

## **AN OPTIMISED SOLUTION FOR ELECTRICAL POWER AND ENERGY STORAGE SYSTEM AND METHOD FOR A WIND TURBINE INSTALLATION VESSEL**

### **FIELD**

**[0001]** The present invention generally relates to electrical power systems, and in particular to an electrical power system and method incorporating an energy storage system. While the present invention will be described with reference to its application in wind turbine installation vessels, it is to be appreciated that the invention is not restricted to this application, and that other applications are also envisaged.

### **BACKGROUND**

**[0002]** The following discussion of the background to the invention is intended to facilitate an understanding of the present invention only. It should be appreciated that the discussion is not an acknowledgement or admission that any of the material referred to was published, known or part of the common general knowledge of the person skilled in the art in any jurisdiction as at the priority date of the invention.

**[0003]** Wind turbine installation vessels (WTIV) typically utilise a very large number of electric motors in their operation. A WTIV requires AC motors to allow for the jacking up or down of the vessel hull. The AC motors used for this application are known as 'jacking' motors. Furthermore, many other AC motors are required to operate other ancillary equipment such as the stabilisers, cargo elevators and pumps of the WTIV, these AC motors being referred to as 'non-jacking' motors. Therefore, an elaborate electrical power system is required to control and supply all these AC motors with electric power.

**[0004]** During the lowering of the hull or leg of the WTIV, the jacking motors will effectively operate as an AC generator thereby providing regenerative energy

back into the electric power system. This regenerative energy has however generally been dissipated as heat using a resistive load. This regenerative energy could however be reutilized to power the jacking and non-jacking motors. Systems have therefore been developed that include arrangements to capture and store the regenerative energy produced by the motors, and to subsequently feed that energy back into the power supply to supplement the power generated to run the motors thereby leading to energy savings.

**[0005]** Such a system is shown in U.S. Patent 10797510 (Keppel Offshore & Marine Technology Centre Pte Ltd et. Al.) which describes a power storage and supply system used for drilling rigs, the system being provided with energy storage systems (ESS) that can be charged by the regenerative energy produced by the jacking motors. The design shown in this patent does not however allow the use of Variable Frequency Drive (VFD) control of these jacking motors due to the direct connection of the AC jacking motors to the AC Bus described in this patent which will in practice mean that the jacking motors must operate at a fixed speed. The use of VFD control of the jacking motors allows them to be soft started with reduced starting current, controlled torque and operated at varying speeds which can lead to reduction in mechanical stress to the jacking system components and greater efficiencies in the power usage of the jacking motors.

**[0006]** It would be advantageous to provide an electric power and power storage system and method that can be optimised to minimise operational losses and initial capital expenditure.

## **SUMMARY**

**[0007]** According to an aspect of the present disclosure, there is provided an electrical power and energy storage system for a wind turbine installation vessel including:

a Jacking VFD DC Bus;

a Thruster VFD DC Bus connected to the Jacking VFD DC Bus;

at least one energy storage module connected to the Jacking VFD DC Bus and/or to the Thruster VFD DC Bus;

at least one motor module connected to the Jacking VFD DC Bus, the or each motor module including an AC jacking motor, an AC non-jacking motor, a DC to AC motor inverter module (MIV) for providing variable frequency drive (VFD) control of the AC jacking motor and AC non-jacking motor, and a change-over switch for alternatively connecting the MIV to the AC jacking motor or the AC non-jacking motor, the MIV being adapted to alternatively provide VFD control of the AC jacking motor or the AC non-jacking motor when connected thereto by the change-over switch;

wherein regenerative energy generated by the AC jacking motor or AC non-jacking motor of the or each motor module is transferrable through the MIV of the motor module to the Jacking VFD DC Bus and/or to the Thruster VFD DC Bus, and subsequently to the or each energy storage module.

**[0008]** In some embodiments, the energy storage module includes an Energy Storage System (ESS), and a DC to DC Converter connecting the ESS to the Jacking VFD DC Bus and/or to the Thruster VFD DC Bus.

**[0009]** In some embodiments, the system includes at least one DC power source connection for connecting the Jacking VFD DC Bus to supply DC power to an external MIV for VFD control.

**[0010]** In some embodiments, the system further includes at least one DC to AC power connection including a DC to AC motor inverter (MIV) for connecting the Jacking VFD DC Bus to an external ac motor for variable speed control.

**[0011]** In some embodiments, the system further includes at least one DC to AC power supply connection for connecting the Jacking VFD DC Bus to an AC ship services consumer bus, the DC to AC connection including a DC to AC Inverter and a transformer.

**[0012]** In some embodiments, the Jacking VFD DC Bus is configured as a ring Bus.

**[0013]** In some embodiments, the DC Ring bus is operated as fully closed ring bus or partially closed ring bus or fully opened island bus.

**[0014]** In some embodiments, wherein the system includes an AC Bus, and one or more generators connected to the AC Bus, the AC Bus is connected to at least one Thruster Module, the Thruster Module comprising at least one AC to DC converter connected between the AC Bus and the Thruster VFD DC Bus, at least one DC to AC inverter MIV connected to a thruster AC motor, and a DC Interconnector connecting the Thruster VFD DC Bus to the Jacking VFD DC Bus.

**[0015]** In some embodiments, the system further includes a thruster transformer connected between the AC Bus and the AC to DC converter within the Thruster Module.

**[0016]** In some embodiments, the system further includes at least one Thruster VFD DC Bus connected energy storage module including an Energy Storage System (ESS), and a DC to DC Converter connecting the ESS to the Thruster VFD DC Bus.

**[0017]** In some embodiments, the system further includes at least one AC Bus connected energy storage modules including an energy storage system (ESS), a transformer, and AC to DC converter.

**[0018]** According to another aspect of the present disclosure, there is provided a method of controlling an electrical power and energy storage system for a wind turbine installation vessel, the system including:

a Jacking VFD DC Bus;

a Thruster VFD DC Bus connected to the Jacking VFD DC;

at least one energy storage module connected to the Jacking VFD DC Bus;  
and/or to the Thruster VFD DC Bus;

at least one motor module connected to the Jacking VFD DC Bus, the or each motor module including an AC jacking motor, an AC non-jacking motor, a DC to AC motor inverter module (MIV) for providing variable frequency drive (VFD) control of the AC jacking motor and AC non-jacking motor, and a change-over switch for alternatively connecting the MIV to the AC jacking motor or the AC non-jacking motor, the MIV being adapted to alternatively provide VFD control of the AC jacking motor or the AC non-jacking motor when connected thereto by the change-over switch;

the method including:

connecting the MIV within the or each motor module to either the AC jacking motor or AC non-jacking motor depending on the motor that is being used at the time to thereby provide Variable Frequency Drive (VFD) control to the connected AC jacking motor or AC non-jacking motor; and

further enabling regeneration energy generated by the AC jacking motor or AC non-jacking motor of the or each motor module to be transferred through the MIV of the motor module to the Jacking VFD DC Bus and/or to the Thruster VFD DC Bus, and subsequently to the or each energy storage module.

**[0019]** In some embodiments, the system includes an AC Bus, and one or more generators connected to the AC Bus, wherein the AC Bus is connected to the Jacking VFD DC Bus via a Thruster Module, the Thruster Module comprising the Thruster VFD DC Bus, at least one AC to DC converter connected to the Thruster DC Bus, a DC to AC MIV converter connected to a thruster AC motor, and a DC Interconnector connecting the Thruster VFD DC Bus to the Jacking VFD DC Bus, and at least one AC Bus connected Energy Storage Module including an energy storage system (ESS), DC to AC Inverter and with or without a transformer connected to the AC Bus;

wherein the method includes storing energy delivered from the AC Bus to the or each AC Bus connected Energy Storage Module during a low load period of the system, and supplying the stored energy from the AC Bus connected Energy Storage Module back to the AC Bus connected load and/or to any load

connected to the Thruster DC Bus and/or connected to the Jacking DC Bus during a peak load period of the system.

**[0020]** In some embodiments, the method includes storing energy delivered from the AC Bus through the or each thruster module to charge the or each Jacking VFD DC Bus connected Energy Storage Module during a low load period of the system via the DC Interconnector Bus connection, and the supplying of the stored energy from the or each Jacking VFD DC Bus connected Energy Storage Module with DC to DC converter to the Thruster VFD DC Bus to the thruster ac motor during peak load period of the system via the DC Interconnector.

**[0021]** In some embodiments, the Thruster Module further includes a Thruster VFD DC Bus connected Energy Storage Module including an Energy Storage System (ESS), and a DC to DC Converter connecting the ESS to the Thruster VFD DC Bus, wherein the method includes the Thruster VFD DC Bus connected Energy Storage Module storing regenerative energy from the thruster motor, jacking and/or non-jacking motors. These ESS are also capable to discharge its stored energy from ESS back to the thruster ac motor, jacking and non-jacking ac motor through its DC Interconnector and its MIV.

**[0022]** Other aspects and features will become apparent to those of ordinary skill in the art upon review of the following description of specific embodiments in conjunction with the accompanying figures.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0023]** In the figures, which illustrate, by way of example only, embodiments of the present invention,

**[0024]** Figure 1 shows a first part of a single line diagram (SLD) of an electric power and energy storage system according to the present disclosure; and

**[0025]** Figure 2 shows a second part of a single line diagram (SLD) of an electric power and energy storage system of Fig. 1; and

**[0026]** Figure 3 shows a third part of a single line diagram (SLD) of an electric power and energy storage system of Fig. 1.

## DETAILED DESCRIPTION

**[0027]** Throughout this document, unless otherwise indicated to the contrary, the terms “comprising”, “consisting of”, “having” and the like, are to be construed as non-exhaustive, or in other words, as meaning “including, but not limited to”.

**[0028]** Furthermore, throughout the specification, unless the context requires otherwise, the word “include” or variations such as “includes” or “including” will be understood to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

**[0029]** Figs. 1 to 3 respectively show different parts of a partial single line diagram (SLD) of an electric power and energy storage system according to the present disclosure that is suitable for use in a WTIV. Figs. 1 to 3 therefore together show the complete SLD of the system 1 when joined together, with the SLD part shown Fig. 1 being joined to the left of the SLD part shown in Fig. 2, and SLD part of Fig. 2 being joined to the left of the SLD part shown in Fig. 3.

**[0030]** The electric power and energy storage system

**[0031]** The electric power and energy storage system generally comprises a Jacking VFD DC Bus 102 connected to a jacking motor electrical variable speed drive (VFD) system. The jacking system comprises one or more motor modules 2, each motor module 2 comprising a DC to AC Motor Inverter Module (MIV) 200 connected via a change-over switch 201 to an AC jacking motor 202 and AC non-jacking motor 203. One or more energy storage modules 3 are also connected to the Jacking VFD DC Bus 102, each energy storage module 3 comprising an energy storage system (ESS) 301 connected via a bidirectional DC to DC converter 302 to the Jacking VFD DC Bus 102. The ESS 301 can receive and store regenerative braking energy from the AC jacking motor 202 or AC non-jacking motor 203 of the motor module 2 and from thruster motor 409

through thruster MIV 407 and DC Interconnector 411 for later consumption. The system 4 is also provided with a main AC bus 105 to which is connected one or more generators 106, which may typically be diesel generators. The AC Bus 105 is connected to the Jacking VFD DC Bus 102 via one or more thruster transformers 108, each thruster transformer 108 being respectively connected to one or more AC to DC thruster converters 400 which are in turn connected to a Thruster VFD DC Bus 107. The Jacking VFD DC Bus 102 is connected to the Thruster VFD DC Bus 107 via a DC interconnector 411 that may be either a cable or a bus duct, and may also include one or more fuses 412. For some system, AC Bus can be connected through an AC Input Choke to the AC input of an AC to DC Converter 400 without a Thruster transformer 108 if the AC Bus voltage suits the required AC input voltage to the AC to DC converter 400.

**[0032]**     Motor Module 2

**[0033]**     The MIV 200 of each motor module 2 provides variable frequency drive (VFD) control for both the jacking motor 202 and non-jacking motor 203 when connected thereto. The change-over switch 201 can be electrically or manually operated to switch the MIV 200 to provide an AC power supply to alternatively drive the jacking motor 202 or the non-jacking motor 203. The MIV 200 can store parameters in relation to both the jacking and non-jacking motors 202, 203. The appropriate pre-stored motor parameters will be applied to the appropriate jacking or non-jacking motor 202, 203 through the selection of the change-over switch position selected for that motor. When the jacking motor 202 is selected through the selection of the change-over switch 201, the MIV 200 together with the associated jacking motor 202 can be arranged to operate together in one or more than one jacking group or independently of a jacking group. When the non-jacking motor 203 is selected through selection by the change-over switch 201, the MIV 200 together with the associated non-jacking motor 203 can be arranged to operate in a non-jacking group. Alternatively, the MIV 200 together with its associated non-jacking motor 203 can also be arranged to operate as an individual non-jacking motor 203 with MIV 200.

**[0034]** The motor module 2 provides several advantages. When the jacking motors 202 are in operation, the non-jacking motors 203 are generally not required to operate and vice versa. The provision of a change-over switch 201 eliminates the need for a separate MIV 200 for the non-jacking motor 202. This can lead to a substantial reduction in capital expenditure for the system 1. Furthermore, the elimination of the MIV 200 for the non-jacking motors 203 reduces the amount of expensive room space required on the WTIV. In addition, the maintenance and spare parts costs for a separate non-jacking motor MIV is eliminated. This can also lead to a reduction in the steel structure cost for the system leading to an overall reduction in the dead weight tonne of the WTIV, this could lead to a reduction in the height for the centre of gravity in the overall WTIV leading to a more stable vessel.

**[0035]** Energy Storage Module 3

**[0036]** Because the energy storage modules 3, each comprising an ESS 301 and a bidirectional DC to DC converter 302, are connected to the Jacking VFD DC Bus 102, regenerative energy generated by the jacking or non-jacking motors 202, 203 from each motor module 2 can flow and be stored within the ESS 301 of the or each energy storage module 3. The regenerative energy generated by the jacking or non-jacking motor 202, 203 passes through the MIV 200 to the Jacking VFD DC Bus 102, and then flows from the Jacking VFD DC Bus 102 through the bidirectional DC to DC converter 302 to the ESS 301 of the or each Energy Storage Module 3. It is envisaged that the ESS 301 be a battery, super capacitor or other type of energy storage device.

**[0037]** In addition, the energy storage modules 3 is also capable to discharge or charge its energy to/from thruster ac motor through the DC Interconnector, the Thruster VFD DC Bus, the Thruster motor MIV. This added versatility allow ESS be located in decentralised locations (in thruster room and jacking VFD room) to solve space constraint in a particular room space or for ESS be centralised within one big room and yet able to serve load demand requirements into or out of thruster motor, jacking and non-jacking motor and assist a reduction in number

of generators running in parallel during high peak load demand such as during DP operation.

**[0038]** In general, an ESS is more expensive when compared to braking resistor. In some embodiments to reduce the cost on having many ESS units or to reduce ratings in ESS, Braking Resistor module 430 will assist to reduce ESS rating. Braking Resistor module 430 comprise of a DC to DC Converter 432 with a braking resistor bank 431 connected to the Jacking VFD DC Bus can be designed to reduce the capacity of ESS. The ESS rating for this type of embodiment may not be sized to the full regenerative braking rating but is being assisted by braking module 430 to dissipate the remainder regenerative braking energy from jacking motor and/or from thruster motor after the ESS is fully charged.

**[0039]** As VFD control is used for each jacking and non-jacking motor 202,203, this facilitates the recovery of regenerative braking energy that can be harvested and stored in the ESS 301. Commercially available VFD controllers are typically based on a voltage source Pulse Width Modulation (PWM) and Pulse Edge Modulation principle, and therefore by necessity, require an inherent stage of a dc supply within its VFD configuration due the need to convert from ac to dc and then from dc to ac in order to achieve variable voltage with variable frequency output to the ac motor. This requirement of a DC supply within a VFD controller, makes recovery of motor regenerative power easily achievable. During the lowering of the hull or legs of the WTIV, the jacking motors 202 operate as an ac generator, regenerating power and energy back to the Thruster VFD DC Bus 107 and Jacking VFD DC Bus 102 through the MIV 200, converting ac from the ac motor to dc onto the Jacking VFD DC Bus 102 for the Jacking System. The non-jacking motors 203 may also generate regenerative energy in particular motor applications.

**[0040]** By comparison, in other known jacking systems using VFD control for their jacking motors, they are provided with only a DC to DC converter or a DC to AC converter with a braking resistor to dissipate the regenerative energy thereby wasting this energy as heat which is dissipated into water or air. In the

system according to the present disclosure, this regenerative energy is stored in the ESS 301 and/or 405 and/or 801 for later consumption. This will result in fuel cost savings, and lower carbon footprint for the present system when compared with other systems that dissipate this energy into wasted heat.

**[0041]**    DC Power Source Connection 5

**[0042]**    The electric power and energy storage system according to the present disclosure may also provide a DC Power Source Connection 5 to allow external machinery including VFD for cranes to be connected to the Jacking VFD DC Bus 102 as shown in Fig. 1.

**[0043]**    Some major crane manufacturers produce cranes complete with their own VFD complete with dc-to-dc converter with braking resistor for dissipation of regenerative energy from the crane motor MIV. This arrangement is provided to protect the proprietary crane control software used within their cranes. Therefore, in order to comply to the crane manufacturer's power supply requirements, the vessel has to provide one or more AC circuit breaker feeders, and at least one or more step down transformers rated for the high kW crane motor load and its secondary circuit breaker feeder. The crane manufacturers therefore also need to supply an AC to DC rectifier and a crane motor MIV to provide VFD control of the crane motors.

**[0044]**    In the system according to the present disclosure, the DC Power Source Connection 5, provides one or more dc power supply sources to the crane manufacturer's crane motor MIV. The crane manufacturer can eliminate the need for their own AC to DC rectifier which has no intelligence in its crane control system. The crane manufacturer can now take in a dc power supply source and supply only the crane MIV. This allows the crane manufacturer to keep their proprietary crane control software within their crane motor MIV without exposing that software to other vendors.

**[0045]**    The benefit to the WTIV owner includes cost and space savings in not requiring another separate AC circuit breaker feeder for crane VFD, its step-down transformer, its AC to DC rectifier and its dc to dc converter with braking

resistor. The benefit for this system according to the present disclosure is that regenerative braking energy from the crane motor MIV can be fed back to the Jacking VFD DC Bus 102 and Thruster VFD DC Bus and be recovered as stored energy within the ESS 301 and/or ESS 405 and/or ESS 801.

**[0046]**     Jacking VFD DC Bus 102

**[0047]**     The Jacking VFD DC Bus 102 can be a fully closed ring bus. It is however also envisaged that the Jacking VFD DC Bus 102 be a partially open ring bus with one or more bus tie breakers 104 open, or a fully open ring bus in an independent island mode. One or more Energy Storage Modules 3 can be connected to the Thruster VFD DC Bus and Jacking VFD DC Bus to recover regenerative energy for later consumption as previously discussed.

**[0048]**     A ring bus configuration of the Jacking VFD DC Bus 102 provides benefits including high redundancy, reliability and flexibility in operation. This ring bus connection can allow for continuous jacking operation and continuous VFD operation for the MIVs 200 connected to the Jacking VFD DC Bus 102. With VFD DC Bus connected in ring bus configuration whether operated in open ring or closed ring, in the event of one thruster VFD not operating, the affected Jacking VFD DC Bus section can still be switched over to connect with another DC power supply source from another Thruster VFD DC Bus to obtain an alternative DC power supply source providing high security in DC power supply to the Jacking VFD DC Bus.

**[0049]**     Low harmonics content is expected and guarantee to meet marine class certification requirement for harmonics content without installation of any harmonics filter.

**[0050]**     DC to AC Power Connection 6

**[0051]**     A DC to AC Power Connection 6 can also be connected to the Jacking VFD DC Bus 102 as shown in Fig. 2. The DC to AC Power Connection 6 includes a DC to AC motor inverter MIV 601 located between and connected to the Jacking VFD DC Bus 102, and a crane or other ac motor 602. This integrated

approach with one or more pieces of crane MIV (601) saves space for any crane or other heavy load consumer using VFDs to drive their motors. The benefits achieved by this DC to AC Power Connection is similar to that provided by the DC Power Source Connection 5.

**[0052]**    DC to AC Power Supply 7

**[0053]**    The system according to the present disclosure may also be provided with one or more DC to AC Power Supply connections 7 connected to the Jacking VFD DC Bus 102 as shown in Fig. 2. Each DC to AC Power Supply connection 7 includes a DC to AC fixed frequency inverter 701 and a transformer 702 for connection to provide ac power supply to consumer connected on a AC Ship Services Bus 703.

**[0054]**    During light load conditions, for example in a port, energy stored within ESS 301 connected on Jacking VFD DC Bus 102, ESS 405 connected on Thruster VFD DC Bus, ESS 801 connected on AC Bus, can provide energy to the AC Ship Services consumer 703. These ESS can operate alone without any generator or operate in parallel with a Harbour Generator or Ship Service Transformer. This mode of operation reduces carbon emission during port visit.

**[0055]**    The benefit of this arrangement is that it allows flexibility for the energy stored within any ESS to be consumed through any MIV load connected onto Jacking VFD DC Bus 102, Thruster VFD DC Bus 107 or to be consumed by consumers connected on AC Ship Services Bus 703.

**[0056]**    AC Bus connected Energy Storage Module 8

**[0057]**    The system according to the present disclosure may also be provided with one or more AC Bus connected Energy Storage Modules 8 connected to the AC Bus 105 as shown in Figs. 1 and 3. Each AC Bus connected Energy Storage Module 8 includes an ESS 801 connected via a bidirectional AC to DC Converter 802 to a stepdown transformer 803 which is then connected to the AC Bus 105. For AC Bus voltage that suits the ac voltage rating of the AC to DC

Converter, the step down transformer 803 could be omitted. It is envisaged that the ESS 801 be a battery, super capacitor or other type of energy storage device.

**[0058]** These ESS 801, similar to ESS 405 and ESS 301, can cater for spinning reserve or allow operation of the main diesel engine generators 106 to operate at as close to its full load as possible through a reduction in quantity of one or more main engine generators 106, using the ESS 801 to supply the peak load and for peak load shaving on the generation load or for spinning reserve.

**[0059]** During low generation load period, the ESS 801 is charged and stored with energy delivered from the AC Main bus 105 to the ESS 801. During peak load conditions with a higher kW load rating beyond that each main diesel engine generator 106 could generate, the Energy Supply Module 8 will supply the energy from the ESS 801 to the AC Main Bus 105 through the bi-direction DC to AC inverter 802. This can allow for a reduction in number of main diesel engine generator 106 that need to operate in parallel operation thereby saving fuel and reducing the carbon footprint of the system.

**[0060]** The benefits in using any of the AC Bus connected Energy Storage Modules 8 or DC Bus connected Energy Storage Module 3 or Energy Storage Module 402 include cost savings in diesel fuel by running a lesser number of generators 106 than otherwise required to operate for at high loads. Furthermore, the generators 106 can operate at a higher efficiency because they are operating at a higher loading point of operation. There will also be a reduction in the maintenance cost and spare part costs of the diesel engine generators 106 due to the reduction in the number of generators operating in parallel.

**[0061]** Thruster Module 4

**[0062]** AC power from the AC Bus 105 can flow to the Jacking VFD DC Bus 102 through one or more thruster transformers 108, with each thruster transformer 108 being connected to a Thruster Module 4, which is in turn connected to the Jacking VFD DC Bus 102 as shown in Fig. 1. It is also possible for the AC Bus 105 to be directly connected to the Thruster Module 4 without the thruster transformer 108.

**[0063]** Each Thruster Module 4 comprises the Thruster VFD DC Bus 107, and one or more AC to DC thruster convertors 400 connecting the thruster transformer 108 to the Thruster VFD DC Bus 107. The Thruster Module 4 further comprises a DC to AC inverter MIV 407 connecting the Thruster VFD DC Bus 107 to a thruster ac motor 409 used to power a thruster assembly of the WTIV. Because the Thruster VFD DC Bus 107 is connected via the DC interconnector 411 to the Jacking VFD DC Bus 102, this allows the ESS Modules 3 connected to the Jacking VFD DC Bus 102 to be charged by regenerative braking energy generated by the thruster motors 409. The ESS Modules 3 can also discharge its stored energy to the thruster motors 409 using energy stored in the ESS Modules 3 through thruster MIV 407. It is however also possible that each Thruster Module 4 further comprises a Thruster VFD DC Bus connected Energy Storage Module 402 comprising a DC to DC converter 403 connecting an ESS 405 to the Thruster VFD DC Bus 107. This ESS 405 can then perform storage and discharge of energy with same functionality as ESS 301. Similarly, the ESS 405 can also perform same functionality as ESS 301 to store and discharge energy from and to jacking and non-jacking motors 202,203. The Thruster VFD DC Bus connected Energy Storage Module 402 can therefore operate in the same way as the Jacking VFD DC Bus connected Energy Storage Module 3, and can therefore be used in place of the Energy Storage Module 3, for example where there is insufficient room on the Jacking VFD DC Bus 102 to connect any Energy Storage Modules 3.

**[0064]** The DC Interconnector 411 provides DC power supply from the Thruster VFD DC Bus 107 to the Jacking VFD DC Bus 102 without the need of a Jacking VFD Transformer, Energy stored in one or more ESS 301, 405 connected onto the Thruster VFD DC Bus 107 and/or the Jacking VFD DC Bus 102 can be discharged to supply power through Thruster VFD 407 to the thruster ac motor 409 during peak loading situation for peak shaving or act as spinning reserve to reduce the total quantity of running generators. The stored regenerative energy can also be consumed by jacking and non-jacking motor 202, 203 through its respective MIV 200.

**[0065]** In the present disclosure, the Thruster VFD DC Bus 107 is being

described as supplying dc power to the thruster motor VFD 407 and to the jacking motor VFD 200. Instead of being taken from a Thruster VFD DC Bus, this DC power supply could alternatively be any large AC to DC converter, not described as a thruster motor VFD, not performing the duty of a thruster motor VFD but instead providing DC power to that particular high dc power load, and having excess capacity or being designed with higher capacity so that it is able to also provide dc power to the Jacking VFD DC Bus 102 using same DC Interconnector concept to share DC power among the various VFDs.

**[0066]** The above-described arrangement has a number of features and advantages as follows:

- The dc power supply for the jacking motor and the non-jacking motor inverter 200 is provided through at least one dc interconnection 411 between at least one of the Thruster VFD DC Bus 107 and to at least one of the Jacking VFD DC Bus 102. This dc interconnection can be realised by means of cable or bus duct resulting in a virtual common dc bus between Thruster VFD DC Bus 107 and Jacking VFD DC Bus 102.
- ESS 301 connected onto Jacking VFD DC Bus 102 has same effectiveness as an ESS 405 connected onto Thruster VFD DC Bus 107.
- Power can flow from the Thruster VFD DC Bus 107 to the Jacking VFD DC Bus 102 and vice versa.
- The ESS 301 connected onto the Jacking VFD DC Bus 102 can be charged through the Thruster VFD DC Bus 107 during low load condition to operate later as spinning reserve or as standby power without additional generator running during peak loading.
- The ESS 301 connected onto the Jacking VFD DC Bus 102 can also be charged through the Jacking Motor 202 and Non-Jacking Motor 203 during its motor regenerative braking action.
- The ESS 301 connected onto the Jacking VFD DC Bus 102 can also be

charged through regenerative braking energy during thruster motor speed reduction and its motor stop action. This shortens the braking time of thruster motor.

- The ESS 301 connected onto Jacking VFD DC Bus 102 can provide stored energy to provide power to assist ac generator in powering thruster motor operation during peak loading of generator, especially during dynamic positioning operation of the vessel.
- The stored energy in ESS 301 connected onto the Jacking VFD DC Bus 102 can serve as standby power or act as spinning reserve for ac generators, allowing the running generators to operate with a higher operating load point and at a higher efficiency load point with lower fuel consumption.
- The ESS stored energy connected onto DC Bus 102 and/or DC Bus 107, being fast acting in transient response, can allow for reduced number of generators be running in parallel resulting in further fuel savings and maintenance cost savings.

**[0067]** Other benefits in having a DC interconnector 411 between the Thruster VFD DC Bus 107 and the Jacking VFD DC Bus 102 includes:

- It allows for a quick and fast braking action for the thruster motor through absorbing the thruster motor kinetic energy which otherwise wasted in propeller seawater turbulence, to charge ESS during thruster motor braking. This feature will result in an improved response during dynamic positioning operation of the vessel when thruster speed needs to be reduced or to go to zero rpm to stop thruster motor.
- It allows any ESS connected onto Jacking VFD DC Bus and/or Thruster VFD DC Bus to provide stored energy as spinning reserve or as peak shaving to the thruster motor load during peak loading to perform peak shaving of load for generator allowing a reduced number of generators to

be operated to run online. This saves fuel and maintenance cost due to reduced generator running.

**[0068]** In conventional power systems, single direction AC to DC rectifiers are installed to convert the AC power from an AC Bus to DC power for a DC Bus, with DC power being provided to the MIV of the motors in combination with a DC to DC converter and Braking Resistor connected onto the DC Bus to dissipate regenerative energy from the MIV of the jacking motor.

**[0069]** The system according to the present disclosure, depending on how large is the power system kW rating and its required ESS rating, this may as an option, use ~~the~~ a bidirectional AC to DC convertors 400 instead of a lower cost AC to DC rectifier 400 within of the Thruster Module 4 for converting AC power from the AC Bus 105 to DC power for the Thruster DC Bus 107, and through the DC Interconnector for the Jacking VFD DC Bus 102. The advantage of using bidirectional AC to DC Converters 400 is that it allows the Energy Storage Modules 3 connected to the main Jacking VFD DC Bus 102 and Energy Storage Module 402 connected to Thruster VFD DC Bus107 to discharge its stored energy to the AC Bus and also be utilized to provide those functions provided by the previously described AC Bus connected Energy Storage Modules 8. These functions include the generation of a peak shaving and spinning reserve through reverse power flow from ESS 301 through the Thruster Module 4 and the thruster transformers 108 to supply energy to the Main AC Bus 105. The ESS 301 installed on the Jacking VFD DC Bus 102 can be designed as an additional energy source to supplement the ESS 801 installed on the AC Bus 105 to reduce the rating for ESS 801 installed on the AC Bus 105. Alternatively, the ESS 301 installed on the Jacking VFD DC Bus 102 and ESS installed on Thruster VFD DC Bus 107 can also be designed as an ESS energy storage source to eliminate the need for installation of the ESS 801 installed on the AC Bus 105 by not installing inexpensive single direction AC to DC Converter 400 using rectifier for cost saving in moderate size power system which does not require high capacity in ESS rating. This allow ESS 301 and ESS 405 to supply its stored energy to the thruster motor through the thruster VFD dc bus 107 to the thruster MIV 407. The benefits of this arrangement include greater flexibility in the energy storage

operation of the system, and potential cost reductions and cost elimination of an AC Bus ESS 801 and its floor space.

**[0070]** Unless defined otherwise, all technical and scientific terms used herein have the same meaning as is commonly understood by a skilled person to which the subject matter herein belongs.

**[0071]** It should be appreciated by the person skilled in the art that the above invention is not limited to the embodiment described. It is appreciable that modifications and improvements may be made without departing from the scope of the present invention.

It should be further appreciated by the person skilled in the art that one or more of the above modifications or improvements, not being mutually exclusive, may be further combined to form yet further embodiments of the present invention.

## CLAIMS

1. An electrical power and energy storage system for a wind turbine installation vessel including:

a Jacking VFD DC Bus;

a Thruster VFD DC Bus connected to the Jacking VFD DC Bus;

at least one energy storage module connected to the Jacking VFD DC Bus; and/or to the thruster VFD DC Bus

at least one motor module connected to the Jacking VFD DC Bus, the or each motor module including an AC jacking motor, an AC non-jacking motor, a DC to AC motor inverter module (MIV) for providing variable frequency drive (VFD) control of the AC jacking motor and AC non-jacking motor, and a change-over switch for alternatively connecting the MIV to the AC jacking motor or the AC non-jacking motor, the MIV being adapted to alternatively provide VFD control of the AC jacking motor or the AC non-jacking motor when connected thereto by the change-over switch;

wherein regenerative energy generated by the AC jacking motor or AC non-jacking motor of the or each motor module is transferrable through the MIV of the motor module to the Jacking VFD DC Bus and/or to the Thruster VFD DC Bus, and subsequently to the or each energy storage module.

2. An electrical power and energy storage system for a wind turbine installation vessel according to claim 1, wherein the energy storage module includes an Energy Storage System (ESS), and a DC to DC Converter connecting the ESS to the Jacking VFD DC Bus and/or to the Thruster VFD DC Bus.

3. An electrical power and energy storage system for a wind turbine installation vessel according to claim 1 or 2, further including at least one DC power source connection for connecting the Jacking VFD DC Bus to supply DC power to an

external MIV for VFD control.

4. An electrical power and energy storage system for a wind turbine installation vessel according to any one of the preceding claims, further including at least one DC to AC power connection including a DC to AC motor inverter MIV for connecting the Jacking VFD DC Bus to an external ac motor for speed control.

5. An electrical power and energy storage system for a wind turbine installation vessel according to any one of the preceding claims, further including at least one DC to AC connection for connecting the Jacking VFD DC Bus to an AC ship services consumer Bus, the DC to AC connection including a DC to AC Inverter of fixed frequency and a transformer.

6. An electrical power and energy storage system for a wind turbine installation vessel according to any one of the preceding claims, wherein the Jacking VFD DC Bus is configured as a DC ring Bus

7. An electrical power and energy storage system for a wind turbine installation vessel according to claim 6, wherein the DC Ring bus is be operated as fully closed ring bus or partially closed ring bus or fully opened independent island buses.

8. An electrical power and energy storage system for a wind turbine installation vessel according to any one of the preceding claims, wherein the system includes an AC Bus, and one or more generators connected to the AC Bus, the AC Bus is connected to at least one Thruster Module, the Thruster Module comprising at least one AC to DC converter connected between the AC Bus and the Thruster VFD DC Bus, at least one DC to AC inverter MIV connected to a thruster AC motor, and a DC Interconnector connecting the Thruster VFD DC Bus to the Jacking VFD DC Bus.

9. An electrical power and energy storage system for a wind turbine installation vessel according to claim 8, wherein the system further includes a thruster transformer connected between the AC Bus to the AC to DC converter within the Thruster Module.

10. An electrical power and energy storage system for a wind turbine installation vessel according to claim 8 or 9, further including at least one Thruster VFD DC Bus connected energy storage module including an Energy Storage System (ESS), and a DC to DC Converter connecting the ESS to the Thruster VFD DC Bus.

11. An electrical power and energy storage system for a wind turbine installation vessel according to any one of claims 8 to 10, further including as an option, at least one AC Bus connected energy storage module including an energy storage system (ESS), a transformer, and AC to DC converter.

12. A method of controlling an electrical power and energy storage system for a wind turbine installation vessel, the system including:

a Jacking VFD DC Bus;

a Thruster VFD DC Bus connected to the Jacking VFD DC Bus;

at least one energy storage module connected to the Jacking VFD DC Bus, and/or to the Thruster VFD DC Bus; and

at least one motor module connected to the Jacking VFD DC Bus, the or each motor module including an AC jacking motor, an AC non-jacking motor, a DC to AC motor inverter module (MIV) for providing variable frequency drive (VFD) control of the AC jacking motor and AC non-jacking motor, and a change-over switch for alternatively connecting the MIV to the AC jacking motor or the AC non-jacking motor, the MIV being adapted to alternatively provide VFD control of the AC jacking motor or the AC non-jacking motor when connected thereto by the change-over switch;

the method including:

connecting the MIV within the or each motor module to either the AC jacking motor or AC non-jacking motor depending on the motor that is being used at the time to thereby provide Variable Frequency Drive (VFD) control to the connected AC jacking motor or AC non-jacking motor; and

further enabling regeneration energy generated by the AC jacking motor or AC non-jacking motor of the or each motor module to be transferred through the MIV of the motor module to the Jacking VFD DC Bus and/or to the Thruster VFD DC Bus, and subsequently to the or each energy storage module.

13. A method of controlling an electrical power and energy storage system for a wind turbine installation vessel according to claim 12, the system including an AC Bus, and one or more generators connected to the AC Bus, wherein the AC Bus is connected to the Jacking VFD DC Bus via a Thruster Module, the Thruster Module comprising the Thruster VFD DC Bus, at least one AC to DC converter connected to the Thruster DC Bus, a DC to AC motor inverter MIV connected to a thruster AC motor, and a DC Interconnector connecting the Thruster VFD DC Bus to the Jacking VFD DC Bus, and at least one AC Bus connected Energy Storage Module including an energy storage system (ESS), DC to AC Inverter and transformer connected to the AC Bus;

wherein the method includes storing energy delivered from the AC Bus to the or each AC Bus connected Energy Storage Module during a low load period of the system, and supplying the stored energy from the AC Bus connected Energy Storage Module during a peak load period of the system.

14. A method of controlling an electrical power and energy storage system for a wind turbine installation vessel according to claim 13, the method including storing energy delivered from the AC Bus through the or each thruster module to charge the or each Jacking VFD DC Bus connected Energy Storage Module during a low load period of the system via the DC Interconnector Bus connection, and the supplying of the stored energy from the or each Jacking VFD DC Bus connected Energy Storage Module to the Thruster VFD DC Bus to the thruster ac motor during peak load period of the system via the DC Interconnector.

15. A method of controlling an electrical power and energy storage system for a wind turbine installation vessel according to claim 13 or 14, the Thruster Module further including a Thruster VFD DC Bus connected Energy Storage Module including an Energy Storage System (ESS), and a DC to DC Converter

connecting the ESS to the Thruster VFD DC Bus, wherein the method includes the Thruster VFD DC Bus connected Energy Storage Module collecting regenerative energy from the thruster, jacking and/or non-jacking motors and later discharging its stored energy to thruster motor and jacking and non-jacking motor.