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United States Patent	12391124
Kind Code	B2
Date of Patent	August 19, 2025
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Hybrid-electric propulsion architecture and method for dissipating electrical energy in such an architecture

Abstract

A hybrid/electric propulsion architecture for a multi-rotor rotary wing aircraft, including an electricity generator driven by an internal combustion engine, and configured to operate in motor mode, a rectifier configured to convert an alternating current delivered by the electricity generator into direct current, an electrical network including a high voltage direct current (HVDC) bus, electrical energy storage means connected to the electrical network, during electrical energy regeneration on the HVDC bus, depending on the state of charge of the storage means: the storage means are configured to recover electrical energy, the storage means and the rectifier are configured to recover electrical energy, and the electricity generator operating in motor mode is configured to recover electrical energy.

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Appl. No.:	**17/433545**
Filed (or PCT Filed):	**February 24, 2020**
PCT No.:	**PCT/FR2020/050343**
PCT Pub. No.:	**WO2020/174165**
PCT Pub. Date:	September 03, 2020

Prior Publication Data

Document Identifier	Publication Date
US 20220153423 A1	May. 19, 2022

Foreign Application Priority Data

FR	1901979	Feb. 26, 2019

Publication Classification

Int. Cl.: **B64D27/24** (20240101); **B60L53/24** (20190101); **B60L58/10** (20190101); **B60L58/12** (20190101); **B64D27/02** (20060101); **F03D9/25** (20160101)

U.S. Cl.:

CPC **B64D27/24** (20130101); **B60L53/24** (20190201); **B60L58/10** (20190201); **B60L58/12** (20190201); **F03D9/25** (20160501); B60L2200/10 (20130101); B64D27/026 (20240101); F05B2220/706 (20130101)

Field of Classification Search

CPC: B60L (53/24); B64D (2027/026); B60W (10/24); B60W (10/26); B60W (20/13); B60W (20/14)

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Background/Summary

TECHNICAL FIELD OF THE INVENTION

(1) The invention relates to a hybrid-electric propulsion architecture for a multi-rotor rotary wing aircraft, an aircraft comprising such a hybrid-electric propulsion architecture and a method for dissipating electrical energy in such a hybrid-electric propulsion architecture.

BACKGROUND

(2) The prior art comprises, in particular the patent applications FR-A1-3 056 555, US-A1-2018/162379, US-A1-2016/070266, DE-A1-10 2010 031540 and EP-A1-2 684 798.

(3) It is known from the prior art a hybrid propulsion architecture of an aircraft, commonly called series hybridization, with a thermoelectric power generation.

(4) As shown in FIG. **1**, a hybrid propulsion architecture **10** generally comprises: an internal combustion engine **12**, an electric generator **14** coupled to the internal combustion engine so that in operation the internal combustion engine **12** drives the electric generator **14**, a rectifier **16** connected to the electric generator **14** and configured to convert an alternative current delivered by the electric generator **14** into a direct current, means for converting **18***a*, **18***b*, **18***c*, **18***d* the direct current into alternative current, an electrical network **20** connecting the rectifier **16** to the conversion means **18***a*, **18***b*, **18***c*, **18***d*, electric motors **22***a*, **22***b*, **22***c*, **22***d* connected to the conversion means **18***a*, **18***b*, **18***c*, **18***d* so that in operation the conversion means **18***a*, **18***b*, **18***c*, **18***d* supply the electric motors **22***a*, **22***b*, **22***c*, **22***d* with alternative current, and propellers **24***a*, **24***b*, **24***c*, **24***d* coupled to the electric motors **22***a*, **22***b*, **22***c*, **22***d* so that in operation the electric motors **22***a*, **22***b*, **22***c*, **22***d* drive the propellers **24***a*, **24***b*, **24***c*, **24***d*.

(5) In addition, the electrical network **20** typically comprises a high-voltage direct current (HVDC) bus.

(6) The architecture **10** may also comprise a storage unit **26**, for example a battery, to absorb the excess of electrical energy from the HVDC bus or ensure an additional energy during transient phases. In particular, when there is a return of electrical energy on the HVDC bus, the storage unit **26** absorbs this excess of electrical energy to protect the components of the HVDC bus.

(7) In such an architecture, from a source of fossil fuel, the internal combustion engine **12**, and via a mechanical-electrical conversion, by the electric generator **14**, an electrical propulsion chain composed of the conversion means **18***a*, **18***b*, **18***c*, **18***d*, the electric motors **22***a*, **22***b*, **22***c*, **22***d* and the propellers **24***a*, **24***b*, **24***c*, **24***d* allows to fly an aircraft with rotating multi-wings.

(8) An aircraft comprising such a hybrid propulsion architecture is multi-rotor, which allows to provide additional degrees of freedom, compared to the conventional aircrafts, with respect to the controllability of the aircraft, for example the braking, the avoidance strategy, the change of direction, or the tilting of the rotors.

(9) However, such an architecture has a significant on-board mass, and it is necessary to ensure an electrical risk management in the particular context of the on-board aeronautical environment.

(10) Indeed, this architecture must necessarily integrate electrical equipment, which are heavy and imposing, to allow a good regulation of the HVDC bus of the electrical network **20** and a good stability.

(11) The hybrid propulsion architecture **10** of FIG. **1** also comprises an energy recovery system **28** on the HVDC bus of the electrical network **20**. The energy recovery system **28** is generally used when the storage unit **26** is fully charged, and in transient, so-called “regeneration” phases, i.e., when there is a return of electrical energy from loads located downstream back to the storage unit **26** and the electric generator **14** coupled to the internal combustion engine **12**. In particular, this occurs when a propeller **24***a*, **24***b*, **24***c*, **24***d* brakes and rejects electrical energy onto the HVDC bus. In fact, this return of electrical energy occurs when the electromotive force generated in the

electric motors **22***a*, **22***b*, **22***c*, **22***d*, known as the propulsion motors, is greater than the voltage of the HVDC bus and the conversion means **18***a*, **18***b*, **18***c*, **18***d* are reversible in current. The energy recovery system allows to provide a protection for the electronic components located upstream such as transistors. The energy recovery system **28** generally consists of an electrical resistor **30** that converts the electrical energy into thermal energy and a chopper **32** that allows to set a voltage threshold at which it is useful to absorb the voltage peak. This energy recovery system is therefore a dissipative circuit, since it allows a dissipation of the electrical energy in a calorific way.
(12) However, the mass of this system can be relatively imposing and is dependent on the energy that will be dissipated.
(13) The purpose of the invention is to provide a solution allowing to remedy at least some of these drawbacks.
(14) In particular, the present invention provides an electrical energy management that allows the elimination of the energy recovery system of the prior art. The present invention therefore proposes to lighten the hybrid propulsion architecture by managing the electrical energy of the HVDC bus, so as to eliminate the electrical equipment used to dissipate the "overflow" of electrical energy on the HVDC bus, which would result in a dangerous rise in voltage for the static components, such as transistors, and the passive components, such as the filtering or decoupling capacitors.
SUMMARY OF THE INVENTION
(15) To this end, the invention relates to a hybrid-electric propulsion architecture for a multi-rotor rotary wing aircraft, comprising: an internal combustion engine, an electric generator coupled to the internal combustion engine so that in operation the internal combustion engine drives the electric generator, a rectifier connected to the electric generator and configured to convert an alternative current delivered by the electric generator into a direct current, means for converting direct current into alternative current, an electrical network connecting the rectifier to the conversion means, the electrical network comprising a high-voltage direct current (HVDC) bus, electrical energy storage means connected to the electrical network in parallel with the electric generator, electric motors connected to the conversion means so that in operation the conversion means supply the electric motors with alternative current, propellers coupled to the electric motors so that in operation the electric motors drive the propellers,
(16) the architecture being characterized in that the electric generator is an engine-generator, and in operation the internal combustion engine drives the electric generator in generator mode,
(17) in that, during a regeneration of electrical energy on the high-voltage direct current bus of the electrical network, depending on the state of charge of the storage means, the storage means are configured to recover the electrical energy,
(18) in that, during a regeneration of electrical energy on the high-voltage direct current bus of the electrical network, depending on the state of charge of the storage means, the rectifier is configured to recover the electrical energy,
(19) and in that during a regeneration of electrical energy on the high-voltage direct current bus of the electrical network, depending on the state of charge of the storage means, the electric generator is configured to operate in a motor mode so that in operation the electric generator recovers the electrical energy.
(20) Advantageously, the present invention allows an electrical energy system allowing the suppression of the energy recovery system of the prior art. Indeed, this architecture allows a good regulation of the HVDC bus of the electrical network and a good stability, without integrating an energy recovery system. The mass of the architecture according to the invention is therefore optimized, and does not depend on the electrical energy that will be dissipated.
(21) In particular, unlike the architectures according to the prior art, the architecture according to the invention does not comprise an energy recovery system in the form of a resistive dissipation circuit. This advantageously allows to reduce the weight and the volume of the architecture according to the invention, such a circuit being generally very heavy and bulky.

(22) According to an embodiment of the invention, when the state of charge of the storage means is less than 60%, the storage means are configured to recover the electrical energy; when the state of charge of the storage means is between 60% and 80%, the storage means and the rectifier are configured to recover the electrical energy; and when the state of charge of the storage means is greater than 80%, the electric generator operating in motor mode is configured to recover the electrical energy.
(23) The electrical network can be bidirectional. In other words, the current can flow in both directions in the electrical network, for example from the rectifier to the electrical propulsion chains, or vice versa.
(24) The conversion means may comprise one or a plurality of inverters.
(25) The conversion means and the rectifier can be configured to be current reversible. This advantageously allows a power absorption on the HVDC bus, without necessarily needing a dissipative circuit.
(26) The electric generator may be a synchronous electrical machine. Alternatively, the electric generator may be an asynchronous electrical machine.
(27) The internal combustion engine may be configured to consume the electrical energy recovered by the electric generator operating in motor mode.
(28) The invention also relates to a multi-rotor rotary wing aircraft, comprising a hybrid-electric propulsion architecture according to the invention.
(29) The invention also relates to a method for dissipating electrical energy in a hybrid-electric propulsion architecture according to the invention, comprising the steps of: a regeneration of electrical energy on the high-voltage direct current bus of the electrical network, an acquisition of the state of charge of the storage means, and a recovery of the regenerated electrical energy from the high-voltage direct current bus of the electrical network, and depending on the state of charge of the storage means: the recovery of the regenerated electrical energy from the high-voltage direct current bus of the electrical network is carried out by the storage means, or the recovery of the regenerated electrical energy on the high-voltage direct current bus of the electrical network is carried out by the storage means and the rectifier, or the recovery of the electrical energy regenerated on the high-voltage direct current bus of the electrical network is carried out by the electric generator operating in motor mode.
(30) According to an embodiment of the invention, during the step of recovering the regenerated electrical energy on the high-voltage direct current bus of the electrical network: the recovery of the electrical energy is carried out by the storage means when the state of charge of the storage means is less than 60%, the recovery of the electrical energy is carried out by the storage means and the rectifier when the state of charge of the storage means is between 60% and 80%, the recovery of the electrical energy is carried out by the electric generator operating in motor mode when the state of charge of the storage means is greater than 80%.
(31) In other words, when acquiring the state of charge of the storage means, when the state of charge of the storage means is low, for example less than 60%, the recovery of the electrical energy is carried out by the storage means. When acquiring the state of charge of the storage means, when the state of charge of the storage means is intermediate, for example between 60% and 80%, the recovery of the electrical energy is carried out by the storage means and the rectifier. When acquiring the state of charge of the storage means, when the state of charge of the storage means is high, e.g. above 80%, the recovery of the electrical energy is carried out by the electric generator operating in motor mode.
(32) According to one embodiment of the invention, when the state of charge of the storage means is greater than 80%, prior to the step of recovering the electrical energy by the electric generator operating in motor mode, the method comprises a step consisting of a defluxing of the electrical motors. This advantageously allows to avoid the direct re-injection of the electrical energy.
(33) According to one embodiment of the invention, when the state of charge of the storage means

is greater than 80%, prior to the step of recovering the electrical energy by the electric generator operating in motor mode, the method comprises a step consisting of a recovering of the electrical energy by the rectifier.
(34) According to an embodiment of the invention, when the state of charge of the storage means is greater than 80%, prior to the step of recovering electrical energy by the electric generator operating in motor mode, the method comprises a step consisting of an increase of the electrical voltage of the high-voltage direct current bus of the electrical network. This advantageously allows to avoid an increase in the electromotive force of the electric motors.

Description

BRIEF DESCRIPTION OF FIGURES
(1) The invention will be better understood and other details, characteristics and advantages of the present invention will become clearer from the following description made by way of non-limiting example and with reference to the attached drawings, in which:
(2) FIG. **1** represents a hybrid-electric propulsion architecture of an aircraft according to the prior art,
(3) FIG. **2** represents a hybrid-electric propulsion architecture of an aircraft according to the invention,
(4) FIG. **3** is a flowchart of a method for dissipating electrical energy in a hybrid-electric propulsion architecture according to the invention.
(5) The elements having the same functions in the different implementations have the same references in the figures.
DETAILED DESCRIPTION OF THE INVENTION
(6) FIG. **2** represents a hybrid-electric propulsion architecture **100** of an aircraft, for example of the helicopter or airplane type, with a multi-rotor rotary wing according to the invention. For example, the architecture **100** can be integrated into an aircraft weighing less than 5000 kg, with an on-board mechanical power of between 50 kW and 2000 kW.
(7) An internal combustion engine **112**, such as a turbomachine, for example an Auxiliary Power Unit (APU), is coupled to an electric generator **114**. In operation, the electric generator **114** is driven by the internal combustion engine **112**.
(8) The electric generator **114** is a motor-generator, i.e., it is adapted to operate in both generator mode and motor mode. In other words, the electric generator **114** may operate in generator mode, in particular when driven by the internal combustion engine **112**, or in motor mode. The electric generator **114** may be a synchronous or asynchronous electrical machine. Thus, the electric generator **114** is a reversible electrical machine. The electric generator **114** allows to provide a bidirectional mechanical-to-electrical energy conversion, i.e., a mechanical-to-electrical conversion and an electrical-to-mechanical conversion. The electric generator **114** may generate a polyphase electrical current, for example a three-phase current as shown in FIG. **2**.
(9) The rotational speed N**1** of the rotor shaft of the internal combustion engine **112** connected to the electric generator **114** can be controlled by control means **102** (EECU, Electronic Engine Control Unit). These control means **102** may control parameters of the internal combustion engine **112** , such as the fuel weight flow, noted WF, on the basis of the rotation speed N**1** and other parameters, such as the frequency N**1*** of the electric generator **114** or an anticipation of the load Ω**1***, Ω**2***, Ω**3***, Ω**4*** for each electrical propulsion chain.
(10) A starter **104** may be connected to the electric generator **114** by an auxiliary gearbox **106**. The starter **104** provides, for example, a direct current of 28 V. A control unit **108** may control the starter **104**. The starter **104** may be connected via a switch **110** to a battery **128**, for example of 28 V in direct current. The switch **110** allows to connect the starter **104** to the battery **128**, and thus to

the network **129** of 28 V in direct current. A rectifier **116** is connected to an input to the electric generator **114** and configured to convert the alternative current delivered by the electric generator **114** into a direct current. The rectifier **116** may be current reversible. A capacitor **130** may be arranged in parallel with the electric generator **114**.

(11) An electrical network **120** connects in parallel an output of the rectifier **116** to inputs of conversion means **118***a*, **118***b*, **118***c*, **118***d*.

(12) The conversion means **118***a*, **118***b*, **118***c*, **118***d* are configured to convert a direct current into an alternative current. The conversion means **118***a*, **118***b*, **118***c*, **118***d* may comprise direct current to alternative current converters.

(13) The conversion means **118***a*, **118***b*, **118***c*, **118***d* may comprise inverters. In FIG. **2**, DC means direct current and AC means alternative current. Each inverter may comprise three inverter arms respectively delivering the three phases **119**, **121**, **123** (referenced only for the conversion means **118***d*) of alternative current to each of the electric motors **122***a*, **122***b*, **122***c*, **122***d*.

(14) The conversion means **118***a*, **118***b*, **118***c*, **118***d*, and in particular the inverters, may be current reversible. A capacitor **136***a*, **136***b*, **136***c*, **136***d* may be arranged in parallel with each of the conversion means **118***a*, **118***b*, **118***c*, **118***d*.

(15) The electrical network **120** may be bidirectional, that is, the electrical current may flow from the rectifier **116** to the conversion means **118***a*, **118***b*, **118***c*, **118***d*, and in the opposite direction. Electric motors **122***a*, **122***b*, **122***c*, **122***d* are connected to the conversion means **118***a*, **118***b*, **118***c*, **118***d*. In operation, the electric motors **122***a*, **122***b*, **122***c*, **122***d* are supplied with alternative current by the conversion means **118***a*, **118***b*, **118***c*, **118***d*.

(16) The electric motors **122***a*, **122***b*, **122***c*, **122***d* may be polyphase synchronous motors. These motors can be of different types, such as induction motors or variable reluctance motors. These motors can be of the single-stator or multi-rotor type. This advantageously allows to reduce the mass and the volume of the electric motors **122***a*, **122***b*, **122***c*, **122***d*.

(17) The connection between the electric generator **114** and the electric motors **122***a*, **122***b*, **122***c*, **122***d* is operated in direct current, at a relatively high-voltage, so as to improve the stability of the electrical network **120** and the power management. The rectifier **116** thus allows to ensure the conversion of the alternative current delivered by the electric generator **120** into direct current, while the conversion means **118***a*, **118***b*, **118***c*, **118***d* ensure the conversion of this direct current into alternative current intended for the electric motors **122***a*, **122***b*, **122***c*, **122***d*.

(18) Propellers **124***a*, **124***b*, **124***c*, **124***d* are coupled to electric motors **122***a*, **122***b*, **122***c*, **122***d*. In operation, the propellers **124***a*, **124***b*, **124***c*, **124***d* are driven by the electric motors **122***a*, **122***b*, **122***c*, **122***d*. The propellers **124***a*, **124***b*, **124***c*, **124***d* may be coaxial counter-rotating propellers.

(19) In particular, the conversion means **118***a*, respectively **118***b*, **118***c*, **118***d*, the electric motor **122***a*, respectively **122***b*, **122***c*, **122***d*, and the propeller or the propellers **124***a*, respectively **124***b*, **124***c*, **124***d*, form an electrical propulsion chain **125***a*, respectively **125***b*, **125***c*, **125***d*. In FIG. **2**, there are therefore four electrical propulsion chains **125***a*, **125***b*, **125***c*, **125***d*.

(20) For each electrical propulsion chain **125***a*, **125***b*, **125***c*, **125***d*, the rotational speed Ω**1**, Ω**2**, Ω**3**, Ω**4** of the shaft connecting the electric motor **122***a*, **122***b*, **122***c*, **122***d* and the propellers **124***a*, **124***b*, **124***c*, **124***d*, via a gearbox **134***a*, **134***b*, **134***c*, **134***d*, can be controlled by control means **132***a*, **132***b*, **132***c*, **132***d*. Similarly, the voltage U**1**, U**2**, U**3**, U**4** from the conversion means **118***a*, **118***b*, **118***c*, **118***d* for supplying each electric motor **122***a*, **122***b*, **122***c*, **122***d* can be controlled by control means **132***a*, **132***b*, **132***c*, **132***d*. These control means **132***a*, **132***b*, **132***c*, **132***d* can control parameters of the conversion means **118***a*, **118***b*, **118***c*, **118***d*, such as the voltage U**1**, U**2**, U**3**, U**4** of the electric motors **122***a*, **122***b*, **122***c*, **122***d* and the switching frequency set points (also referred to as duty cycles), noted F**1**, F**2**, F**3**, F**4**, based on the rotational speed Ω**1**, Ω**2**, Ω**3**, Ω**4** and the voltage U**1**, U**2**, U**3**, U**4** of the electric motors **122***a*, **122***b*, **122***c*, **122***d*, and other parameters, such as the anticipation of the load Ω**1***, Ω**2***, Ω**3***, Ω**4***.

(21) Storage means **126** are connected to the electrical network **120** in parallel to the electric

generator **114**, so as to absorb an excess of electrical energy from the HVDC bus of the electrical network **120**. The storage means **126** may also be configured to temporarily power the electric motors **122***a*, **122***b*, **122***c*, **122***d* by supplementing or substituting the electric generator **114**. The storage means **126** may be of the electrochemical type, the electrostatic type, for example capacitive, or the mechanical type. In particular, the electrical energy storage means **126** may comprise one or a plurality of batteries, one or a plurality of capacitors, or one or a plurality of supercapacitors.
(22) A pre-charge circuit **138** of the HDVC bus of the electrical network **120** may also be integrated so as to pre-charge the HDVC bus.
(23) In order to be able to absorb the overvoltage on the HVDC bus of the electrical network **120**, in particular during a braking phase of the propellers **124***a*, **124***b*, **124***c*, **124***d*, and thus to avoid the breakage for example of the capacitors of the HVDC bus and of the electronic components such as insulated gate bipolar transistors (IGBTs) or metal oxide semi-conductor field effect transistors (MOSFETs), a method for managing the transient phases is implemented.
(24) As shown in FIG. **3**, which represents the steps of a method for dissipating an electrical energy in an architecture **100** as described above, the management of the transient phases is a function of the state of charge of the storage means **126**.
(25) The step S**01** represents a step of regenerating electrical energy on the HVDC bus of the electrical network **120**. During this regeneration phase, an excess of electrical energy is emitted from at least one of the electrical propulsion chains **125***a*, **125***b*, **125***c*, **125***d* to the HVDC bus of the electrical network **120**. On FIG. **2**, this surplus of electrical energy is represented by the arrows I**1**, I**2**, I**3**, I**4**, corresponding to the electrical intensity respectively of each electrical propulsion chain **125***a*, **125***b*, **125***c*, **125***d*. Of course, only one, or several, or all of the electrical propulsion chains can regenerate electrical energy. The step S**02** represents a step of acquiring the state of charge of the storage means **126**. During this step S**02**, it is determined whether the state of charge of the storage means **126** is low, intermediate, or high.
(26) A low state of charge of the storage means **126** may correspond to a state of charge of less than 40%, preferably less than 50%, and more preferably less than 60%.
(27) An intermediate state of charge of the storage means **126** may correspond to a state of charge between 40% and 90%, preferably between 50% and 80%, and more preferably between 60% and 80%. Alternatively, the intermediate state of charge of the storage means **126** may be any value range between 40% and 90%, for example between 40% and 80%, or between 50% or 60% or 70% or 80% and 90%, or between 70% and 80%. A high state of charge of the storage means **126** may correspond to a state of charge of more than 80%, preferably more than 90%
(28) The step S**10** represents a step of recovering the regenerated electrical energy on the HVDC bus of the electrical network **120** by the storage means **126**, and in particular only by the storage means **126**. This step S**10** is carried out when the state of charge of the storage means **126** is low, for example less than 60%. In particular, when the storage means **126** is in a state of charge of less than 60%, for example between 50% and 60%, the recovery of electrical energy may be carried out by the storage means **126**, and in particular only by the storage means **126**. In FIG. **2**, this electrical energy recovery is represented by the arrow IR**126**.
(29) For the absorption of high-frequency electrical power peaks, the storage means **126** advantageously comprise capacitive elements, of the super-capacitor type.
(30) The step S**20** represents a step of recovering the regenerated electrical energy on the HVDC bus of the electrical network **120** by the storage means **126** and the rectifier **116**. This step S**20** is carried out when the storage means **126** are in an intermediate state of charge, for example when the state of charge of the storage means **126** is between 60% and 80%.
(31) This step S**20** may also be carried out when the storage means **126** are in a thermal state that does not allow a full recharging of the storage means **126**, i.e., when the storage means **126** are in a thermal state that risks unnecessary overheating of the elements constituting it.

(32) This step S**20** is a high frequency electrical energy management in order to allow a protection of the static components such as transistors. The term "high frequency" refers to frequencies at the level of the currents on the HVDC bus of the electrical network **120** being higher than 1 kHz.
(33) The absorption of the overcurrent is achieved by the capacitive components integrated in the storage means **126** on the one hand, and via the rectifier **116** on the other hand. The rectifier **116** absorbs the overcurrent, denoted IR**116** in FIG. **2**, and converts it to a current with a large reactive component, i.e., to a current with a large change in the current Id received by the rectifier **116** from the electric generator **114** in the Park reference frame. This results in degrading the performance of the electric machine, formed by the electric generator **114**, by degrading the power factor of the electric machine. This advantageously allows to absorb the excess of electrical energy by degrading the efficiency of the electrical machine, but without adding an energy recovery circuit as in the architectures according to the prior art.
(34) The electrical machine, and thus the electric generator **114**, may be a synchronous or asynchronous machine.
(35) In the case of a synchronous machine, the degradation of the performance results in a voluntary defluxing, i.e. the magnetic field created in the stator is opposite to the magnetic field of the rotating magnets. This results in a magnetic loss and an increase in temperature at the level of the magnets of the synchronous machine. Moreover, in the case where the machine is said to be salient, the increase in the intensity Id in the generator increases the electromagnetic torque applied to the mechanical transmission by a few percent, the turbine thus contributing to the absorption of the excess of electrical power.
(36) On an asynchronous machine, the performance degradation is due to an increase in slip, i.e. an increase in the difference between the rotation frequency of the asynchronous machine and the frequency of the stator currents (i.e. the frequency of the currents of the stator of the asynchronous machine). As the Joule losses in the rotor are proportional to the slip, this slip variation results in a rotor heating of the synchronous machine (i.e. a heating of the rotor of the synchronous machine) during long phases of electric power absorption.
(37) The step S**30** represents a step of recovering the electrical energy regenerated on the HVDC bus of the electrical network **120** by the electric generator **114** operating in motor mode. This step S**30** is carried out when the storage means **126** are almost fully charged, or even fully charged, i.e. when the state of charge of the storage means **126** is high, for example above 80%, preferably above 90%.
(38) This step S**30** is also a high frequency electrical energy management.
(39) When the electric motors **122***a*, **122***b*, **122***c*, **122***d* send back electrical energy to the HVDC bus of the electrical network **120**, it means that the electric motors **122***a*, **122***b*, **122***c*, **122***d* have to brake very quickly, or that several electric motors are no longer driven, i.e. the torque set point of the electric motors is zero and their propeller is still rotating, and at the same time the other electric motors are, on the contrary, in full acceleration. This happens, for example, when the aircraft has to change direction, or in the case of an avoidance maneuver.
(40) In this case, the electric motors **122***a*, **122***b*, **122***c*, **122***d* are defluxed, i.e. the intensity Id or Iq provided by the electric generator **114** is modified according to the angle of the mark, in order to decrease the electromotive force (known by the acronym EMF) and to directly avoid the re-injection of the electrical energy. However, the avoiding of the re-injection of the electrical energy is not always possible in some cases, for example when the electric motors **122***a*, **122***b*, **122***c*, **122***d* are already overheated preventing the defluxing, or if a decentralized control of the electric motors is used making the acquisition of the state of charge of the storage means **126** difficult. In this case, the electrical energy is performed by the electrical energy generation part of the architecture **100**.
(41) When the defluxing of the electric motors **122***a*, **122***b*, **122***c*, **122***d* is impossible or insufficient to avoid the re-injection, an electrical energy management strategy via the rectifier **116**, as described above, may be associated therewith. In this case, the parameters of the management of

the electrical energy can be the defluxing of the synchronous machine or a variation of the slip.
(42) When the power peak is very high, the recovering of the electrical energy is carried out by the electric generator **114** operating in motor mode. Indeed, the quadrant of the electric generator **114** can be changed, by switching it to motor mode, which imposes a torque on the internal combustion engine **112**, which thus becomes a consumer of electrical energy.
(43) In addition, the voltage of the HVDC bus of the electrical network **120** may be increased, anticipating the set points on the electric motors **122***a*, **122***b*, **122***c*, **122***d*, and more specifically, increasing the rotational speed of the shaft of the rotor of the internal combustion engine **112** so as to guard against the increase in the electromotive force of the electric motors **122***a*, **122***b*, **122***c*, **122***d*. This also allows to reduce the Joule losses.

Claims

1. A hybrid-electric propulsion architecture for a multi-rotor rotary wing aircraft, comprising: an internal combustion engine, an electric generator coupled to the internal combustion engine such that in operation the internal combustion engine drives the electric generator, a rectifier connected to the electric generator and configured to convert an alternative current delivered by the electric generator into a direct current, means for converting direct current into alternative current, an electrical network connecting the rectifier to the conversion means, the electrical network comprising a high-voltage direct current bus, electrical energy storage means connected to the electrical network in parallel to the electric generator, electric motors connected to the conversion means so that in operation the conversion means supply the electric motors with alternative current, propellers coupled to the electric motors so that in operation the electric motors drive the propellers, the architecture being characterized in that the electric generator is an engine-generator, and in operation the internal combustion engine drives the electric generator in generator mode, in that, during a regeneration of electrical energy on the high-voltage direct current bus of the electrical network, depending on a state of charge of the storage means, the storage means is configured to recover the electrical energy, in that, during the regeneration of electrical energy on the high-voltage direct current bus of the electrical network, depending on the state of charge of the storage means, the rectifier is configured to recover the electrical energy, by converting an overcurrent to a current with a reactive component degrading a power factor of an electric machine formed by the electric generator, wherein the electric machine is used only in said generator mode when said power factor is degraded, in that, during the regeneration of the electrical energy on the high-voltage direct current bus of the electrical network, depending on the state of charge of the storage means, the electric generator is configured to operate in a motor mode so that in operation the electric generator recovers the electrical energy, and in that, when the state of charge of the storage means is less than 60%, the storage means is configured to recover the electrical energy, when the state of charge of the storage means is between 60% and 80%, the storage means and the rectifier are configured to recover the electrical energy, and when the state of charge of the storage means is greater than 80%, the electric generator operating in the motor mode is configured to recover the electrical energy.
2. The architecture according to claim 1, wherein the conversion means and the rectifier are configured to be current reversible.
3. The architecture according to claim 1, wherein the electric generator is a synchronous or asynchronous electrical machine.
4. A multi-rotor rotary wing aircraft comprising the hybrid-electric propulsion architecture according to claim 1.
5. A method for dissipating electrical energy in the hybrid-electric propulsion architecture according to claim 1, comprising steps of: the regeneration of the electrical energy on the high-voltage direct current bus of the electrical network, an acquisition of the state of charge of the

storage means, and a recovery of the regenerated electrical energy from the high-voltage direct current bus of the electrical network, and depending on the state of charge of the storage means: the recovery of the regenerated electrical energy from the high-voltage direct current bus of the electrical network is carried out by the storage means, or the recovery of the regenerated electrical energy from the high-voltage direct current bus of the electrical network is carried out by the storage means and the rectifier, or the recovery of the electrical energy regenerated on the high-voltage direct current bus of the electrical network is carried out by the electric generator operating in the motor mode.

6. The method according to claim 5, wherein during the step of recovering the regenerated electrical energy from the high-voltage direct current bus of the electrical network: the recovery of the electrical energy is carried out by the storage means when the state of charge of the storage means is less than 60%, the recovery of the electrical energy is carried out by the storage means and the rectifier when the state of charge of the storage means is between 60% and 80%, the recovery of the electrical energy is carried out by the electric generator operating in the motor mode when the state of charge of the storage means is greater than 80%.

7. The method according to claim 6, comprising, when the state of charge of the storage means is greater than 80% and prior to the step of recovering the electrical energy by the electric generator operating in the motor mode, a step consisting of a defluxing of the electrical motors.

8. The method according to claim 6, comprising, when the state of charge of the storage means is greater than 80% and prior to the step of recovering the electrical energy by the electric generator operating in the motor mode, a step consisting of a recovering of the electrical energy by the rectifier.

9. The method according to claim 6, comprising, when the state of charge of the storage means is greater than 80% and prior to the step of recovering the electrical energy by the electric generator operating in the motor mode, a step consisting of an increase of an electrical voltage of the high-voltage direct current bus of the electrical network.

10. A hybrid-electric propulsion architecture for a multi-rotor rotary wing aircraft, comprising: an internal combustion engine, an electric generator coupled to the internal combustion engine such that in operation the internal combustion engine drives the electric generator, a rectifier connected to the electric generator and configured to convert an alternative current delivered by the electric generator into a direct current, means for converting direct current into alternative current, an electrical network connecting the rectifier to the conversion means, the electrical network comprising a high-voltage direct current bus, electrical energy storage means connected to the electrical network in parallel to the electric generator, electric motors connected to the conversion means so that in operation the conversion means supply the electric motors with alternative current, propellers coupled to the electric motors so that in operation the electric motors drive the propellers, the architecture being characterized in that the electric generator is an engine-generator, and in operation the internal combustion engine drives the electric generator in generator mode, in that, during a regeneration of electrical energy on the high-voltage direct current bus of the electrical network, depending on a state of charge of the storage means, the storage means is configured to recover the electrical energy, in that, during the regeneration of electrical energy on the high-voltage direct current bus of the electrical network, depending on the state of charge of the storage means, the rectifier is configured to recover the electrical energy by converting an overcurrent to a current with a reactive component degrading a power factor of an electric machine formed by the electric generator, wherein the electric machine is used only in said generator mode when said power factor is degraded, in that, during the regeneration of electrical energy on the high-voltage direct current bus of the electrical network, depending on the state of charge of the storage means, the electric generator is configured to operate in a motor mode so that in operation the electric generator recovers the electrical energy, by changing a quadrant of the electric generator so that it imposes a torque on the internal combustion engine which becomes consumer

of the electrical energy, and in that, when the state of charge of the storage means is less than 60%, the storage means is configured to recover the electrical energy, when the state of charge of the storage means is between 60% and 80%, the storage means and the rectifier are configured to recover the electrical energy, and when the state of charge of the storage means is greater than 80%, the electric generator operating in the motor mode is configured to recover the electrical energy.