SYSTEMS AND METHODS FOR INTELLIGENT DIAGNOSTIC SCREENING OF HYBRID GENERATOR SYSTEMS

Abstract

Systems and methods for evaluating an engine associated with a hybrid power system, including initiating a load step on the engine using a battery of the hybrid power system, measuring a plurality of parameters associated with a response of the engine to the load step using a plurality of sensors, comparing the measured parameters associated with the response of the engine to baseline performance data associated with the engine, and calculating an engine performance score for the engine based on the comparison of the measured parameters to the baseline performance data.

Background/Summary

FIELD OF THE DISCLOSURE
[0002] The present disclosure generally relates to systems and methods for intelligent diagnostic screening of engine-driven power systems. More particularly, to systems and methods for intelligent diagnostic screening of the health and performance of an engine-driven power system in a hybrid generator system.

BACKGROUND
[0003] There is an ever-increasing demand for power to support a variety of industry applications, including military applications where power is needed to support communications, surveillance, armament, mobility, medical treatment, and providing the necessities such as food and shelter. This ever-increasing demand for power presents critical logistical support challenges, which become even more challenging as the distances between central supply bases and areas of operation increase.

[0004] With respect to military applications and other contested environments, the need for efficient and reliable utilization of resources is especially critical. Two of the most common terms used to describe the logistical needs of modern warfare are "precision sustainment" and "predictive logistics." When applied to fuel and power systems, these terms necessitate that every drop of fuel and every piece of equipment be managed to the highest levels of efficiency and effectiveness. Equipment nearing the end of its service life and compromised equipment with degraded performance and poor fuel efficiency cannot be sustained where that equipment is vital to the mission of the user. Such equipment also cannot be sustained in environments exposed to high levels of risk and in environments where it is cost prohibitive to transport such equipment.

[0005] Hybrid power systems (e.g., combining engine-driven power systems with energy storage) have greatly enhanced the reliability, resiliency, and efficacy of modern power systems and are being deployed and utilized in a wide variety of applications, not just military applications. Regardless of the application, maintaining the components of the power system at the highest levels of efficiency and effectiveness is crucial for the performance of the power system as a whole and for the performance of the operation. Thus, systems and methods for monitoring and evaluating the performance of components, such as the engine-driven power system of a hybrid power system, in order to assess the health of the system and predict future maintenance, overhauls, and end-of-life, would be an improvement to the technical field of hybrid power systems.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0006] FIG. **1** illustrates an intelligent diagnostic screening ("IDS") system, including a hybrid power system and a computer, according to one or more embodiments of the present disclosure;
[0007] FIG. **2** illustrates the hybrid power system of the IDS system of FIG. **1**, including a generator and an energy storage module ("ESM"), according to one or more embodiments of the present disclosure;
[0008] FIG. **3** illustrates a method of operating the IDS system of FIG. **1**, according to one or more embodiments of the present disclosure;
[0009] FIG. **4** illustrates a table of engine performance scores calculated for the generator during the method of FIG. **3**, according to one or more embodiments of the present disclosure;

[0010] FIGS. **5**A, **5**B, and **5**C illustrate other tables of engine performance scores calculated for the generator during the method of FIG. **3**, according to one or more embodiments of the present disclosure;

[0011] FIGS. **6-8** illustrate measurements of a plurality of parameters associated with a response of the generator to the IDS test performed by the method of FIG. **3**, according to one or more embodiments of the present disclosure;

[0012] FIG. **9** illustrates another embodiment of the IDS system, including a hybrid power system having a plurality of generators, an ESM, and a computer, according to one or more embodiments of the present disclosure;

[0013] FIG. **10** illustrates a method of operating the IDS system of FIG. **9**, according to one or more embodiments of the present disclosure;

[0014] FIGS. **11**A, **11**B, and **11**C illustrate measured electrical output and work performed by each generator, according to one or more embodiments; and

[0015] FIG. **12** illustrates a node for implementing one or more of the above embodiments, according to one or more embodiments of the present disclosure.

DETAILED DESCRIPTION

[0016] The following disclosure provides many different embodiments. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, or course, merely examples and are not intended to be limiting. In addition, the present disclosure may repeat reference numerals and/or letters in the various embodiments. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

[0017] The systems and methods disclosed herein provide improvements to the use of hybrid power systems and to the deployment, servicing, and support of such power systems and the critical resources associated therewith. By utilizing sophisticated sensors associated with the hybrid power system and applying the methods of the present disclosure, including enhanced predictive logistics, precision sustainment of the components of the hybrid power system is achieved.

[0018] FIG. **1** illustrates an example intelligent diagnostic screening ("IDS") system **100** that includes a hybrid power system **105** that is in communication with a computer **110** and a digital twin **115** via a network **120**.

[0019] As illustrated, the hybrid power system **105** includes an energy storage module ("ESM") **125** and a generator **130** configured to serve as the primary source of power in the hybrid power system **105**. The ESM **125** includes one or more batteries **135**, a plurality of sensors **140**, and a controller **145** operably coupled together. Generally, the one or more batteries **135** is configured to store power and supply power to the various resources associated with the operation in which the hybrid power system **105** is deployed.

[0020] The generator **130** is operably coupled to the ESM **125** and includes an engine **150**, a generator controller **155**, and a plurality of sensors **158**. The plurality of sensors **158**, the engine controller **155**, and the engine **150** are operably coupled together. In one or more embodiments, the engine **150** is a gas-powered internal combustion engine and the plurality of sensors **158** are integrated with the engine **150** by the manufacturer of the engine **150**. In other embodiments, the plurality of sensors **158** are retrofitted to the engine **150**. In some embodiments, the manufacturer of the engine **150** may not enable a user to access and utilize the factory original sensors, necessitating the need for the retrofit to add the plurality of sensors **158**. The plurality of sensors **158** monitor or measure specific parameters associated with the engine **150** or a performance of the engine **150**. The plurality of sensors **158** may include: (i) an engine coolant temperature ("ECT") sensor that measures/indicates the amount of thermal energy absorbed into the engine coolant; (ii) a throttle inlet pressure ("TIP") sensor that measures/indicates the relative pressure on the supply side of the engine's throttle plate; (iii) a manifold absolute pressure ("MAP") sensor that measures/indicates the mass air flow in the engine's induction system; (iv) a throttle position sensor

("TPS") that measures/indicates the relative position of the throttle device in response to the load command; (v) an intake air temperature ("IAT") sensor that measures/indicates the temperature of the induction air used in combustion; (vi) a fuel flow ("FF") sensor that measures/indicates the amount of fuel being delivered to the engine to support the commanded load; (vii) an oil pressure ("OP") sensor that measures/indicates the pressure of the lubricating oil in the engine lube system; (viii) an exhaust gas temperature ("EGT") sensor that measures/indicates the temperature of the combustion gases after exiting the combustion chamber; (ix) a vibration ("Vib") sensor that measures/indicates the magnitude, frequency, and oscillatory direction in the engine; and (x) a crank case pressure ("CCP") sensor that measures/indicates the pressure of the crankcase gases.

[0021] In some embodiments, the engine **150** of the generator **130** provides all or a majority of the power output from the hybrid power system **105** during normal, relatively high-power demand cycles and the one or more batteries **135** of the ESM **125** provide all or a majority of the power during periods of reduced power demand. The one or more batteries **135** can also provide supplemental power to supplement the power provided by the engine **150** during peak loading at the lower and upper edges of the connected load profile, which can significantly improve peak load capability or reduce a required size of the generator for applications with relatively high peak loads and much lower normal operating loads. This provides a means to improve efficiency, reduce fuel consumption, and/or operate in "stealth mode" with a much lower heat and noise signature. The ability of the ESM **125** to supplement the power of the generator **130** provides smoother responses to increases in load as the engine **150** of the generator **130** "throttles-up" to meet the demands of the increased load, improves fuel efficiency by as much as 90%, and enables a more robust response to loading and unloading events.

[0022] While only one generator **130** is illustrated in FIG. **1**, the hybrid power system **105** may include a plurality of generators coupled to the ESM **125**. In such embodiments, one of the plurality of generators may be selected to be the primary power source such that the selected generator is the first generator activated to satisfy a demand for power while the additional generators are sequentially activated to share the load as needed. In one or more embodiments, additional sources of power may be connected to the ESM **125** to supplement the battery and engine-driven power supplies. These additional power sources may include a pre-existing grid or renewable energy-based power sources, including, for example, wind turbines, solar panels, and hydroelectric dams.

[0023] With continued reference to FIG. **1**, the computer **110** includes a graphical user interface ("GUI") **160**, a processor **165**, and a computer readable medium **170** coupled thereto. Instructions accessible to, and executable by, the processor **165** are stored on the computer readable medium **170**. A database **175** is also stored in the computer readable medium **170**. Generally, the GUI **160** can display a plurality of windows or screens to a user. The computer **110** also includes an input device **180** and an output device **185**. In one or more embodiments, the input device **180** and the output device **185** are the GUI **160**. In one or more embodiments, the user provides inputs to the IDS system **100** via a window that is displayed on the GUI **160**. However, in one or more other embodiments, the input device **180** may also be a microphone and the output device **180** may be a speaker. In several embodiments, the computer **110** is, or includes, a telephone, a personal computer, a personal digital assistant, a cellular telephone or mobile phone, other types of telecommunications devices, other types of computing devices, and/or any combination thereof. In several embodiments, the computer **110** includes a plurality of remote user devices. In some embodiments, the computer **110** further includes an IDS application **190** executable using the processor **165** of the computer **110**. In one or more embodiments, the IDS application **190** may be stored on the computer readable medium **170** of the computer **110**. As will be discussed in more detail below, the IDS application **190** is configured to be used to test the health and performance of the engine **150** of the generator **130** using the ESM **125**.

[0024] In some embodiments, the database **175** stored in the computer readable medium **170** of the

computer **110** includes historical performance data **195** associated with the results of the tests performed on the engine **150** of the generator **130** using the IDS application **190** and the ESM **125**. In one or more embodiments, the historical performance data **195** may include engine performance scores calculated using the computer **110** and associated with the health and performance of the engine **150**.

[0025] In one or more embodiments, the computer **110** is positioned remotely relative to the hybrid power system **105**. In one or more other embodiments, the computer **110** is positioned locally relative to the ESM **125** of the hybrid power system **105**. In such embodiments, the controller **145** of the ESM **125** may include the computer **110**. In still other embodiments, the IDS system **100** may include two or more computers, such as computer **110**, with one positioned locally relative to the ESM **125** and the other positioned remotely relative to the hybrid power system **105**. In such embodiments, the IDS application **190** may be stored on the computer **110** positioned locally relative to the ESM **125**, on the computer **110** positioned remotely relative to the hybrid power system **105**, or may be shared between the two or more computers. Thus, the IDS application **190** can be communicated to, stored on, and/or executed by the controller **145** of the ESM **125**.

[0026] In some embodiments, the digital twin **115** is associated with the engine **150** of the generator **130** and includes engine specification data **192** and baseline performance data **194** associated with the engine **150** of the generator **130**. In one or more embodiments, the IDS system **100** may include a catalog or library of a plurality of digital twins associated with a plurality of engines of a plurality of generators. Each engine of each respective generator of the plurality of generators may be associated with a respective digital twin.

[0027] In one or more embodiments, the digital twin **115** may be originally stored on the engine controller **155** of the generator **130**. In such embodiments, the digital twin **115** is accessed by the controller **145** of the ESM **125** when the generator **130** is connected to the ESM **125**. In one or more other embodiments, the digital twin **115** may be originally stored remotely relative to the generator **130** and the ESM **125**. In such embodiments, the digital twin **115** may be stored in a database or cloud storage system associated with the manufacturer of the engine **150** such that the digital twin **115** may be accessed by the controller **145** of the ESM **125** via the network **120** by accessing a manufacturer website or by directly accessing the database or cloud storage system associated with the manufacturer.

[0028] In one or more embodiments, once the controller **145** of the ESM **125** has accessed the digital twin **115**, the digital twin **115** may be stored locally on the controller **145** of the ESM **125**. In one or more other embodiments, once the controller **145** of the ESM **125** has accessed the digital twin **115**, the digital twin **115** may be stored remotely relative to the ESM **125** but in communication with the controller **145** of the ESM **125** via the network **120**.

[0029] In one or more embodiments, the network **120** includes the Internet, one or more local area networks, one or more wide area networks, one or more cellular networks, one or more wireless networks, one or more voice networks, one or more data networks, one or more communication systems, and/or any combination thereof. In some embodiments, the network **120** also includes WIFI, Bluetooth, and Long-Term Evolution ("LTE") or other wireless broadband communication technology.

[0030] FIG. **2** is a schematic of the hybrid power system **105**, according to one or more embodiments of the present disclosure. As illustrated, the hybrid power system **105** includes the ESM **125** and the generator **130** and the hybrid power system **105** is connected to a load **205**. The load **205** may comprise any one or more devices or systems, and no limitation with respect to the same is provided herewith. For example, ESMs and generators of the present disclosure can provide electrical power to a pre-existing grid, a facility (e.g. a hospital building), a stand-alone device (e.g. a downhole pump), and various other systems and devices that require electrical power and that will be recognized by one of ordinary skill in the art.

[0031] As illustrated, the ESM **125** comprises a battery portion **235** and an inverter and control

portion **240**. The various features and components of the inverter and control portion **240** are operable to convert a direct current provided by the batteries of the battery portion **235** to an alternating current suitable for output to various devices and systems. The inverter and control portion **240** is further operable to monitor, analyze, and control an output. As illustrated, the ESM controller **145** is in communication with an inverter **250**, the generator controller **155**, and at least one battery, such as the battery **135**. The controller **145** is operable to perform at least one of the following functions: detect a change in generator output (voltage, current, and/or frequency), signal a change in demand or load to the battery **135**, demand additional power from the battery **135**, and demand or signal an increase or decrease in generator functions (e.g. engine speed). The controller **145** is operable to perform these tasks and communicate with the aforementioned devices using a variety of methods/protocols such as Modbus TCP/IP **265**, Canbus **270**, and others know to those skilled in the art. An example ESM is described in FIG. 6 of U.S. patent application Ser. No. 17/839,042, the entirety of which is hereby incorporated by reference. Generally, the ESM **125** comprises a housing that is configured to be mobile and/or mobilized quickly and efficiently. For example, in some embodiments the ESM **125** includes a plurality of wheels and is configured to be towed by a vehicle; includes forklift channels configured to receive a forklift; a plurality of eye bolts and/or hoist rings configured for use with a crane; and the like. In some embodiments, the ESM **125** comprises a housing that forms the battery portion **235** and the inverter and control portion **240**. In some embodiments, the housing of the ESM **125** is or includes an enclosure designed for outdoor use. In some embodiments, the enclosure of the ESM includes electrical connections configured for use with the plurality of generators, with the electrical connections forming a portion of an external surface of the housing.

[0032] While only one battery **135** is illustrated in FIG. **2**, the battery **135** can be combined with other batteries in series or in parallel to provide a power source. In some embodiments, any single battery may have nominal voltages of about 936 VDC, voltage ranges from about 650 to about 1066 VDC, capacity of 123.5 KWH, as well as a number of other electrical properties. The voltage and capacity, however, are flexible. In order to reduce noise, the battery portion **235** is contemplated as being provided in communication with an electromagnetic interference (EMI) filter **275**. The EMI filter **275** reduces noise from the battery **135** and from other ESM components or external devices. EMI filters can also be used to control noise in the inverter and control portion **240**. A ground fault detector **280** is contemplated as being provided in various locations within systems of the present disclosure, including proximal to the EMI filter **275**.

[0033] In some embodiments, the battery portion **235** includes a fire suppression system **285**. The fire suppression system **285** is preferably provided proximal to the battery **135**, outside of the battery portion **235**, and/or outside the ESM **125**. Furthermore, additional heat management may be contained in the battery portion **235**, such as an air conditioner **290** or a fan **295**. One of ordinary skill in the art will recognize that various devices of the present disclosure, including batteries (e.g. lithium-ion batteries) must be maintained within a preferred temperature range to optimize performance and safety of the battery or batteries.

[0034] Safety features are also contemplated as being incorporated into the inverter and control portion **240**. For instance, the inverter **250** is contemplated as being in thermal communication with a heat exchanger **300**. In some embodiments, the thermal communication pathway between the inverter **250** and heat exchanger **300** is contemplated as being equipped with temperature sensors **305**, flow sensors **310**, a filter **315**, a pump **320**, and a reservoir **325**. The various devices help to further ensure the safety and reliability of the ESM **125**. Furthermore, additional pumps/fans **330** can be added to the inverter and control portion **240** to aid in cooling.

[0035] Referring to FIG. **3**, with continued reference to FIGS. **1** and **2**, a method **335** of operating the IDS system **100** to perform an IDS test with respect to the engine **150** of the generator **130** is provided. The IDS test enables the health and performance of the engine **150** to be evaluated and monitored. In some embodiments, the method **335** includes accessing engine specification data and

baseline performance data associated with an engine of a generator at step **340**; initiating, using an ESM, a load step on the engine at step **345**; receiving, from a plurality of sensors associated with the engine, data associated with a response of the engine to the load step at step **350**; comparing the data associated with the response to the baseline performance data associated with the engine at step **355**; calculating an engine performance score associated with a performance of the engine at step **360**; storing the engine performance score in a database at step **365**; repeating the steps **340-365** at step **370**; and comparing two or more engine performance scores associated with the engine to detect a change in the performance of the engine at step **375**.

[0036] In some embodiments and at the step **340**, the controller **145** of the ESM **125** accesses the digital twin **115** associated with the engine **150** of the generator **130**. As described above, in one or more embodiments, the controller **145** of the ESM **125** may access the digital twin **115** directly from the engine controller **155** of the generator **130** once the generator **130** is connected to the ESM **125**. As also described above, in one or more other embodiments, the controller **145** of the ESM **125** may access the digital twin **115**, via the network **120**, from a manufacturer database positioned remotely relative to the hybrid power system **105**. From the digital twin **115**, the controller **145** of the ESM **125** accesses the engine specification data **192** and the baseline performance data **194** associated with the engine **150** that will be subjected to the IDS test.

[0037] In some embodiments and at the step **345**, the controller **145** of the ESM **125** initiates the IDS test on the engine **150** of the generator **130**. To initiate the IDS test, the controller **145** accesses and executes the IDS application **190**. In doing so, the controller **145** of the ESM **125** initiates a load step on the engine **150** of the generator **130**. Generally, the IDS test commands a 0-100% rated load step on the engine **150**. The specifications of the load step are based on the engine specification data **192** accessed from the digital twin **115** and associated with the engine **150**. In one or more embodiments, the engine specification data **192** defines a maximum load rating or an ideal load rating for the engine **150**. The controller **145** of the ESM **125** executing the IDS application **190** uses these load ratings to define the specifications of the load step placed across the engine **150**. In one or more embodiments, the baseline performance data **194** associated with the engine **150** is based on the performance of the engine **150** when subjected to the maximum load rating or the ideal load rating defined by the engine specification data **192**.

[0038] The battery **130** of the ESM **125** is used by the controller **145** to provide the controlled load step on the engine **150**. In some embodiments, the load step initiated on the engine **150** using the battery **130** is less than or equal to the available charging capacity of the battery **130** to ensure that the battery **130** has adequate capacity to absorb the output of the engine **150** in response to the IDS test.

[0039] An inverter associated with the ESM **125**, such as the inverter **250** of FIG. **2**, and controls associated therewith, make precision measurements of the power output generated by the engine **150** in response to the IDS test. In one or more embodiments, the inverter is able to generate precision measurements relating to the voltage, current, ramp rates, and harmonic distortion associated with the response of the engine **150** to the IDS test. This provides a relative and measured response to power commands.

[0040] During normal operation of the hybrid power system **105**, the battery **130** of the ESM **125** supplements the power output of the engine **150** in response to a "droop" resulting from a load being placed on the engine **150**. Such operation can mask performance issues associated with the engine **150**. Thus, upon initiation of the IDS test, the controller **145** of the ESM **125** adjusts the tuning of the inverter to prevent the battery **130** of the ESM **125** from supplementing the power of the engine **150** in response to the load step. As such, the engine **150** is isolated during the IDS test so that the performance of the engine **150** can be accurately evaluated.

[0041] The engine **150** of the generator **130** is equipped with various measuring devices, such as the plurality of sensors **158** described above. With respect to the response of the engine **150** to the load step of the IDS test, the plurality of sensors **158** are configured to identify a plurality of

parameters associated with engine performance, stability, thermal efficiency, mechanical efficiency, and vibration. As described above, these parameters include all or some of the following: engine coolant temperature, exhaust gas temperature, manifold pressure, throttle inlet pressure, oil pressure, crankcase pressure, intake air temperature, fuel flow, throttle position, and vibration measured through an accelerometer. The plurality of sensors **158** generate data associated with these parameters and the response of the engine **150** to the load step.

[0042] In some embodiments and at the step **350**, the data generated by the plurality of sensors **158** and associated with the response of the engine **150** to the load step of the IDS test is transmitted to, and received by, the controller **145** of the ESM **125**.

[0043] In some embodiments and at the step **355**, the controller **145** of the ESM **125** compares the data received from the plurality of sensors **158** with the baseline performance data **194** of the engine **150** in order to evaluate the current performance of the engine **150** during the IDS test relative to a baseline performance of the engine **150** specified by the manufacturer of the engine **150**.

[0044] In some embodiments and at the step **360**, the controller **145** of the ESM **125** calculates an engine performance score for the engine **150** based on the comparison of the data received form the plurality of sensors **158** and the baseline performance data **194** performed at step **355**. In one or more embodiments, each parameter associated with each sensor of the plurality of sensors **158** may be evaluated on a graded scale and given a score from 1 to 10 based on the comparison of the IDS test data of each parameter to the baseline performance data of each respective parameter. In one or more embodiments, the plurality of engine performance scores calculated for the plurality of parameters may then be averaged together to calculate a single engine performance score for the engine **150**.

[0045] In some embodiments and at the step **365**, the engine performance score(s) calculated at step **360** for the engine **150** based on the IDS test performed on the engine **150** are stored in a database, such as the database **175** of the computer **110**. The engine performance scores are stored as the historical performance data **195** in the database **175**. The engine performance scores calculated for the engine **150** during each IDS test are stored as historical performance data **195** so that the evolution of the health and performance of the engine **150** can be monitored and evaluated over time.

[0046] In some embodiments and at the step **370**, the IDS test, including step **340** through step **365**, is repeated for the engine **150** at a future time. The IDS tests performed with respect to the engine **150** may be scheduled at predetermined intervals or may be performed as needed.

[0047] In some embodiments and at the step **375**, after two or more IDS tests have been performed on the engine **150**, the engine performance scores from the two or more IDS tests are compared to detect a change in the performance of the engine **150**. Generally, an engine and its performance will deteriorate over time, which would be reflected by a change, either up or down, in engine performance scores over time and between successive IDS tests. However, when maintenance is performed on an engine, the engine and its performance may improve, which would be reflected by a change in engine performance scores in the opposite direction between successive IDS tests.

[0048] Using the engine performances scores and the comparison of the engine performance scores over time, a number of estimations and determinations can be made regarding the engine **150** of the generator **130**. In one or more embodiments, for example, the engine performance scores may be used to estimate a remaining life, or remaining useful life of the engine **150** before the engine **150** will need replacing, rebuilding, or routine maintenance performed. In one or more embodiments, the individual engine performance scores associated with the individual engine parameters may be used to identify particular components of the engine **150** that are deteriorating and in need of replacement or preventative maintenance. As such, the engine performance scores can be used to determine maintenance and overhaul schedules for the engine **150** so that maintenance and replacement can be performed at convenient times and avoid the incidence of sudden failures

during critical periods of operation.

[0049] In one or more embodiments, after performing one or more IDS tests on an engine of a first generator, the first generator may be disconnected from the ESM **125** and a second generator that is different from the first generator may be connected to the ESM **125**. The ESM **125** may then be used to execute method **335** to perform one or more IDS tests with respect to an engine of the second generator. In such embodiments, the controller **145** of the ESM **125** may retain the digital twin and the historical performance data of the first generator after the first generator has been disconnected. In this way, the controller **145** of the ESM **125** generates a catalog of a plurality of digital twins and historical performance data for a plurality of different generators.

[0050] In one or more embodiments, the steps of the method **335** are implemented by the controller **145** executing the IDS application **190** and sent, via the network **120**, to a location and/or computer **110** remote from the generator **130** and ESM **125**. In one or more embodiments, the controller **145** executing the IDS application **190** initiates the steps of the method **335** without human input. In one or more embodiments, the controller **145** executing the IDS application **190** monitors the hybrid power system **105** and alerts/communicates, via the network **120**, a potential load performance issue, a potential or identified maintenance issue, a predicted future load performance issue, or a predicted future life-span.

[0051] Referring to FIG. **4**, a table **400** is provided showing the calculated engine performance scores for each measured engine parameter associated with the plurality of sensors **158**, as well as an average, or composite, engine performance score for the engine **150** as a result of the IDS test. In one or more embodiments, all or a portion of the information shown in the table **400** may be displayed via the GUI **160** such that this information is visible to an operator of the hybrid power system **105**.

[0052] Referring to FIGS. **5**A, **5**B, and **5**C, tables **505, 510**, and **515** are provided showing the results of multiple IDS tests performed with respect to the engine **150** of the generator **130**. For example, the table **505** is associated with test results after 5,000 hours of use, the table **510** is associated with test results after 10,000 hours of us, and the table **515** is associated with test results after 20,000 hours. In one or more embodiments, the historical performance data **195** associated with the engine **150** may be displayed via the GUI **160** so that general trends in engine performance can be made visible to the operator. In one or more embodiments, the current engine performance scores as well as the historical performance data **195** may be displayed simultaneously via the GUI **160**. In one or more embodiments, the total run-time in hours that the engine **150** has been operating at the time an IDS test was performed may be displayed with the calculated engine performance scores. In one or more embodiments, an estimated remaining life in hours of the engine **150**, which may be estimated based on the results of each IDS test, may be displayed along with the calculated engine performance scores of each IDS test. By displaying this information to operators, the operators are better informed regarding engine operation, overhaul and maintenance requirements, and replacement cycles.

[0053] Storing and comparing the historical performance data **195** associated with the engine **150** also facilitates improved inventory control for greater reliability and resiliency. In one or more embodiments, an IDS program, based on the measured parameters and compared scores over time, predicts the repair and replacement needs of individual components of the engine, for example, if one parameter is showing a more significant drop in performance as compared to the rest of the parameters.

[0054] Referring to FIGS. **6-8**, example responses of the engine **150** to the load step of the IDS test measured by a portion of the plurality of sensors **158** are provided.

[0055] FIG. **6** provides a graph **600** depicting the throttle response (measured using the TPS) and the deflection in RPM, or droop in RPM, over time. The graph **600** illustrates the time required for the engine **150** to fully recover to the commanded engine speed, which is 1800 RPM in the example shown.

[0056] FIG. **7** provides a graph **700** further depicting the MAP and TIP responses of the engine **150** during the IDS test. The plurality of sensors **158** capture and record the MAP and TIP to characterize the mechanical efficiency and the effectiveness of the induction system of the engine **150**.

[0057] FIG. **8** provides a graph **800** further depicting the FF response required to support the commanded load step of the IDS test. The amount of fuel required to support the response of the engine **150** to the load step is accessed through a fuel valve of the engine **150** or through an external source. The graphs **600**, **700**, and **800** utilize an engine control platform to illustrate IDS functionality. In one or more embodiments, the IDS application utilizes a separate purpose-built diagnostic and data acquisition platform.

[0058] Referring to FIG. **9**, with continued reference to FIGS. **1-8**, another embodiment of the hybrid power system **105** of the IDS system **100** is shown. As described above, the ESM **125** of the hybrid power system **105** is configured to be connected to a plurality of generators or other power sources simultaneously. In the embodiment shown in FIG. **9**, the ESM **125** is connected to the generator **130**, a second generator **900**, a third generator **905**, and an n'th generator **910**. The generator **130** is a first type of generator, the second generator **900** is a second type of generator, the third generator **905** is a third type of generator, and the n'th generator **910** is an n'th type of generator. In one or more embodiments, the first, second, and third types of generators are all different types of generators. As used herein, the "type" of generator refers to the type of engine (e.g., make and model) associated with the generator.

[0059] Each generator of the plurality of generators connected to the ESM **125** has a controller, an engine, and a plurality of sensors similar to those described above with respect to the generator **130**. In some embodiments, a digital twin catalog **915** including a digital twin associated with each engine of the plurality of generators, or each type of engine of each generator of the plurality of generators. The digital twin catalog **915** includes the digital twin **115** associated with the first type of engine of the generator **130**, a digital twin **920** associated with the second type of engine of the second generator **900**, a digital twin **925** associated with the third type of engine of the third generator **905**, and a digital twin **930** associated with the n'th type of engine of the n'th generator **910**.

[0060] In the embodiment shown in FIG. **9**, the hybrid power system **105** including the ESM **125** and the plurality of generators are connected to form a multi-unit microgrid. Such a system is operated in parallel and load-shares the connected loads. Often, only the generator(s) required to support the load are operated. In this way, fuel savings can be achieved by turning off or not starting the generators not required for the reduced load. The additional generators are brought online with the running generators as the load is presented. This is commonly referred to as "auto-sequencing" with each generator in the microgrid assigned an operating order priority. For example, in a four-unit microgrid the generator assigned as "Unit 1" would be operating continuously and support the minimum load. As the load increases, "Unit 2" would be brought online and the load shared equally between the two running power systems. The hybrid part of the system provides the "ride-through" power required to allow Unit 2 to start and begin load sharing. The process continues as the load continues to increase until all of the plurality of generators are online and sharing the connected load.

[0061] Historically, the sequencing order of the generators has been either randomly selected by the operator or assigned by unsophisticated methods such as total run hours on the generators. Such methods do not consider the relative "health" of each generator.

[0062] Using the method of evaluating the health and performance of a generator described above, the selection of the sequencing order for a plurality of generators in a hybrid power system can be significantly improved. Using engine performance scores calculated for each generator in the system after performing one or more IDS test with respect to each generator, the most robust generator can be assigned as Unit 1 followed by the second best as Unit 2, and so on. In this way,

the hybrid power system better distributes the workload across the generators for added reliability and resiliency.

[0063] Referring to FIG. **10**, with continued reference to FIGS. **1-9**, a method **1000** of using the IDS system **100** to optimize the sequencing order of two or more generators in a hybrid power system, such as the hybrid power system **105** shown in FIG. **9**, is provided. In some embodiments, the method **100** includes selecting a first engine of a first generator at step **1005**; executing the method **335** with respect to the first engine at step **1010**; selecting a second engine of a second generator at step **1015**; executing the method **335** with respect to the second engine at step **1020**; comparing the engine performance score associated with the first engine and the engine performance score associated with the second engine at step **1025**; and creating, based on the comparison of the engine performance scores of the first and second engines, a sequencing order defining the order in which the first generator and the second generator will be brought online to generate power at step **1030**.

[0064] In some embodiments, the method **1000** may be performed while the two or more generators are simultaneously connected to the ESM **125**. In one or more embodiments, the method **100** may be performed while only the generator being tested is connected to the ESM **125**. For example, a plurality of generators may be located in a storage facility. The plurality of generators may be subjected to an IDS test one at a time, and the results of each test can be used to determine the sequencing order when two or more of the generators are eventually connected to the ESM **125**.

[0065] In some embodiments and at the step **1005**, the controller **145** of the ESM **125** selects the generator **130**.

[0066] In some embodiments and at the step **1010**, the method **335** is executed as described above such that an IDS test is performed with respect to the generator **130** and such that a first engine performance score is generated for the generator **130**. In order to execute the method **335** with respect to the generator **130**, the digital twin **115** associated with the generator **130** is accessed by the controller **145** from the digital twin catalog **395**. In some embodiments, execution of the method **335** excludes the step **370**. That is, the step **1010** may only include calculating one engine performance score associated with the first engine.

[0067] In some embodiments and at the step **1015**, the controller **145** of the ESM **125** selects the second generator **900**. In one or more embodiments, the controller **145** may deselect the generator **130** prior to selecting the second generator **900**.

[0068] In some embodiments and at the step **1020**, the method **335** is executed as described above such that an IDS test is performed with respect to the second generator **900** and such that a first engine performance score is generated for the second generator **900**. In order to execute the method **335** with respect to the second generator **900**, the digital twin **920** associated with the second generator **900** is accessed by the controller **145** from the digital twin catalog **915**. In some embodiments, execution of the method **335** excludes the step **370**. That is, the step **1020** may only include calculating one engine performance score associated with the second engine.

[0069] In some embodiments and at the step **1025**, the controller **145** of the ESM **125** compares the first engine performance score of the generator **130** and the first engine performance score of the second generator **900**. Based on this comparison, the controller **145** can determine which generator is the healthiest or has better performance.

[0070] In some embodiments and at the step **1030**, the controller **145** of the ESM **125** determines and creates, based on the comparison of step **1025**, the sequencing order for the hybrid power system **105**. In one or more embodiments, as discussed above, it is most efficient to operate the hybrid power system **105** with a sequencing order that brings each generator of the two or more generators online in the order of best performance. In one or more embodiments, operating the hybrid power system with the sequencing order that brings each generator online in the order of best performance reduces greenhouse gas emissions compared to conventional systems.

[0071] In some embodiments, the method **1000** also includes bringing each of the generators **120**,

900, **905**, and **910** online in accordance with the sequencing order.

[0072] In one or more embodiments, the method **1000** can include executing the method **335** (i.e., performing an IDS test) for as many generators, with as many different types of engines, as needed, desired, or required for a particular application.

[0073] In one or more embodiments, the method **1000** can be repeated as many times as needed, desired, or required for a particular application in order to update and optimize the sequencing order of the two or more generators connected to the ESM **125** to ensure the most efficient generators of the hybrid power system are coming online first. For example, in one or more embodiments, first engine performance scores may be generated for the two or more generators. Based on the first engine performance scores, the sequencing order for the two or more generators can be determined. Then, at random or at scheduled intervals, each of the two or more generators may be subjected to a second IDS test such that second engine performance scores are generated for the two or more generators. Based on a comparison of the second engine performance scores, the sequencing order of the two or more generators can be updated if needed.

[0074] Referring to FIGS. **11**A, **11**B, and **11**C, graphs **1100**, **1105**, and **1110** depict the responses of three example generators to an IDS test. Graph **1100** depicts the measured voltage associated with the response of each generator during the load ramping of the IDS test. Graph **1105** depicts the measure current associated with the response of each generator during the load ramping of the IDS test. Graph **1110** depicts the load ramp rate during the IDS test. Measuring the electrical output and work performed by each generator during an IDS test facilitates the evaluation and comparison of the health and performance of each generator.

[0075] The hybrid power systems disclosed herein, such as those used in military applications, are often stored for long periods before being transported thousands of miles to the area of operations where the system is put into service. Even with extensive periodic maintenance practices and sophisticated diagnostic tools, these systems are often prone to early failures or soon require an unplanned major repair that renders them inoperable. This can impact the mission readiness of critical connected equipment, thereby putting the warfighter at risk. Weapons systems, radar and communications systems, or an entire field hospital can be severely impacted or unavailable because of the unexpected loss of a supporting power system. The IDS system **100** disclosed herein significantly reduces these events by providing the current engine performance scores along with the average engine performance scores. A system nearing the end of its service life or in need of significant repair would be readily apparent based on the score on the GUI without the need for additional service inspections or diagnostic tools.

[0076] In one or more embodiments, the hybrid power system **105** provides load support to the prime mover that powers the loads. The inverter injects current in response to a droop in frequency that results from the loss in RPM as an engine-driven generator responds to significant load steps. This frequency regulation provides a consistent flow of stable energy to the connected loads as load events occur. While this is desirable and a key advantage to a hybrid power system, it can create an unintended risk to the overall resiliency of the complete hybrid power plant by "masking" the reduced performance in an aging engine-driven system or by compensating for a poorly performing system in need of service or repair. These issues can be masked and allow the system to further degrade until a catastrophic failure occurs or the affected system is incapable of satisfying the necessary output required to support the hybrid power plant. The systems and methods regarding IDS testing disclosed herein not only expose the compromised power system's underperformance, but it also provides a score used to assess the relative degree of underperformance compared to the established performance baseline.

[0077] In one or more embodiments, the IDS system disclosed herein, including the controller and program, provide the testing protocol, store and display data, and manage the IDS testing. In one or more embodiments, the IDS system includes sensing devices and the interface device that connects and transfers data to the controller. In one or more embodiments, the sensing devices are not part of

the power system controls used by the OEM and do not impact the performance or management of the power system. The MAP and IAT sensors are specialized devices that measure ambient temperature and barometric pressure to account for normal performance degradation due to high ambient temperatures and altitudes.

[0078] Advanced diagnostics and "smart" microgrid controls coupled with the ESM used on a hybrid power system provide a controllable load that can be connected to the power system's prime mover (i.e., the generator). Specific data can be measured, stored, and compared during consistent loading and unloading events made possible by the available capacity of the ESM, the precise energy analysis provided by advanced power electronics, and the measurement of relevant engine diagnostic data. Each IDS test can be evaluated and compared against an established standard, such as the baseline performance data associated with the engine of the generator, and with the historical performance data associated with past IDS tests performed on the engine, to better inform predictive maintenance events, overhaul schedules, and end-of-life. IDS tests could be scheduled into the normal operating functions performed by the power system with no impact on the intended application or power system functionality.

[0079] The inverter and power electronics used on a hybrid power system use highly sensitive and accurate power-measuring devices that are used in the integration of the stored energy with the electrical output of the engine-driven generator. These same devices are repurposed with the IDS program to provide precise measurements of the electrical output and work performed by the connected power system during the IDS test. The hybrid controller modifies the tuning during an IDS test to allow "droop" to occur and can assess the response from the power system and the system's ability to accept load commands. This sophisticated analysis uses onboard devices and eliminates the need to connect external power analyzers while providing similar data that is used in the engine performance score computations.

[0080] In one or more embodiments, equipment in inventory can be "graded" via an IDS test and/or engine performance score to provide better inventory control of viable assets. For example, a remote site (e.g., a site that has an ingress or egress time beyond a threshold) may require a minimum engine performance score to be considered as a viable power system eligible to deploy but a lower score may be acceptable if the equipment is to be used for a local training exercise.

[0081] In an example embodiment, as illustrated in FIG. **12**, with continued reference to FIGS. **1-11**, an illustrative node **1200** for implementing one or more of the example embodiments described above and/or illustrated in FIGS. **1-11** is depicted. The node **1200** includes a microprocessor **1200***a*, an input device **1200***b*, a storage device **1200***c*, a video controller **1200***d*, a system memory **1200***e*, a display **1200***f*, and a communication device **1200***g* all interconnected by one or more buses **1200***h*. In several example embodiments, the storage device **1200***c* may include a floppy drive, hard drive, CD-ROM, optical drive, any other form of storage device and/or any combination thereof. In several example embodiments, the storage device **1200***c* may include, and/or be capable of receiving, a floppy disk, CD-ROM, DVD-ROM, or any other form of computer-readable medium that may contain executable instructions. In several example embodiments, the communication device **1200***g* may include a modem, network card, or any other device to enable the node to communicate with other nodes. In several example embodiments, any node represents a plurality of interconnected (whether by intranet or Internet) computer systems, including without limitation, personal computers, mainframes, PDAs, smartphones and cell phones.

[0082] In several example embodiments, one or more of the components of the systems described above and/or illustrated in FIGS. **1-11** include at least the node **1200** and/or components thereof, and/or one or more nodes that are substantially similar to the node **1200** and/or components thereof. In several example embodiments, one or more of the above-described components of the node **1200** and/or the example embodiments described above and/or illustrated in FIGS. **1-11** include respective pluralities of same components.

[0083] In several example embodiments, one or more of the applications, systems, and application

programs described above and/or illustrated in FIGS. **1-11** include a computer program that includes a plurality of instructions, data, and/or any combination thereof; an application written in, for example, Arena, HyperText Markup Language (HTML), Cascading Style Sheets (CSS), JavaScript, Extensible Markup Language (XML), asynchronous JavaScript and XML (Ajax), and/or any combination thereof; a web-based application written in, for example, Java or Adobe Flex, which in several example embodiments pulls real-time information from one or more servers, automatically refreshing with latest information at a predetermined time increment; or any combination thereof. The one or more server(s), in some embodiments may be remote and accessible by a cloud or other network described herein.

[0084] In several example embodiments, a computer system typically includes at least hardware capable of executing machine readable instructions, as well as the software for executing acts (typically machine-readable instructions) that produce a desired result. In several example embodiments, a computer system may include hybrids of hardware and software, as well as computer sub-systems.

[0085] In several example embodiments, hardware generally includes at least processor-capable platforms, such as client-machines (also known as personal computers or servers), and hand-held processing devices (such as smart phones, tablet computers, personal digital assistants (PDAs), or personal computing devices (PCDs), for example). In several example embodiments, hardware may include any physical device that is capable of storing machine-readable instructions, such as memory or other data storage devices. In several example embodiments, other forms of hardware include hardware sub-systems, including transfer devices such as modems, modem cards, ports, and port cards, for example.

[0086] In several example embodiments, software includes any machine code stored in any memory medium, such as RAM or ROM, and machine code stored on other devices (such as floppy disks, flash memory, or a CD ROM, for example). In several example embodiments, software may include source or object code. In several example embodiments, software encompasses any set of instructions capable of being executed on a node such as, for example, on a client machine or server. In some embodiments, software includes one or more software modules including code, programming object, programming structure, or combinations thereof. In one or more embodiments, the one or more software modules comprise, by way of nonlimiting examples, a web application, a mobile application, and a standalone application. In various embodiments, software modules are in more than one computer program or application. In some embodiments, the software modules are hosted by more than one machine. In some embodiments, the software modules are hosted by more than one machine in more than one location.

[0087] In several example embodiments, combinations of software and hardware could also be used for providing enhanced functionality and performance for certain embodiments of the present disclosure. In an example embodiment, software functions may be directly manufactured into a silicon chip. Accordingly, it should be understood that combinations of hardware and software are also included within the definition of a computer system and are thus envisioned by the present disclosure as possible equivalent structures and equivalent methods.

[0088] In several example embodiments, computer readable mediums include, for example, passive data storage, such as a random-access memory (RAM) as well as semi-permanent data storage such as a compact disk read only memory (CD-ROM). One or more example embodiments of the present disclosure may be embodied in the RAM of a computer to transform a standard computer into a new specific computing machine. In several example embodiments, data structures are defined organizations of data that may enable an embodiment of the present disclosure. In an example embodiment, a data structure may provide an organization of data, or an organization of executable code.

[0089] In several example embodiments, any networks and/or one or more portions thereof may be designed to work on any specific architecture. In an example embodiment, one or more portions of

any networks may be executed on a single computer, local area networks, client-server networks, wide area networks, internets, hand-held and other portable and wireless devices and networks.

[0090] In several example embodiments, a database may be any standard or proprietary database software. In several example embodiments, the database may have fields, records, data, and other database elements that may be associated through database specific software. In several example embodiments, data may be mapped. In several example embodiments, mapping is the process of associating one data entry with another data entry. In an example embodiment, the data contained in the location of a character file can be mapped to a field in a second table. In several example embodiments, the physical location of the database is not limiting, and the database may be distributed. In an example embodiment, the database may exist remotely from the server, and run on a separate platform. In an example embodiment, the database may be accessible across the Internet. In several example embodiments, more than one database may be implemented.

[0091] In several example embodiments, instructions are stored on a non-transitory computer readable medium and executed by one or more processors to cause the one or more processors to carry out or implement in whole or in part the above-described operation of each of the above-described example embodiments of the system, the method, and/or any combination thereof. In several example embodiments, such a processor may include one or more of the microprocessor **1200***a*, any processor(s) that are part of the components of the system, and/or any combination thereof, and such a computer readable medium may be distributed among one or more components of the system. In several example embodiments, such a processor may execute the plurality of instructions in connection with a virtual computer system. In several example embodiments, such a plurality of instructions may communicate directly with the one or more processors, and/or may interact with one or more operating systems, middleware, firmware, other applications, and/or any combination thereof, to cause the one or more processors to execute the instructions.

[0092] In several example embodiments, the elements and teachings of the various illustrative example embodiments may be combined in whole or in part in some or all of the illustrative example embodiments. In addition, one or more of the elements and teachings of the various illustrative example embodiments may be omitted, at least in part, and/or combined, at least in part, with one or more of the other elements and teachings of the various illustrative embodiments.

[0093] The present disclosure introduces a method for testing engine performance of generator(s) using an energy storage module ("ESM"), the ESM comprising one or more batteries and a controller configured to be operably coupled to the generator(s), each of the generator(s) comprising an engine associated with a plurality of engine sensors, engine specification data, and baseline performance data, and the method comprising: (a) accessing, using the controller, engine specification data and baseline performance data associated with a selected engine of one of the generator(s); (b) initiating, using the controller and the one or more batteries, a load step on the selected engine, the load step being based on the engine specification data associated with the selected engine; (c) receiving, by the controller and from a plurality of sensors associated with the selected engine, data associated with a response of the selected engine to the load step of step (b); (d) comparing, using the controller, the data of step (c) to the baseline performance data associated with the selected engine; (e) calculating, using the controller and based on the comparison of step (d), an engine performance score associated with a performance of the selected engine; and (f) storing, using the controller, the engine performance score of step (e) in a database associated with the controller. In one embodiment, the selected engine is a first engine of a first generator of the generator(s) and the engine performance score calculated for the selected engine is a first engine performance score associated with a performance of the first engine. In one embodiment, the method further includes (g) identifying, using the controller and based on the first engine performance score, a future maintenance activity for the first engine. In one embodiment, the method further includes (h) predicting, using the controller and based on the first engine performance score, a service life of the first engine. In one embodiment, step (a) further comprises

accessing a digital twin associated with the first engine; and the digital twin comprises the engine specification data and the baseline performance data associated with the first engine. In one embodiment, the method further includes (i) repeating the steps (b)-(f) such that the engine performance score calculated for the selected engine is a second engine performance score associated with the performance of the first engine; and (j) comparing, using the controller, the first engine performance score and the second engine performance score to detect a change in the performance of the first engine. In one embodiment, the method further includes (k) selecting, using the controller, a second engine of a second generator of the generator(s) such that the second engine is the selected engine; and (l) executing steps (a)-(f) such that the engine performance score calculated for the selected engine is a first engine performance score associated with a performance of the second engine. In one embodiment, the method further includes (m) comparing, using the controller, the first engine performance score associated with the performance of the first engine and the first engine performance score associated with the performance of the second engine; and (n) creating, using the controller and based on the comparison of step (m), a sequencing order defining the order in which the first generator and the second generator will be brought online to generate power. In one embodiment, the comparison of step (m) indicates that the performance of the first engine is greater than the performance of the second engine; and the sequencing order of step (n) defines that the first generator will be brought online before the second generator. In one embodiment, the performance of the first engine is the fuel efficiency of the first engine and the performance of the second engine is the fuel efficiency of the second engine; and the sequencing order of step (n) is created such that the more fuel efficient engine of the first and second engines is ordered to be brought online first in order to reduce the amount of fuel used by the generator(s). In one embodiment, the method further includes (o) repeating the steps (b)-(f) such that the engine performance score calculated for the selected engine is a second engine performance score associated with the performance of the first engine; (p) executing steps (b)-(f) such that the engine performance score calculated for the selected engine is a second engine performance score associated with a performance of the second engine; (q) comparing, using the controller, the second engine performance score associated with the performance of the first engine and the second engine performance score associated with the performance of the second engine; and (r) updating, using the controller and based on the comparison of step (q), the sequencing order defining the order in which the first generator and the second generator will be brought online to generate power. In one embodiment, the comparison of step (q) indicates that the performance of the second engine is greater than the performance of the first engine; and the updated sequencing order of step (r) defines that the second generator will be brought online before the first generator.

[0094] The present disclosure introduces an energy storage module ("ESM") capable of testing engine performance of generator(s), the ESM comprising: one or more batteries; and a controller configured to be operably coupled to the generator(s), each generator comprising an engine and a plurality of engine sensors and each engine being associated with engine specification data and baseline performance data, the controller being configured to execute a performance test with respect to a selected engine of the generator(s) by completing the following steps with respect to the selected engine: (a) accessing engine specification data and baseline performance data associated with a selected engine of one of the generator(s); (b) initiating, using the one or more batteries, a load step on the selected engine, the load step being based on the engine specification data associated with the selected engine; (c) receiving, from a plurality of sensors associated with the selected engine, data associated with a response of the selected engine to the load step of step (b); (d) comparing the data of step (c) to the baseline performance data associated with the selected engine; (e) calculating, based on the comparison of step (d), an engine performance score associated with a performance of the selected engine; and (f) storing the engine performance score of step (e) in a database associated with the controller. In one embodiment, the selected engine is a first engine of a first generator of the generator(s) and the engine performance score calculated for

the selected engine is a first engine performance score associated with a performance of the first engine. In one embodiment, the controller completes the following additional steps with respect to the selected engine: (g) repeating the steps (b)-(f) such that the engine performance score calculated for the selected engine is a second engine performance score associated with the performance of the first engine; and (h) comparing the first engine performance score and the second engine performance score to detect a change in the performance of the first engine. In one embodiment, the controller completes the following additional steps with respect to the selected engine: (i) selecting, using the controller, a second engine of a second generator of the generator(s) such that the second engine is the selected engine; and (j) executing steps (a)-(f) such that the engine performance score calculated for the selected engine is a first engine performance score associated with a performance of the second engine. In one embodiment, the controller completes the following additional steps with respect to the selected engine: (k) comparing the first engine performance score associated with the performance of the first engine and the first engine performance score associated with the performance of the second engine; and (l) creating, based on the comparison of step (k), a sequencing order defining the order in which the first generator and the second generator will be brought online to generate power. In one embodiment, the comparison of step (k) indicates that the performance of the first engine is greater than the performance of the second engine; and the sequencing order of step (l) defines that the first generator will be brought online before the second generator. In one embodiment, step (a) further comprises accessing a digital twin associated with the first engine; the digital twin comprises the engine specification data and the baseline performance data associated with the first engine; and the digital twin is accessed from either a manufacturer database or the selected engine. In one embodiment, the controller completes the following additional step with respect to the selected engine: (m) receiving, by the one or more batteries of the ESM, a power output from the engine, the power output being associated with the response of the engine to the first load.

[0095] Any spatial references such as, for example, "upper," "lower," "above," "below," "between," "bottom," "vertical," "horizontal," "angular," "upwards," "downwards," "side-to-side," "left-to-right," "right-to-left," "top-to-bottom," "bottom-to-top," "top," "bottom," "bottom-up," "top-down," etc., are for the purpose of illustration only and do not limit the specific orientation or location of the structure described above.

[0096] In several example embodiments, while different steps, processes, and procedures are described as appearing as distinct acts, one or more of the steps, one or more of the processes, and/or one or more of the procedures may also be performed in different orders, simultaneously, and/or sequentially. In several example embodiments, the steps, processes and/or procedures may be merged into one or more steps, processes, and/or procedures.

[0097] In several example embodiments, one or more of the operational steps in each embodiment may be omitted. Moreover, in some instances, some features of the present disclosure may be employed without a corresponding use of the other features. Moreover, one or more of the above-described embodiments and/or variations may be combined in whole or in part with any one or more of the other above-described embodiments and/or variations and this is within the contemplated scope of disclosure herein, unless stated otherwise.

[0098] The phrase "at least one of A and B" should be understood to mean "A, B, or both A and B." The phrases "one or more of the following: A, B, and C" and "one or more of A, B, and C" should each be understood to mean "A, B, or C; A and B, B and C, or A and C; or all three of A, B, and C."

[0099] It is understood that variations may be made in the foregoing without departing from the scope of the present disclosure.

[0100] In several embodiments, one or more of the operational steps in each embodiment may be omitted. Moreover, in some instances, some features of the present disclosure may be employed without a corresponding use of the other features. Moreover, one or more of the embodiments disclosed above, or variations thereof, may be combined in whole or in part with any one or more

of the other embodiments described above, or variations thereof.

[0101] Although several embodiments have been described in detail above, the embodiments described are illustrative only and are not limiting, and those skilled in the art will readily appreciate that many other modifications, changes and/or substitutions are possible in the embodiments without materially departing from the novel teachings and advantages of the present disclosure. Accordingly, all such modifications, changes, and/or substitutions are intended to be included within the scope of this disclosure as defined in the following claims. In the claims, any means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents, but also equivalent structures. Moreover, it is the express intention of the applicant not to invoke 35 U.S.C. § 112(f) for any limitations of any of the claims herein, except for those in which the claim expressly uses the word "means" together with an associated function.

Claims

1. A method for generating power by bringing a plurality of generators online using a sequencing order and an energy storage module ("ESM"), the ESM comprising one or more batteries and a controller configured to be operably coupled to each of the plurality of generators, each of the plurality of generators comprising an engine associated with a plurality of engine sensors, engine specification data, and baseline performance data, and the method comprising: (a) accessing, using the controller, engine specification data and baseline performance data associated with a selected engine of one of the plurality of generators, wherein the selected engine is a first engine of a first generator of the plurality of generators; (b) initiating, using the controller and the one or more batteries, a load step on the selected engine, the load step being based on the engine specification data associated with the selected engine; (c) receiving, by the controller and from a plurality of sensors associated with the selected engine, data associated with a response of the selected engine to the load step of step (b); (d) comparing, using the controller, the data of step (c) to the baseline performance data associated with the selected engine; (e) calculating, using the controller and based on the comparison of step (d), an engine performance score associated with a performance of the selected engine, wherein the engine performance score calculated for the selected engine is a first engine performance score associated with a performance of the first engine; (f) storing, using the controller, the engine performance score of step (e) in a database associated with the controller; (g) selecting, using the controller, a second engine of a second generator of the plurality of generators such that the second engine is the selected engine; (h) executing steps (a)-(f) with the second engine being the selected engine such that the engine performance score calculated for the selected engine is a first engine performance score associated with a performance of the second engine; (i) comparing, using the controller, the first engine performance score associated with the performance of the first engine and the first engine performance score associated with the performance of the second engine; (i) creating, using the controller and based on the comparison of step (i), a sequencing order defining the order in which the first generator and the second generator will be brought online to generate power; and (k) generating power by bringing online, using the controller, the first generator and the second generator based on the sequencing order.

2. (canceled)

3. The method of claim 1, further comprising: (l) identifying, using the controller and based on the first engine performance score, a future maintenance activity for the first engine.

4. The method of claim 1, further comprising: (m) predicting, using the controller and based on the first engine performance score, a service life of the first engine.

5. The method of claim 1, wherein step (a) further comprises accessing a digital twin associated with the first engine; and wherein the digital twin comprises the engine specification data and the baseline performance data associated with the first engine.

6. The method of claim 1, further comprising: (n) repeating the steps (b)-(f) with the first engine being the selected engine such that the engine performance score calculated for the selected engine is a second engine performance score associated with the performance of the first engine; and (o) comparing, using the controller, the first engine performance score associated with the performance of the first engine and the second engine performance score associated with the performance of the first engine to detect a change in the performance of the first engine.

7. (canceled)

8. (canceled)

9. The method of claim 1, wherein the comparison of step (i) indicates that the performance of the first engine is greater than the performance of the second engine; and wherein the sequencing order of step (j) defines that the first generator will be brought online before the second generator.

10. The method of claim 9, wherein the performance of the first engine is the fuel efficiency of the first engine and the performance of the second engine is the fuel efficiency of the second engine; and wherein the sequencing order of step (j) is created such that the more fuel efficient engine of the first and second engines is ordered to be brought online first in order to reduce the amount of fuel used by the plurality of generators.

11. The method of claim 1, further comprising: (p) repeating the steps (b)-(f) with the first engine being the selected engine such that the engine performance score calculated for the selected engine is a second engine performance score associated with the performance of the first engine; (q) repeating the steps (b)-(f) with the second engine being the selected engine such that the engine performance score calculated for the selected engine is a second engine performance score associated with the performance of the second engine; (r) comparing, using the controller, the second engine performance score associated with the performance of the first engine and the second engine performance score associated with the performance of the second engine; and (s) updating, using the controller and based on the comparison of step (r), the sequencing order of step (j) defining the order in which the first generator and the second generator will be brought online to generate power.

12. The method of claim 11, wherein the comparison of step (r) indicates that the performance of the second engine is greater than the performance of the first engine; and wherein the updated sequencing order of step (s) defines that the second generator will be brought online before the first generator.

13. An energy storage module ("ESM") capable of testing engine performance of a plurality of generators and bringing the plurality of generators online, the ESM comprising: one or more batteries; and a controller configured to be operably coupled to the each of the plurality of generators, each generator of the plurality of generators comprising an engine and a plurality of engine sensors and each engine being associated with engine specification data and baseline performance data, the controller being configured to execute a performance test with respect to a selected engine of the plurality of generators by completing the following steps with respect to the selected engine: (a) accessing engine specification data and baseline performance data associated with a selected engine of one of the plurality of generators, wherein the selected engine is a first engine of a first generator of the plurality of generators; (b) initiating, using the one or more batteries, a load step on the selected engine, the load step being based on the engine specification data associated with the selected engine; (c) receiving, from a plurality of sensors associated with the selected engine, data associated with a response of the selected engine to the load step of step (b); (d) comparing the data of step (c) to the baseline performance data associated with the selected engine; (e) calculating, based on the comparison of step (d), an engine performance score associated with a performance of the selected engine, wherein the engine performance score calculated for the selected engine is a first engine performance score associated with a performance of the first engine; (f) storing the engine performance score of step (e) in a database associated with the controller (g) selecting a second engine of a second generator of the plurality of generators such

that the second engine is the selected engine; (h) executing steps (a)-(f) with the second engine being the selected engine such that the engine performance score calculated for the selected engine is a first engine performance score associated with a performance of the second engine; (i) comparing the first engine performance score associated with the performance of the first engine and the first engine performance score associated with the performance of the second engine; (j) creating, based on the comparison of step (i), a sequencing order defining the order in which the first generator and the second generator will be brought online to generate power; and (k) generating power by bringing online, using the controller, the first generator and the second generator based on the sequencing order.

14. (canceled)

15. The ESM of claim 13, wherein the controller completes the following additional steps with respect to the selected engine: (l) repeating the steps (b)-(f) with the first engine being the selected engine such that the engine performance score calculated for the selected engine is a second engine performance score associated with the performance of the first engine; and (m) comparing the first engine performance score associated with the performance of the first engine and the second engine performance score associated with the performance of the first engine to detect a change in the performance of the first engine.

16. (canceled)

17. (canceled)

18. The ESM of claim 13, wherein the comparison of step (i) indicates that the performance of the first engine is greater than the performance of the second engine; and wherein the sequencing order of step (j) defines that the first generator will be brought online before the second generator.

19. The ESM of claim 13, wherein step (a) further comprises accessing a digital twin associated with the selected engine; wherein the digital twin comprises the engine specification data and the baseline performance data associated with the selected engine; and wherein the digital twin is accessed from either a manufacturer database or the selected engine.

20. The ESM of claim 13, wherein the controller completes the following additional step with respect to the selected engine: (n) receiving, by the one or more batteries of the ESM, a power output from the selected engine, the power output being associated with the response of the selected engine to the first load.

21. A method for using an energy storage module ("ESM") in servicing at least one of a plurality of engines, the ESM comprising one or more batteries and a controller configured to be operably coupled to a plurality of generators, each generator of the plurality of generators comprising an engine of the plurality of engines, each engine of each respective generator being associated with a plurality of engine sensors, engine specification data, and baseline performance data, and the method comprising: (a) accessing, using the controller, engine specification data and baseline performance data associated with a selected engine of one of the plurality of generators, wherein the selected engine is a first engine of a first generator of the plurality of generators; (b) initiating, using the controller and the one or more batteries, a load step on the selected engine, the load step being based on the engine specification data associated with the selected engine; (c) receiving, by the controller and from a plurality of sensors associated with the selected engine, data associated with a response of the selected engine to the load step of step (b); (d) comparing, using the controller, the data of step (c) to the baseline performance data associated with the selected engine; (e) calculating, using the controller and based on the comparison of step (d), an engine performance score associated with a performance of the selected engine, wherein the engine performance score calculated for the selected engine is a first engine performance score associated with a performance of the first engine; (f) storing, using the controller, the engine performance score of step (e) in a database associated with the controller; (g) identifying, using the controller and based on the first engine performance score associated with the performance of the first engine, a future maintenance activity for the first engine; and (h) performing maintenance on the first engine based on the future

maintenance activity identified in step (g).

22. The method of claim 21, further comprising: (i) predicting, using the controller and based on the first engine performance score, a service life of the first engine.

23. The method of claim 21, wherein step (a) further comprises accessing a digital twin associated with the first engine; and wherein the digital twin comprises the engine specification data and the baseline performance data associated with the first engine.

24. The method of claim 21, further comprising: (j) repeating the steps (b)-(f) with the first engine being the selected engine and after the maintenance has been performed on the first engine such that the engine performance score calculated for the selected engine is a second engine performance score associated with the performance of the first engine; and (k) comparing the first engine performance score associated with the performance of the first engine and the second engine performance score associated with the performance of the first engine to detect a change in the performance of the first engine after the maintenance has been performed on the first engine.

25. The method of claim 21, further comprising: (l) selecting, using the controller, a second engine of a second generator of the plurality of generators such that the second engine is the selected engine; (m) executing steps (a)-(f) with the second engine being the selected engine such that the engine performance score calculated for the selected engine is a first engine performance score associated with a performance of the second engine; (n) identifying, using the controller and based on the first engine performance score associated with the performance of the second engine, a future maintenance activity for the second engine; and (o) performing maintenance on the second engine based on the future maintenance activity identified in step (n).

26. The method of claim 25, further comprising: (p) comparing the first engine performance score associated with the performance of the first engine and the first engine performance score associated with the performance of the second engine; (q) creating, based on the comparison of step (p), a sequencing order defining the order in which the first generator and the second generator will be brought online to generate power; and (r) generating power by bringing online, using the controller, the first generator and the second generator based on the sequencing order.