010
Determining an Initial Power Load Demand ("IPLD") based on a First Power Load Demand ("FPLD") for a first motor ("1M") and a Second Power Load Demand ("SPLD") for a second motor ("2M")
7020
Determining the Maximum Power Output ("MPO") from a first motor controller's ("1MC") power capacity ("1MCPC"), a second motor controller's ("2MC") power capacity ("2MCPC"), and a third motor controller's ("3MC") power capacity ("3MCPC")
7030
Determining that the 1MCPC is sufficient to match the FPLD and that the 2MCPC is sufficient to match the SPLD
7040
Assigning a first set of system-wide priorities based at least in part on the MPO, the FPLD, and the SPLD
7050
Configuring a Power Switching Network ("PSN") to couple together the 1MC to the 1M and the 2MC to the 2M
7060
Receiving a power request from a control unit for provision of a Third Power Load Demand ("TPLD") for a third motor ("3M")
7070
Determining an Updated Power Load Demand ("UPLD") based on the IPLD and the TPLD
7080
Determining that the UPLD is greater than the MPO
7090
Assigning a second set of system-wide priorities that designates the 3M with a higher priority level than the 2M, and is based at least in part on the MPO, the FPLD, the SPLD, and the TPLD
OR
7100
7111
Determining that the 3MCPC in combination with the 2MCPC are required to match the TPLD
7112
Configuring the PSN to decouple the 2MC from the 2M, and then couple the 2MC and the 3MC to the 3M
7113
Identifying that the power request is no longer valid
7114
Reassigning the first set of system-wide priorities
7115
Configuring the PSN to decouple the 2MC from the 3M, and then recouple the 2MC to the 2M
7121
Determining that the 3MCPC in combination with a first portion of the 2MCPC is sufficient to match the TPLD
7122
Configuring the PSN to couple the 2MC to the 3M, to direct the 2MC to deliver the first portion of the 2MCPC to the 3M, and to couple the 3MC to the 3M
7123
Identifying that the power request is no longer valid
7124
Reassigning the first set of system-wide priorities
7125
Configuring the PSN to decouple the 2MC from the 3M, and then recouple the 2MC to the 2M

Fig. 7

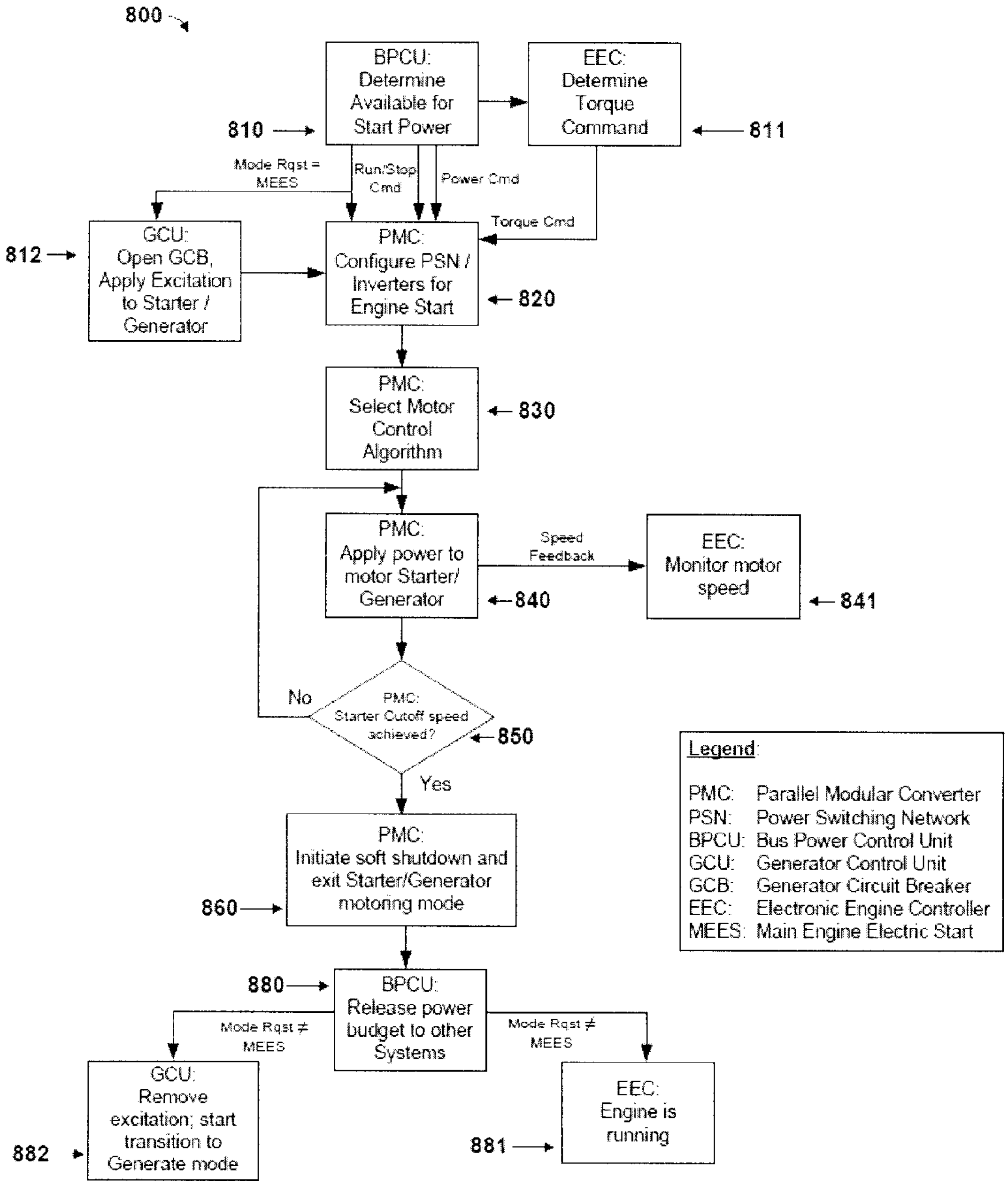
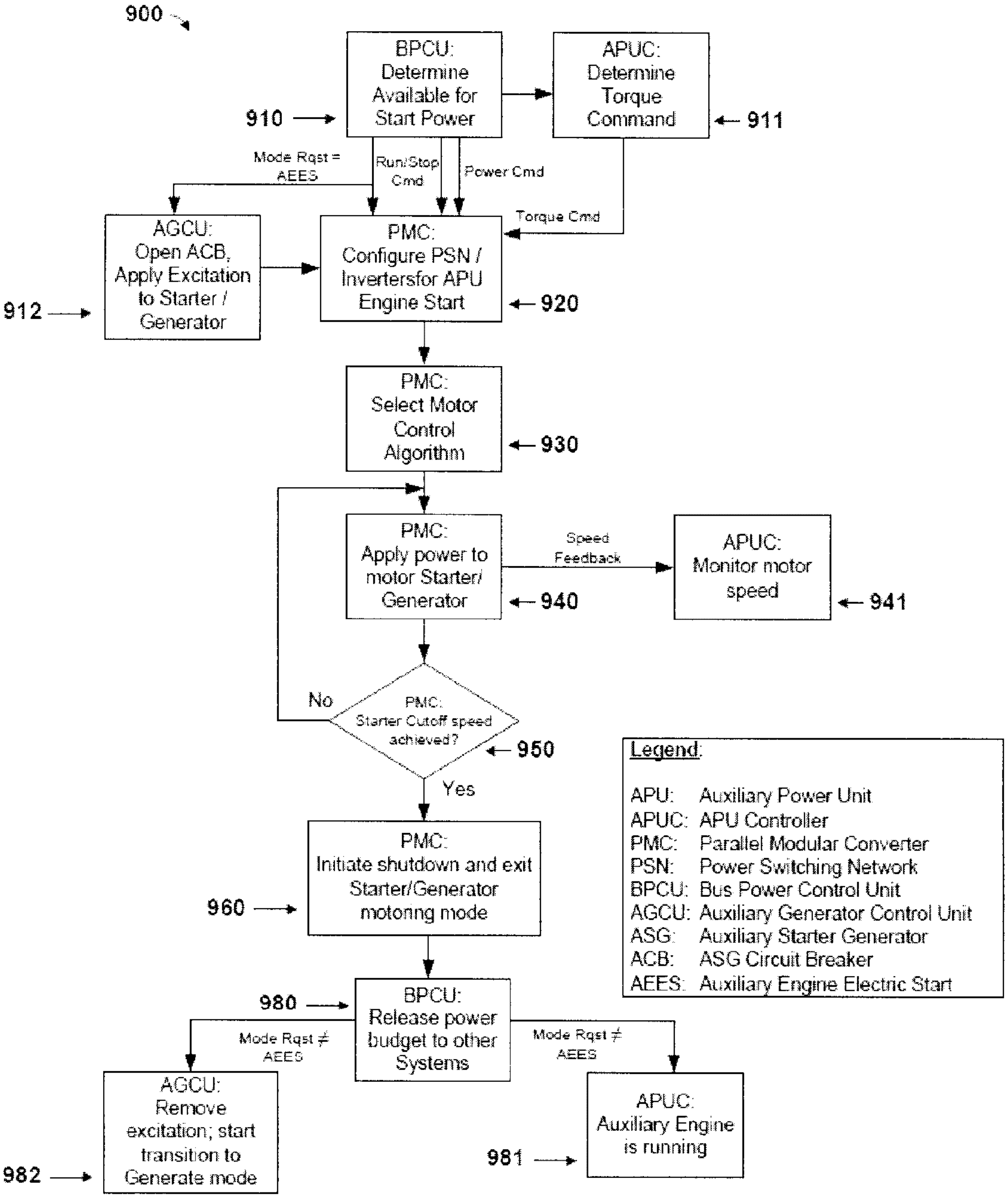

800
BPCU: Determine Available for Start Power
810
EEC: Determine Torque Command
811
Mode Rqst = MEES
Run/Stop Cmd
Power Cmd
Torque Cmd
GCU: Open GCB, Apply Excitation to Starter / Generator
812
PMC: Configure PSN / Inverters for Engine Start
820
PMC: Select Motor Control Algorithm
830
PMC: Apply power to motor Starter/ Generator
840
Speed Feedback
EEC: Monitor motor speed
841
No
PMC: Starter Cutoff speed achieved?
850
Yes
PMC: Initiate soft shutdown and exit Starter/Generator motoring mode
860
880
BPCU: Release power budget to other Systems
Mode Rqst ≠ MEES
Mode Rqst ≠ MEES
GCU: Remove excitation; start transition to Generate mode
882
EEC: Engine is running
881
Legend:
PMC: Parallel Modular Converter
PSN: Power Switching Network
BPCU: Bus Power Control Unit
GCU: Generator Control Unit
GCB: Generator Circuit Breaker
EEC: Electronic Engine Controller
MEES: Main Engine Electric Start

Fig. 8



900
BPCU: Determine Available for Start Power
910
APUC: Determine Torque Command
911
Mode Rqst = AEES
Run/Stop Cmd
Power Cmd
Torque Cmd
AGCU: Open ACB, Apply Excitation to Starter / Generator
912
PMC: Configure PSN / Invertersfor APU Engine Start
920
PMC: Select Motor Control Algorithm
930
PMC: Apply power to motor Starter/ Generator
940
Speed Feedback
APUC: Monitor motor speed
941
No
PMC: Starter Cutoff speed achieved?
950
Yes
PMC: Initiate shutdown and exit Starter/Generator motoring mode
960
980
BPCU: Release power budget to other Systems
Mode Rqst ≠ AEES
Mode Rqst ≠ AEES
AGCU: Remove excitation; start transition to Generate mode
982
APUC: Auxiliary Engine is running
981
Legend:
APU: Auxiliary Power Unit
APUC: APU Controller
PMC: Parallel Modular Converter
PSN: Power Switching Network
BPCU: Bus Power Control Unit
AGCU: Auxiliary Generator Control Unit
ASG: Auxiliary Starter Generator
ACB: ASG Circuit Breaker
AEES: Auxiliary Engine Electric Start

Fig. 9

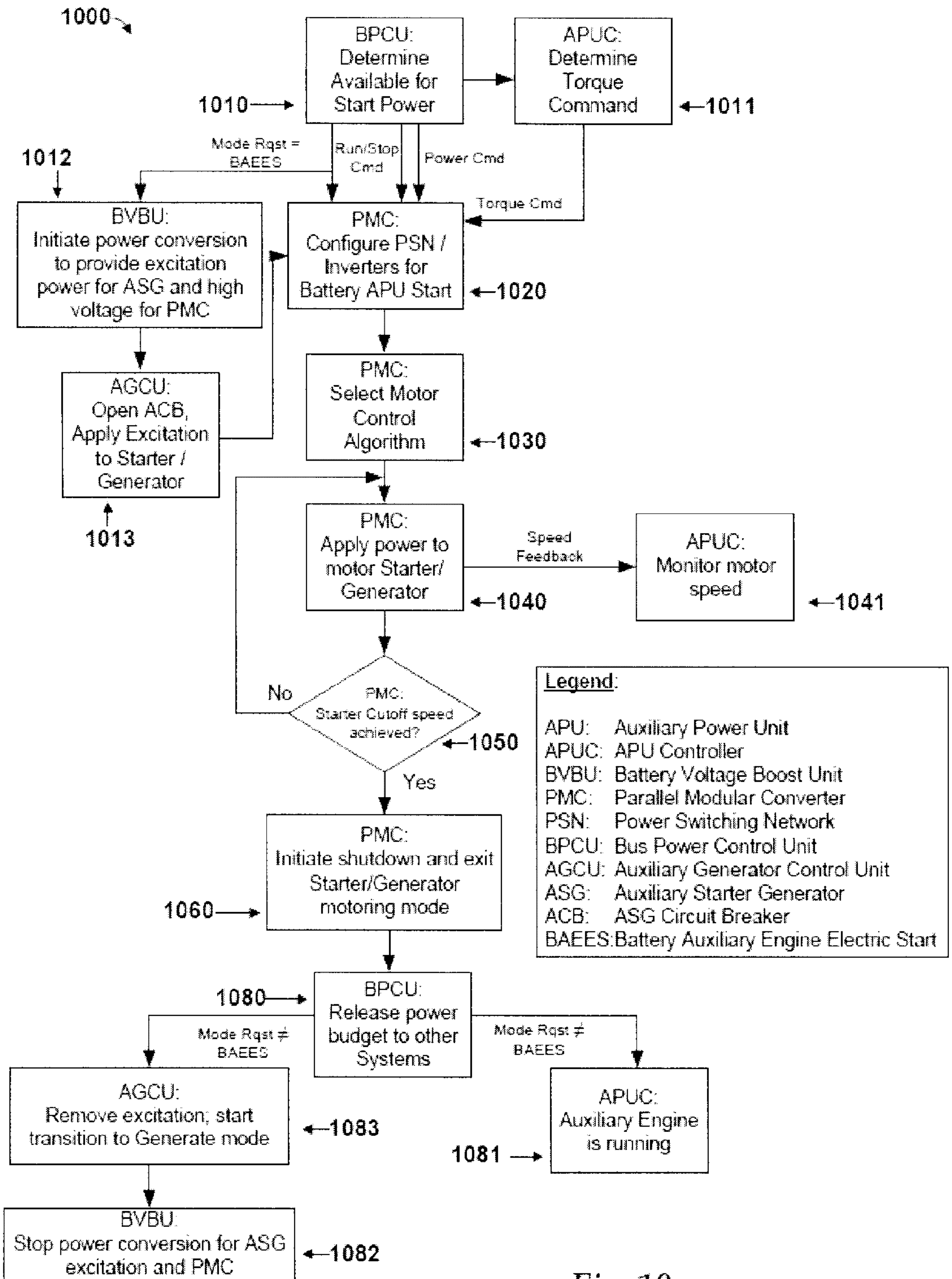

1000
BPCU: Determine Available for Start Power
1010
APUC: Determine Torque Command
1011
Mode Rqst = BAEES
Run/Stop Cmd
Power Cmd
Torque Cmd
1012
BVBU: Initiate power conversion to provide excitation power for ASG and high voltage for PMC
PMC: Configure PSN / Inverters for Battery APU Start
1020
AGCU: Open ACB, Apply Excitation to Starter / Generator
1013
PMC: Select Motor Control Algorithm
1030
PMC: Apply power to motor Starter/ Generator
1040
Speed Feedback
APUC: Monitor motor speed
1041
No
PMC: Starter Cutoff speed achieved?
1050
Yes
PMC: Initiate shutdown and exit Starter/Generator motoring mode
1060
Legend:
APU: Auxiliary Power Unit
APUC: APU Controller
BVBU: Battery Voltage Boost Unit
PMC: Parallel Modular Converter
PSN: Power Switching Network
BPCU: Bus Power Control Unit
AGCU: Auxiliary Generator Control Unit
ASG: Auxiliary Starter Generator
ACB: ASG Circuit Breaker
BAEES: Battery Auxiliary Engine Electric Start
1080
BPCU: Release power budget to other Systems
Mode Rqst ≠ BAEES
Mode Rqst ≠ BAEES
AGCU: Remove excitation; start transition to Generate mode
1083
APUC: Auxiliary Engine is running
1081
BVBU: Stop power conversion for ASG excitation and PMC
1082

Fig. 10

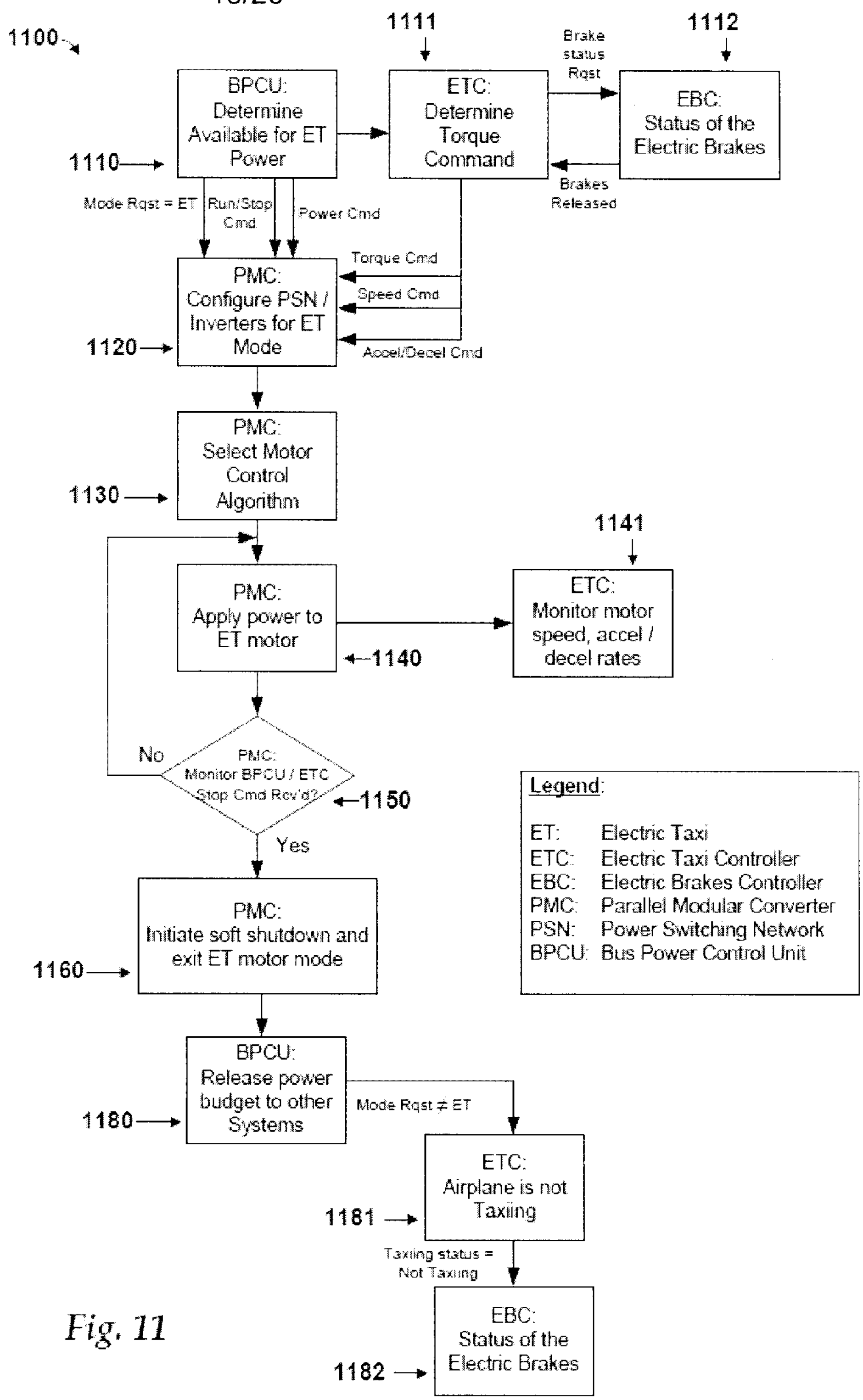

1100
1111
1112
1110
BPCU:
Determine
Available for ET
Power
ETC:
Determine
Torque
Command
Brake
status
Rqst
EBC:
Status of the
Electric Brakes
Brakes
Released
Mode Rqst = ET
Run/Stop
Cmd
Power Cmd
Torque Cmd
Speed Cmd
Accel/Decel Cmd
PMC:
Configure PSN /
Inverters for ET
Mode
1120
PMC:
Select Motor
Control
Algorithm
1130
1141
PMC:
Apply power to
ET motor
1140
ETC:
Monitor motor
speed, accel /
decel rates
No
PMC:
Monitor BPCU / ETC
Stop Cmd Rcv'd?
1150
Yes
PMC:
Initiate soft shutdown and
exit ET motor mode
1160
BPCU:
Release power
budget to other
Systems
1180
Mode Rqst ≠ ET
ETC:
Airplane is not
Taxiing
1181
Taxiing status =
Not Taxiing
EBC:
Status of the
Electric Brakes
1182
Legend:
ET: Electric Taxi
ETC: Electric Taxi Controller
EBC: Electric Brakes Controller
PMC: Parallel Modular Converter
PSN: Power Switching Network
BPCU: Bus Power Control Unit

Fig. 11

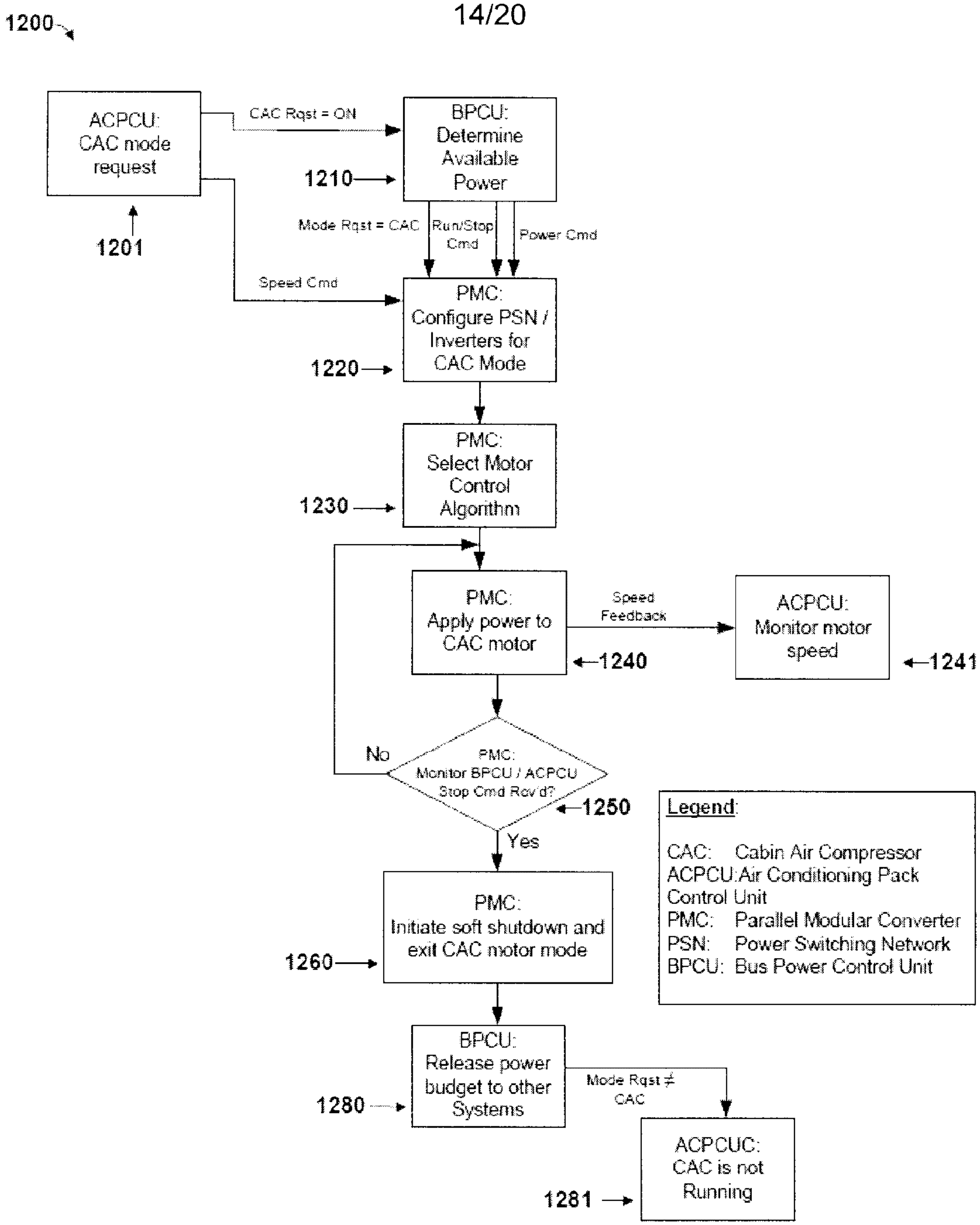
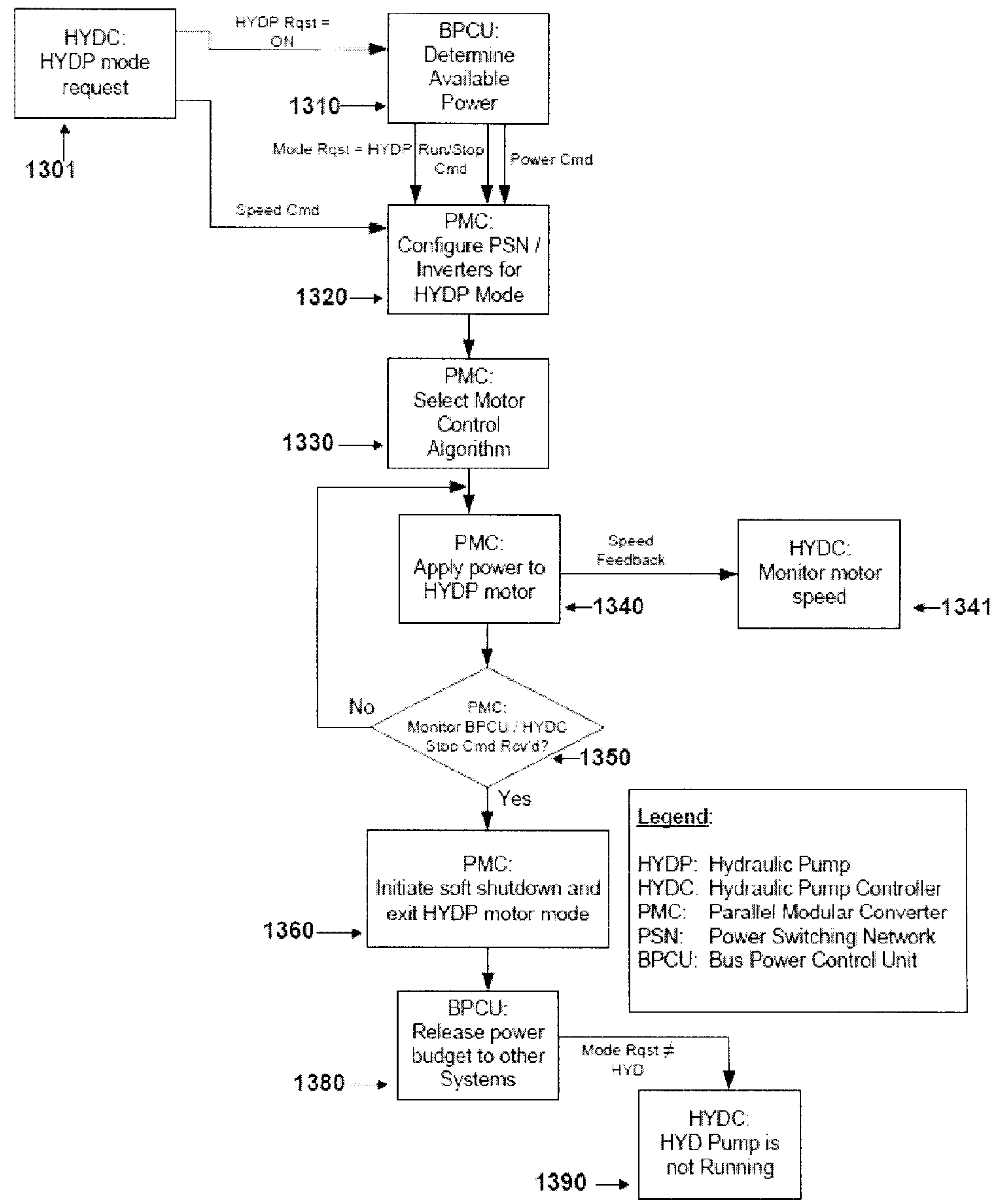

1200
ACPCU:
CAC mode
request
1201
CAC Rqst = ON
BPCU:
Determine
Available
Power
1210
Mode Rqst = CAC
Run/Stop
Cmd
Power Cmd
Speed Cmd
PMC:
Configure PSN /
Inverters for
CAC Mode
1220
PMC:
Select Motor
Control
Algorithm
1230
PMC:
Apply power to
CAC motor
1240
Speed
Feedback
ACPCU:
Monitor motor
speed
1241
No
PMC:
Monitor BPCU / ACPCU
Stop Cmd Rcv'd?
1250
Yes
PMC:
Initiate soft shutdown and
exit CAC motor mode
1260
Legend:
CAC: Cabin Air Compressor
ACPCU: Air Conditioning Pack
Control Unit
PMC: Parallel Modular Converter
PSN: Power Switching Network
BPCU: Bus Power Control Unit
BPCU:
Release power
budget to other
Systems
1280
Mode Rqst ≠
CAC
ACPCUC:
CAC is not
Running
1281

Fig. 12

1300



HYDC:
HYDP mode
request
1301
HYDP Rqst =
ON
BPCU:
Determine
Available
Power
1310
Mode Rqst = HYDP
Run/Stop
Cmd
Power Cmd
Speed Cmd
PMC:
Configure PSN /
Inverters for
HYDP Mode
1320
PMC:
Select Motor
Control
Algorithm
1330
PMC:
Apply power to
HYDP motor
1340
Speed
Feedback
HYDC:
Monitor motor
speed
1341
No
PMC:
Monitor BPCU / HYDC
Stop Cmd Rcv'd?
1350
Yes
PMC:
Initiate soft shutdown and
exit HYDP motor mode
1360
BPCU:
Release power
budget to other
Systems
1380
Mode Rqst ≠
HYD
HYDC:
HYD Pump is
not Running
1390
Legend:
HYDP: Hydraulic Pump
HYDC: Hydraulic Pump Controller
PMC: Parallel Modular Converter
PSN: Power Switching Network
BPCU: Bus Power Control Unit

Fig. 13

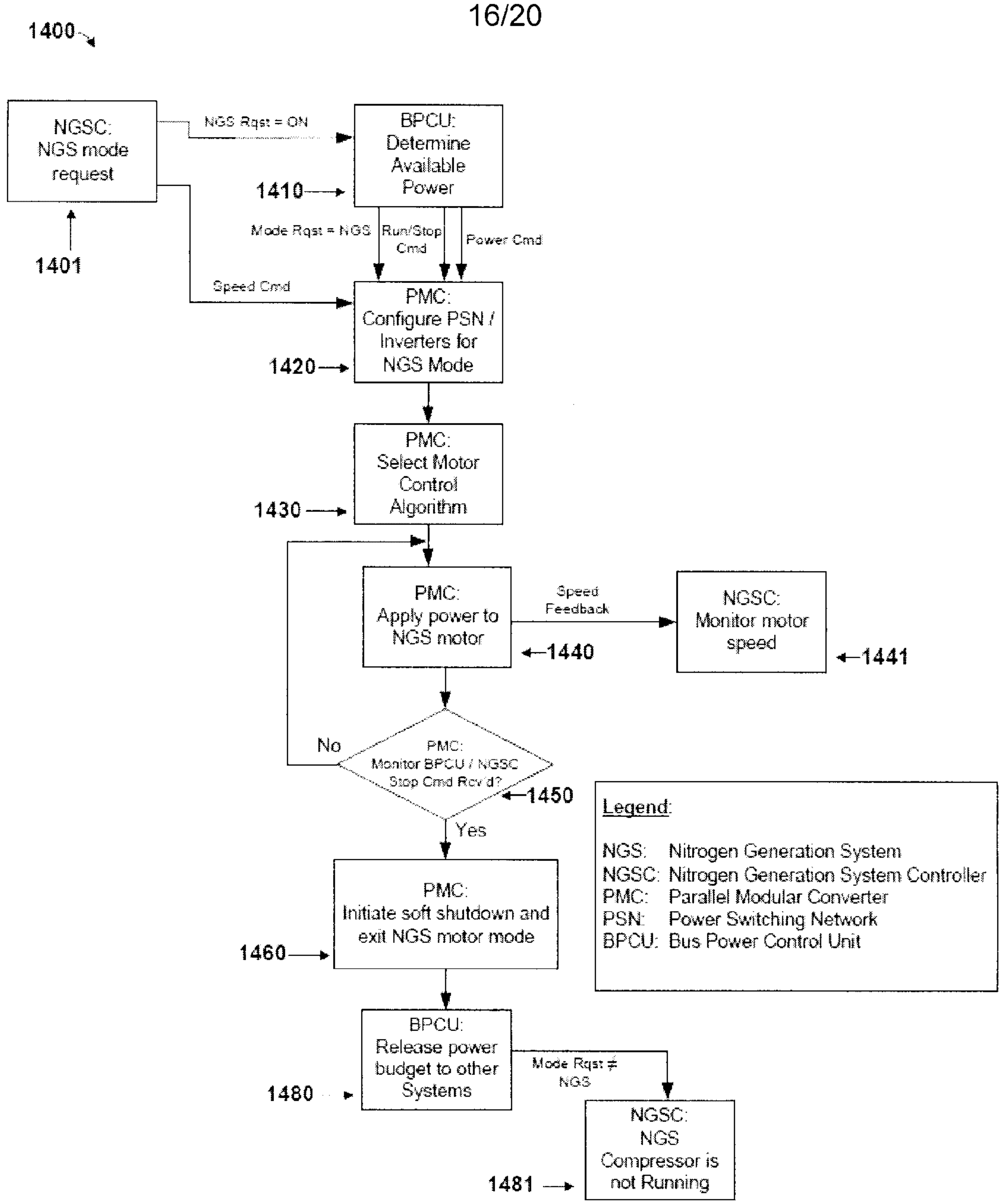

1400
NGSC:
NGS mode
request
1401
NGS Rqst = ON
BPCU:
Determine
Available
Power
1410
Mode Rqst = NGS
Run/Stop
Cmd
Power Cmd
Speed Cmd
PMC:
Configure PSN /
Inverters for
NGS Mode
1420
PMC:
Select Motor
Control
Algorithm
1430
PMC:
Apply power to
NGS motor
1440
Speed
Feedback
NGSC:
Monitor motor
speed
1441
No
PMC:
Monitor BPCU / NGSC
Stop Cmd Rcv'd?
1450
Yes
PMC:
Initiate soft shutdown and
exit NGS motor mode
1460
BPCU:
Release power
budget to other
Systems
1480
Mode Rqst ≠
NGS
NGSC:
NGS
Compressor is
not Running
1481
Legend:
NGS: Nitrogen Generation System
NGSC: Nitrogen Generation System Controller
PMC: Parallel Modular Converter
PSN: Power Switching Network
BPCU: Bus Power Control Unit

Fig. 14

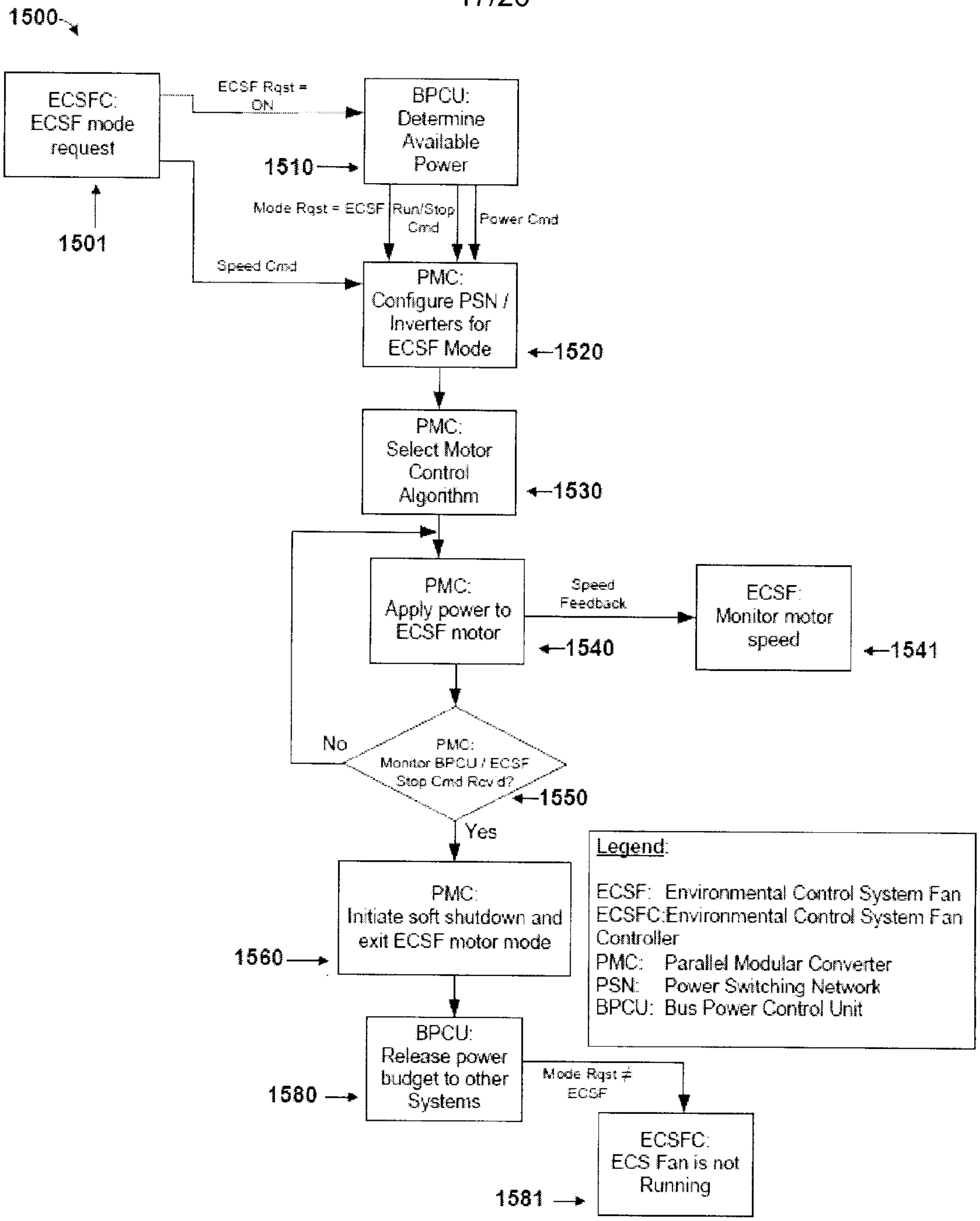
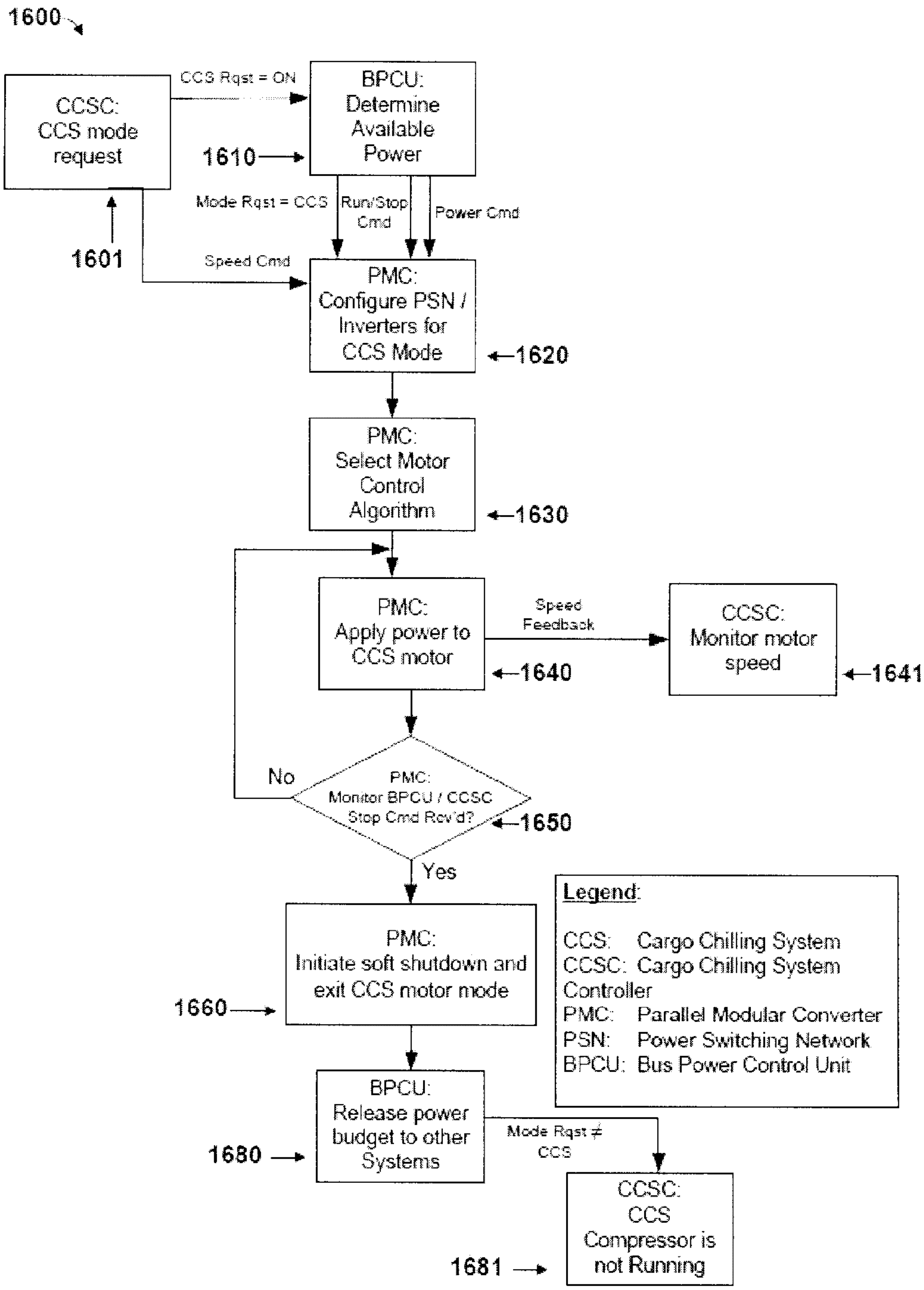

1500
ECSFC:
ECSF mode
request
1501
ECSF Rqst =
ON
BPCU:
Determine
Available
Power
1510
Mode Rqst = ECSF
Run/Stop
Cmd
Power Cmd
Speed Cmd
PMC:
Configure PSN /
Inverters for
ECSF Mode
1520
PMC:
Select Motor
Control
Algorithm
1530
PMC:
Apply power to
ECSF motor
1540
Speed
Feedback
ECSF:
Monitor motor
speed
1541
No
PMC:
Monitor BPCU / ECSF
Stop Cmd Rcv'd?
1550
Yes
PMC:
Initiate soft shutdown and
exit ECSF motor mode
1560
Legend:
ECSF: Environmental Control System Fan
ECSFC: Environmental Control System Fan
Controller
PMC: Parallel Modular Converter
PSN: Power Switching Network
BPCU: Bus Power Control Unit
BPCU:
Release power
budget to other
Systems
1580
Mode Rqst ≠
ECSF
ECSFC:
ECS Fan is not
Running
1581

Fig. 15



1600
CCSC:
CCS mode
request
CCS Rqst = ON
BPCU:
Determine
Available
Power
1610
1601
Mode Rqst = CCS
Run/Stop
Cmd
Power Cmd
Speed Cmd
PMC:
Configure PSN /
Inverters for
CCS Mode
1620
PMC:
Select Motor
Control
Algorithm
1630
PMC:
Apply power to
CCS motor
Speed
Feedback
CCSC:
Monitor motor
speed
1640
1641
No
PMC:
Monitor BPCU / CCSC
Stop Cmd Rcv'd?
1650
Yes
PMC:
Initiate soft shutdown and
exit CCS motor mode
1660
Legend:
CCS: Cargo Chilling System
CCSC: Cargo Chilling System
Controller
PMC: Parallel Modular Converter
PSN: Power Switching Network
BPCU: Bus Power Control Unit
BPCU:
Release power
budget to other
Systems
1680
Mode Rqst ≠
CCS
CCSC:
CCS
Compressor is
not Running
1681

Fig. 16

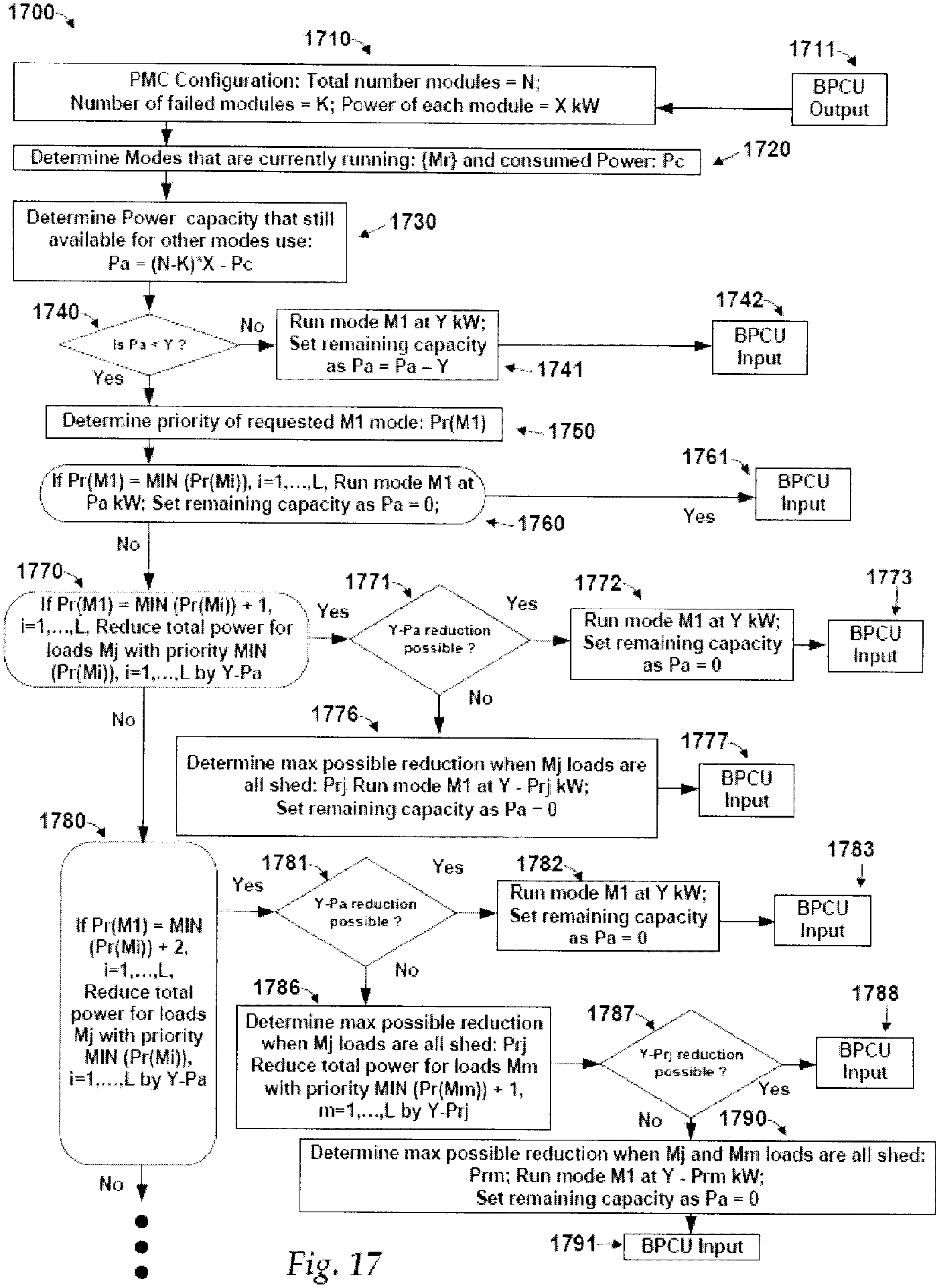

1700
1710
PMC Configuration: Total number modules = N; Number of failed modules = K; Power of each module = X kW
1711
BPCU Output
Determine Modes that are currently running: {Mr} and consumed Power: Pc
1720
Determine Power capacity that still available for other modes use: Pa = (N-K)*X - Pc
1730
1740
Is Pa < Y ?
No
Yes
Run mode M1 at Y kW; Set remaining capacity as Pa = Pa – Y
1741
1742
BPCU Input
Determine priority of requested M1 mode: Pr(M1)
1750
If Pr(M1) = MIN (Pr(Mi)), i=1,...,L, Run mode M1 at Pa kW; Set remaining capacity as Pa = 0;
1760
1761
Yes
BPCU Input
No
1770
If Pr(M1) = MIN (Pr(Mi)) + 1, i=1,...,L, Reduce total power for loads Mj with priority MIN (Pr(Mi)), i=1,...,L by Y-Pa
1771
Y-Pa reduction possible ?
Yes
Yes
No
1772
Run mode M1 at Y kW; Set remaining capacity as Pa = 0
1773
BPCU Input
No
1776
Determine max possible reduction when Mj loads are all shed: Prj Run mode M1 at Y - Prj kW; Set remaining capacity as Pa = 0
1777
BPCU Input
1780
If Pr(M1) = MIN (Pr(Mi)) + 2, i=1,...,L, Reduce total power for loads Mj with priority MIN (Pr(Mi)), i=1,...,L by Y-Pa
1781
Y-Pa reduction possible ?
Yes
Yes
No
1782
Run mode M1 at Y kW; Set remaining capacity as Pa = 0
1783
BPCU Input
1786
Determine max possible reduction when Mj loads are all shed: Prj Reduce total power for loads Mm with priority MIN (Pr(Mm)) + 1, m=1,...,L by Y-Prj
1787
Y-Prj reduction possible ?
Yes
No
1788
BPCU Input
1790
Determine max possible reduction when Mj and Mm loads are all shed: Prm; Run mode M1 at Y - Prm kW; Set remaining capacity as Pa = 0
1791
BPCU Input
No

Fig. 17

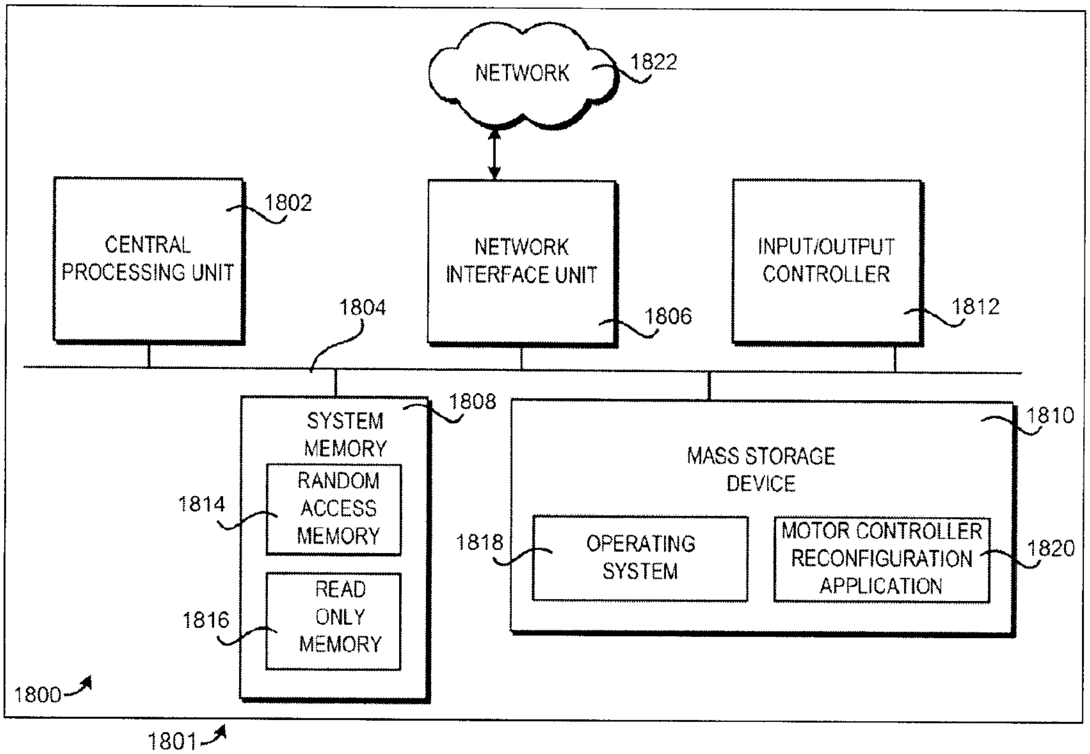
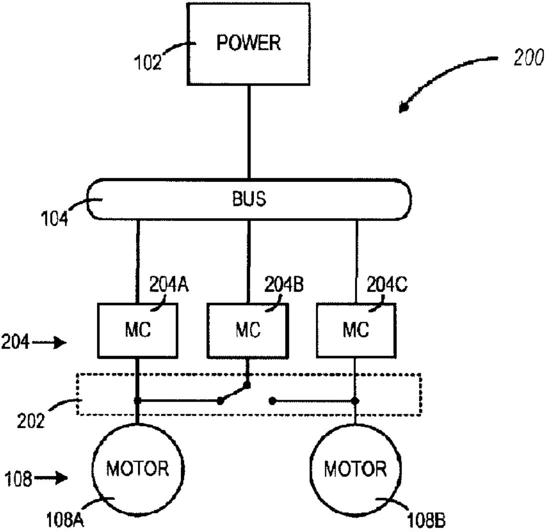

NETWORK
1822
CENTRAL PROCESSING UNIT
1802
NETWORK INTERFACE UNIT
1806
INPUT/OUTPUT CONTROLLER
1812
1804
SYSTEM MEMORY
1808
RANDOM ACCESS MEMORY
1814
READ ONLY MEMORY
1816
MASS STORAGE DEVICE
1810
OPERATING SYSTEM
1818
MOTOR CONTROLLER RECONFIGURATION APPLICATION
1820
1800
1801

Fig. 18


POWER
102
200
BUS
104
204A
204B
204C
MC
MC
MC
204
202
MOTOR
MOTOR
108
108A
108B