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(54) **Title:** ELECTRICAL POWER SYSTEM MODELING, DESIGN, ANALYSIS, AND REPORTING VIA A CLIENT-SERVER APPLICATION FRAMEWORK

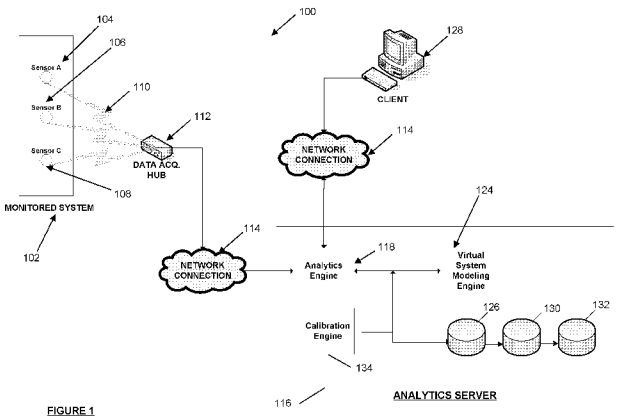


FIGURE 1

(57) **Abstract:** A system for an intelligent web-based monitoring and management of an electrical system is disclosed. The system comprises a data acquisition component communicatively connected to a sensor configured to acquire real-time data output from the electrical system; a web application server communicatively connected to the data acquisition component, the web application server configured to transmit a user interface to a client terminal, the web application server comprising: a virtual system model database communicatively connected to the data acquisition component, the virtual system model database configured to store a virtual system model of the electrical system, a power analytic simulation engine comprising a virtual system modeling engine, communicatively configured to generate a predicted data output for the electrical system utilizing the virtual system model of the electrical system, is connected to the virtual system model database, and an analytics engine communicatively connected to the virtual system model database.

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SPECIFICATION

ELECTRICAL POWER SYSTEM MODELING, DESIGN, ANALYSIS, AND REPORTING VIA A CLIENT-SERVER APPLICATION FRAMEWORK

BACKGROUND

1. Technical Field

[0001] The present invention relates generally to computer modeling and management of systems and, more particularly, to a Client-Server Application Framework for energy management systems for monitoring and managing the cost, quality, reliability of an electrical power system.

2. Related Art

[0002] Computer models of complex systems enable improved system design, development, and implementation through techniques for off-line simulation of system operation. That is, system models can be created on computers and then "operated" in a virtual environment to assist in the determination of system design parameters. All manner of systems can be modeled, designed, and operated in this way, including machinery, factories, electrical power and distribution systems, processing plants, devices, chemical processes, biological systems, and the like. Such simulation techniques have resulted in reduced development costs and superior operation.

[0003] Design and production processes have benefited greatly from such computer simulation techniques, and such techniques are relatively well developed, but they have not been applied in real-time, e.g., for real-time operational monitoring and management. In addition, predictive failure analysis techniques do not generally use real-time data that reflect

actual system operation. Greater efforts at real-time operational monitoring and management would provide more accurate and timely suggestions for operational decisions, and such techniques applied to failure analysis would provide improved predictions of system problems before they occur.

[0004] That is, an electrical network model that can age and synchronize itself in real-time with the actual facility's operating conditions is critical to obtaining predictions that are reflective of the system's reliability, availability, health and performance in relation to the life cycle of the system. Static systems simply cannot adjust to the many daily changes to the electrical system that occur at a facility (e.g., motors and pumps switching on or off, changes to on-site generation status, changes to utility electrical feed…etc.) nor can they age with the facility to accurately predict the required indices. Without a synchronization or aging ability, reliability indices and predictions are of little value as they are not reflective of the actual operational status of the facility and may lead to false conclusions. With such improved techniques, operational costs and risks can be greatly reduced.

[0005] For example, mission critical electrical systems, e.g., for data centers or nuclear power facilities, must be designed to ensure that power is always available. Thus, the systems must be as failure proof as possible, and many layers of redundancy must be designed in to ensure that there is always a backup in case of a failure. It will be understood that such systems are highly complex, a complexity made even greater as a result of the required redundancy. Computer design and modeling programs allow for the design of such systems by allowing a designer to model the system and simulate its operation. Thus, the designer can ensure that the system will operate as intended before the facility is constructed.

[0006] As with all analytical tools, predictive or otherwise, the manner in which data and results are communicated to the user is often as important as the choice of analytical tool itself. Ideally, the data and results are communicated in a fashion that is simple to understand while also painting a comprehensive and accurate picture for the user. For example, graphical displays (e.g., two-dimensional and three-dimensional views) of the operational aspects of an electrical system greatly enhances the ability of a system operator, owner and/or executive to understand the health and predicted performance of the electrical system.

[0007] Moreover, the unremitting rise in the costs of generating and/or procuring energy necessitates pro-actively and intelligently managing energy through technological solutions that allow energy to be treated as a business critical commodity that can be managed in real-time while also extending the tools that electrical system/network owners and operators need to observe, comprehend and manage the cost, quality and reliability of energy.

[0008] Currently, no solution exists that provide a facility owner, administrator and/or operator with an instant view of the real-time, predicted and/or historical energy consumption profile of an electrical system, the cost of energy, the cost of losses and the cost of running the electrical system inefficiently.

[0009] Furthermore, current simulation technologies are PC or thick client applications that require the installation and management of desktop software in order to operate. Currently, no existing solutions take advantage of the next generation Web. 2.0 workplace and they fail to deliver a set of rich power system design, analysis Internet applications (RIAs) to substantially improve the way power system engineers create and access content, complete sizing and calculations, and produce reports.

SUMMARY

[0010] Systems and methods for a client/server application framework that can provide intelligent monitoring and management of an electrical system are disclosed.

[0011] According to one aspect, a system for intelligent web-based management of an electrical system, can comprise a data acquisition component communicatively connected to a sensor configured to acquire real-time data output from the electrical system; a web application server communicatively connected to the data acquisition component, the web application server configured to transmit a user interface to a client terminal, the web application server comprising: a virtual system model database communicatively connected to the data acquisition component, the virtual system model database configured to store a virtual system model of the electrical system, a power analytic simulation engine comprising a virtual system modeling engine communicatively connected to the virtual system model database, the virtual system modeling engine configured to generate a predicted data output for the electrical system utilizing the virtual system model of the electrical system, and an analytics engine communicatively connected to the virtual system model database, the analytics engine configured to monitor the real-time data output and the predicted data output of the electrical system, and to initiate a calibration and synchronization operation to update the virtual system model when a difference between the real-time data output and the predicted data output exceeds a threshold, and a client terminal communicatively connected to the web application server, the client terminal configured to display the user interface.

[0012] According to another aspect, a method for interacting with an electrical system management application to perform power analytic analysis simulations on a virtual system model of the electrical power system, can comprise: a web application server, receiving a

user request to access the electrical management system from a client terminal, and sending a user interface for interaction with the electrical management system to a client terminal; the client terminal, receiving the user interface for interaction with the electrical management system, and sending user interaction data to the electrical system management application; and, the electrical system management application, performing analytic analysis on a virtual system model of the electrical power system.

[0013] These and other features, aspects, and embodiments are described below in the section entitled "Detailed Description."

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Features, aspects, and embodiments are described in conjunction with the attached drawings, in which:

[0015] For a more complete understanding of the principles disclosed herein, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

[0016] Figure 1 is an illustration of a system for utilizing real-time data for predictive analysis of the performance of a monitored system, in accordance with one embodiment.

[0017] Figure 2 is a diagram illustrating a detailed view of an analytics server included in the system of figure 1, in accordance with one embodiment.

[0018] Figure 3 is a diagram illustrating how the system of figure 1 operates to synchronize the operating parameters between a physical facility and a virtual system model of the facility, in accordance with one embodiment.

[0019] Figure 4 is an illustration of the scalability of a system for utilizing real-time data for predictive analysis of the performance of a monitored system, in accordance with one embodiment.

[0020] Figure 5 is a block diagram that shows the configuration details of the system illustrated in Figure 1, in accordance with one embodiment.

[0021] Figure 6 is an illustration of a flowchart describing a method for real-time monitoring and predictive analysis of a monitored system, in accordance with one embodiment.

[0022] Figure 7 is an illustration of a flowchart describing a method for managing real-time updates to a virtual system model of a monitored system, in accordance with one embodiment.

[0023] Figure 8 is an illustration of a flowchart describing a method for synchronizing real-time system data with a virtual system model of a monitored system, in accordance with one embodiment.

[0024] Figure 9 is a flow chart illustrating an example method for updating the virtual model, in accordance with one embodiment.

[0025] Figure 10 is a diagram illustrating an example process for monitoring the status of protective devices in a monitored system and updating a virtual model based on monitored data, in accordance with one embodiment.

[0026] Figure 11 is a flowchart illustrating an example process for determining the protective capabilities of the protective devices being monitored, in accordance with one embodiment.

[0027] Figure 12 is a diagram illustrating an example process for determining the protective capabilities of a High Voltage Circuit Breaker (HVCB), in accordance with one embodiment.

[0028] Figure 13 is a flowchart illustrating an example process for determining the protective capabilities of the protective devices being monitored, in accordance with another embodiment.

[0029] Figure 14 is a diagram illustrating a process for evaluating the withstand capabilities of a MVCB, in accordance with one embodiment

[0030] Figure 15 is a flow chart illustrating an example process for analyzing the reliability of an electrical power distribution and transmission system, in accordance with one embodiment.

[0031] Figure 16 is a flow chart illustrating an example process for analyzing the reliability of an electrical power distribution and transmission system that takes weather information into account, in accordance with one embodiment.

[0032] Figure 17 is a diagram illustrating an example process for predicting in real-time various parameters associated with an alternating current (AC) arc flash incident, in accordance with one embodiment.

[0033] Figure 18 is a flow chart illustrating an example process for real-time analysis of the operational stability of an electrical power distribution and transmission system, in accordance with one embodiment.

[0034] Figure 19 is a flow chart illustrating an example process for conducting a real-time power capacity assessment of an electrical power distribution and transmission system, in accordance with one embodiment.

[0035] Figure 20 is a flow chart illustrating an example process for performing real-time harmonics analysis of an electrical power distribution and transmission system, in accordance with one embodiment.

[0036] Figure 21 is a diagram illustrating how the HTM Pattern Recognition and Machine Learning Engine works in conjunction with the other elements of the analytics system to make predictions about the operational aspects of a monitored system, in accordance with one embodiment.

[0037] Figure 22 is an illustration of the various cognitive layers that comprise the neocortical catalyst process used by the HTM Pattern Recognition and Machine Learning Engine to analyze and make predictions about the operational aspects of a monitored system, in accordance with one embodiment.

[0038] Figure 23 is an example process for real-time three-dimensional (3D) visualization of the health, reliability, and performance of an electrical system, in accordance with one embodiment.

[0039] Figure 24 is a diagram illustrating how the 3D Visualization Engine works in conjunction with the other elements of the analytics system to provide 3D visualization of the health, reliability, and performance of an electrical system, in accordance with one embodiment.

[0040] Figure 25 provides a client terminal screenshot of some 2D and 3D model views that are generated by the power analytics server, in accordance with one embodiment.

[0041] Figure 26 is a diagram illustrating how the Schematic Interface Creator Engine works in conjunction with the other elements of the analytics system to automatically

generate a schematic user interface for visualizing the health, reliability, and performance of an electrical system, in accordance with one embodiment.

[0042] Figure 27 is an example process for automatically generating a schematic user interface for visualizing the health, reliability, and performance of an electrical system, in accordance with one embodiment.

[0043] Figure 28 is a diagram illustrating how the Energy Management System Engine works in conjunction with the other elements of the analytics system to intelligently monitor and manage the cost, quality and reliability of energy generated and/or utilized by an electrical system, in accordance with one embodiment.

[0044] Figure 29 is a logic flow diagram depicting how the various elements of the Energy Management System can interact to provide intelligent energy monitoring and management of an electrical system, in accordance with one embodiment.

[0045] Figure 30 is a diagram illustrating how the various elements of the Client/Server system can interact to provide intelligent energy monitoring and management of an electrical system, in accordance with one embodiment.

[0046] Figure 31 is a diagram illustrating various elements of the web application server illustrated in Figure 30, in accordance with one embodiment.

[0047] Figure 32 is a logic flow diagram depicting how the various elements of the Client/Server system can interact to provide intelligent energy monitoring and management of an electrical system, in accordance with one embodiment.

DETAILED DESCRIPTION

[0048] Systems and methods for a client/server application framework that can provide intelligent monitoring and management of an electrical system are disclosed. It will be clear, however, that the present invention may be practiced without some or all of these specific details. In other instances, well known process operations have not been described in detail in order not to unnecessarily obscure the present invention.

[0049] As used herein, a system denotes a set of components, real or abstract, comprising a whole where each component interacts with or is related to at least one other component within the whole. Examples of systems include machinery, factories, electrical systems, processing plants, devices, chemical processes, biological systems, data centers, aircraft carriers, and the like. An electrical system can designate a power generation and/or distribution system that is widely dispersed (i.e., power generation, transformers, and/or electrical distribution components distributed geographically throughout a large region) or bounded within a particular location (e.g., a power plant within a production facility, a bounded geographic area, on board a ship, a factory, a data center, etc.).

[0050] A network application is any application that is stored on an application server connected to a network (e.g., local area network, wide area network, etc.) in accordance with any contemporary client/server architecture model and can be accessed via the network. In this arrangement, the network application programming interface (API) resides on the application server separate from the client machine. The client interface would typically be a web browser (e.g. INTERNET EXPLORER™, FIREFOX™, NETSCAPE™, etc) that is in communication with the network application server via a network connection (e.g., HTTP, HTTPS, RSS, etc.).

[0051] Figure 1 is an illustration of a system for utilizing real-time data for predictive analysis of the performance of a monitored system, in accordance with one embodiment. As shown herein, the system 100 includes a series of sensors (i.e., Sensor A 104, Sensor B 106, Sensor C 108) interfaced with the various components of a monitored system 102, a data acquisition hub 112, an analytics server 116, and a thin-client device 128. In one embodiment, the monitored system 102 is an electrical power generation plant. In another embodiment, the monitored system 102 is an electrical power transmission infrastructure. In still another embodiment, the monitored system 102 is an electrical power distribution system. In still another embodiment, the monitored system 102 includes a combination of one or more electrical power generation plant(s), power transmission infrastructure(s), and/or an electrical power distribution system. It should be understood that the monitored system 102 can be any combination of components whose operations can be monitored with conventional sensors and where each component interacts with or is related to at least one other component within the combination. For a monitored system 102 that is an electrical power generation, transmission, or distribution system, the sensors can provide data such as voltage, frequency, current, power, power factor, and the like.

[0052] The sensors are configured to provide output values for system parameters that indicate the operational status and/or "health" of the monitored system 102. For example, in an electrical power generation system, the current output or voltage readings for the various components that comprise the power generation system is indicative of the overall health and/or operational condition of the system. In one embodiment, the sensors are configured to also measure additional data that can affect system operation. For example, for an electrical power distribution system, the sensor output can include environmental

information, e.g., temperature, humidity, etc., which can impact electrical power demand and can also affect the operation and efficiency of the power distribution system itself.

[0053] Continuing with Figure 1, in one embodiment, the sensors are configured to output data in an analog format. For example, electrical power sensor measurements (e.g., voltage, current, etc.) are sometimes conveyed in an analog format as the measurements may be continuous in both time and amplitude. In another embodiment, the sensors are configured to output data in a digital format. For example, the same electrical power sensor measurements may be taken in discrete time increments that are not continuous in time or amplitude. In still another embodiment, the sensors are configured to output data in either an analog or digital format depending on the sampling requirements of the monitored system 102.

[0054] The sensors can be configured to capture output data at split-second intervals to effectuate "real time" data capture. For example, in one embodiment, the sensors can be configured to generate hundreds of thousands of data readings per second. It should be appreciated, however, that the number of data output readings taken by a sensor may be set to any value as long as the operational limits of the sensor and the data processing capabilities of the data acquisition hub 112 are not exceeded.

[0055] Still with Figure 1, each sensor is communicatively connected to the data acquisition hub 112 via an analog or digital data connection 110. The data acquisition hub 112 may be a standalone unit or integrated within the analytics server 116 and can be embodied as a piece of hardware, software, or some combination thereof. In one embodiment, the data connection 110 is a "hard wired" physical data connection (e.g., serial, network, etc.). For example, a serial or parallel cable connection between the sensor and the

hub 112. In another embodiment, the data connection 110 is a wireless data connection. For example, a radio frequency (RF), BLUETOOTH™, infrared or equivalent connection between the sensor and the hub 112.

[0056] The data acquisition hub 112 is configured to communicate "real-time" data from the monitored system 102 to the analytics server 116 using a network connection 114. In one embodiment, the network connection 114 is a "hardwired" physical connection. For example, the data acquisition hub 112 may be communicatively connected (via Category 5 (CAT5), fiber optic or equivalent cabling) to a data server (not shown) that is communicatively connected (via CAT5, fiber optic or equivalent cabling) through the Internet and to the analytics server 116 server. The analytics server 116 being also communicatively connected with the Internet (via CAT5, fiber optic, or equivalent cabling). In another embodiment, the network connection 114 is a wireless network connection (e.g., Wi-Fi, WLAN, etc.). For example, utilizing an 802.11b/g or equivalent transmission format. In practice, the network connection utilized is dependent upon the particular requirements of the monitored system 102.

[0057] Data acquisition hub 112 can also be configured to supply warning and alarms signals as well as control signals to monitored system 102 and/or sensors 104, 106, and 108 as described in more detail below.

[0058] As shown in Figure1, in one embodiment, the analytics server 116 hosts an analytics engine 118, virtual system modeling engine 124 and several databases 126, 130, and 132. The virtual system modeling engine can, e.g., be a computer modeling system, such as described above. In this context, however, the modeling engine can be used to precisely model and mirror the actual electrical system. Analytics engine 118 can be configured to

generate predicted data for the monitored system and analyze difference between the predicted data and the real-time data received from hub 112.

[0059] Figure 2 is a diagram illustrating a more detailed view of analytic server 116. As can be seen, analytic server 116 is interfaced with a monitored facility 102 via sensors 202, e.g., sensors 104, 106, and 108. Sensors 202 are configured to supply real-time data from within monitored facility 102. The real-time data is communicated to analytic server 116 via a hub 204. Hub 204 can be configure to provide real-time data to server 116 as well as alarming, sensing and control featured for facility 102.

[0060] The real-time data from hub 204 can be passed to a comparison engine 210, which can form part of analytics engine 118. Comparison engine 210 can be configured to continuously compare the real-time data with predicted values generated by simulation engine 208. Based on the comparison, comparison engine 210 can be further configured to determine whether deviations between the real-time and the expected values exists, and if so to classify the deviation, e.g., high, marginal, low, etc. The deviation level can then be communicated to decision engine 212, which can also comprise part of analytics engine 118.

[0061] Decision engine 212 can be configured to look for significant deviations between the predicted values and real-time values as received from the comparison engine 210. If significant deviations are detected, decision engine 212 can also be configured to determine whether an alarm condition exists, activate the alarm and communicate the alarm to Human-Machine Interface (HMI) 214 for display in real-time via, e.g., thin client 128. Decision engine 212 can also be configured to perform root cause analysis for significant deviations in order to determine the interdependencies and identify the parent-child failure relationships that may be occurring. In this manner, parent alarm conditions are not drowned

out by multiple children alarm conditions, allowing the user/operator to focus on the main problem, at least at first.

[0062] Thus, in one embodiment, and alarm condition for the parent can be displayed via HMI 214 along with an indication that processes and equipment dependent on the parent process or equipment are also in alarm condition. This also means that server 116 can maintain a parent-child logical relationship between processes and equipment comprising facility 102. Further, the processes can be classified as critical, essential, non-essential, etc.

[0063] Decision engine 212 can also be configured to determine health and performance levels and indicate these levels for the various processes and equipment via HMI 214. All of which, when combined with the analytic capabilities of analytics engine 118 allows the operator to minimize the risk of catastrophic equipment failure by predicting future failures and providing prompt, informative information concerning potential/predicted failures before they occur. Avoiding catastrophic failures reduces risk and cost, and maximizes facility performance and up time.

[0064] Simulation engine 208 operates on complex logical models 206 of facility 102. These models are continuously and automatically synchronized with the actual facility status based on the real-time data provided by hub 204. In other words, the models are updated based on current switch status, breaker status, e.g., open-closed, equipment on/off status, etc. Thus, the models are automatically updated based on such status, which allows simulation engine to produce predicted data based on the current facility status. This in turn, allows accurate and meaningful comparisons of the real-time data to the predicted data.

[0065] Example models 206 that can be maintained and used by server 116 include power flow models used to calculate expected kW, kVAR, power factor values, etc., short

circuit models used to calculate maximum and minimum available fault currents, protection models used to determine proper protection schemes and ensure selective coordination of protective devices, power quality models used to determine voltage and current distortions at any point in the network, to name just a few. It will be understood that different models can be used depending on the system being modeled.

[0066] In certain embodiments, hub 204 is configured to supply equipment identification associated with the real-time data. This identification can be cross referenced with identifications provided in the models.

[0067] In one embodiment, if the comparison performed by comparison engine 210 indicates that the differential between the real-time sensor output value and the expected value exceeds a Defined Difference Tolerance (DDT) value (i.e., the "real-time" output values of the sensor output do not indicate an alarm condition) but below an alarm condition (i.e., alarm threshold value), a calibration request is generated by the analytics engine 118. If the differential exceeds, the alarm condition, an alarm or notification message is generated by the analytics engine 118. If the differential is below the DTT value, the analytics engine does nothing and continues to monitor the real-time data and expected data.

[0068] In one embodiment, the alarm or notification message is sent directly to the client (i.e., user) 128, e.g., via HMI 214, for display in real-time on a web browser, pop-up message box, e-mail, or equivalent on the client 128 display panel. In another embodiment, the alarm or notification message is sent to a wireless mobile device (e.g., BLACKBERRY™, laptop, pager, etc.) to be displayed for the user by way of a wireless router or equivalent device interfaced with the analytics server 116. In still another embodiment, the alarm or notification message is sent to both the client 128 display and the

wireless mobile device. The alarm can be indicative of a need for a repair event or maintenance to be done on the monitored system. It should be noted, however, that calibration requests should not be allowed if an alarm condition exists to prevent the models form being calibrated to an abnormal state.

[0069] Once the calibration is generated by the analytics engine 118, the various operating parameters or conditions of model(s) 206 can be updated or adjusted to reflect the actual facility configuration. This can include, but is not limited to, modifying the predicted data output from the simulation engine 208, adjusting the logic/processing parameters utilized by the model(s) 206, adding/subtracting functional elements from model(s) 206, etc. It should be understood, that any operational parameter of models 206 can be modified as long as the resulting modifications can be processed and registered by simulation engine 208.

[0070] Referring back to figure 1, models 206 can be stored in the virtual system model database 126. As noted, a variety of conventional virtual model applications can be used for creating a virtual system model, so that a wide variety of systems and system parameters can be modeled. For example, in the context of an electrical power distribution system, the virtual system model can include components for modeling reliability, voltage stability, and power flow. In addition, models 206 can include dynamic control logic that permits a user to configure the models 206 by specifying control algorithms and logic blocks in addition to combinations and interconnections of generators, governors, relays, breakers, transmission line, and the like. The voltage stability parameters can indicate capacity in terms of size, supply, and distribution, and can indicate availability in terms of remaining capacity of the presently configured system. The power flow model can specify voltage, frequency, and power factor, thus representing the "health" of the system.

[0071] All of models 206 can be referred to as a virtual system model. Thus, virtual system model database can be configured to store the virtual system model. A duplicate, but synchronized copy of the virtual system model can be stored in a virtual simulation model database 130. This duplicate model can be used for what-if simulations. In other words, this model can be used to allow a system designer to make hypothetical changes to the facility and test the resulting effect, without taking down the facility or costly and time consuming analysis. Such hypothetical can be used to learn failure patterns and signatures as well as to test proposed modifications, upgrades, additions, etc., for the facility. The real-time data, as well as trending produced by analytics engine 118 can be stored in a real-time data acquisition database 132.

[0072] As discussed above, the virtual system model is periodically calibrated and synchronized with "real-time" sensor data outputs so that the virtual system model provides data output values that are consistent with the actual "real-time" values received from the sensor output signals. Unlike conventional systems that use virtual system models primarily for system design and implementation purposes (i.e., offline simulation and facility planning), the virtual system models described herein are updated and calibrated with the real-time system operational data to provide better predictive output values. A divergence between the real-time sensor output values and the predicted output values generate either an alarm condition for the values in question and/or a calibration request that is sent to the calibration engine 134.

[0073] Continuing with Figure 1, the analytics engine 118 can be configured to implement pattern/sequence recognition into a real-time decision loop that, e.g., is enabled by a new type of machine learning called associative memory, or hierarchical temporal memory

(HTM), which is a biological approach to learning and pattern recognition. Associative memory allows storage, discovery, and retrieval of learned associations between extremely large numbers of attributes in real time. At a basic level, an associative memory stores information about how attributes and their respective features occur together. The predictive power of the associative memory technology comes from its ability to interpret and analyze these co-occurrences and to produce various metrics. Associative memory is built through "experiential" learning in which each newly observed state is accumulated in the associative memory as a basis for interpreting future events. Thus, by observing normal system operation over time, and the normal predicted system operation over time, the associative memory is able to learn normal patterns as a basis for identifying non-normal behavior and appropriate responses, and to associate patterns with particular outcomes, contexts or responses. The analytics engine 118 is also better able to understand component mean time to failure rates through observation and system availability characteristics. This technology in combination with the virtual system model can be characterized as a "neocortical" model of the system under management.

[0074] This approach also presents a novel way to digest and comprehend alarms in a manageable and coherent way. The neocortical model could assist in uncovering the patterns and sequencing of alarms to help pinpoint the location of the (impending) failure, its context, and even the cause. Typically, responding to the alarms is done manually by experts who have gained familiarity with the system through years of experience. However, at times, the amount of information is so great that an individual cannot respond fast enough or does not have the necessary expertise. An "intelligent" system like the neocortical system that

observes and recommends possible responses could improve the alarm management process by either supporting the existing operator, or even managing the system autonomously.

[0075] Current simulation approaches for maintaining transient stability involve traditional numerical techniques and typically do not test all possible scenarios. The problem is further complicated as the numbers of components and pathways increase. Through the application of the neocortical model, by observing simulations of circuits, and by comparing them to actual system responses, it may be possible to improve the simulation process, thereby improving the overall design of future circuits.

[0076] The virtual system model database 126, as well as databases 130 and 132, can be configured to store one or more virtual system models, virtual simulation models, and real-time data values, each customized to a particular system being monitored by the analytics server 118. Thus, the analytics server 118 can be utilized to monitor more than one system at a time. As depicted herein, the databases 126, 130, and 132 can be hosted on the analytics server 116 and communicatively interfaced with the analytics engine 118. In other embodiments, databases 126, 130, and 132 can be hosted on a separate database server (not shown) that is communicatively connected to the analytics server 116 in a manner that allows the virtual system modeling engine 124 and analytics engine 118 to access the databases as needed.

[0077] Therefore, in one embodiment, the client 128 can modify the virtual system model stored on the virtual system model database 126 by using a virtual system model development interface using well-known modeling tools that are separate from the other network interfaces. For example, dedicated software applications that run in conjunction

with the network interface to allow a client 128 to create or modify the virtual system models.

[0078] The client 128 may utilize a variety of network interfaces (e.g., web browser, CITRIX™, WINDOWS TERMINAL SERVICES™, telnet, or other equivalent thin-client terminal applications, etc.) to access, configure, and modify the sensors (e.g., configuration files, etc.), analytics engine 118 (e.g., configuration files, analytics logic, etc.), calibration parameters (e.g., configuration files, calibration parameters, etc.), virtual system modeling engine 124 (e.g., configuration files, simulation parameters, etc.) and virtual system model of the system under management (e.g., virtual system model operating parameters and configuration files). Correspondingly, data from those various components of the monitored system 102 can be displayed on a client 128 display panel for viewing by a system administrator or equivalent.

[0079] As described above, server 116 is configured to synchronize the physical world with the virtual and report, e.g., via visual, real-time display, deviations between the two as well as system health, alarm conditions, predicted failures, etc. This is illustrated with the aid of figure 3, in which the synchronization of the physical world (left side) and virtual world (right side) is illustrated. In the physical world, sensors 202 produce real-time data 302 for the processes 312 and equipment 314 that make up facility 102. In the virtual world, simulations 304 of the virtual system model 206 provide predicted values 306, which are correlated and synchronized with the real-time data 302. The real-time data can then be compared to the predicted values so that differences 308 can be detected. The significance of these differences can be determined to determine the health status 310 of the system. The

health stats can then be communicated to the processes 312 and equipment 314, e.g., via alarms and indicators, as well as to thin client 128, e.g., via web pages 316.

[0080] Figure 4 is an illustration of the scalability of a system for utilizing real-time data for predictive analysis of the performance of a monitored system, in accordance with one embodiment. As depicted herein, an analytics central server 422 is communicatively connected with analytics server A 414, analytics server B 416, and analytics server *n* 418 (i.e., one or more other analytics servers) by way of one or more network connections 114. Each of the analytics servers is communicatively connected with a respective data acquisition hub (i.e., Hub A 408, Hub B 410, Hub *n* 412) that communicates with one or more sensors that are interfaced with a system (i.e., Monitored System A 402, Monitored System B 404, Monitored System *n* 406) that the respective analytical server monitors. For example, analytics server A 414 is communicative connected with data acquisition hub A 408, which communicates with one or more sensors interfaced with monitored system A 402.

[0081] Each analytics server (i.e., analytics server A 414, analytics server B 416, analytics server *n* 418) is configured to monitor the sensor output data of its corresponding monitored system and feed that data to the central analytics server 422. Additionally, each of the analytics servers can function as a proxy agent of the central analytics server 422 during the modifying and/or adjusting of the operating parameters of the system sensors they monitor. For example, analytics server B 416 is configured to be utilized as a proxy to modify the operating parameters of the sensors interfaced with monitored system B 404.

[0082] Moreover, the central analytics server 422, which is communicatively connected to one or more analytics server(s) can be used to enhance the scalability. For example, a central analytics server 422 can be used to monitor multiple electrical power

generation facilities (i.e., monitored system A 402 can be a power generation facility located in city A while monitored system B 404 is a power generation facility located in city B) on an electrical power grid. In this example, the number of electrical power generation facilities that can be monitored by central analytics server 422 is limited only by the data processing capacity of the central analytics server 422. The central analytics server 422 can be configured to enable a client 128 to modify and adjust the operational parameters of any the analytics servers communicatively connected to the central analytics server 422. Furthermore, as discussed above, each of the analytics servers are configured to serve as proxies for the central analytics server 422 to enable a client 128 to modify and/or adjust the operating parameters of the sensors interfaced with the systems that they respectively monitor. For example, the client 128 can use the central analytics server 422, and vice versa, to modify and/or adjust the operating parameters of analytics server A 414 and utilize the same to modify and/or adjust the operating parameters of the sensors interfaced with monitored system A 402. Additionally, each of the analytics servers can be configured to allow a client 128 to modify the virtual system model through a virtual system model development interface using well-known modeling tools.

[0083] In one embodiment, the central analytics server 422 can function to monitor and control a monitored system when its corresponding analytics server is out of operation. For example, central analytics server 422 can take over the functionality of analytics server B 416 when the server 416 is out of operation. That is, the central analytics server 422 can monitor the data output from monitored system B 404 and modify and/or adjust the operating parameters of the sensors that are interfaced with the system 404.

[0084] In one embodiment, the network connection 114 is established through a wide area network (WAN) such as the Internet. In another embodiment, the network connection is established through a local area network (LAN) such as the company intranet. In a separate embodiment, the network connection 114 is a "hardwired" physical connection. For example, the data acquisition hub 112 may be communicatively connected (via Category 5 (CAT5), fiber optic or equivalent cabling) to a data server that is communicatively connected (via CAT5, fiber optic or equivalent cabling) through the Internet and to the analytics server 116 server hosting the analytics engine 118. In another embodiment, the network connection 114 is a wireless network connection (e.g., Wi-Fi, WLAN, etc.). For example, utilizing an 802.11b/g or equivalent transmission format.

[0085] In certain embodiments, regional analytics servers can be placed between local analytics servers 414, 416, . . ., 418 and central analytics server 422. Further, in certain embodiments a disaster recovery site can be included at the central analytics server 422 level.

[0086] Figure 5 is a block diagram that shows the configuration details of analytics server 116 illustrated in Figure 1 in more detail. It should be understood that the configuration details in Figure 5 are merely one embodiment of the items described for Figure 1, and it should be understood that alternate configurations and arrangements of components could also provide the functionality described herein.

[0087] The analytics server 116 includes a variety of components. In the Figure 5 embodiment, the analytics server 116 is implemented in a Web-based configuration, so that the analytics server 116 includes (or communicates with) a secure web server 530 for communication with the sensor systems 519 (e.g., data acquisition units, metering devices, sensors, etc.) and external communication entities 534 (e.g., web browser, "thin client"

applications, etc.). A variety of user views and functions 532 are available to the client 128 such as: alarm reports, Active X controls, equipment views, view editor tool, custom user interface page, and XML parser. It should be appreciated, however, that these are just examples of a few in a long list of views and functions 532 that the analytics server 116 can deliver to the external communications entities 534 and are not meant to limit the types of views and functions 532 available to the analytics server 116 in any way.

[0088] The analytics server 116 also includes an alarm engine 506 and messaging engine 504, for the aforementioned external communications. The alarm engine 506 is configured to work in conjunction with the messaging engine 504 to generate alarm or notification messages 502 (in the form of text messages, e-mails, paging, etc.) in response to the alarm conditions previously described. The analytics server 116 determines alarm conditions based on output data it receives from the various sensor systems 519 through a communications connection (e.g., wireless 516, TCP/IP 518, Serial 520, etc) and simulated output data from a virtual system model 512, of the monitored system, processed by the analytics engines 118. In one embodiment, the virtual system model 512 is created by a user through interacting with an external communication entity 534 by specifying the components that comprise the monitored system and by specifying relationships between the components of the monitored system. In another embodiment, the virtual system model 512 is automatically generated by the analytics engines 118 as components of the monitored system are brought online and interfaced with the analytics server 508.

[0089] Continuing with Figure 5, a virtual system model database 526 is communicatively connected with the analytics server 116 and is configured to store one or more virtual system models 512, each of which represents a particular monitored system.

For example, the analytics server 116 can conceivably monitor multiple electrical power generation systems (e.g., system A, system B, system C, etc.) spread across a wide geographic area (e.g., City A, City B, City C, etc.). Therefore, the analytics server 116 will utilize a different virtual system model 512 for each of the electrical power generation systems that it monitors. Virtual simulation model database 538 can be configured to store a synchronized, duplicate copy of the virtual system model 512, and real-time data acquisition database 540 can store the real-time and trending data for the system(s) being monitored.

[0090] Thus, in operation, analytics server 116 can receive real-time data for various sensors, i.e., components, through data acquisition system 202. As can be seen, analytics server 116 can comprise various drivers configured to interface with the various types of sensors, etc., comprising data acquisition system 202. This data represents the real-time operational data for the various components. For example, the data may indicate that a certain component is operating at a certain voltage level and drawing certain amount of current. This information can then be fed to a modeling engine to generate a virtual system model 612 that is based on the actual real-time operational data.

[0091] Analytics engine 118 can be configured to compare predicted data based on the virtual system model 512 with real-time data received from data acquisition system 202 and to identify any differences. In some instances, analytics engine can be configured to identify these differences and then update, i.e., calibrate, the virtual system model 512 for use in future comparisons. In this manner, more accurate comparisons and warnings can be generated.

[0092] But in other instances, the differences will indicate a failure, or the potential for a failure. For example, when a component begins to fail, the operating parameters will

begin to change. This change may be sudden or it may be a progressive change over time. Analytics engine 118 can detect such changes and issue warnings that can allow the changes to be detected before a failure occurs. The analytic engine 118 can be configured to generate warnings that can be communicated via interface 532.

[0093] For example, a user can access information from server 116 using thin client 534. For example, reports can be generate and served to thin client 534 via server 540. These reports can, for example, comprise schematic or symbolic illustrations of the system being monitored. Status information for each component can be illustrated or communicated for each component. This information can be numerical, i.e., the voltage or current level. Or it can be symbolic, i.e., green for normal, red for failure or warning. In certain embodiments, intermediate levels of failure can also be communicated, i.e., yellow can be used to indicate operational conditions that project the potential for future failure. It should be noted that this information can be accessed in real-time. Moreover, via thin client 534, the information can be accessed form anywhere and anytime.

[0094] Continuing with Figure 5, the Analytics Engine 118 is communicatively interfaced with a HTM Pattern Recognition and Machine Learning Engine 551. The HTM Engine 551 is configured to work in conjunction with the Analytics Engine 118 and a virtual system model of the monitored system to make real-time predictions (i.e., forecasts) about various operational aspects of the monitored system. The HTM Engine 551 works by processing and storing patterns observed during the normal operation of the monitored system over time. These observations are provided in the form of real-time data captured using a multitude of sensors that are imbedded within the monitored system. In one embodiment, the virtual system model is also updated with the real-time data such that the

virtual system model "ages" along with the monitored system. Examples of a monitored system includes machinery, factories, electrical systems, processing plants, devices, chemical processes, biological systems, data centers, aircraft carriers, and the like. It should be understood that the monitored system can be any combination of components whose operations can be monitored with conventional sensors and where each component interacts with or is related to at least one other component within the combination.

[0095] Figure 6 is an illustration of a flowchart describing a method for real-time monitoring and predictive analysis of a monitored system, in accordance with one embodiment. Method 600 begins with operation 602 where real-time data indicative of the monitored system status is processed to enable a virtual model of the monitored system under management to be calibrated and synchronized with the real-time data. In one embodiment, the monitored system 102 is a mission critical electrical power system. In another embodiment, the monitored system 102 can include an electrical power transmission infrastructure. In still another embodiment, the monitored system 102 includes a combination of thereof. It should be understood that the monitored system 102 can be any combination of components whose operations can be monitored with conventional sensors and where each component interacts with or is related to at least one other component within the combination.

[0096] Method 600 moves on to operation 604 where the virtual system model of the monitored system under management is updated in response to the real-time data. This may include, but is not limited to, modifying the simulated data output from the virtual system model, adjusting the logic/processing parameters utilized by the virtual system modeling engine to simulate the operation of the monitored system, adding/subtracting functional

elements of the virtual system model, etc. It should be understood, that any operational parameter of the virtual system modeling engine and/or the virtual system model may be modified by the calibration engine as long as the resulting modifications can be processed and registered by the virtual system modeling engine.

[0097] Method 600 proceeds on to operation 606 where the simulated real-time data indicative of the monitored system status is compared with a corresponding virtual system model created at the design stage. The design stage models, which may be calibrated and updated based on real-time monitored data, are used as a basis for the predicted performance of the system. The real-time monitored data can then provide the actual performance over time. By comparing the real-time time data with the predicted performance information, difference can be identified a tracked by, e.g., the analytics engine 118. Analytics engines 118 can then track trends, determine alarm states, etc., and generate a real-time report of the system status in response to the comparison.

[0098] In other words, the analytics can be used to analyze the comparison and real-time data and determine if there is a problem that should be reported and what level the problem may be, e.g., low priority, high priority, critical, etc. The analytics can also be used to predict future failures and time to failure, etc. In one embodiment, reports can be displayed on a conventional web browser (e.g. INTERNET EXPLORER™, FIREFOX™, NETSCAPE™, etc) that is rendered on a standard personal computing (PC) device. In another embodiment, the "real-time" report can be rendered on a "thin-client" computing device (e.g., CITRIX™, WINDOWS TERMINAL SERVICES™, telnet, or other equivalent thin-client terminal application). In still another embodiment, the report can be displayed on a wireless mobile device (e.g., BLACKBERRY™, laptop, pager, etc.). For example, in one

embodiment, the "real-time" report can include such information as the differential in a particular power parameter (i.e., current, voltage, etc.) between the real-time measurements and the virtual output data.

[0099] Figure 7 is an illustration of a flowchart describing a method for managing real-time updates to a virtual system model of a monitored system, in accordance with one embodiment. Method 700 begins with operation 702 where real-time data output from a sensor interfaced with the monitored system is received. The sensor is configured to capture output data at split-second intervals to effectuate "real time" data capture. For example, in one embodiment, the sensor is configured to generate hundreds of thousands of data readings per second. It should be appreciated, however, that the number of data output readings taken by the sensor may be set to any value as long as the operational limits of the sensor and the data processing capabilities of the data acquisition hub are not exceeded.

[00100] Method 700 moves to operation 704 where the real-time data is processed into a defined format. This would be a format that can be utilized by the analytics server to analyze or compare the data with the simulated data output from the virtual system model. In one embodiment, the data is converted from an analog signal to a digital signal. In another embodiment, the data is converted from a digital signal to an analog signal. It should be understood, however, that the real-time data may be processed into any defined format as long as the analytics engine can utilize the resulting data in a comparison with simulated output data from a virtual system model of the monitored system.

[00101] Method 700 continues on to operation 706 where the predicted (i.e., simulated) data for the monitored system is generated using a virtual system model of the monitored system. As discussed above, a virtual system modeling engine utilizes dynamic

control logic stored in the virtual system model to generate the predicted output data. The predicted data is supposed to be representative of data that should actually be generated and output from the monitored system.

[00102] Method 700 proceeds to operation 708 where a determination is made as to whether the difference between the real-time data output and the predicted system data falls between a set value and an alarm condition value, where if the difference falls between the set value and the alarm condition value a virtual system model calibration and a response can be generated. That is, if the comparison indicates that the differential between the "real-time" sensor output value and the corresponding "virtual" model data output value exceeds a Defined Difference Tolerance (DDT) value (i.e., the "real-time" output values of the sensor output do not indicate an alarm condition) but below an alarm condition (i.e., alarm threshold value), a response can be generated by the analytics engine. In one embodiment, if the differential exceeds, the alarm condition, an alarm or notification message is generated by the analytics engine 118. In another embodiment, if the differential is below the DTT value, the analytics engine does nothing and continues to monitor the "real-time" data and "virtual" data. Generally speaking, the comparison of the set value and alarm condition is indicative of the functionality of one or more components of the monitored system.

[00103] Figure 8 is an illustration of a flowchart describing a method for synchronizing real-time system data with a virtual system model of a monitored system, in accordance with one embodiment. Method 800 begins with operation 802 where a virtual system model calibration request is received. A virtual model calibration request can be generated by an analytics engine whenever the difference between the real-time data output and the predicted system data falls between a set value and an alarm condition value.

[00104] Method 800 proceeds to operation 804 where the predicted system output value for the virtual system model is updated with a real-time output value for the monitored system. For example, if sensors interfaced with the monitored system outputs a real-time current value of A, then the predicted system output value for the virtual system model is adjusted to reflect a predicted current value of A.

[00105] Method 800 moves on to operation 806 where a difference between the real-time sensor value measurement from a sensor integrated with the monitored system and a predicted sensor value for the sensor is determined. As discussed above, the analytics engine is configured to receive "real-time" data from sensors interfaced with the monitored system via the data acquisition hub (or, alternatively directly from the sensors) and "virtual" data from the virtual system modeling engine simulating the data output from a virtual system model of the monitored system. In one embodiment, the values are in units of electrical power output (i.e., current or voltage) from an electrical power generation or transmission system. It should be appreciated, however, that the values can essentially be any unit type as long as the sensors can be configured to output data in those units or the analytics engine can convert the output data received from the sensors into the desired unit type before performing the comparison.

[00106] Method 800 continues on to operation 808 where the operating parameters of the virtual system model are adjusted to minimize the difference. This means that the logic parameters of the virtual system model that a virtual system modeling engine uses to simulate the data output from actual sensors interfaced with the monitored system are adjusted so that the difference between the real-time data output and the simulated data output is minimized. Correspondingly, this operation will update and adjust any virtual system model output

parameters that are functions of the virtual system model sensor values. For example, in a power distribution environment, output parameters of power load or demand factor might be a function of multiple sensor data values. The operating parameters of the virtual system model that mimic the operation of the sensor will be adjusted to reflect the real-time data received from those sensors. In one embodiment, authorization from a system administrator is requested prior to the operating parameters of the virtual system model being adjusted. This is to ensure that the system administrator is aware of the changes that are being made to the virtual system model. In one embodiment, after the completion of all the various calibration operations, a report is generated to provide a summary of all the adjustments that have been made to the virtual system model.

[00107] As described above, virtual system modeling engine 124 can be configured to model various aspects of the system to produce predicted values for the operation of various components within monitored system 102. These predicted values can be compared to actual values being received via data acquisition hub 112. If the differences are greater than a certain threshold, e.g., the DTT, but not in an alarm condition, then a calibration instruction can be generated. The calibration instruction can cause a calibration engine 134 to update the virtual model being used by system modeling engine 124 to reflect the new operating information.

[00108] It will be understood that as monitored system 102 ages, or more specifically the components comprising monitored system 102 age, then the operating parameters, e.g., currents and voltages associated with those components will also change. Thus, the process of calibrating the virtual model based on the actual operating information provides a

mechanism by which the virtual model can be aged along with the monitored system 102 so that the comparisons being generated by analytics engine 118 are more meaningful.

[00109] At a high level, this process can be illustrated with the aid of Figure 9, which is a flow chart illustrating an example method for updating the virtual model in accordance with one embodiment. In step 902, data is collected from, e.g., sensors 104, 106, and 108. For example, the sensors can be configured to monitor protective devices within an electrical distribution system to determine and monitor the ability of the protective devices to withstand faults, which is describe in more detail below.

[00110] In step 904, the data from the various sensors can be processed by analytics engine 118 in order to evaluate various parameters related to monitored system 102. In step 905, simulation engine 124 can be configured to generate predicted values for monitored system 102 using a virtual model of the system that can be compared to the parameters generated by analytics engine 118 in step 904. If there are differences between the actual values and the predicted values, then the virtual model can be updated to ensure that the virtual model ages with the actual system 102.

[00111] It should be noted that as the monitored system 102 ages, various components can be repaired, replaced, or upgraded, which can also create differences between the simulated and actual data that is not an alarm condition. Such activity can also lead to calibrations of the virtual model to ensure that the virtual model produces relevant predicted values. Thus, not only can the virtual model be updated to reflect aging of monitored system 102, but it can also be updated to reflect retrofits, repairs, etc.

[00112] As noted above, in certain embodiments, a logical model of a facilities electrical system, a data acquisition system (data acquisition hub 112), and power system simulation

engines (modeling engine 124) can be integrated with a logic and methods based approach to the adjustment of key database parameters within a virtual model of the electrical system to evaluate the ability of protective devices within the electrical distribution system to withstand faults and also effectively "age" the virtual system with the actual system.

[00113] Only through such a process can predictions on the withstand abilities of protective devices, and the status, security and health of an electrical system be accurately calculated. Accuracy is important as the predictions can be used to arrive at actionable, mission critical or business critical conclusions that may lead to the re-alignment of the electrical distribution system for optimized performance or security.

[00114] Figures 10-12 are flow charts presenting logical flows for determining the ability of protective devices within an electrical distribution system to withstand faults and also effectively "age" the virtual system with the actual system in accordance with one embodiment. Figure 10 is a diagram illustrating an example process for monitoring the status of protective devices in a monitored system 102 and updating a virtual model based on monitored data. First, in step 1002, the status of the protective devices can be monitored in real time. As mentioned, protective devices can include fuses, switches, relays, and circuit breakers. Accordingly, the status of the fuses/switches, relays, and/or circuit breakers, e.g., the open/close status, source and load status, and on or off status, can be monitored in step 1002. It can be determined, in step 1004, if there is any change in the status of the monitored devices. If there is a change, then in step 1006, the virtual model can be updated to reflect the status change, i.e., the corresponding virtual components data can be updated to reflect the actual status of the various protective devices.

[00115] In step 1008, predicted values for the various components of monitored system 102 can be generated. But it should be noted that these values are based on the current, real-time status of the monitored system. Real time sensor data can be received in step 1012. This real time data can be used to monitor the status in step 1002 and it can also be compared with the predicted values in step 1014. As noted above, the difference between the predicted values and the real time data can also be determined in step 1014.

[00116] Accordingly, meaningful predicted values based on the actual condition of monitored system 102 can be generated in steps 1004 to 1010. These predicted values can then be used to determine if further action should be taken based on the comparison of step 1014. For example, if it is determined in step 1016 that the difference between the predicted values and the real time sensor data is less than or equal to a certain threshold, e.g., DTT, then no action can be taken e.g., an instruction not to perform calibration can be issued in step 1018. Alternatively, if it is determined in step 1020 that the real time data is actually indicative of an alarm situation, e.g., is above an alarm threshold, then a do not calibrate instruction can be generated in step 1018 and an alarm can be generated as described above. If the real time sensor data is not indicative of an alarm condition, and the difference between the real time sensor data and the predicted values is greater than the threshold, as determined in step 1022, then an initiate calibration command can be generated in step 1024.

[00117] If an initiate calibration command is issued in step 1024, then a function call to calibration engine 134 can be generated in step 1026. The function call will cause calibration engine 134 to update the virtual model in step 1028 based on the real time sensor data. A comparison between the real time data and predicted data can then be generated in step 1030 and the differences between the two computed. In step 1032, a user can be prompted as to

whether or not the virtual model should in fact be updated. In other embodiments, the update can be automatic, and step 1032 can be skipped. In step 1034, the virtual model could be updated. For example, the virtual model loads, buses, demand factor, and/or percent running information can be updated based on the information obtained in step 1030. An initiate simulation instruction can then be generated in step 1036, which can cause new predicted values to be generated based on the update of virtual model.

[00118] In this manner, the predicted values generated in step 1008 are not only updated to reflect the actual operational status of monitored system 102, but they are also updated to reflect natural changes in monitored system 102 such as aging. Accordingly, realistic predicted values can be generated in step 1008.

[00119] Figure 11 is a flowchart illustrating an example process for determining the protective capabilities of the protective devices being monitored in step 1002. Depending on the embodiment, the protective devices can be evaluated in terms of the International Electrotechnical Commission (IEC) standards or in accordance with the United States or American National Standards Institute (ANSI) standards. It will be understood, that the process described in relation to Figure 11 is not dependent on a particular standard being used.

[00120] First, in step 1102, a short circuit analysis can be performed for the protective device. Again, the protective device can be any one of a variety of protective device types. For example, the protective device can be a fuse or a switch, or some type of circuit breaker. It will be understood that there are various types of circuit breakers including Low Voltage Circuit Breakers (LVCBs), High Voltage Circuit Breakers (HVCBs), Mid Voltage Circuit Breakers (MVCBs), Miniature Circuit Breakers (MCBs), Molded Case Circuit Breakers

(MCCBs), Vacuum Circuit Breakers, and Air Circuit Breakers, to name just a few. Any one of these various types of protective devices can be monitored and evaluated using the processes illustrated with respect to Figures 10-12.

[00121] For example, for LVCBs, or MCCBs, the short circuit current, symmetric (I_{sym}) or asymmetric (I_{asym}), and/or the peak current (I_{peak}) can be determined in step 1102. For, e.g., LVCBs that are not instantaneous trip circuit breakers, the short circuit current at a delayed time ($I_{symdelay}$) can be determined. For HVCBs, a first cycle short circuit current (I_{sym}) and/or I_{peak} can be determined in step 1102. For fuses or switches, the short circuit current, symmetric or asymmetric, can be determined in step 1102. And for MVCBs the short circuit current interrupting time can be calculated. These are just some examples of the types of short circuit analysis that can be performed in Step 1102 depending on the type of protective device being analyzed.

[00122] Once the short circuit analysis is performed in step 1102, various steps can be carried out in order to determine the bracing capability of the protective device. For example, if the protective device is a fuse or switch, then the steps on the left hand side of Figure 11 can be carried out. In this case, the fuse rating can first be determined in step 1104. In this case, the fuse rating can be the current rating for the fuse. For certain fuses, the X/R can be calculated in step 1105 and the asymmetric short circuit current (I_{asym}) for the fuse can be determined in step 1106 using equation 1.

$$\text{Eq 1}: I_{ASYM} = I_{SYM}\sqrt{1+2e^{-2p/(X/R)}}$$

[00123] In other implementations, the inductants/reactants (X/R) ratio can be calculated instep 1108 and compared to a fuse test X/R to determine if the calculated X/R is greater than the fuse test X/R. The calculated X/R can be determined using the predicted values provided in step 1008. Various standard tests X/R values can be used for the fuse test X/R values in step 1108. For example, standard test X/R values for a LVCB can be as follows:

PCB, ICCB = 6.59	
MCCB, ICCB rated <= 10,000 A	= 1.73
MCCB, ICCB rated 10,001 - 20,000A	= 3.18
MCCB, ICCB rated > 20,000 A	= 4.9

[00124] If the calculated X/R is greater than the fuse test X/R, then in step 1112, equation 12 can be used to calculate an adjusted symmetrical short circuit current (I_{adjsym}).

$$\text{Eq } 12 : I_{ADJSYM} = I_{SYM}\left\{\frac{\sqrt{1+2e^{-2p/(\text{CALC X/R})}}}{\sqrt{1+2e^{-2p/(\text{TEST X/R})}}}\right\}$$

[00125] If the calculated X/R is not greater than the fuse test X/R then Iadjsym can be set equal to I_{sym} in step 1110. In step 1114, it can then be determined if the fuse rating (step 1104) is greater than or equal to I_{adjsym} or I_{asym}. If it is, then it can determine in step 1118 that the protected device has passed and the percent rating can be calculated in step 1120 as follows:

$$\% \text{ rating} = \frac{I_{ADJSYM}}{\text{Device rating}}$$

or

$$\% \text{ rating} = \frac{I_{ASYM}}{\text{Device rating}}$$

[00126] If it is determined in step 1114 that the device rating is not greater than or equal to I_{adjsym}, then it can be determined that the device as failed in step 1116. The percent rating can still be calculating in step 1120.

[00127] For LVCBs, it can first be determined whether they are fused in step 1122. If it is determined that the LVCB is not fused, then in step 1124 can be determined if the LVCB is an instantaneous trip LVCB. If it is determined that the LVCB is an instantaneous trip LVCB, then in step 1130 the first cycle fault X/R can be calculated and compared to a circuit breaker test X/R (see example values above) to determine if the fault X/R is greater than the circuit breaker test X/R. If the fault X/R is not greater than the circuit breaker test X/R, then in step 1132 it can be determined if the LVCB is peak rated. If it is peak rated, then I_{peak} can be used in step 1146 below. If it is determined that the LVCB is not peak rated in step 1132, then I_{adjsym} can be set equal to I_{sym} in step 1140. In step 1146, it can be determined if the device rating is greater or equal to $I_{adjsym,}$ or to I_{peak} as appropriate, for the LVCB.

[00128] If it is determined that the device rating is greater than or equal to I_{adjsym}, then it can be determined that the LVCB has passed in step 1148. The percent rating can then be determined using the equations for I_{adjsym} defined above (step 1120) in step 1152. If it is determined that the device rating is not greater than or equal to I_{adjsym}, then it can be determined that the device has failed in step 1150. The percent rating can still be calculated in step 1152.

[00129] If the calculated fault X/R is greater than the circuit breaker test X/R as determined in step 1130, then it can be determined if the LVCB is peak rated in step 1134. If the LVCB is not peak rated, then the I_{adjsym} can be determined using equation 12. If the LVCB is peak rated, then I_{peak} can be determined using equation 11.

$$\text{Eq } 11: I_{PEAK} = \sqrt{2}\, I_{SYM} \left\{1.02 + 0.98 e^{-3/(X/R)}\right\}$$

[00130] It can then be determined if the device rating is greater than or equal to I_{adjsym} or I_{peak} as appropriate. The pass/fail determinations can then be made in steps 1148 and 1150 respectively, and the percent rating can be calculated in step 1152.

$$\% \text{ rating} = \frac{I_{ADJSYM}}{\text{Device rating}}$$

or

$$\% \text{ rating} = \frac{I_{PEAK}}{\text{Device rating}}$$

[00131] If the LVCB is not an instantaneous trip LVCB as determined in step 1124, then a time delay calculation can be performed at step 1128 followed by calculation of the fault X/R and a determination of whether the fault X/R is greater than the circuit breaker test X/R. If it is not, then Iadjsym can be set equal to Isym in step 1136. If the calculated fault at X/R is greater than the circuit breaker test X/R, then Iadjsymdelay can be calculated in step 1138 using the following equation with, e.g., a 0.5 second maximum delay:

$$\text{Eq 14: } I_{\underset{\text{DELAY}}{\text{ADJSYM}}} = I_{\underset{\text{DELAY}}{\text{SYM}}} \left\{ \frac{\sqrt{1+2e^{-60p/(\text{CALC X/R})}}}{\sqrt{1+2e^{-60p/(\text{TEST X/R})}}} \right\}$$

[00132] It can then be determined if the device rating is greater than or equal to I_{adjsym} or $I_{adjsymdelay}$. The pass/fail determinations can then be made in steps 1148 and 1150, respectively and the percent rating can be calculated in step 1152.

[00133] If it is determined that the LVCB is fused in step 1122, then the fault X/R can be calculated in step 1126 and compared to the circuit breaker test X/R in order to determine if the calculated fault X/R is greater than the circuit breaker test X/R. If it is greater, then I_{adjsym} can be calculated in step 1154 using the following equation:

$$\text{Eq 13: } I_{ADJSYM} = I_{SYM} \left\{ \frac{1.02+0.98\,e^{-3/(\text{CALC X/R})}}{1.02+0.98\,e^{-3/(\text{TEST X/R})}} \right\}$$

[00134] If the calculated fault X/R is not greater than the circuit breaker test X/R, then I_{adjsym} can be set equal to I_{sym} in step 1156. It can then be determined if the device rating is greater than or equal to I_{adjsym} in step 1146. The pass/fail determinations can then be carried out in steps 1148 and 1150 respectively, and the percent rating can be determined in step 1152.

[00135] Figure 12 is a diagram illustrating an example process for determining the protective capabilities of a HVCB. In certain embodiments, X/R can be calculated in step 1157 and a peak current (I_{peak}) can be determined using equation 11 in step 1158. In step 1162, it can be determined whether the HVCB's rating is greater than or equal to I_{peak} as

determined in step 1158. If the device rating is greater than or equal to I_{peak}, then the device has passed in step 1164. Otherwise, the device fails in step 1166. In either case, the percent rating can be determined in step 1168 using the following:

$$\% \text{ rating} = \frac{I_{PEAK}}{\text{Device rating}}$$

[00136] In other embodiments, an interrupting time calculation can be made in step 1170. In such embodiments, a fault X/R can be calculated and then can be determined if the fault X/R is greater than or equal to a circuit breaker test X/R in step 1172. For example, the following circuit breaker test X/R can be used;

50 Hz Test X/R = 13.7
60 Hz Test X/R = 16.7
(DC Time contant = 0.45ms)

[00137] If the fault X/R is not greater than the circuit breaker test X/R then $I_{adjintsym}$ can be set equal to I_{sym} in step 1174. If the calculated fault X/R is greater than the circuit breaker test X/R, then contact parting time for the circuit breaker can be determined in step 1176 and equation 15 can then be used to determine $I_{adjintsym}$ in step 1178.

$$\text{Eq 15}: I_{\substack{\text{ADJINT} \\ \text{SYM}}} = I_{\substack{\text{INT} \\ \text{SYM}}} \left\{ \frac{\sqrt{1+2e^{-4\mathbf{p}f*t/(\text{CALCX/R})}}}{\sqrt{1+2e^{-4\mathbf{p}f*t/(\text{TEST X/R})}}} \right\}$$

[00138] In step 1180, it can be determined whether the device rating is greater than or equal to $I_{adjintsym}$. The pass/fail determinations can then be made in steps 1182 and 1184 respectively and the percent rating can be calculated in step 1186 using the following:

$$\% \text{ rating} = \frac{I_{ADJINTSYM}}{\text{Device rating}}$$

[00139] Figure 13 is a flowchart illustrating an example process for determining the protective capabilities of the protective devices being monitored in step 1002 in accordance with another embodiment. The process can start with a short circuit analysis in step 1302. For systems operating at a frequency other than 60hz, the protective device X/R can be modified as follows:

$$(X/R)\text{mod} = (X/R) * 60H/(\text{system Hz}).$$

[00140] For fuses/switches, a selection can be made, as appropriate, between use of the symmetrical rating or asymmetrical rating for the device. The Multiplying Factor (MF) for the device can then be calculated in step 1304. The MF can then be used to determine $I_{adjasym}$ or I_{adjsym}. In step 1306, it can be determined if the device rating is greater than or equal to $I_{adjasym}$ or I_{adjsym}. Based on this determination, it can be determined whether the device passed or failed in steps 1308 and 1310 respectively, and the percent rating can be determined in step 1312 using the following:

$$\% \text{ rating} = I_{adjasym} * 100/\text{device rating; or}$$
$$\% \text{ rating} = I_{adjsym} * 100/\text{device rating.}$$

[00141] For LVCBs, it can first be determined whether the device is fused in step 1314. If the device is not fused, then in step 1315 it can be determined whether the X/R is known for the device. If it is known, then the LVF can be calculated for the device in step 1320. It should be noted that the LVF can vary depending on whether the LVCB is an instantaneous trip device or not. If the X/R is not known, then it can be determined in step 1317, e.g., using the following:

PCB, ICCB = 6.59
MCCB, ICCB rated <= 10,000 A = 1.73
MCCB, ICCB rated 10,001 - 20,000A = 3.18
MCCB, ICCB rated > 20,000 A = 4.9

[00142] If the device is fused, then in step 1316 it can again be determined whether the X/R is known. If it is known, then the LVF can be calculated in step 1319. If it is not known, then the X/R can be set equal to, e.g., 4.9.

[00143] In step 1321, it can be determined if the LVF is less than 1 and if it is, then the LVF can be set equal to 1. In step 1322 I_{intadj} can be determined using the following:

MCCB/ICCB/PCBWith Instantaneous :
$Iint, adj = LVF * Isym, rms$
PCB Without Instantaneous :
$Iint, adj = LVFp * Isym, rms(½ Cyc)$
$int, adj = LVFasym * Isym, rms(3 - 8 Cyc)$

[00144] In step 1323, it can be determined whether the device's symmetrical rating is greater than or equal to I_{intadj}, and it can be determined based on this evaluation whether the

device passed or failed in steps 1324 and 1325 respectively. The percent rating can then be determined in step 1326 using the following:

$$\% \text{ rating} = I_{intadj} * 100/\text{device rating}.$$

[00145] Figure 14 is a diagram illustrating a process for evaluating the withstand capabilities of a MVCB in accordance with one embodiment. In step 1328, a determination can be made as to whether the following calculations will be based on all remote inputs, all local inputs or on a No AC Decay (NACD) ratio. For certain implementations, a calculation can then be made of the total remote contribution, total local contribution, total contribution ($I_{intrmssym}$), and NACD. If the calculated NACD is equal to zero, then it can be determined that all contributions are local. If NACD is equal to 1, then it can be determined that all contributions are remote.

[00146] If all the contributions are remote, then in step 1332 the remote MF (MFr) can be calculated and I_{int} can be calculated using the following:

$$I_{int} = MFr * I_{intrmssym}$$

[00147] If all the inputs are local, then MFl can be calculated and I_{int} can be calculated using the following:

$$I_{int} = MF1 * I_{intrmssym}$$

[00148] If the contributions are from NACD, then the NACD, MFr, MFl, and AMFl can be calculated. If AMFl is less than 1, then AMFl can be set equal to 1. I_{int} can then be calculated using the following:

$$I_{int} = AMF1 * I_{intrmssym}/S$$

[00149] In step 1338, the 3-phase device duty cycle can be calculated and then it can be determined in step 1340, whether the device rating is greater than or equal to I_{int}. Whether the device passed or failed can then be determined in steps 1342 and 1344, respectively. The percent rating can be determined in step 1346 using the following:

$$\%\ \text{rating} = I_{int} * 100/3p\ \text{device rating}.$$

[00150] In other embodiments, it can be determined, in step 1348, whether the user has selected a fixed MF. If so, then in certain embodiments the peak duty (crest) can be determined in step 1349 and MFp can be set equal to 2.7 in step 1354. If a fixed MF has not been selected, then the peak duty (crest) can be calculated in step 1350 and MFp can be calculated in step 1358. In step 1362, the MFp can be used to calculate the following:

$$I_{mompeak} = MFp * I_{symrms}$$

[00151] In step 1366, it can be determined if the device peak rating (crest) is greater than or equal to $I_{mompeak}$. It can then be determined whether the device passed or failed in steps 1368 and 1370 respectively, and the percent rating can be calculated as follows:

$$\%\ \text{rating} = I_{mompeak} * 100/\text{device peak (crest) rating.}$$

[00152] In other embodiments, if a fixed MF is selected, then a momentary duty cycle (C&L) can be determined in step 1351 and MFm can be set equal to, e.g., 1.6. If a fixed MF has not been selected, then in step 1352 MFm can be calculated. MFm can then be used to determine the following:

$$I_{momsym} = MFm * I_{symrms}$$

[00153] It can then be determined in step 1374 whether the device C&L, rms rating is greater than or equal to I_{momsym}. Whether the device passed or failed can then be determined in steps 1376 and 1378 respectively, and the percent rating can be calculated as follows:

$$\%\ \text{rating} = I_{momasym} * 100/\text{device C \& L, rms rating.}$$

[00154] Thus, the above methods provide a mean to determine the withstand capability of various protective devices, under various conditions and using various standards, using an aged, up to date virtual model of the system being monitored.

[00155] The influx of massive sensory data, e.g., provided via sensors 104, 106, and 108, intelligent filtration of this dense stream of data into manageable and easily understandable knowledge. For example, as mentioned, it is important to be able to assess the real-time ability of the power system to provide sufficient generation to satisfy the system load requirements and to move the generated energy through the system to the load points. Conventional systems do not make use of an on-line, real-time system snap shot captured by a real-time data acquisition platform to perform real time system availability evaluation.

[00156] Figure 15 is a flow chart illustrating an example process for analyzing the reliability of an electrical power distribution and transmission system in accordance with one embodiment. First, in step 1502, reliability data can be calculated and/or determined. The inputs used in step 1502 can comprise power flow data, e.g., network connectivity, loads, generations, cables/transformer impedances, etc., which can be obtained from the predicted values generated in step 1008, reliability data associated with each power system component, lists of contingencies to be considered, which can vary by implementation including by region, site, etc., customer damage (load interruptions) costs, which can also vary by implementation, and load duration curve information. Other inputs can include failure rates, repair rates, and required availability of the system and of the various components.

[00157] In step 1504 a list of possible outage conditions and contingencies can be evaluated including loss of utility power supply, generators, UPS, and/or distribution lines and infrastructure. In step 1506, a power flow analysis for monitored system 102 under the various contingencies can be performed. This analysis can include the resulting failure rates, repair rates, cost of interruption or downtime versus the required system availability, etc. In step 1510, it can be determined if the system is operating in a deficient state when confronted

with a specific contingency. If it is, then is step 1512, the impact on the system, load interruptions, costs, failure duration, system unavailability, etc. can all be evaluated.

[00158] After the evaluation of step 1512, or if it is determined that the system is not in a deficient state in step 1510, then it can be determined if further contingencies need to be evaluated. If so, then the process can revert to step 1506 and further contingencies can be evaluated. If no more contingencies are to be evaluated, then a report can be generated in step 1514. The report can include a system summary, total and detailed reliability indices, system availability, etc. The report can also identify system bottlenecks are potential problem areas.

[00159] The reliability indices can be based on the results of credible system contingencies involving both generation and transmission outages. The reliability indices can include load point reliability indices, branch reliability indices, and system reliability indices. For example, various load/bus reliability indices can be determined such as probability and frequency of failure, expected load curtailed, expected energy not supplied, frequency of voltage violations, reactive power required, and expected customer outage cost. The load point indices can be evaluated for the major load buses in the system and can be used in system design for comparing alternate system configurations and modifications.

[00160] Overall system reliability indices can include power interruption index, power supply average MW curtailment, power supply disturbance index, power energy curtailment index, severity index, and system availability. For example, the individual load point indices can be aggregated to produce a set of system indices. These indices are indicators of the overall adequacy of the composite system to meet the total system load demand and energy

requirements and can be extremely useful for the system planner and management, allowing more informed decisions to be made both in planning and in managing the system.

[00161] The various analysis and techniques can be broadly classified as being either Monte Carlo simulation or Contingency Enumeration. The process can also use AC, DC and fast linear network power flow solutions techniques and can support multiple contingency modeling, multiple load levels, automatic or user-selected contingency enumeration, use a variety of remedial actions, and provides sophisticated report generation.

[00162] The analysis of step 1506 can include adequacy analysis of the power system being monitored based on a prescribed set of criteria by which the system must be judged as being in the success or failed state. The system is considered to be in the failed state if the service at load buses is interrupted or its quality becomes unacceptable, i.e., if there are capacity deficiency, overloads, and/or under/over voltages

[00163] Various load models can be used in the process of figure 15 including multi-step load duration curve, curtailable and Firm, and Customer Outage Cost models. Additionally, various remedial actions can be proscribed or even initiated including MW and MVAR generation control, generator bus voltage control, phase shifter adjustment, MW generation rescheduling, and load curtailment (interruptible and firm).

[00164] In other embodiments, the effect of other variables, such as the weather and human error can also be evaluated in conjunction with the process of figure 15 and indices can be associated with these factors. For example, figure 16 is a flow chart illustrating an example process for analyzing the reliability of an electrical power distribution and transmission system that takes weather information into account in accordance with one embodiment. Thus, in step 1602, real-time weather data can be received, e.g., via a data feed

such as an XML feed from National Oceanic and Atmosphere Administration (NOAA). In step 1604, this data can be converted into reliability data that can be used in step 1502.

[00165] It should also be noted that National Fire Protection Association (NFPA) and the Occupational Safety and Health Association (OSHA) have mandated that facilities comply with proper workplace safety standards and conduct Arc Flash studies in order to determine the incident energy, protection boundaries and PPE levels needed to be worn by technicians. Unfortunately, conventional approaches/systems for performing such studies do not provide a reliable means for the real-time prediction of the potential energy released (in calories per centimeter squared) for an arc flash event. Moreover, no real-time system exists that can predict the required personal protective equipment (PPE) required to safely perform repairs as required by NFPA 70E and IEEE 1584.

[00166] When a fault in the system being monitored contains an arc, the heat released can damage equipment and cause personal injury. It is the latter concern that brought about the development of the heat exposure programs referred to above. The power dissipated in the arc radiates to the surrounding surfaces. The further away from the arc the surface is, the less the energy is received per unit area.

[00167] As noted above, conventional approaches are based on highly specialized static simulation models that are rigid and non-reflective of the facilities operational status at the time a technician may be needed to conduct repairs on electrical equipment. But the PPE level required for the repair, or the safe protection boundary may change based on the actual operational status of the facility and alignment of the power distribution system at the time repairs are needed. Therefore, a static model does not provide the real-time analysis that can be critical for accurate PPE level determination. This is because static systems cannot adjust

to the many daily changes to the electrical system that occur at a facility, e.g., motors and pumps may be on or off, on-site generation status may have changed by having diesel generators on-line, utility electrical feed may also change, etc., nor can they age with the facility to accurately predict the required PPE levels.

[00168] Accordingly, existing systems rely on exhaustive studies to be performed off-line by a power system engineer or a design professional/specialist. Often the specialist must manually modify a simulation model so that it is reflective of the proposed facility operating condition and then conduct a static simulation or a series of static simulations in order to come up with recommended safe working distances, energy calculations and PPE levels. But such a process is not timely, accurate nor efficient, and as noted above can be quite costly.

[00169] Using the systems and methods described herein a logical model of a facility electrical system can be integrated into a real-time environment, with a robust AC Arc Flash simulation engine (system modeling engine 124), a data acquisition system (data acquisition hub 112), and an automatic feedback system (calibration engine 134) that continuously synchronizes and calibrates the logical model to the actual operational conditions of the electrical system. The ability to re-align the simulation model in real-time so that it mirrors the real facility operating conditions, coupled with the ability to calibrate and age the model as the real facility ages, as describe above, provides a desirable approach to predicting PPE levels, and safe working conditions at the exact time the repairs are intended to be performed. Accordingly, facility management can provide real-time compliance with, e.g., NFPA 70E and IEEE 1584 standards and requirements.

[00170] Figure 17 is a diagram illustrating an example process for predicting in real-time various parameters associated with an alternating current (AC) arc flash incident. These

parameters can include for example, the arc flash incident energy, arc flash protection boundary, and required Personal Protective Equipment (PPE) levels, e.g., in order to comply with NFPA-70E and IEEE-1584. First, in step 1702, updated virtual model data can be obtained for the system being model, e.g., the updated data of step 1006, and the operating modes for the system can be determined. In step 1704, an AC 3-phase short circuit analysis can be performed in order to obtain bolted fault current values for the system. In step 1706, e.g., IEEE 1584 equations can be applied to the bolted fault values and any corresponding arcing currents can be calculated in step 1708.

[00171] The ratio of arc current to bolted current can then be used, in step 1710, to determine the arcing current in a specific protective device, such as a circuit breaker or fuse. A coordinated time-current curve analysis can be performed for the protective device in step 1712. In step 1714, the arcing current in the protective device and the time current analysis can be used to determine an associated fault clearing time, and in step 1716 a corresponding arc energy can be determined based on, e.g., IEEE 1584 equations applied to the fault clearing time and arcing current.

[00172] In step 1718, the 100% arcing current can be calculated and for systems operating at less than 1kV the 85% arcing current can also be calculated. In step 1720, the fault clearing time in the protective device can be determined at the 85% arcing current level. In step 1722, e.g., IEEE 1584 equations can be applied to the fault clearing time (determined in step 1720) and the arcing current to determine the 85% arc energy level, and in step 1724 the 100% arcing current can be compared with the 85% arcing current, with the higher of the two being selected. IEEE 1584 equations, for example, can then be applied to the selected arcing

current in step 1726 and the PPE level and boundary distance can be determined in step 1728. In step 1730, these values can be output, e.g., in the form of a display or report.

[00173] In other embodiments, using the same or a similar procedure as illustrated in figure 17, the following evaluations can be made in real-time and based on an accurate, e.g., aged, model of the system:

Arc Flash Exposure based on IEEE 1584;

Arc Flash Exposure based on NFPA 70E;

Network-Based Arc Flash Exposure on AC Systems/Single Branch Case;

Network-Based Arc Flash Exposure on AC Systems/Multiple Branch Cases;

Network Arc Flash Exposure on DC Networks;

Exposure Simulation at Switchgear Box, MCC Box, Open Area and Cable Grounded and Ungrounded;

Calculate and Select Controlling Branch(s) for Simulation of Arc Flash;

Test Selected Clothing;

Calculate Clothing Required;

Calculate Safe Zone with Regard to User Defined Clothing Category;

Simulated Art Heat Exposure at User Selected locations;

User Defined Fault Cycle for 3-Phase and Controlling Branches;

User Defined Distance for Subject;

100% and 85% Arcing Current;

100% and 85% Protective Device Time;

Protective Device Setting Impact on Arc Exposure Energy;

User Defined Label Sizes;

Attach Labels to One-Line Diagram for User Review;

Plot Energy for Each Bus;

Write Results into Excel;

View and Print Graphic Label for User Selected Bus(s); and

Work permit.

[00174] With the insight gained through the above methods, appropriate protective measures, clothing and procedures can be mobilized to minimize the potential for injury should an arc flash incident occur. Facility owners and operators can efficiently implement a real-time safety management system that is in compliance with NFPA 70E and IEEE 1584 guidelines.

[00175] Figure 18 is a flow chart illustrating an example process for real-time analysis of the operational stability of an electrical power distribution and transmission system in accordance with one embodiment. The ability to predict, in real-time, the capability of a power system to maintain stability and/or recover from various contingency events and disturbances without violating system operational constraints is important. This analysis determines the real-time ability of the power system to: 1. sustain power demand and maintain sufficient active and reactive power reserve to cope with ongoing changes in demand and system disturbances due to contingencies, 2. operate safely with minimum operating cost while maintaining an adequate level of reliability, and 3. provide an acceptably high level of power quality (maintaining voltage and frequency within tolerable limits) when operating under contingency conditions.

[00176] In step 1802, the dynamic time domain model data can be updated to re-align the virtual system model in real-time so that it mirrors the real operating conditions of the facility. The updates to the domain model data coupled with the ability to calibrate and age

the virtual system model of the facility as it ages (i.e., real-time condition of the facility), as describe above, provides a desirable approach to predicting the operational stability of the electrical power system operating under contingency situations. That is, these updates account for the natural aging effects of hardware that comprise the total electrical power system by continuously synchronizing and calibrating both the control logic used in the simulation and the actual operating conditions of the electrical system

[00177] The domain model data includes data that is reflective of both the static and non-static (rotating) components of the system. Static components are those components that are assumed to display no changes during the time in which the transient contingency event takes place. Typical time frames for disturbance in these types of elements range from a few cycles of the operating frequency of the system up to a few seconds. Examples of static components in an electrical system include but are not limited to transformers, cables, overhead lines, reactors, static capacitors, etc. Non-static (rotating) components encompass synchronous machines including their associated controls (exciters, governors, etc), induction machines, compensators, motor operated valves (MOV), turbines, static var compensators, fault isolation units (FIU), static automatic bus transfer (SABT) units, etc. These various types of non-static components can be simulated using various techniques. For example:

a. For Synchronous Machines: thermal (round rotor) and hydraulic (salient pole) units can be both simulated either by using a simple model or by the most complete two-axis including damper winding representation.

b. For Induction Machines: a complete two-axis model can be used. Also it is possible to model them by just providing the testing curves (current, power factor, and torque as a function of speed).

c. For Motor Operated Valves (MOVs): Two modes of MOV operation are of interest, namely, opening and closing operating modes. Each mode of operation consists of five distinct stages, a) start, b) full speed, c) unseating, d) travel, and e) stall. The system supports user-defined model types for each of the stages. That is, "start" may be modeled as a constant current while "full speed" may be modeled by constant power. This same flexibility exists for all five distinct stages of the closing mode.

d. For AVR and Excitation Systems: There are a number of models ranging form rotating (DC and AC) and analogue to static and digital controls. Additionally, the system offers a user-defined modeling capability, which can be used to define a new excitation model.

e. For Governors and Turbines: The system is designed to address current and future technologies including but not limited to hydraulic, diesel, gas, and combined cycles with mechanical and/or digital governors.

f. For Static Var Compensators (SVCs): The system is designed to address current and future technologies including a number of solid-state (thyristor) controlled SVC's or even the saturable reactor types.

g. For Fault Isolation Units (FIUs): The system is designed to address current and future technologies of FIUs also known as Current Limiting Devices, are devices installed between the power source and loads to limit the magnitude of fault currents that occur within loads connected to the power distribution networks.

h. For Static Automatic Bus Transfers (SABT): The system is designed to address current and future technologies of SABT (i.e., solid-state three phase, dual position, three-pole switch, etc.)

[00178] In one embodiment, the time domain model data includes "built-in" dynamic model data for exciters, governors, transformers, relays, breakers, motors, and power system stabilizers (PSS) offered by a variety of manufactures. For example, dynamic model data for the electrical power system may be OEM manufacturer supplied control logic for electrical equipment such as automatic voltage regulators (AVR), governors, under load tap changing transformers, relays, breakers motors, etc. In another embodiment, in order to cope with recent advances in power electronic and digital controllers, the time domain model data includes "user-defined" dynamic modeling data that is created by an authorized system administrator in accordance with user-defined control logic models. The user-defined models interacts with the virtual system model of the electrical power system through "Interface Variables" 1816 that are created out of the user-defined control logic models. For example, to build a user-defined excitation model, the controls requires that generator terminal voltage to be measured and compared with a reference quantity (voltage set point). Based on the specific control logic of the excitation and AVR, the model would then compute the predicted generator field voltage and return that value back to the application. The user-defined modeling supports a large number of pre-defined control blocks (functions) that are used to assemble the required control systems and put them into action in a real-time environment for assessing the strength and security of the power system. In still another embodiment, the time domain model data includes both built-in dynamic model data and user-defined model data.

[00179] Moving on to step 1804, a contingency event can be chosen out of a diverse list of contingency events to be evaluated. That is, the operational stability of the electrical power system can be assessed under a number of different contingency event scenarios including but not limited to a singular event contingency or multiple event contingencies (that are simultaneous or sequenced in time). In one embodiment, the contingency events assessed are manually chosen by a system administrator in accordance with user requirements. In another embodiment, the contingency events assessed are automatically chosen in accordance with control logic that is dynamically adaptive to past observations of the electrical power system. That is the control logic "learns" which contingency events to simulate based on past observations of the electrical power system operating under various conditions.

[00180] Some examples of contingency events include but are not limited to:

Application/removal of three-phase fault.

Application/removal of phase-to-ground fault

Application/removal of phase-phase-ground fault.

Application/removal of phase-phase fault.

Branch Addition.

Branch Tripping

Starting Induction Motor.

Stopping Induction Motor

Shunt Tripping.

Shunt Addition (Capacitor and/or Induction)

Generator Tripping.

SVC Tripping.

Impact Loading (Load Changing Mechanical Torque on Induction Machine. With this option it is actually possible to turn an induction motor to an induction generator)

Loss of Utility Power Supply/Generators/UPS/Distribution Lines/System Infrastructure

Load Shedding

[00181] In step 1806, a transient stability analysis of the electrical power system operating under the various chosen contingencies can be performed. This analysis can include identification of system weaknesses and insecure contingency conditions. That is, the analysis can predict (forecast) the system's ability to sustain power demand, maintain sufficient active and reactive power reserve, operate safely with minimum operating cost while maintaining an adequate level of reliability, and provide an acceptably high level of power quality while being subjected to various contingency events. The results of the analysis can be stored by an associative memory engine 1818 during step 1814 to support incremental learning about the operational characteristics of the system. That is, the results of the predictions, analysis, and real-time data may be fed, as needed, into the associative memory engine 1818 for pattern and sequence recognition in order to learn about the logical realities of the power system. In certain embodiments, engine 1818 can also act as a pattern recognition engine or a Hierarchical Temporal Memory (HTM) engine. Additionally, concurrent inputs of various electrical, environmental, mechanical, and other sensory data can be used to learn about and determine normality and abnormality of business and plant operations to provide a means of understanding failure modes and give recommendations.

[00182] In step 1810, it can be determined if the system is operating in a deficient state when confronted with a specific contingency. If it is, then in step 1812, a report is generated providing a summary of the operational stability of the system. The summary may include general predictions about the total security and stability of the system and/or detailed predictions about each component that makes up the system.

[00183] Alternatively, if it is determined that the system is not in a deficient state in step 1810, then step 1808 can determine if further contingencies needs to be evaluated. If so, then the process can revert to step 1806 and further contingencies can be evaluated.

[00184] The results of real-time simulations performed in accordance with figure 18 can be communicated in step 1812 via a report, such as a print out or display of the status. In addition, the information can be reported via a graphical user interface (thick or thin client) that illustrated the various components of the system in graphical format. In such embodiments, the report can simply comprise a graphical indication of the security or insecurity of a component, subsystem, or system, including the whole facility. The results can also be forwarded to associative memory engine 1818, where they can be stored and made available for predictions, pattern/sequence recognition and ability to imagine, e.g., via memory agents or other techniques, some of which are describe below, in step 1820.

[00185] The process of figure 18 can be applied to a number of needs including but not limited to predicting system stability due to: Motor starting and motor sequencing, an example is the assessment of adequacy of a power system in emergency start up of auxiliaries; evaluation of the protections such as under frequency and under-voltage load shedding schemes, example of this is allocation of required load shedding for a potential loss of a power generation source; determination of critical clearing time of circuit breakers to

maintain stability; and determination of the sequence of protective device operations and interactions.

[00186] Figure 19 is a flow chart illustrating an example process for conducting a real-time power capacity assessment of an electrical power distribution and transmission system, in accordance with one embodiment. The stability of an electrical power system can be classified into two broad categories: transient (angular) stability and voltage stability (i.e., power capacity). Voltage stability refers to the electrical system's ability to maintain acceptable voltage profiles under different system topologies and load changes (i.e., contingency events). That is, voltage stability analyses determine bus voltage profiles and power flows in the electrical system before, during, and immediately after a major disturbance. Generally speaking, voltage instability stems from the attempt of load dynamics to restore power consumption beyond the capability of the combined transmission and generation system. One factor that comes into play is that unlike active power, reactive power cannot be transported over long distances. As such, a power system rich in reactive power resources is less likely to experience voltage stability problems. Overall, the voltage stability of a power system is of paramount importance in the planning and daily operation of an electrical system.

[00187] Traditionally, transient stability has been the main focus of power system professionals. However, with the increased demand for electrical energy and the regulatory hurdles blocking the expansion of existing power systems, the occurrences of voltage instability has become increasingly frequent and therefore has gained increased attention from power system planners and power system facility operators. The ability to learn, understand and make predictions about available power system capacity and system

susceptibility to voltage instability, in real-time would be beneficial in generating power trends for forecasting purposes.

[00188] In step 1902, the voltage stability modeling data for the components comprising the electrical system can be updated to re-align the virtual system model in "real-time" so that it mirrors the real operating conditions of the facility. These updates to the voltage stability modeling data coupled with the ability to calibrate and age the virtual system model of the facility as it ages (i.e., real-time condition of the facility), as describe above, provides a desirable approach to predicting occurrences of voltage instability (or power capacity) in the electrical power system when operating under contingency situations. That is, these updates account for the natural aging effects of hardware that comprise the total electrical power system by continuously synchronizing and calibrating both the control logic used in the simulation and the actual operating conditions of the electrical system

[00189] The voltage stability modeling data includes system data that has direct influence on the electrical system's ability to maintain acceptable voltage profiles when the system is subjected to various contingencies, such as when system topology changes or when the system encounters power load changes. Some examples of voltage stability modeling data are load scaling data, generation scaling data, load growth factor data, load growth increment data, etc.

[00190] In one embodiment, the voltage stability modeling data includes "built-in" data supplied by an OEM manufacturer of the components that comprise the electrical equipment. In another embodiment, in order to cope with recent advances power system controls, the voltage stability data includes "user-defined" data that is created by an authorized system administrator in accordance with user-defined control logic models. The user-defined

models interact with the virtual system model of the electrical power system through "Interface Variables" 1916 that are created out of the user-defined control logic models. In still another embodiment, the voltage stability modeling data includes a combination of both built-in model data and user-defined model data

[00191] Moving on to step 1904, a contingency event can be chosen out of a diverse list of contingency events to be evaluated. That is, the voltage stability of the electrical power system can be assessed under a number of different contingency event scenarios including but not limited to a singular event contingency or multiple event contingencies (that are simultaneous or sequenced in time). In one embodiment, the contingency events assessed are manually chosen by a system administrator in accordance with user requirements. In another embodiment, the contingency events assessed are automatically chosen in accordance with control logic that is dynamically adaptive to past observations of the electrical power system. That is the control logic "learns" which contingency events to simulate based on past observations of the electrical power system operating under various conditions. Some examples of contingency events include but are not limited to: loss of utility supply to the electrical system, loss of available power generation sources, system load changes/fluctuations, loss of distribution infrastructure associated with the electrical system, etc.

[00192] In step 1906, a voltage stability analysis of the electrical power system operating under the various chosen contingencies can be performed. This analysis can include a prediction (forecast) of the total system power capacity, available system power capacity and utilized system power capacity of the electrical system of the electrical system under various contingencies. That is, the analysis can predict (forecast) the electrical system's ability to

maintain acceptable voltage profiles during load changes and when the overall system topology undergoes changes. The results of the analysis can be stored by an associative memory engine 1918 during step 1914 to support incremental learning about the power capacity characteristics of the system. That is, the results of the predictions, analysis, and real-time data may be fed, as needed, into the associative memory engine 1918 for pattern and sequence recognition in order to learn about the voltage stability of the electrical system in step 1920. Additionally, concurrent inputs of various electrical, environmental, mechanical, and other sensory data can be used to learn about and determine normality and abnormality of business and plant operations to provide a means of understanding failure modes and give recommendations.

[00193] In step 1910, it can be determined if there is voltage instability in the system when confronted with a specific contingency. If it is, then in step 1912, a report is generated providing a summary of the specifics and source of the voltage instability. The summary may include general predictions about the voltage stability of the overall system and/or detailed predictions about each component that makes up the system.

[00194] Alternatively, if it is determined that the system is not in a deficient state in step 1910, then step 1908 can determine if further contingencies needs to be evaluated. If so, then the process can revert to step 1906 and further contingencies can be evaluated.

[00195] The results of real-time simulations performed in accordance with figure 19 can be communicated in step 1912 via a report, such as a print out or display of the status. In addition, the information can be reported via a graphical user interface (thick or thin client) that illustrated the various components of the system in graphical format. In such embodiments, the report can simply comprise a graphical indication of the capacity of a

subsystem or system, including the whole facility. The results can also be forwarded to associative memory engine 1918, where they can be stored and made available for predictions, pattern/sequence recognition and ability to imagine, e.g., via memory agents or other techniques, some of which are describe below, in step 1920

[00196] The systems and methods described above can also be used to provide reports (step 1912) on, e.g., total system electrical capacity, total system capacity remaining, total capacity at all busbars and/or processes, total capacity remaining at all busbars and/or processes, total system loading, loading at each busbar and/or process, etc.

[00197] Thus, the process of figure 19 can receive input data related to power flow, e.g., network connectivity, loads, generations, cables/transformers, impedances, etc., power security, contingencies, and capacity assessment model data and can produce as outputs data related to the predicted and designed total system capacity, available capacity, and present capacity. This information can be used to make more informed decisions with respect to management of the facility.

[00198] Figure 20 is a flow chart illustrating an example process for performing real-time harmonics analysis of an electrical power distribution and transmission system, in accordance with one embodiment. As technological advances continue to be made in the field of electronic devices, there has been particular emphasis on the development of energy saving features. Electricity is now used quite differently from the way it used be used with new generations of computers and peripherals using very large-scale integrated circuitry operating at low voltages and currents. Typically, in these devices, the incoming alternating current (AC) voltage is diode rectified and then used to charge a large capacitor. The electronic device then draws direct current (DC) from the capacitor in short non-linear pulses to power

its internal circuitry. This sometimes causes harmonic distortions to arise in the load current, which may result in overheated transformers and neutrals, as well as tripped circuit breakers in the electrical system.

[00199] The inherent risks (to safety and the operational life of components comprising the electrical system) that harmonic distortions poses to electrical systems have led to the inclusion of harmonic distortion analysis as part of traditional power analysis. Metering and sensor packages are currently available to monitor harmonic distortions within an electrical system. However, it is not feasible to fully sensor out an electrical system at all possible locations due to cost and the physical accessibility limitations in certain parts of the system. Therefore, there is a need for techniques that predict, through real-time simulation, the sources of harmonic distortions within an electrical system, the impacts that harmonic distortions have or may have, and what steps (i.e., harmonics filtering) may be taken to minimize or eliminate harmonics from the system.

[00200] Currently, there are no reliable techniques for predicting, in real-time, the potential for periodic non-sinusoidal waveforms (i.e. harmonic distortions) to occur at any location within an electrical system powered with sinusoidal voltage. In addition, existing techniques do not take into consideration the operating conditions and topology of the electrical system or utilizes a virtual system model of the system that "ages" with the actual facility or its current condition. Moreover, no existing technique combines real-time power quality meter readings and predicted power quality readings for use with a pattern recognition system such as an associative memory machine learning system to predict harmonic distortions in a system due to changes in topology or poor operational conditions within an electrical system.

[00201] The process, described herein, provides a harmonics analysis solution that uses a real-time snap shot captured by a data acquisition system to perform a real-time system power quality evaluation at all locations regardless of power quality metering density. This process integrates, in real-time, a logical simulation model (i.e., virtual system model) of the electrical system, a data acquisition system, and power system simulation engines with a logic based approach to synchronize the logical simulation model with conditions at the real electrical system to effectively "age" the simulation model along with the actual electrical system. Through this approach, predictions about harmonic distortions in an electrical system may be accurately calculated in real-time. Condensed, this process works by simulating harmonic distortions in an electrical system through subjecting a real-time updated virtual system model of the system to one or more simulated contingency situations.

[00202] In step 2002, the harmonic frequency modeling data for the components comprising the electrical system can be updated to re-align the virtual system model in "real-time" so that it mirrors the real operating conditions of the facility. These updates to the harmonic frequency modeling data coupled with the ability to calibrate and age the virtual system model of the facility as it ages (i.e., real-time condition of the facility), as describe above, provides a desirable approach to predicting occurrences of harmonic distortions within the electrical power system when operating under contingency situations. That is, these updates account for the natural aging effects of hardware that comprise the total electrical power system by continuously synchronizing and calibrating both the control logic used in the simulation and the actual operating conditions of the electrical system.

[00203] Harmonic frequency modeling data has direct influence over how harmonic distortions are simulated during a harmonics analysis. Examples of data that is included with

the harmonic frequency modeling data include: IEEE 519 and/or Mil 1399 compliant system simulation data, generator/cable/motor skin effect data, transformer phase shifting data, generator impedance data, induction motor impedance data, etc.

[00204] Moving on to step 2004, a contingency event can be chosen out of a diverse list of contingency events to be evaluated. That is, the electrical system can be assessed for harmonic distortions under a number of different contingency event scenarios including but not limited to a singular event contingency or multiple event contingencies (that are simultaneous or sequenced in time). In one embodiment, the contingency events assessed are manually chosen by a system administrator in accordance with user requirements. In another embodiment, the contingency events assessed are automatically chosen in accordance with control logic that is dynamically adaptive to past observations of the electrical power system. That is the control logic "learns" which contingency events to simulate based on past observations of the electrical power system operating under various conditions. Some examples of contingency events include but are not limited to additions (bringing online) and changes of equipment that effectuate a non-linear load on an electrical power system (e.g., as rectifiers, arc furnaces, AC/DC drives, variable frequency drives, diode-capacitor input power supplies, uninterruptible power supplies, etc.) or other equipment that draws power in short intermittent pulses from the electrical power system.

[00205] Continuing with Figure 20, in step 2006, a harmonic distortion analysis of the electrical power system operating under the various chosen contingencies can be performed. This analysis can include predictions (forecasts) of different types of harmonic distortion data at various points within the system. Harmonic distortion data may include but are not limited to:

Wave-shape Distortions/Oscillations data

Parallel and Series Resonant Condition data

Total Harmonic Distortion Level data (both Voltage and Current type)

Data on the true RMS system loading of lines, transformers, capacitors, etc.

Data on the Negative Sequence Harmonics being absorbed by the AC motors

Transformer K-Factor Level data

Frequency scan at positive, negative, and zero angle response throughout the entire scanned spectrum in the electrical system.

[00206] That is, the harmonics analysis can predict (forecast) various indicators (harmonics data) of harmonic distortions occurring within the electrical system as it is being subjected to various contingency situations. The results of the analysis can be stored by an associative memory engine 2016 during step 2014 to support incremental learning about the harmonic distortion characteristics of the system. That is, the results of the predictions, analysis, and real-time data may be fed, as needed, into the associative memory engine 2016 for pattern and sequence recognition in order to learn about the harmonic distortion profile of the electrical system in step 2018. Additionally, concurrent inputs of various electrical, environmental, mechanical, and other sensory data can be used to learn about and determine normality and abnormality of business and plant operations to provide a means of understanding failure modes and give recommendations.

[00207] In step 2010, it can be determined if there are harmonic distortions within the system when confronted with a specific contingency. If it is, then in step 2012, a report is generated providing a summary of specifics regarding the characteristics and sources of the harmonic distortions. The summary may include forecasts about the different types of

harmonic distortion data (e.g., Wave-shape Distortions/Oscillations data, Parallel and Series Resonant Condition data, etc.) generated at various points throughout the system. Additionally, through these forecasts, the associative memory engine 2016 can make predictions about the natural oscillation response(s) of the facility and compare those predictions with the harmonic components of the non-linear loads that are fed or will be fed from the system as indicated form the data acquisition system and power quality meters. This will give an indication of what harmonic frequencies that the potential resonant conditions lie at and provide facility operators with the ability to effectively employ a variety of harmonic mitigation techniques (e.g., addition of harmonic filter banks, etc.)

[00208] Alternatively, if it is determined that the system is not in a deficient state in step 2010, then step 2008 can determine if further contingencies needs to be evaluated. If so, then the process can revert to step 2006 and further contingencies can be evaluated.

[00209] The results of real-time simulations performed in accordance with figure 20 can be communicated in step 2012 via a report, such as a print out or display of the status. In addition, the information can be reported via a graphical user interface (thick or thin client) that illustrated the various components of the system in graphical format. In such embodiments, the report can simply comprise a graphical indication of the harmonic status of subsystem or system, including the whole facility. The results can also be forwarded to associative memory engine 2016, where they can be stored and made available for predictions, pattern/sequence recognition and ability to imagine, e.g., via memory agents or other techniques, some of which are describe below, in step 2018

[00210] Thus, the process of Figure 20 can receive input data related to power flow, e.g., network connectivity, loads, generations, cables/transformers, impedances, etc., power

security, contingencies, and can produce as outputs data related to Point Specific Power Quality Indices, Branch Total Current Harmonic Distortion Indices, Bus and Node Total Voltage Harmonic Distortion Indices, Frequency Scan Indices for Positive Negative and Zero Sequences, Filter(s) Frequency Angle Response, Filter(s) Frequency Impedance Response, and Voltage and Current values over each filter elements (r, xl, xc).

[00211] Figure 21 is a diagram illustrating how the HTM Pattern Recognition and Machine Learning Engine works in conjunction with the other elements of the analytics system to make predictions about the operational aspects of a monitored system, in accordance with one embodiment. As depicted herein, the HTM Pattern Recognition and Machine Learning Engine 551 is housed within an analytics server 116 and communicatively connected via a network connection 114 with a data acquisition hub 112, a client terminal 128 and a virtual system model database 526. The virtual system model database 526 is configured to store the virtual system model of the monitored system. The virtual system model is constantly updated with real-time data from the data acquisition hub 112 to effectively account for the natural aging effects of the hardware that comprise the total monitored system, thus, mirroring the real operating conditions of the system. This provides a desirable approach to predicting the operational aspects of the monitored power system operating under contingency situations.

[00212] The HTM Machine Learning Engine 551 is configured to store and process patterns observed from real-time data fed from the hub 112 and predicted data output from a real-time virtual system model of the monitored system. These patterns can later be used by the HTM Engine 551 to make real-time predictions (forecasts) about the various operational aspects of the system.

[00213] The data acquisition hub 112 is communicatively connected via data connections 110 to a plurality of sensors that are embedded throughout a monitored system 102. The data acquisition hub 112 may be a standalone unit or integrated within the analytics server 116 and can be embodied as a piece of hardware, software, or some combination thereof. In one embodiment, the data connections 110 are "hard wired" physical data connections (e.g., serial, network, etc.). For example, a serial or parallel cable connection between the sensors and the hub 112. In another embodiment, the data connections 110 are wireless data connections. For example, a radio frequency (RF), BLUETOOTH™, infrared or equivalent connection between the sensor and the hub 112.

[00214] Examples of a monitored system includes machinery, factories, electrical systems, processing plants, devices, chemical processes, biological systems, data centers, aircraft carriers, and the like. It should be understood that the monitored system can be any combination of components whose operations can be monitored with conventional sensors and where each component interacts with or is related to at least one other component within the combination.

[00215] Continuing with Figure 21, the client 128 is typically a conventional "thin-client" or "thick client" computing device that may utilize a variety of network interfaces (e.g., web browser, CITRIX™, WINDOWS TERMINAL SERVICES™, telnet, or other equivalent thin-client terminal applications, etc.) to access, configure, and modify the sensors (e.g., configuration files, etc.), power analytics engine (e.g., configuration files, analytics logic, etc.), calibration parameters (e.g., configuration files, calibration parameters, etc.), virtual system modeling engine (e.g., configuration files, simulation parameters, etc.) and virtual system model of the system under management (e.g., virtual system model operating

parameters and configuration files). Correspondingly, in one embodiment, the data from the various components of the monitored system and the real-time predictions (forecasts) about the various operational aspects of the system can be displayed on a client 128 display panel for viewing by a system administrator or equivalent. In another embodiment, the data may be summarized in a hard copy report 2102.

[00216] As discussed above, the HTM Machine Learning Engine 551 is configured to work in conjunction with a real-time updated virtual system model of the monitored system to make predictions (forecasts) about certain operational aspects of the monitored system when it is subjected to a contingency event. For example, where the monitored system is an electrical power system, in one embodiment, the HTM Machine Learning Engine 551 can be used to make predictions about the operational reliability of an electrical power system in response to contingency events such as a loss of power to the system, loss of distribution lines, damage to system infrastructure, changes in weather conditions, etc. Examples of indicators of operational reliability include but are not limited to failure rates, repair rates, and required availability of the power system and of the various components that make up the system.

[00217] In another embodiment, the operational aspects relate to an arc flash discharge contingency event that occurs during the operation of the power system. Examples of arc flash related operational aspects include but are not limited to quantity of energy released by the arc flash event, required personal protective equipment (PPE) for personnel operating within the confines of the system during the arc flash event, and measurements of the arc flash safety boundary area around components comprising the power system. In still another embodiment, the operational aspect relates to the operational stability of the system during a

contingency event. That is, the system's ability to sustain power demand, maintain sufficient active and reactive power reserve, operate safely with minimum operating cost while maintaining an adequate level of reliability, and provide an acceptably high level of power quality while being subjected to a contingency event.

[00218] In still another embodiment, the operational aspect relates to the voltage stability of the electrical system immediately after being subjected to a major disturbance (i.e., contingency event). Generally speaking, voltage instability stems from the attempt of load dynamics to restore power consumption, after the disturbance, in a manner that is beyond the capability of the combined transmission and generation system. Examples of predicted operational aspects that are indicative of the voltage stability of an electrical system subjected to a disturbance include the total system power capacity, available system power capacity and utilized system power capacity of the electrical system under being subjected to various contingencies. Simply, voltage stability is the ability of the system to maintain acceptable voltage profiles while under the influence of the disturbances.

[00219] In still yet another embodiment, the operational aspect relates to harmonic distortions in the electrical system subjected to a major disturbance. Harmonic distortions are characterized by non-sinusoidal (non-linear) voltage and current waveforms. Most harmonic distortions result from the generation of harmonic currents caused by nonlinear load signatures. A nonlinear load is characteristic in products such as computers, printers, lighting and motor controllers, and much of today's solid-state equipment. With the advent of power semiconductors and the use of switching power supplies, the harmonics distortion problem has become more severe.

[00220] Examples of operational aspects that are indicative of harmonic distortions include but are not limited to: wave-shape distortions/oscillations, parallel and series resonance, total harmonic distortion level, transformer K-Factor levels, true RMS loading of lines/transformers/capacitors, indicators of negative sequence harmonics being absorbed by alternating current (AC) motors, positive/negative/zero angle frequency response, etc.

[00221] Figure 22 is an illustration of the various cognitive layers that comprise the neocortical catalyst process used by the HTM Pattern Recognition and Machine Learning Engine to analyze and make predictions about the operational aspects of a monitored system, in accordance with one embodiment. As depicted herein, the neocortical catalyst process is executed by a neocortical model 2202 that is encapsulated by a real-time sensory system layer 2204, which is itself encapsulated by an associative memory model layer 2206. Each layer is essential to the operation of the neocortical catalyst process but the key component is still the neocortical model 2202. The neocortical model 2202 represents the "ideal" state and performance of the monitored system and it is continually updated in real-time by the sensor layer 2204. The sensory layer 2204 is essentially a data acquisition system comprised of a plurality of sensors imbedded within the electrical system and configured to provide real-time data feedback to the neocortical model 2202. The associative memory layer observes the interactions between the neocortical model 2202 and the real-time sensory inputs from the sensory layer 2204 to learn and understand complex relationships inherent within the monitored system. As the neocortical model 2202 matures over time, the neocortical catalyst process becomes increasingly accurate in making predictions about the operational aspects of the monitored system. This combination of the neocortical model 2202, sensory layer 2204

and associative memory model layer 2206 works together to learn, refine, suggest and predict similarly to how the human neocortex operates.

[00222] Figure 23 is an example process for real-time three-dimensional (3D) visualization of the health, reliability, and performance of an electrical system, in accordance with one embodiment. The complexity of electrical power systems coupled with the many operational conditions the systems can be asked to operate under pose significant challenges to owners, operators and managers of critical electrical networks. It is vital for owners and operators alike to have a precise and well understood perspective of the overall health and performance of the electrical network. Communication of such status through three-dimensional (3D) visualization views (such as 3D Plant Lifecycle Models), in addition to the traditional two-dimensional (2D) views, greatly enhances the ability of operators, owners and executives to understand the health and predicted performance of their power networks, elegantly and efficiently.

[00223] In step 2302, the power analytics server can determine which operating mode(s) that the electrical system is being simulated under. That is, the virtual system model of the electrical system can be modified by the user to simulate the system operating under multiple different operating scenarios (conditions) and system contingencies. The power analytics server is configured to utilize the operating mode settings while simulating the operation of the electrical system to make predictions about the system's health, performance, availability and reliability. In one embodiment, the operating mode(s) relate to the multiple contingency events that the electrical system may be subjected to during regular operations. The contingency events can be chosen out of a diverse list of contingency events to be evaluated. That is, the operational health, performance, availability and reliability of the electrical

power system can be assessed under a number of different contingency event scenarios including but not limited to a singular event contingency or multiple event contingencies (that are simultaneous or sequenced in time). That is, in one embodiment, the contingency events assessed are manually chosen by a user in accordance with the his/her requirements. In another embodiment, the contingency events assessed are automatically chosen in accordance with control logic that is dynamically adaptive to past observations of the electrical power system. That is the control logic "learns" which contingency events to simulate based on past observations of the electrical power system operating under various conditions.

[00224] Some examples of contingency events include but are not limited to:

Application/removal of three-phase fault

Application/removal of phase-to-ground fault

Application/removal of phase-phase-ground fault

Application/removal of phase-phase fault

Branch Addition

Branch Tripping

Starting Induction Motor

Stopping Induction Motor

Shunt Tripping

Shunt Addition (Capacitor and/or Induction)

Generator Tripping

SVC Tripping

Impact Loading (Load Changing Mechanical Torque on Induction Machine. With this option it is actually possible to turn an induction motor to an induction generator)

Loss of Utility Power Supply/Generators/UPS/Distribution Lines/System Infrastructure

Load Shedding

[00225] In another embodiment, the operating mode(s) can relate to the multiple load levels that the electrical system operates under. That is, the virtual system model of the electrical system can be simulated under various power system load configurations or capacity conditions. In one embodiment, the system is simulated as operating under a base load power configuration. That is, the electrical system can be simulated as operating continuously at its maximum rated power output. Under this configuration, power systems only shut down to perform maintenance or if something breaks. Accordingly, the ability to test under such conditions cannot be achieved in conventional systems. In another embodiment, the electrical system can be simulated as operating under a load following power configuration. That is, the electrical system is simulated as operating in a fluctuating manner by adjusting its power output as demand for electricity fluctuates throughout the day. In still another embodiment, the electrical system is simulated as operating at various different power load capacity levels. For example, the electrical system may be simulated as operating at 10%, 25%, 50%, 75%, or 100% of its rated power generation capacity.

[00226] Continuing with Figure 23, the operating mode(s) can relate to different system and load point reliability indices assigned to the components that make up the electrical system. In one embodiment, for example, changes can be made to the reliability indices of

individual components. In another embodiment, changes can be made to all the components that make up the system.

[00227] In still yet another embodiment, the operating mode(s) relate to the different remedial measures or actions that are implemented on the electrical system to respond to the various contingency situations that the system may be subjected to. For example, remedial measures can relate to: the various types of uninterruptible power supply (UPS) systems operating on the electrical system, various protective devices that are integrated to the system, various operating limits and conditions that are placed on the system, etc.

[00228] In step 2304, the power analytics server is configured to utilize the operating mode settings, determined in step 2302, and the updated virtual system model of the electrical system to simulate and predict aspects relating to the real-time health, performance, reliability and availability of the electrical system. For example, the power analytics server can simulate and predict aspects relating to:

- **Power System Health and Performance**
  - Variations or deviations of electrical system performance from the power system design parameters. That is, the ability of the electrical system to resist system output variations or deviations from defined tolerance limits of the electrical system
  - Incorporation of performance and behavioral specifications for all the equipment and components that comprise the electrical system into a real-time management environment
- **System Reliability and Availability**

- As a function of different system, process and load point reliability indices
- Implementation of different technological solutions to achieve reliability centered maintenance targets and goals

• **Power System Capacity levels**

- As-designed total power capacity of the power system.
- How much of the total power capacity remains or is available (ability of the electrical system to maintain availability of its total power capacity)
- Present utilized power capacity.

• **Power System Strength and Resilience**

- Dynamic stability predictions across all contingency events
- Determination of protection system stress and withstand status

[00229] Additionally, the predictions may also relate to the real-time ability of the electrical system to: 1. sustain power demand and maintain sufficient active and reactive power reserve to cope with ongoing changes in demand and system disturbances due to contingencies, 2. operate safely with minimum operating cost while maintaining an adequate level of reliability, and 3. provide an acceptably high level of power quality (maintaining voltage and frequency within tolerable limits) when operating under contingency conditions.

[00230] Continuing with Figure 23, in step 2306, the power analytics server is configured to output the predictions in the form of a print out or display of text, graphics, charts, labels, and model views that readily communicates the health and predicted performance of the

electrical system in an elegant and efficient fashion. The information can be reported via a graphical user interface ("thick" or "thin" client) that illustrates the various components of the system in graphical format. In such embodiments, the report can simply comprise a graphical indication of the capacity of a subsystem or system, including the whole facility. The results can also be forwarded to associative memory engine 2308, where they can be stored and made available for predictions, pattern/sequence recognition and ability to imagine, e.g., via memory agents or other techniques, some of which are describe below, in step 2308.

[00231] In one embodiment, the model views are 3D (i.e., 3D Plant Lifecycle Model) model views of the various components, equipment and sub-systems that comprise the electrical system. Examples of some 3D model views 2502 are depicted in a client interface screenshot in Figure 25. The 3D model views 2502, can be generated by an integrated 3D visualization engine that is an integrated part of the power analytics server. In another embodiment, the model views are 2D model views of the various components, equipment and sub-systems making up the electrical system. An example of a 2D model view 2504 is also depicted in Figure 25.

[00232] As alluded to above, in step 2308, the results of the simulation and predictive analysis can be stored by an associative memory engine to support incremental learning about the power capacity characteristics of the system. That is, the results of the predictions, analysis, and real-time data may be fed, as needed, into an machine learning engine for pattern and sequence recognition in order to learn about the health, performance, reliability and availability of the electrical system. Additionally, concurrent inputs of various electrical, environmental, mechanical, and other sensory data can be used to learn about and determine

normality and abnormality of business and plant operations to provide a means of understanding failure modes and generate recommendations.

[00233] Figure 24 is a diagram illustrating how the 3D Visualization Engine works in conjunction with the other elements of the analytics system to provide 3D visualization of the health, reliability, and performance of an electrical system, in accordance with one embodiment. As depicted herein, the 3D Visualization Engine 2402 is integrated within a power analytics server 116 that is communicatively connected via a network connection 114 with a data acquisition hub 112, a client terminal 128 and a virtual system model database 526. The virtual system model database 526 is configured to store the virtual system model of the electrical system. The virtual system model is constantly updated with real-time data from the data acquisition hub 112 to effectively account for the natural aging effects of the hardware that comprise the total electrical power system, thus, mirroring the real operating conditions of the system. This provides a desirable approach to predicting the operational aspects of the monitored power system and for communicating the predicted aspects through 3D visualization models of the facility.

[00234] The 3D visualization engine 2402 is interfaced with the predictive elements of the power analytics server and communicatively connected to the data acquisition hub 112 and the client 128. The data acquisition hub 112 is communicatively connected via data connections 110 to a plurality of sensors that are embedded throughout the electrical system 102. The data acquisition hub 112 may be a standalone unit or integrated within the analytics server 116 and can be embodied as a piece of hardware, software, or some combination thereof. In one embodiment, the data connections 110 are "hard wired" physical data connections (e.g., serial, network, etc.). For example, a serial or parallel cable connection

between the sensors and the hub 112. In another embodiment, the data connections 110 are wireless data connections. For example, a radio frequency (RF), BLUETOOTH™, infrared or equivalent connection between the sensor and the hub 112. Real-time system data readings can be fed continuously to the data acquisition hub 112 from the various sensors that are embedded within the electrical system 102.

[00235] Continuing with Figure 24, the client 128 is typically a conventional thin-client or thick-client computing device that may utilize a variety of network interfaces (e.g., web browser, CITRIX™, WINDOWS TERMINAL SERVICES™, telnet, or other equivalent thin-client terminal applications, etc.) to access, configure, and modify the sensors (e.g., configuration files, etc.), analytics engine (e.g., configuration files, analytics logic, etc.), calibration parameters (e.g., configuration files, calibration parameters, etc.), virtual system modeling engine (e.g., configuration files, simulation parameters, choice of contingency event to simulate, etc.), 3D visualization engine (e.g., configuration files, 3D visualization parameters, etc.) and virtual system model of the system under management (e.g., virtual system model operating parameters and configuration files). Correspondingly, in one embodiment, the data from the various components of the electrical system and the real-time predictions (forecasts) about the health, performance, reliability and availability of the electrical system can be displayed on a client 128 display panel for viewing by a system administrator or equivalent. In another embodiment, the data may be summarized in a hard copy report 2404.

[00236] Figure 26 is a diagram illustrating how the Schematic User Interface Creator Engine works in conjunction with the other elements of the analytics system to automatically generate a schematic user interface for visualizing the health, reliability, and performance of

an electrical system, in accordance with one embodiment. Conventional electrical power system monitoring technologies typically rely on custom graphical design and user-interface development efforts in order to create a system schematic user interface (displayable on a client terminal) that can be linked to real-time sensory data output by the various components that comprise an electrical power system. In general, custom development efforts tend to be cumbersome and often require an extraordinarily amount of time to implement.

[00237] Given the complexity of modern electrical power systems and the significant challenges they pose to owners, operators and managers of critical (regional, national and international) electrical networks; there is a need for automated software tools that can allow the rapid deployment of schematic based user interfaces to provide precise and well understood perspective of the overall health and performance of the various components that comprise an electrical power system. Ideally, the tools can be configured to automatically read electrical system configuration data from a database containing a virtual system representation (i.e., virtual system model) of the electrical system, generate a schematic user interface view of the electrical system, and intelligently link the various components included in the user interface to the predicted, monitored and/or derived output/values of those various components.

[00238] As depicted herein, the Schematic User Interface Creator Engine 2602 can be integrated within a power analytics server 116 that can be communicatively connected via a network connection 114 with a data acquisition hub 112, a client terminal 128 and a virtual system model database 526. The virtual system model database 526 can be configured to store the virtual system model of the electrical system. The virtual system model can be constantly updated with real-time data from the data acquisition hub 112 to effectively

account for the natural aging effects of the hardware that comprise the total electrical power system, thus, mirroring the real operating conditions of the system. The Schematic User Interface Creator Engine 2602 can be configured to automatically create a schematic user interface that is representative of the electrical system and link that interface to the sensors monitoring the components (i.e., electrical equipment) that comprise the electrical system to enable real-time monitoring of the derived output/values from those components. The user interface can include a visual representation of each piece of electrical equipment (associated/tagged with a unique identifier) that comprises the electrical system. In one embodiment, the schematic user interface is based on a one-line diagram construct. In another embodiment, the schematic user interface is based on a technical system schematic diagram construct. However, it should be appreciated that the user interface can be based on any engineering diagram construct as long as the resulting interface can be displayed on a client terminal 128 to allow viewing by an operator/administrator.

[00239] In addition to being communicatively connected to the data acquisition hub 112 and the client 128, the Schematic User Interface Creator Engine 2602 can also be interfaced with the predictive elements of the power analytics server. The predictive elements of the power analytics server may relate to the real-time health, performance, reliability and availability of the electrical system. For example, the predictions can be indicative of the real-time ability of the electrical system to: 1. sustain power demand and maintain sufficient active and reactive power reserve to cope with ongoing changes in demand and system disturbances due to contingencies, 2. operate safely with minimum operating cost while maintaining an adequate level of reliability, and 3. provide an acceptably high level of power

quality (maintaining voltage and frequency within tolerable limits) when operating under contingency conditions.

[00240] The data acquisition hub 112 can be communicatively connected via data connections 110 to a plurality of sensors that can be embedded throughout the electrical system 102. The data acquisition hub 112 can be a standalone unit or integrated within the analytics server 116 and can be embodied as a piece of hardware, software, or some combination thereof. In one embodiment, the data connections 110 are "hard wired" physical data connections (e.g., serial, network, etc.). For example, a serial or parallel cable connection between the sensors and the hub 112. In another embodiment, the data connections 110 are wireless data connections. For example, a radio frequency (RF), BLUETOOTH™, infrared or equivalent connection between the sensor and the hub 112. Real-time system data readings can be fed continuously to the data acquisition hub 112 from the various sensors that are embedded within the electrical system 102.

[00241] Continuing with Figure 26, the client 128 can be a conventional thin-client or thick-client computing device that can utilize a variety of network interfaces (e.g., web browser, CITRIX™, WINDOWS TERMINAL SERVICES™, telnet, or other equivalent thin-client terminal applications, etc.) to access, configure, and modify the sensors (e.g., configuration files, etc.), power analytics engine (e.g., configuration files, analytics logic, etc.), calibration parameters (e.g., configuration files, calibration parameters, etc.), virtual system modeling engine (e.g., configuration files, simulation parameters, choice of contingency event to simulate, etc.), Schematic User Interface Creator Engine 2602 (e.g., configuration files, schematic interface algorithms, etc.) and virtual system model of the electrical system under management (e.g., virtual system model operating parameters and

configuration files). Correspondingly, in one embodiment, the real-time data from the various monitored components of the electrical system and the real-time predictions (forecasts) about the health, performance, reliability and availability of the electrical system can be simultaneously visualized on the schematic user interface that is displayed on a client terminal 128 for viewing by a system administrator or equivalent. This schematic user interface can provide a desirable approach to communicating the monitored and predicted operational aspects of an electrical system to an operator/administrator. In one embodiment, the schematic user interface is rendered in a 2-dimensional (2D) graphical image format. In another embodiment, the schematic user interface is rendered in a 3-dimensional (3D) graphical image format.

[00242] Figure 27 is an example process for automatically generating a schematic user interface for visualizing the health, reliability, and performance of an electrical system, in accordance with one embodiment. In one embodiment, the operational steps that comprise the process are implemented through a schematic user interface creator engine (application/software tool) that runs on the power analytics server. In another embodiment, the operational steps that comprise the process are implemented through a schematic interface creator engine that runs on a separate (network application) server that is communicatively connected to the power analytics server. In still another embodiment, the operational steps that comprise the process are implemented through a plurality of discrete applications that are distributed amongst one or more (network application) servers that are communicatively connected with the power analytics server. It should be understood, however, that the application(s) can be distributed in any configuration as long as the

application(s) can communicatively access the power analytics server to implement the process.

[00243] The process begins with step 2702, where system configuration data can be extracted from a virtual system model of the electrical system. The virtual system model can be stored in one or more virtual system model database(s) that are communicatively connected to the power analytics server. The configuration data can be stored in the memory of the power analytics server (or a network application server) and can include the unique identifiers (i.e., node IDs) of each of the components (i.e., piece of electrical equipment) that comprise the virtual system model, connectivity information (i.e., the electrical connectivity between the various virtual system model components and/or the data connectivity with the sensors monitoring those components) and/or equipment specific information such as bus or branch specific equipment type (e.g., generator, circuit breaker, transformer, motor, fuse, static load, etc.).

[00244] In step 2704, a logical construct of the virtual system model can be constructed from the system configuration data. In one embodiment, the logical construct can be created in an Extensible Markup Language (XML) format. In another embodiment, the logical construct can be created in an Extensible HyperText Markup Language (XHTML) format. It should be appreciated that the logical construct can be created using any mark-up language as long as it can be utilized to convey system configuration information about the components (i.e., electrical equipment) that make up the virtual system model.

[00245] In step 2706, one or more graphical objects can be generated to represent one or more pieces of electrical equipment included in the logical construct. This can be accomplished through the schematic user interface creator engine or equivalent application(s)

parsing the system configuration data stored in the logical construct and generating appropriate symbol block(s) and/or graphical object(s) for each piece of electrical equipment that comprise the electrical system. The symbol block(s) or graphical object(s) that are generated can then be individually organized as buses and/or branches.

[00246] In step 2708, the one or more graphical objects can be organized to generate a schematic user interface layout of the electrical system. This can be accomplished using a self-executing algorithm that can be either an integrated component of the schematic user interface creator engine or a separate discrete application that is configured to work in conjunction with the schematic user interface creator engine. In one embodiment, the self-executing algorithm is a .NET based application. In another embodiment, the self-executing algorithm is an ACTIVE X based application. In still another embodiment, the self-executing algorithm is a JAVA based application. It should be understood, however, that the self-executing algorithm can be created using any type of programming language as long as the resulting algorithm can function either as a component of the schematic user interface creator engine or in conjunction with the same.

[00247] In one embodiment, the self-executing algorithm is in a force directed layout format. In another embodiment, the self-executing algorithm is in a tree layout format. In still another embodiment, the self-executing algorithm is in a layered diagraph layout format. It should be appreciated that the self-executing algorithm can follow any format as long as each of the one ore more graphical objects/symbol blocks in the resulting schematic user interface layout can later be linked to a corresponding piece of electrical equipment that comprise the electrical system.

[00248] After the schematic user interface layout of the electrical system is generated, it can be further optimized using the schematic interface creator engine (or equivalent application) to scan the schematic user interface layout and re-align the graphical object(s) based on one or more user selected optimization criteria.

[00249] In step 2710, each of the one or more graphical objects in the schematic user interface layout can be communicatively linked to sensors configured to monitor the real-time operational status of the one or more pieces of electrical equipment represented by the one or more graphical objects. This can be accomplished by intelligently linking the unique identifiers (e.g., equipment IDs) associated with each of the graphical objects/symbol blocks to their corresponding database files and creating a tag or communication channel with the same unique identifier to allow the files to be populated with data from the electrical equipment associated with each unique identifier. For example, a Graphical Object A with a unique identifier of "001" can be linked to the database file "A" which is associated with the "001" identifier. A communication channel "001" can then be opened to allow data, acquired from a piece of electrical equipment associated with the "001" identifier, to populate database file "A."

[00250] The communication linkage between the graphical objects in the schematic user interface layout and the database(s) that store real-time data acquired from the operation of the electrical equipment allow the schematic user interface to dynamically represent fluctuations in the real-time health, performance, reliability and availability of the electrical system. For example, the buses and branches in the schematic user interface layout can be configured so that they change colors and/or become animated in response to the monitored real-time data of and/or predicted values for the electrical system during operation.

[00251] Figure 28 is a diagram illustrating how the Energy Management System Engine works in conjunction with the other elements of the analytics system to intelligently monitor and manage the cost, quality and reliability of energy generated and/or utilized by an electrical system, in accordance with one embodiment. Conventional approaches to energy management typically rely on real-time data readings supplied directly from power quality meters and sensors that are interfaced with the components (that comprise an electrical system) to provide a simple live metrics (e.g., voltage, current, frequency, etc.) of how the electrical system is operating. Alternatively, conventional energy management systems may also permit basic historical trending and rudimentary statistical methods to be performed to generate a historical energy profile of how the electrical system has previously operated.

[00252] That is, a conventional energy management system only presents a user (i.e., electrical system owner, administrator, and/or operator) with a view of how the electrical system is currently operating and/or has operated in the past without having the ability to make predictions about how the electrical system will operate in the future or allow the running of simulations based on user programmed "what-if" scenarios. The ability to predict the active power demand, system losses, reactive power demand and other energy parameters via a model (i.e., virtual system model) of the electrical system that can age and synchronize itself in real-time with the electrical system's actual operating conditions is critical in obtaining accurate predictions of the system's energy efficiency (i.e., cost of losses that are inherent to the electrical system and those due to the inefficient operation of the electrical system), energy costs, reliability, availability, health and performance. Without operational conditions synchronization or an aging ability, these predictions are of little value as they are not reflective of the actual facility status and may lead the user to make false conclusions.

[00253] Given the attendant challenges that modern electrical power systems pose to owners, operators and managers of critical (facility specific, regional, national and international) electrical networks and the shortcomings of conventional energy management systems; there is a need for an energy management system that integrates a real-time energy cost computational algorithm (i.e., real-time utility power pricing engine) along with a logical power flow, forecasting, state estimation, reliability and availability model (i.e., virtual system model) of the electrical system, a data acquisition system, and power system simulation engines with a logic based approach to the adjustment of key parameters within the virtual system model to synchronize the virtual system model with the real facility and effectively "age" the virtual system model along with the electrical system it is associated with. Such a system can be configured to make predictions regarding the expected energy efficiency, energy costs, cost of inherent system losses and cost due to running the electrical system at poor power factors along with calculating and comparing the availability and reliability of the electrical system in real-time. These predictions and calculations can then be used to arrive at actionable, reliability centered maintenance and energy management strategies for mission critical or business critical operations which may lead to the re-alignment of the electrical system for optimized performance, maintenance or security.

[00254] As depicted herein, the Energy Management System Engine 2802 can be integrated within a power analytics server 116 that can be communicatively connected via a network connection 114 with a data acquisition hub 112, a client terminal 128 and a virtual system model database 526. The virtual system model database 526 can be configured to store the virtual system model of the electrical system 102. The virtual system model can be constantly updated with real-time data from the data acquisition hub 112 to effectively

account for the natural aging effects of the hardware that comprise the total electrical power system, thus, mirroring the real operating conditions of the system.

[00255] In addition to being communicatively connected to the data acquisition hub 112 and the client 128, the Energy Management System Engine 2802 can also be interfaced with the predictive elements of the power analytics server. The predictive elements of the power analytics server 116 may relate to the real-time health, performance, efficiency, reliability and availability of the electrical system 102. For example, the predictions can be indicative of the real-time ability of the electrical system 102 to: 1. sustain power demand and maintain sufficient active and reactive power reserve to cope with ongoing changes in demand and system disturbances due to contingencies, 2. operate safely with minimum operating cost while maintaining an adequate level of reliability, and 3. provide an acceptably high level of power quality (maintaining voltage and frequency within tolerable limits) when operating under contingency conditions.

[00256] The Energy Management System Engine 2802 can be configured to process the real-time data output, the predicted data output, historical data output and forecasted aspects about the operation of the electrical system 102 to generate a user interface that can convey an operational state of the electrical system 102 to a user (i.e., electrical system 102 owner/system administrator/operator). In one embodiment, the operational state can be the real-time operational performance of the electrical system 102. In another embodiment, the operational state can be the predicted operational performance of the electrical system 102. In still another embodiment, the operational state can be a historical data trending display of the historical operational performance of the electrical system 102.

[00257] For example, the Energy Management System Engine 2802 can be configured to generate a text-based or a graphics-based user interface that conveys real-time, predicted and/or historical operational performance of the electrical system 102 that can include real-time, predicted or historical information regarding the electrical system's 102 energy efficiency (i.e., the cost of energy utilized by the electrical system 102, the cost of intrinsic power losses within the electrical system 102, the cost of power losses due to the electrical system 102 running at poor power factors), reliability (i.e., the predicted ability of the electrical system 102 to withstand a contingency event that results in stress to the electrical system 102), availability (e.g., the predicted ability of the electrical system 102 to maintain availability of total power capacity), health and performance. Moreover, the user interface can also include a visual representation of each piece of electrical equipment (associated/tagged with a unique identifier) that comprises the electrical system 102. In one embodiment, the user interface is based on a one-line diagram construct. In another embodiment, the user interface is based on a technical system schematic diagram construct. However, it should be appreciated that the user interface can be based on any engineering diagram construct as long as the resulting interface can be displayed on a client terminal 128 to allow viewing by an operator/administrator.

[00258] The data acquisition hub 112 can be communicatively connected via data connections 110 to a plurality of sensors that can be embedded throughout the electrical system 102. The data acquisition hub 112 can be a standalone unit or integrated within the analytics server 116 and can be embodied as a piece of hardware, software, or some combination thereof. In one embodiment, the data connections 110 are "hard wired" physical data connections (e.g., serial, network, etc.). For example, a serial or parallel cable

connection between the sensors and the hub 112. In another embodiment, the data connections 110 are wireless data connections. For example, a radio frequency (RF), BLUETOOTH™, infrared or equivalent connection between the sensor and the hub 112. Real-time system data readings can be fed continuously to the data acquisition hub 112 from the various sensors that are embedded within the electrical system 102.

[00259] Continuing with Figure 28, the client 128 can be a conventional thin-client or thick-client computing device that can utilize a variety of network interfaces (e.g., web browser, CITRIX™, WINDOWS TERMINAL SERVICES™, telnet, or other equivalent thin-client terminal applications, etc.) to access, configure, and modify the sensors (e.g., configuration files, etc.), power analytics engine (e.g., configuration files, analytics logic, etc.), calibration parameters (e.g., configuration files, calibration parameters, etc.), virtual system modeling engine (e.g., configuration files, simulation parameters, choice of contingency event to simulate, etc.), Energy Management System Engine 2802 (e.g., configuration files, etc.) and virtual system model of the electrical system 102 under management (e.g., virtual system model operating parameters and configuration files). Correspondingly, in one embodiment, the real-time data from the various monitored components of the electrical system 102 and the real-time predictions (forecasts) about the health, performance, reliability and availability of the electrical system 102 can be simultaneously visualized on the user interface that is displayed on a client 128 terminal for viewing by a system administrator or equivalent. This user interface can provide a desirable approach to communicating the monitored and predicted operational aspects of an electrical system 102 to an operator/administrator. In one embodiment, the user interface is rendered

in a 2-dimensional (2D) graphical image format. In another embodiment, the user interface is rendered in a 3-dimensional (3D) graphical image format.

[00260] Figure 29 is a logic flow diagram depicting how the various elements of the Energy Management System can interact to provide intelligent energy monitoring and management of an electrical system, in accordance with one embodiment. As depicted, the Energy Management System can include a power analytics server 116 that can be communicatively connected to a real-time historical data trending database 2902, a virtual system model database 526, a data acquisition component 112 and a conventional web browser 2904. The data acquisition component 112 can be configured to communicate "real-time" sensor data readings 2906 from the various sensors interfaced throughout the electrical system to the analytics server 116.

[00261] In one embodiment, the connection is a "hardwire" physical connection. For example, the power analytics server 116 can be communicatively connected (via Category 5 (CAT5), fiber optic or equivalent cabling) to the data acquisition component 112. In another embodiment, the connection is a wireless connection (e.g., Wi-Fi, BLUETOOTH, etc.). For example, a wireless connection utilizing an 802.11b/g or equivalent transmission format. In still another embodiment, the connection can be a combination of “hardwire” and “wireless” connection elements that are linked together based on the particular requirements of the Energy Management System.

[00262] Still with Figure 29, the power analytics server 116 can be configured to host one or more analytic engines that allow the Energy Management System to perform its various functions. For example, as depicted herein Figure 29, the power analytics server 116 can host a machine learning engine 2908, a virtual system modeling engine 2922 and/or a

utility power pricing engine 2914. The machine learning engine 2908 can be configured to work in conjunction with the virtual system modeling engine 2922 and a virtual system model of the electrical system to make real-time predictions (i.e., forecasts) about the various operational aspects of the electrical system. The machine learning engine 2908 work by processing and storing patterns observed during the normal operation of the electrical system over time. These observations are provided in the form of real-time data captured using a multitude of sensors that are imbedded within the electrical system.

[00263] The utility pricing engine 2914 can be configured to access a utility power pricing data source 2916 (that includes energy cost tables and other power billing data) to generate real-time energy cost and usage data 2910 that is reflective of the operational efficiency and performance of the electrical system. Examples of real-time energy cost and usage data 2910 can include, but are not limited to: 1. the real-time cost of energy utilized by the electrical system (energy cost), 2. the real-time cost of intrinsic power losses within the electrical system (cost of losses), and/or 3. the real-time cost of power losses due to the electrical system running at poor power factors (cost due to poor power factor).

[00264] In one embodiment, the utility power pricing data source 2916 is populated with static utility power pricing data 2918. That is, utility power pricing data that is either directly supplied by a user of the Energy Management System or data that is extracted from utility data pricing data sheets/tables that are downloaded from the utility power provider supplying electrical power to the electrical system. In another embodiment, the utility power pricing data source 2916 is populated with real-time dynamic power pricing data 2920 directly from the utility power provider supplying the electrical power to the electrical system. For example, the real-time dynamic power pricing data 2920 can be power spot

pricing that is set by a utility power provider based on a variety of different real-time power grid operational factors (e.g., power grid load, cost of power generation, etc.).

[00265] Continuing with Figure 29, the virtual system model database 526 can be configured to store a virtual system model of the electrical system. The virtual system model can be constantly updated with real-time data from the data acquisition hub 112 to effectively account for the natural aging effects of the hardware that comprise the total electrical power system, thus, mirroring the real operating conditions of the system. Moreover, the virtual system model stored in the virtual system model database 526 can be accessed by the power analytic engines (i.e., machine learning engine 2908 and virtual system modeling engine 2922) that are part of the Energy Management System to make various types of power analytics forecasts/predictions including, but not limited to: power system reliability predictions 2928, power system operations forecasts 2926, power system state estimations 2924 and/or power system operational cost predictions (i.e., cost of energy, cost of losses and cost associated with running the electrical system inefficiently).

[00266] The real-time historical data trending database 2902 can be configured to store the real-time data output, the predicted data output and the forecasted aspects output from the power analytics server 116 and apply a historical trending algorithm to generate a historical data trending display that is indicative of the historical performance of the electrical system. The historical data trending display can present many different categories of data relating to the historical operation of the electrical system, including but not limited to:

- Active Power (kW)
- Reactive Power (kVAR)
- Power Factor (%)

- Humidity (%)
- Temperature (°F)
- Total Cost of Energy ($)
- Total Penalty Cost Due to Poor Power Factor ($)
- Frequency (Hz)
- Voltage (p.u.)
- Cost of Losses ($)

[00267] In one embodiment, the network connection 114 is a "hardwired" physical connection. For example, the data acquisition hub 112 may be communicatively connected (via Category 5 (CAT5), fiber optic or equivalent cabling) to a data server (not shown) that is communicatively connected (via CAT5, fiber optic or equivalent cabling) through the Internet and to the analytics server 116 server. The analytics server 116 being also communicatively connected with the Internet (via CAT5, fiber optic, or equivalent cabling). In another embodiment, the network connection 114 is a wireless network connection (e.g., Wi-Fi, WLAN, etc.). For example, utilizing an 802.11b/g or equivalent transmission format. In practice, the network connection utilized is dependent upon the particular requirements of the monitored system 102.

[00268] The energy management system engine, hosted by the power analytics server 116, can be configured to collect and process the real-time data output, the predicted data output and the forecasted aspects output from the various analytic engines (i.e., a machine learning engine 2908, a virtual system modeling engine 2922 and/or a utility power pricing engine 2914) that comprise the Energy Management System and generate a text or graphical user interface that conveys an operational state of the electrical system.

[00269] The embodiments described herein, can be practiced with other computer system configurations including hand-held devices, microprocessor systems, microprocessor-based or programmable consumer electronics, minicomputers, mainframe computers and the like. The embodiments can also be practiced in distributing computing environments where tasks are performed by remote processing devices that are linked through a network.

[00270] It should also be understood that the embodiments described herein can employ various computer-implemented operations involving data stored in computer systems. These operations are those requiring physical manipulation of physical quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. Further, the manipulations performed are often referred to in terms, such as producing, identifying, determining, or comparing.

[00271] Any of the operations that form part of the embodiments described herein are useful machine operations. The invention also relates to a device or an apparatus for performing these operations. The systems and methods described herein can be specially constructed for the required purposes, such as the carrier network discussed above, or it may be a general purpose computer selectively activated or configured by a computer program stored in the computer. In particular, various general purpose machines may be used with computer programs written in accordance with the teachings herein, or it may be more convenient to construct a more specialized apparatus to perform the required operations.

[00272] Certain embodiments can also be embodied as computer readable code on a computer readable medium. The computer readable medium is any data storage device that can store data, which can thereafter be read by a computer system. Examples of the

computer readable medium include hard drives, network attached storage (NAS), read-only memory, random-access memory, CD-ROMs, CD-Rs, CD-RWs, magnetic tapes, and other optical and non-optical data storage devices. The computer readable medium can also be distributed over a network coupled computer systems so that the computer readable code is stored and executed in a distributed fashion.

[00273] Conventional approaches to energy monitoring and management typically rely on real-time data readings supplied directly from power quality meters and sensors that are interfaced with the components (that comprise an electrical system) to provide a simple live metrics (e.g., voltage, current, frequency, etc.) of how the electrical system is operating. Furthermore, conventional simulation technologies are PC or thick client applications that require the installation and management of desktop software in order to operate. Existing solutions do not take advantage of the next generation Web 2.0 workplace and fail to deliver a set of rich power system design, analysis Internet applications (RIAs) which can substantially improve the way power system engineers can e.g. create and access content, complete sizing and calculations, and produce reports.

[00274] Figure 30 is a diagram illustrating how the various elements of the Client/Server system can interact to provide intelligent energy monitoring and management of an electrical system, in accordance with one embodiment. According to one embodiment herein, a true client/server application framework can combine a rich user interface capability of desktop power system engineering client software with the universally accessible, no-download features of web-delivered applications. Accordingly, web-delivered applications can deliver a true thin client system for such tasks as e.g. power system design, analysis, sizing calculations, and reporting applications. This method is an ideal solution for addressing the

need for an outstanding user experience that empowers power system engineers and design specialists to access applications via an all-in-one seamless, personalized, and highly visual engineering design and information workplace based on a RIA technology such as, for instance, AJAX™, FLASH™, DHTML, and others.

[00275] According to one embodiment herein, a system may consist of both a server-side component and client-side components and communicate via a web application server. For instance the server side system can be implemented as a Java Servlet that can run in any Java servlet container (e.g. a J2EE servlet container or a similar JAVA VIRTUAL MACHINE™ technology). The web application server can communicate with the energy monitoring infrastructure and deliver derived content to the client terminal (e.g. via servlets) related to, e.g., the virtual system modeling, system analytics, schematics, reports, or user management.

[00276] As depicted herein, the web application server 3002 can be communicatively connected via a network connection 114 with a data acquisition hub 112, and a client terminal 128. The data acquisition hub 112 can be communicatively connected via data connections 110 to a plurality of sensors that can be embedded throughout the electrical system 102. The data acquisition hub 112 can be a standalone unit or integrated within the web application server 3140 and can be embodied as a piece of hardware, software, or some combination thereof. In one embodiment, the data connections 110 can be "hard wired" physical data connections (e.g., serial, network, etc.). For example, a serial or parallel cable connection between the sensors and the hub 112. In another embodiment, the data connections 110 are wireless data connections. For example, a radio frequency (RF), BLUETOOTH™, infrared or equivalent connection between the sensor and the hub 112.

Real-time system data readings can be fed continuously to the data acquisition hub 112 from the various sensors that are embedded within the electrical system 102.

[00277] The client 128 can be a conventional thin-client or thick-client computing device that can utilize a variety of network interfaces (e.g., web browser, CITRIX™, WINDOWS TERMINAL SERVICES™, telnet, or other equivalent thin-client terminal applications, etc.) to access, configure, and modify the sensors (e.g., configuration files, etc.), power analytics engine (e.g., configuration files, analytics logic, etc.), calibration parameters (e.g., configuration files, calibration parameters, etc.), virtual system modeling engine (e.g., configuration files, simulation parameters, choice of contingency event to simulate, etc.), power analytics engine(s) (e.g., configuration files, etc.) and virtual system model of the electrical system 102 under management (e.g., virtual system model operating parameters and configuration files). Correspondingly, in one embodiment, the real-time data from the various monitored components of the electrical system 102 and the real-time predictions (forecasts) about the health, performance, reliability and availability of the electrical system 102 can be simultaneously visualized on the user interface that is displayed on a client 128 terminal for viewing by a system administrator or equivalent. This user interface can provide a desirable approach to communicating the monitored and predicted operational aspects of an electrical system 102 to an operator/administrator. In one embodiment, the user interface is rendered in a 2-dimensional (2D) graphical image format. In another embodiment, the user interface is rendered in a 3-dimensional (3D) graphical image format.

[00278] The virtual system model can be constantly updated with real-time data from the data acquisition hub 112 to effectively account for the natural aging effects of the hardware

that comprise the total electrical power system, thus, mirroring the real operating conditions of the system.

[00279] Figure 31 is a diagram illustrating various elements of the web application server illustrated in Figure 30, in accordance with one embodiment. In one embodiment, the web application server 3002 can comprise a virtual system model database 526, a power analytic simulation engine 3110, and an analytics services engine 3140. The power analytic simulation engine 3110 can comprise a virtual system modeling engine 124 (as previously described). Optionally, the power analytic simulation engine 3110 can also comprise a number of other engines as described above, for instance, an energy management system engine 2802, a schematic user interface creator engine 2602, a HTM Pattern Recognition and Machine Learning Engine 551, a reporting engine 3114, or an equipment library editor engine 3112. The power analytic simulation engine 3110 may also include other engines described above which are communicatively connected to the virtual system model database 526.

[00280] A virtual system model database 526 can be communicatively connected to the data acquisition component, such as a data acquisition hub 112, and can be configured, for instance, to store a virtual system model of the electrical system. A virtual system modeling engine 526 can be configured to generate a predicted data output for the electrical system utilizing the virtual system model of the electrical system. An analytics engine 3140 can be communicatively connected to the virtual system model database, and can be configured to monitor the real-time data output and the predicted data output of the electrical system 102, and to initiate a calibration and synchronization operation to update the virtual system model

when a difference between the real-time data output and the predicted data output exceeds a threshold.

[00281] According to one embodiment described herein, the virtual system modeling engine 124 may be provided via a graphical and/or text based data entry and layout interface. This engine can support modeling of electrical power system networks such as AC (e.g., 3phase, 1phase, and 3phase/1phase mixed networks) and DC systems or AC/DC mixed networks. Additionally, it can support control system modeling and analysis for time domain simulation models or it can support grounding, cable sizing, and other power system modeling activities as needed. The model database solution and function set can capture and store not only the network topography but also connectivity, interdependencies, costs, part numbers, weight, physical dimensions along with the mechanical, electrical, and other physics based characteristics of the equipment within the electrical network. The database shall also support features such as revision control, revision history, tracking, trending and roll-back features along with Save, Save-As, import and export of data, drawings and other input sources. The database can also contain business logic to expedite the modeling process.

[00282] The equipment library editor engine 3112 can communicate with an equipment library database 3134 to provide a library of equipment, operating characteristics (e.g. electrical characteristics, mechanical characteristics, etc.). The equipment library editor engine 3112, can be used to add, edit, or delete database records within the equipment library database 3134. Furthermore, the equipment library editor engine 3112 can allow users to create and interact with their own custom library of equipment or to a global library which is used by all users.

[00283] The analytics services engine 3140 in various embodiments, can be configured to perform functions and extract data from the virtual system model database 526. In one embodiment, the analytics services engine 3140 can perform requested simulations, reporting, and analysis via an appropriate graphical/textual/audio format as appropriate. The analytics services engine 3140, can be used to input data and check connectivity errors. It can also be used for short circuit and fault analysis analytics (IEEE/ANSI/IEC and similar) for AC and DC systems. The analytics services engine 3140 can provide Power Flow Simulation and voltage control features including load analysis for AC and DC systems. The analytics services engine can be configured to provide protective device coordination and automatic selection expert system type technologies for AC and DC systems.

[00284] The analytics services engine 3140 can also be configured to provide arc flash simulation and reporting for AC and DC systems per latest NFPA and IEEE standards such as NFPA 70E and IEEE 1584 for example. Additionally, the analytics services engine 3140 can be configured to perform transient stability simulation and reporting. The analytics services engine 3140 can be configured to perform power quality analysis and harmonic simulations and mitigation including automatic filter sizing for complex power systems, including phase dependant networks. The analytics services engine 3140 can also be configured to provide protective device evaluation for electrical power systems.

[00285] The power analytics engine 3110 can also provide reporting functionality via a reporting engine 3114. The reporting engine 3114 can communicate to the virtual system model database 526 and/or a reporting database in order to generate a display for reports, permit saving, printing, formatting, and exporting reports. For instance, the reports can

include input data reports, error checking reports, etc., and can be generated in a graphical format, a textual format, or a combination of graphical and textual format.

[00286] Additionally, the server side may include customer interface engines 3102, such as a customer management engine 3106 or an e-commerce engine 3104. In addition to the virtual system model database 526, according to one embodiment herein, the web application server may also comprise or be in communication with additional databases 3130 as needed. For instance, database(s) for users rights management to store electrical on-line diagram models, schematics, reports or other features.

[00287] For example, according to one embodiment, an e-commerce engine 3104 can be configured to communicate with a billing database 3132 to provide an e-commerce component which can be configured to manage use payments and transactions.

[00288] In another embodiment, a customer management engine 3106 can be configured to communicate with a customer database 3136 to provide an customer management component which can be configured to manage customer accounts records, end user rights, and user access levels.

[00289] In additional embodiments, support components can be added to the web application server. These components can include an engine component or a database component as needed. For example, a support component can be added along with on-line reference libraries and tutorials. These can be stored in various mediums for example as rich multimedia files, interactive references, or standard print materials stored in an electronic format (such as a PDF).

[00290] Thus, in the various embodiments the web application server is able to transform the way electrical power system design and simulation applications work together on the

Web and enables delivery of power system engineering applications that combine the rich user interface capabilities of desktop client software with the universally accessible, no-down features of web-delivered applications.

[00291] Figure 32 is a logic flow diagram depicting how the various elements of the Client/Server system can interact to provide intelligent energy monitoring and management of an electrical system, in accordance with one embodiment. According to one embodiment, a method for interacting with an electrical system management application to perform power analytic analysis simulations on a virtual system model of the electrical power system, can comprise: in step 3202, a web application server, receiving a user request to access the electrical management system from a client terminal, and in step 3204, sending a user interface for interaction with the electrical management system to a client terminal; in step 3206, the client terminal, receiving the user interface for interaction with the electrical management system, and in step 3208, sending user interaction data to the electrical system management application; and in step 3210, the electrical system management application, performing analytic analysis on a virtual system model of the electrical power system.

Additionally, in one embodiment described herein, a method for interacting with an electrical system management application to perform power analytic analysis simulations on a virtual system model of the electrical power system can further comprise: the web application server, communicating the user interaction data to a virtual system model engine; the virtual system model engine, accessing a virtual system model of the electrical system stored in a virtual system model database, generating a predicted data output for the electrical system utilizing the virtual system model of the electrical system, and communicating the generated predicted data to the web application server.

Furthermore, in one embodiment described herein, a method for interacting with an electrical system management application to perform power analytic analysis simulations on a virtual system model of the electrical power system can further comprise: the web application server, communicating the user interaction data to an analytics engine; and the analytics engine, monitoring the real-time data output and the predicted data output of the electrical system stored in a virtual system model database, and initiating a calibration and synchronization operation to update the virtual system model when a difference between the real-time data output and the predicted data output exceeds a threshold.

[0100] Any of the operations that form part of the embodiments described herein are useful machine operations. The invention also relates to a device or an apparatus for performing these operations. The systems and methods described herein can be specially constructed for the required purposes, such as the carrier network discussed above, or it may be a general purpose computer selectively activated or configured by a computer program stored in the computer. In particular, various general purpose machines may be used with computer programs written in accordance with the teachings herein, or it may be more convenient to construct a more specialized apparatus to perform the required operations.

[0101] The embodiments described herein can also be embodied as computer readable code on a computer readable medium. The computer readable medium is any data storage device that can store data, which can thereafter be read by a computer system. Examples of the computer readable medium include hard drives, network attached storage (NAS), read-only memory, random-access memory, CD-ROMs, CD-Rs, CD-RWs, magnetic tapes, and other optical and non-optical data storage devices. The computer readable

medium can also be distributed over a network coupled computer systems so that the computer readable code is stored and executed in a distributed fashion.

[0102] Although a few embodiments of the present invention have been described in detail herein, it should be understood, by those of ordinary skill, that the present invention may be embodied in many other specific forms without departing from the spirit or scope of the invention. Therefore, the present examples and embodiments are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details provided therein, but may be modified and practiced within the scope of the appended claims.

CLAIMS

1. A system for intelligent web-based management of an electrical system, comprising:

a data acquisition component communicatively connected to a sensor configured to acquire real-time data output from the electrical system;

a web application server communicatively connected to the data acquisition component, the web server configured to transmit a user interface to a client terminal, the web application server comprising:

a virtual system model database communicatively connected to the data acquisition component, the virtual system model database configured to store a virtual system model of the electrical system,

a power analytic simulation engine comprising a virtual system modeling engine communicatively connected to the virtual system model database, the virtual system modeling engine configured to generate a predicted data output for the electrical system utilizing the virtual system model of the electrical system, and

an analytics engine communicatively connected to the virtual system model database, the analytics engine configured to monitor the real-time data output and the predicted data output of the electrical system, and to initiate a calibration and synchronization operation to update the virtual system model when a difference between the real-time data output and the predicted data output exceeds a threshold, and

a client terminal communicatively connected to the web application server, the client terminal configured to display the user interface.

2. A system as in claim 1, wherein the web application server further comprising a customer interface engine and a customer interface database.

3. A system as in claim 2, wherein the customer interface engine comprises an e-commerce engine configured to manage a billing record, and wherein the customer interface database is communicatively connected to the customer interface engine, and the customer interface database comprises a billing database configured to store the billing record.

4. A system as in claim 2, wherein the customer interface engine comprises a customer management engine, the customer management engine configured to manage a customer record, and wherein the customer interface database comprises a customer database communicatively connected to the customer management engine, the customer database configured to store the customer record.

5. A system as in claim 4, wherein the customer record comprises a customer permission level.

6. A system as in claim 1, the power analytic simulation engine further comprising:

an equipment library engine configured to manage an equipment library record; and

an equipment library database communicatively connected to the equipment library engine, the equipment library database configured to store the equipment library record.

7. A system as in claim 6, wherein the equipment library engine is configured to allow a user to create or modify a user specific library of equipment.

8. A system as in claim 6, wherein the equipment library engine is configured to allow a user to create or modify a global library of equipment.

9. A system as in claim 1, the power analytic simulation engine further comprising a real-time energy pricing engine connected to a utility power pricing data table, the real-time energy pricing engine configured to generate the real-time utility power pricing data.

10. A system as in claim 1, the power analytic simulation engine further comprising a reporting engine configured to permit saving, printing, or exporting reports.

11. A system as in claim 10, wherein the reports are in graphical format.

12. A system as in claim 10, wherein the reports are in a text format.

13. A system as in claim 1, wherein the web server is configured to use servlets to deliver content to the client terminal.

14. A method for interacting with an electrical system management application to perform power analytic analysis simulations on a virtual system model of the electrical power system, comprising:

a web application server,

receiving a user request to access the electrical management system from a client terminal, and

sending a user interface for interaction with the electrical management system to a client terminal;

the client terminal,

receiving the user interface for interaction with the electrical management system, and

sending user interaction data to the electrical system management application; and

the electrical system management application,

performing analytic analysis on a virtual system model of the electrical power system.

15. A method as in claim 14, further including:

the web application server,

communicating the user interaction data to a virtual system model engine;

the virtual system model engine,

accessing a virtual system model of the electrical system stored in a virtual system model database,

generating a predicted data output for the electrical system utilizing the virtual system model of the electrical system, and

communicating the generated predicted data to the web application server.

16. A method as in claim 14, further comprising:

the web application server,

communicating the user interaction data to an analytics engine; and

the analytics engine,

monitoring the real-time data output and the predicted data output of the electrical system stored in a virtual system model database, and

initiating a calibration and synchronization operation to update the virtual system model when a difference between the real-time data output and the predicted data output exceeds a threshold.

17. A method as in claim 11, wherein the user interface is provided in a graphical format.

18. A method as in claim 12, wherein the web application server transmits the user interface to the client terminal through application servlets.

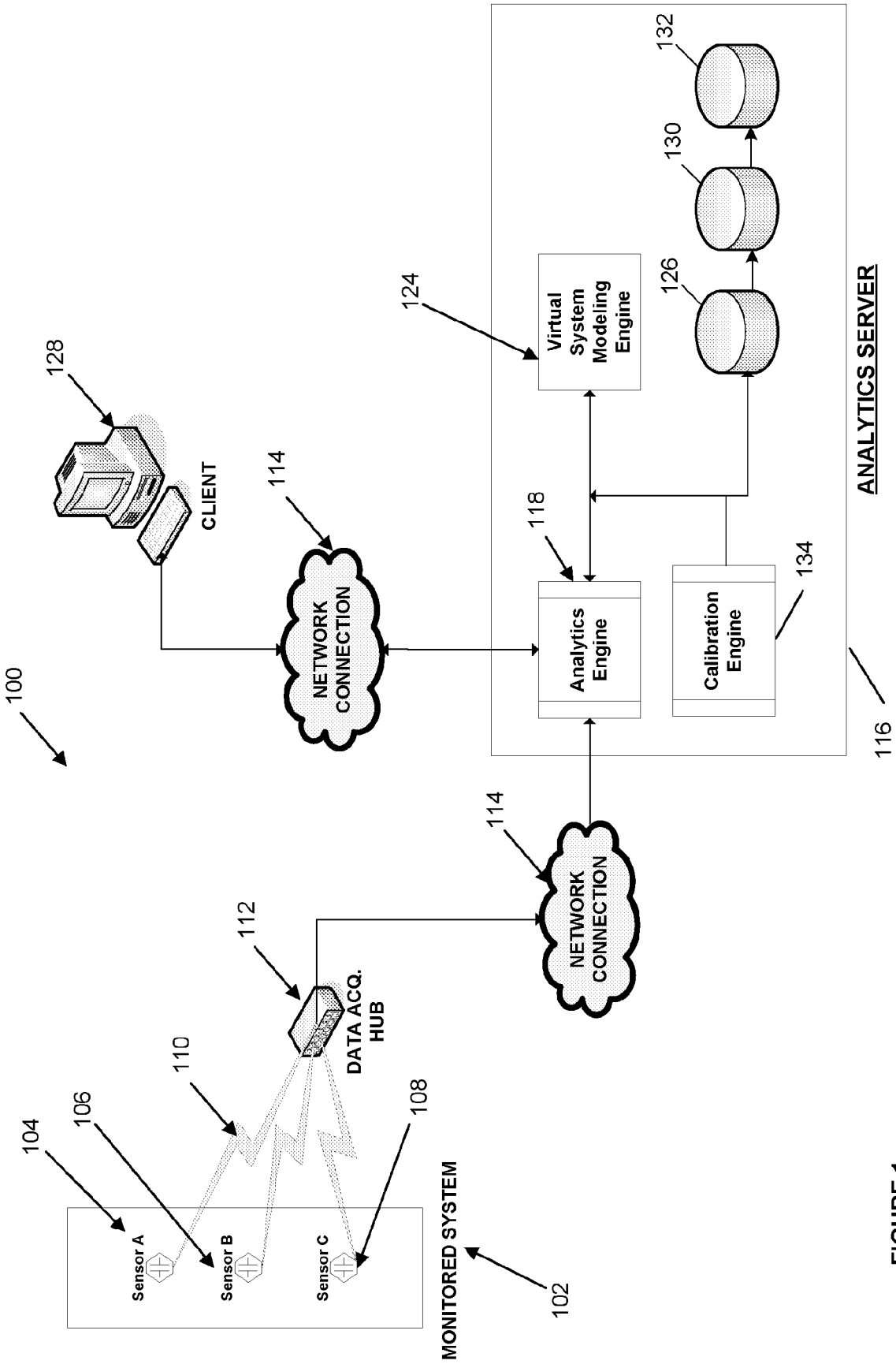

100
128
CLIENT
114
NETWORK CONNECTION
124
Virtual System Modeling Engine
132
130
126
118
Analytics Engine
Calibration Engine
134
ANALYTICS SERVER
116
114
NETWORK CONNECTION
112
DATA ACQ. HUB
110
104
106
108
Sensor A
Sensor B
Sensor C
MONITORED SYSTEM
102

FIGURE 1

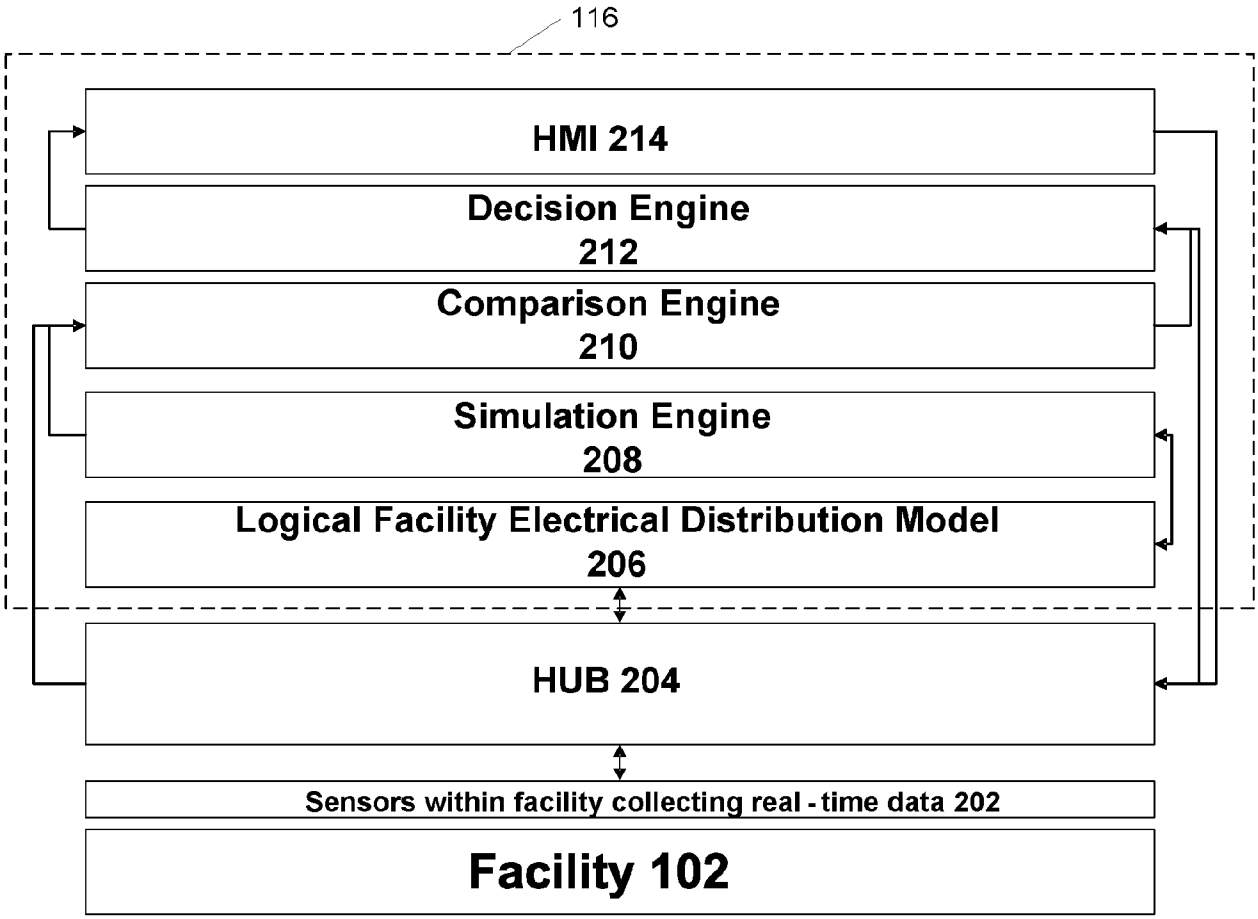

116
HMI 214
Decision Engine
212
Comparison Engine
210
Simulation Engine
208
Logical Facility Electrical Distribution Model
206
HUB 204
Sensors within facility collecting real - time data 202
Facility 102

FIGURE 2

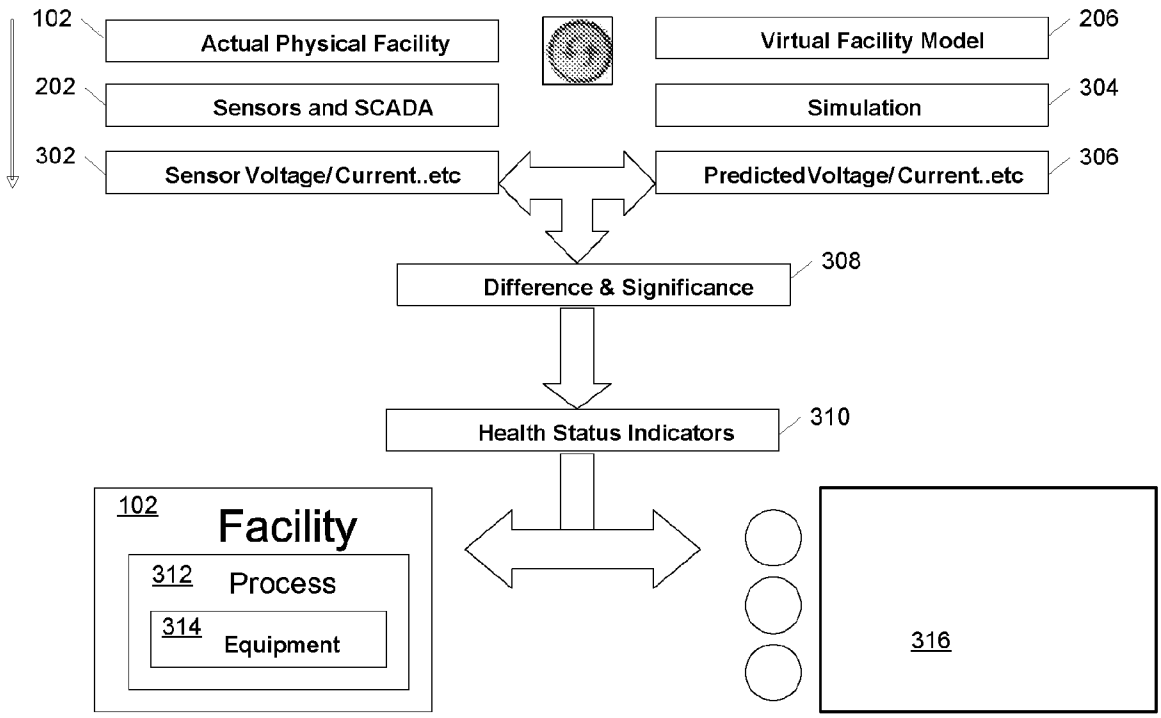

102
Actual Physical Facility
206
Virtual Facility Model
202
Sensors and SCADA
304
Simulation
302
Sensor Voltage/Current..etc
306
PredictedVoltage/Current..etc
308
Difference & Significance
310
Health Status Indicators
102
Facility
312
Process
314
Equipment
316

FIGURE 3

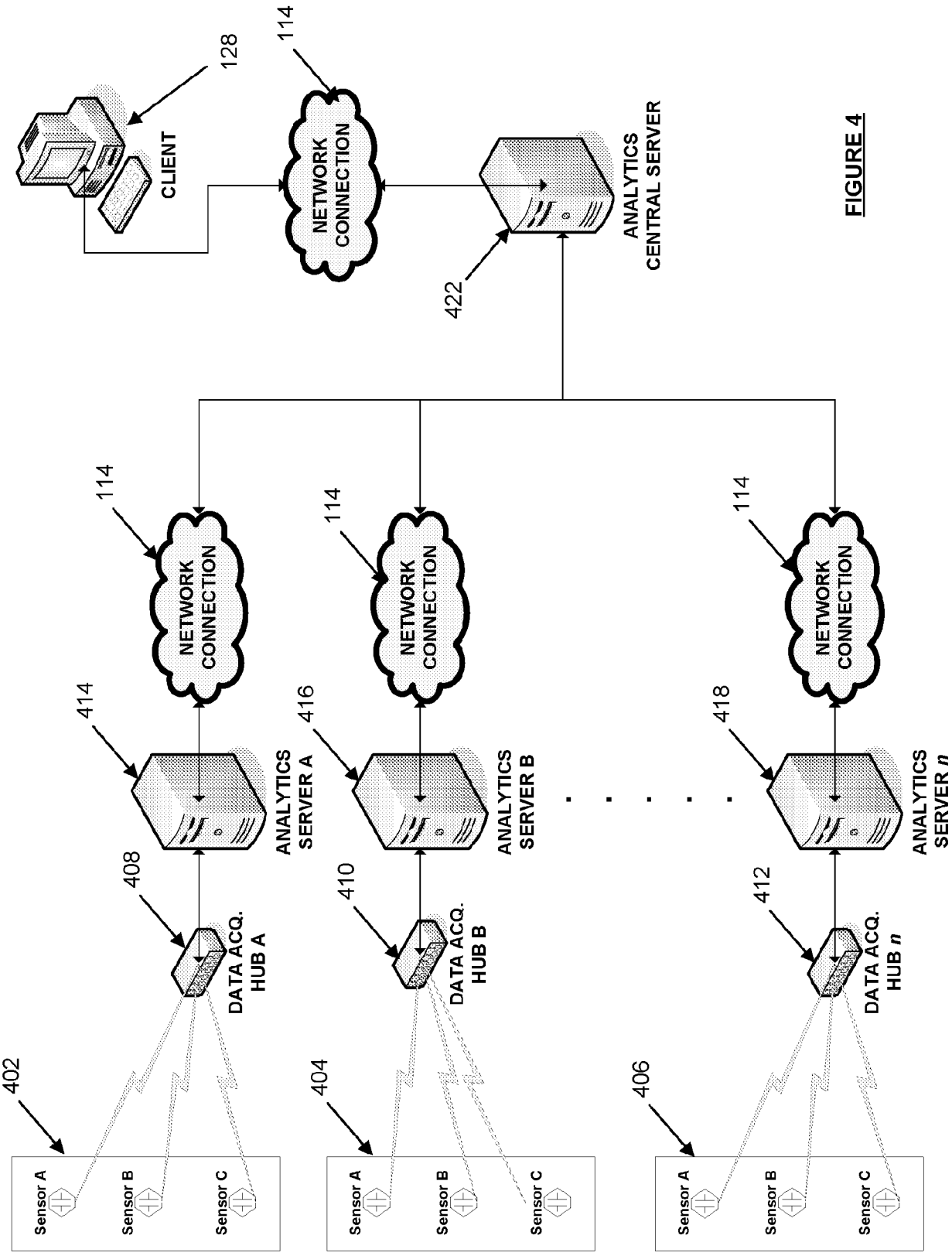

128
CLIENT
114
NETWORK CONNECTION
422
ANALYTICS CENTRAL SERVER
114
NETWORK CONNECTION
414
ANALYTICS SERVER A
408
DATA ACQ. HUB A
402
Sensor A
Sensor B
Sensor C
114
NETWORK CONNECTION
416
ANALYTICS SERVER B
410
DATA ACQ. HUB B
404
Sensor A
Sensor B
Sensor C
114
NETWORK CONNECTION
418
ANALYTICS SERVER n
412
DATA ACQ. HUB n
406
Sensor A
Sensor B
Sensor C

FIGURE 4

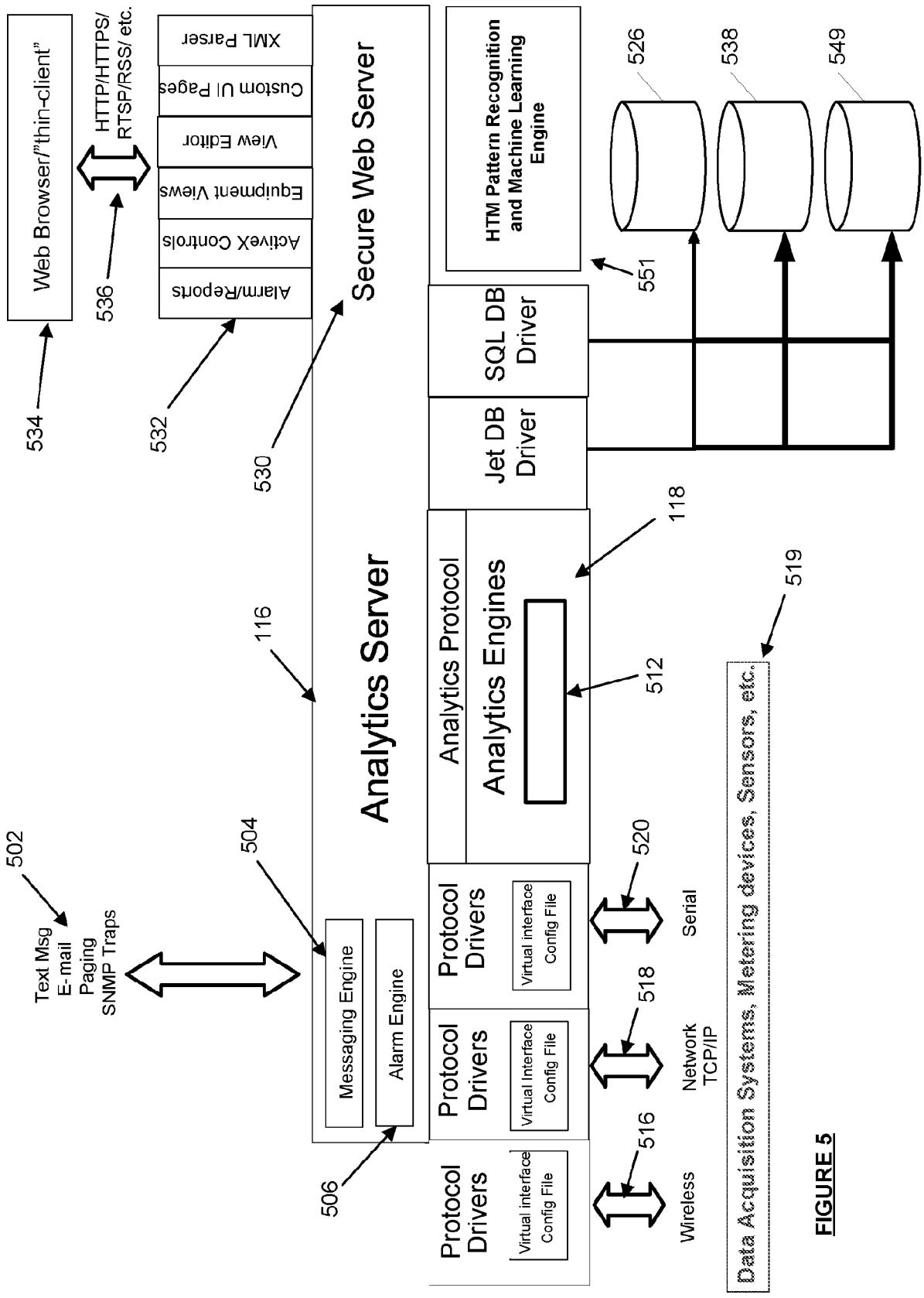

Web Browser/"thin-client"
534
HTTP/HTTPS/
RTSP/RSS/ etc.
536
XML Parser
Custom UI Pages
View Editor
Equipment Views
ActiveX Controls
Alarm/Reports
532
Secure Web Server
530
HTM Pattern Recognition and Machine Learning Engine
551
526
538
549
SQL DB Driver
Jet DB Driver
118
Analytics Protocol
Analytics Engines
512
Analytics Server
116
502
Text Msg
E-mail
Paging
SNMP Traps
504
Messaging Engine
Alarm Engine
506
Protocol Drivers
Virtual interface Config File
520
Serial
Protocol Drivers
Virtual Interface Config File
518
Network TCP/IP
Protocol Drivers
Virtual interface Config File
516
Wireless
519
Data Acquisition Systems, Metering devices, Sensors, etc.

FIGURE 5

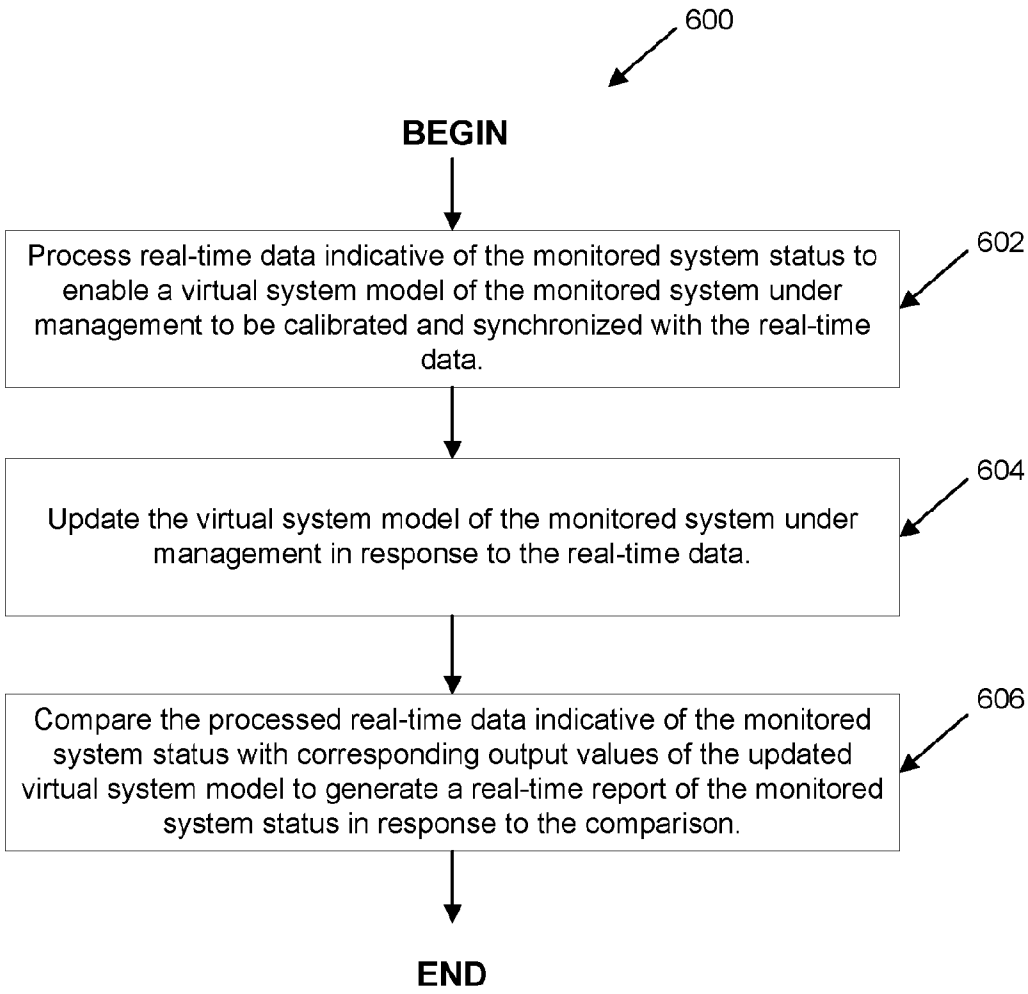

600
BEGIN
Process real-time data indicative of the monitored system status to enable a virtual system model of the monitored system under management to be calibrated and synchronized with the real-time data.
602
Update the virtual system model of the monitored system under management in response to the real-time data.
604
Compare the processed real-time data indicative of the monitored system status with corresponding output values of the updated virtual system model to generate a real-time report of the monitored system status in response to the comparison.
606
END

FIGURE 6

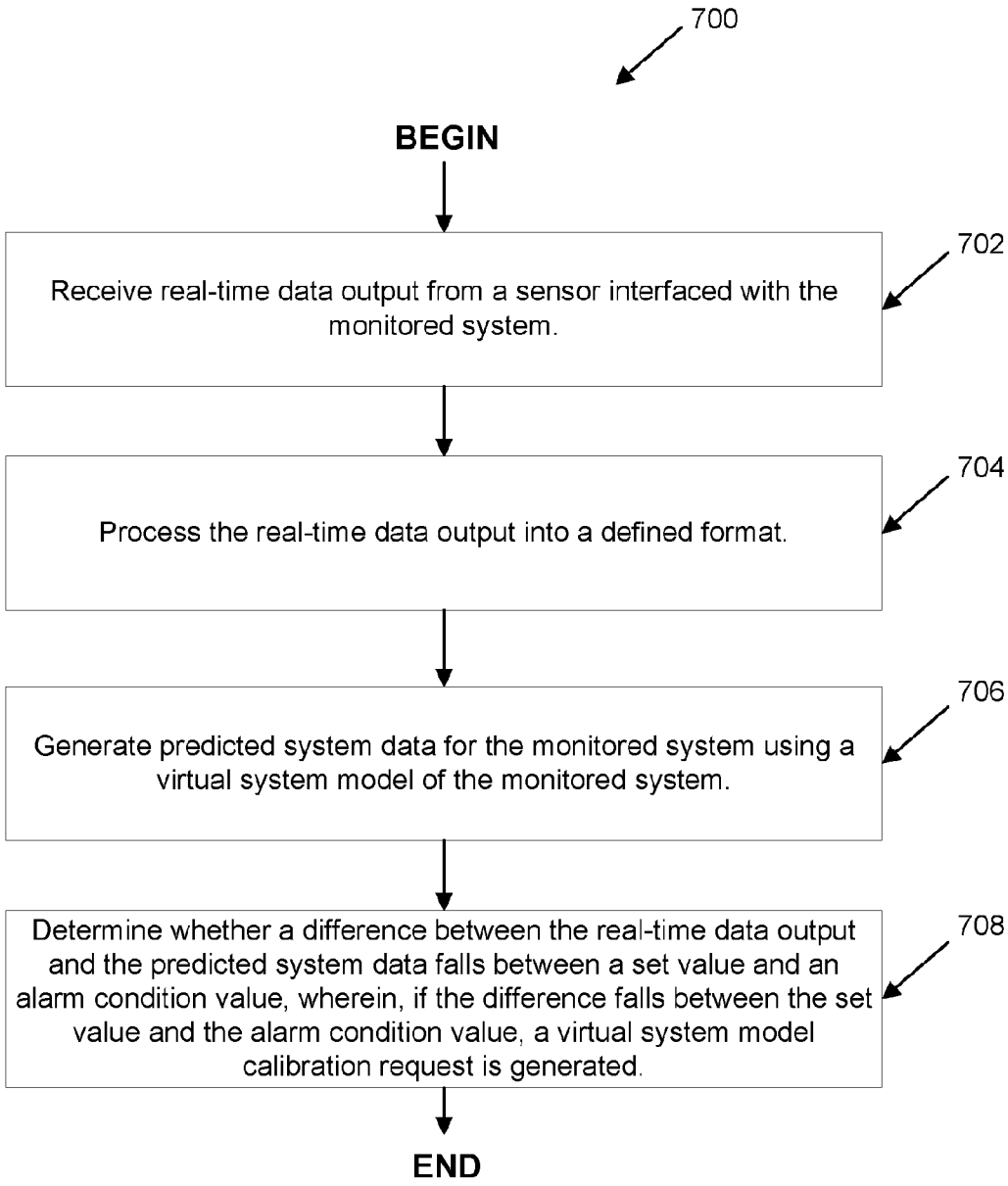

700
BEGIN
Receive real-time data output from a sensor interfaced with the monitored system.
702
Process the real-time data output into a defined format.
704
Generate predicted system data for the monitored system using a virtual system model of the monitored system.
706
Determine whether a difference between the real-time data output and the predicted system data falls between a set value and an alarm condition value, wherein, if the difference falls between the set value and the alarm condition value, a virtual system model calibration request is generated.
708
END

FIGURE 7

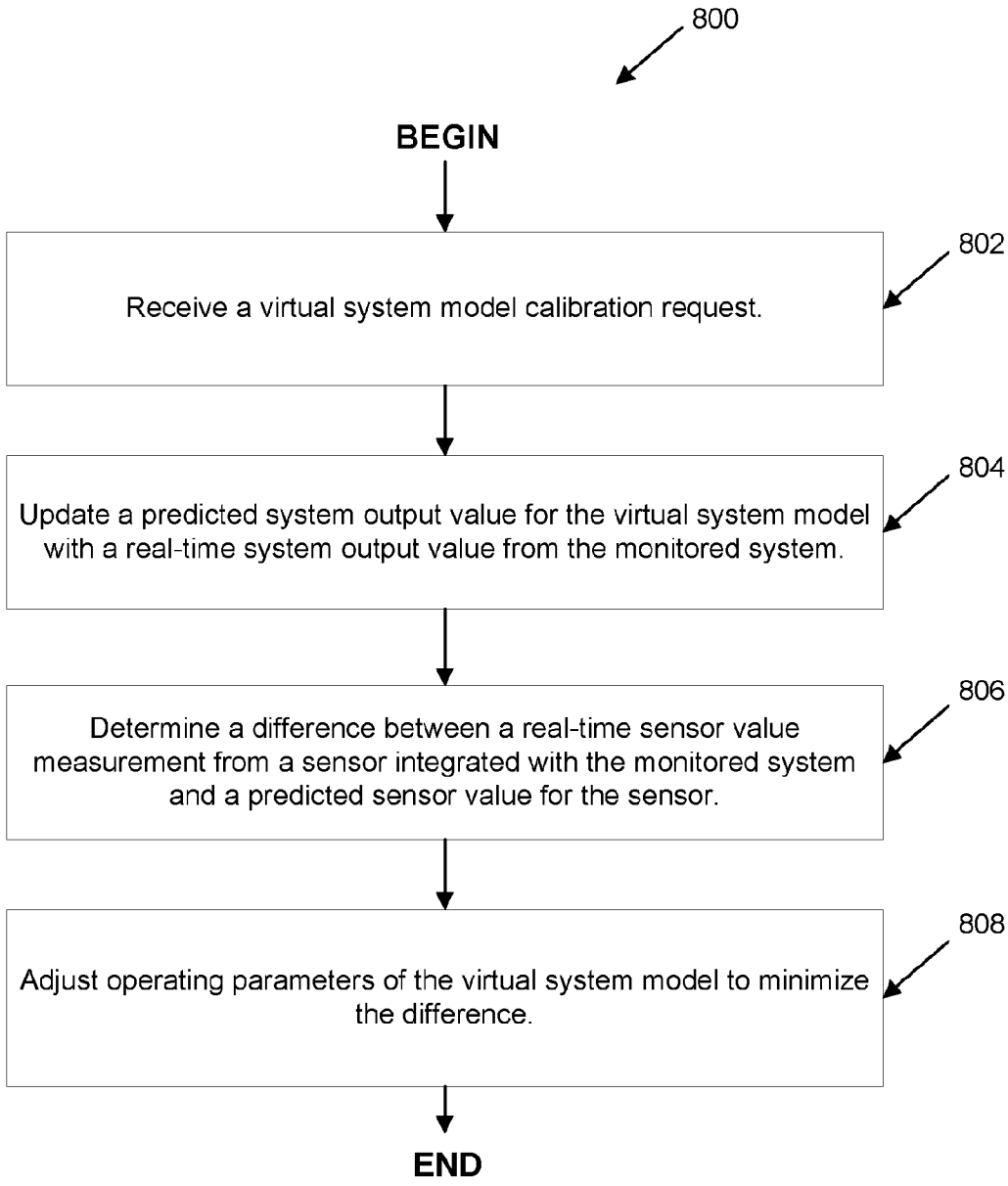

800
BEGIN
Receive a virtual system model calibration request.
802
Update a predicted system output value for the virtual system model with a real-time system output value from the monitored system.
804
Determine a difference between a real-time sensor value measurement from a sensor integrated with the monitored system and a predicted sensor value for the sensor.
806
Adjust operating parameters of the virtual system model to minimize the difference.
808
END

FIGURE 8

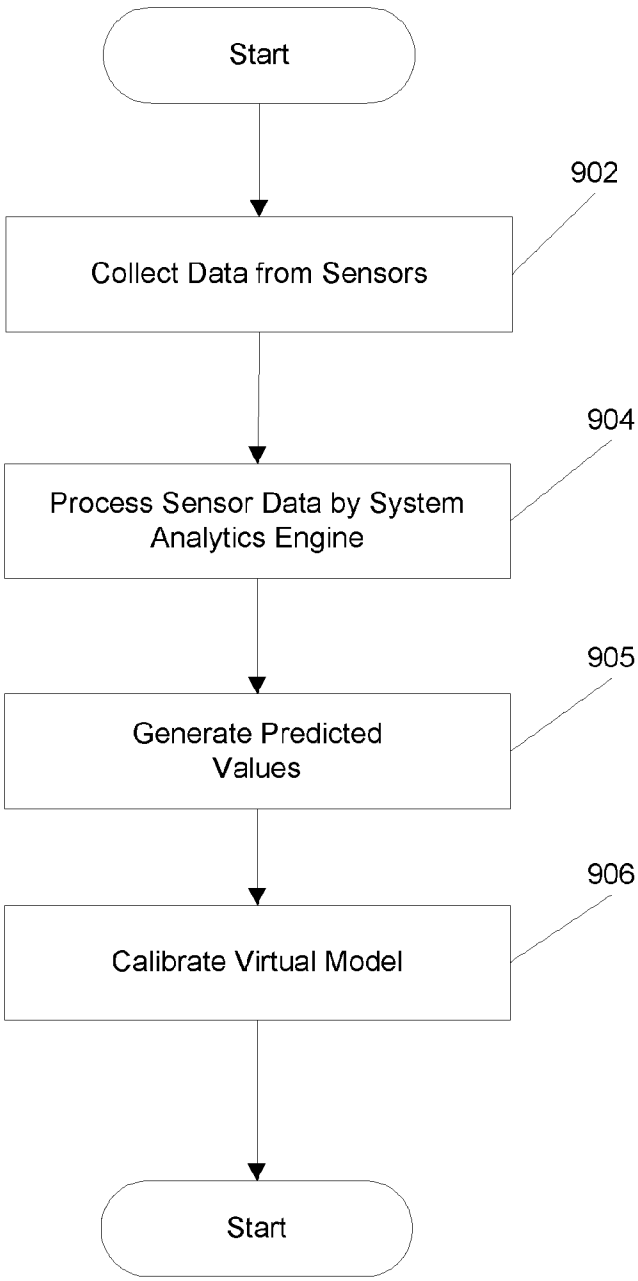

Start
902
Collect Data from Sensors
904
Process Sensor Data by System Analytics Engine
905
Generate Predicted Values
906
Calibrate Virtual Model
Start

Figure 9

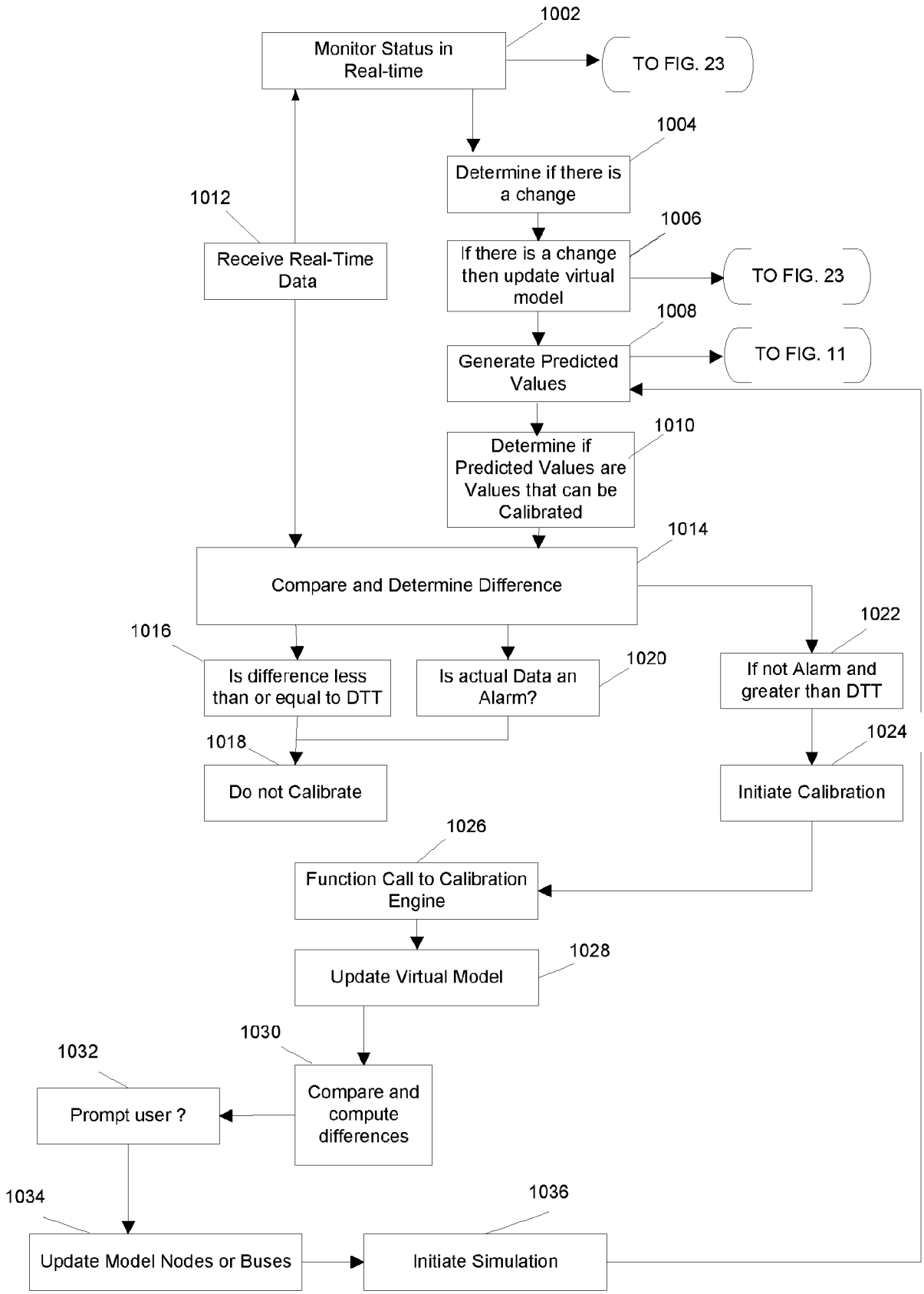

1002
Monitor Status in Real-time
TO FIG. 23
1004
Determine if there is a change
1012
Receive Real-Time Data
1006
If there is a change then update virtual model
TO FIG. 23
1008
Generate Predicted Values
TO FIG. 11
1010
Determine if Predicted Values are Values that can be Calibrated
1014
Compare and Determine Difference
1016
Is difference less than or equal to DTT
Is actual Data an Alarm?
1020
1022
If not Alarm and greater than DTT
1018
Do not Calibrate
1024
Initiate Calibration
1026
Function Call to Calibration Engine
Update Virtual Model
1028
1030
Compare and compute differences
1032
Prompt user ?
1034
Update Model Nodes or Buses
1036
Initiate Simulation

FIG. 10

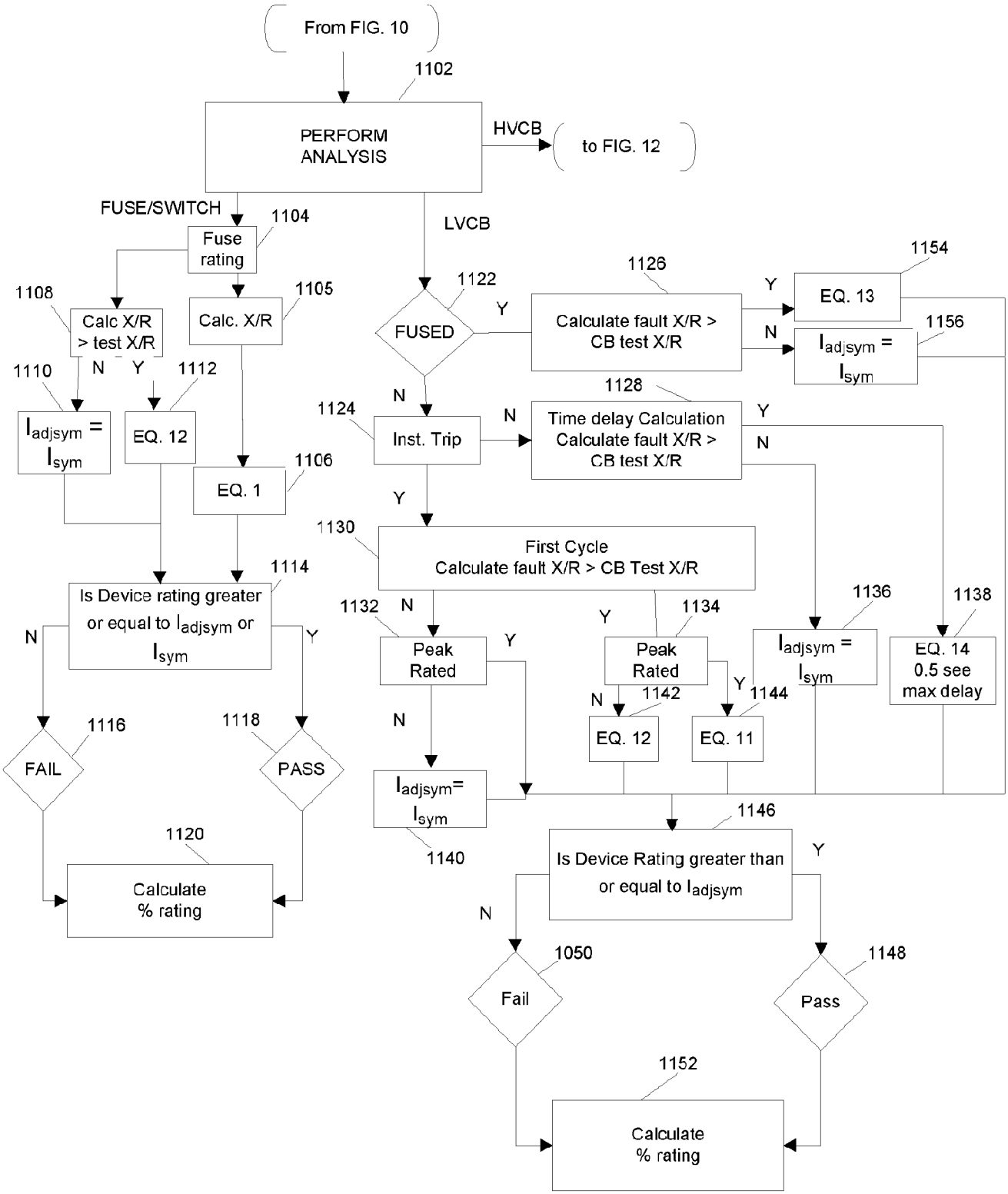

From FIG. 10
1102
PERFORM ANALYSIS
HVCB
to FIG. 12
FUSE/SWITCH
1104
Fuse rating
LVCB
1108
Calc X/R > test X/R
1105
Calc. X/R
1122
FUSED
1126
Calculate fault X/R > CB test X/R
1154
EQ. 13
1156
$I_{adjsym} = I_{sym}$
1110
$I_{adjsym} = I_{sym}$
1112
EQ. 12
1124
Inst. Trip
1128
Time delay Calculation Calculate fault X/R > CB test X/R
1106
EQ. 1
1130
First Cycle Calculate fault X/R > CB Test X/R
1114
Is Device rating greater or equal to I_{adjsym} or I_{sym}
1132
Peak Rated
1134
Peak Rated
1136
$I_{adjsym} = I_{sym}$
1138
EQ. 14 0.5 see max delay
1142
EQ. 12
1144
EQ. 11
1116
FAIL
1118
PASS
1140
$I_{adjsym} = I_{sym}$
1146
Is Device Rating greater than or equal to I_{adjsym}
1120
Calculate % rating
1050
Fail
1148
Pass
1152
Calculate % rating

FIG. 11

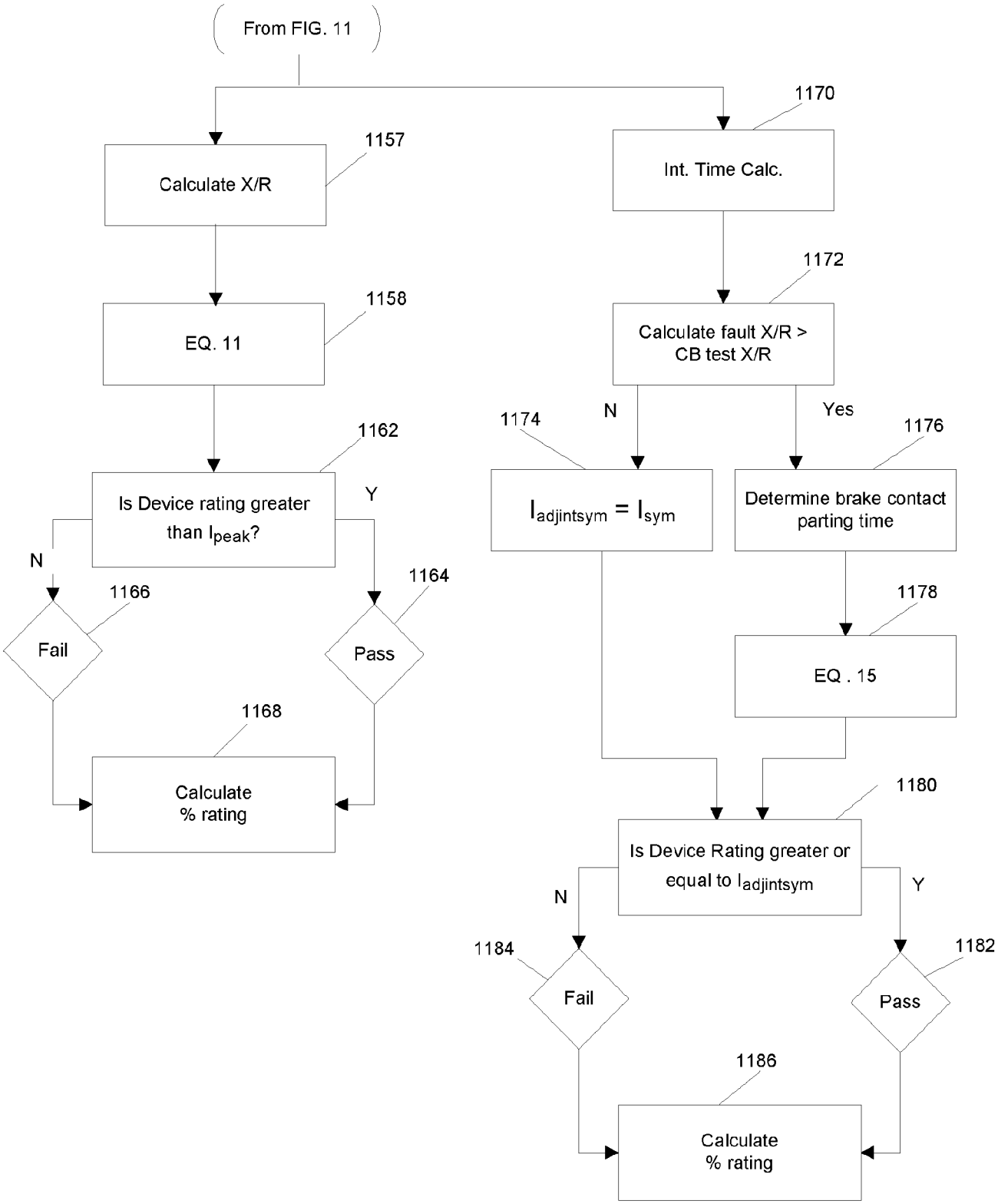

From FIG. 11
1157
Calculate X/R
1158
EQ. 11
1162
Is Device rating greater than I_{peak}?
N
Y
1166
Fail
1164
Pass
1168
Calculate % rating
1170
Int. Time Calc.
1172
Calculate fault X/R > CB test X/R
N
Yes
1174
$I_{adjintsym} = I_{sym}$
1176
Determine brake contact parting time
1178
EQ . 15
1180
Is Device Rating greater or equal to $I_{adjintsym}$
N
Y
1184
Fail
1182
Pass
1186
Calculate % rating

FIG. 12

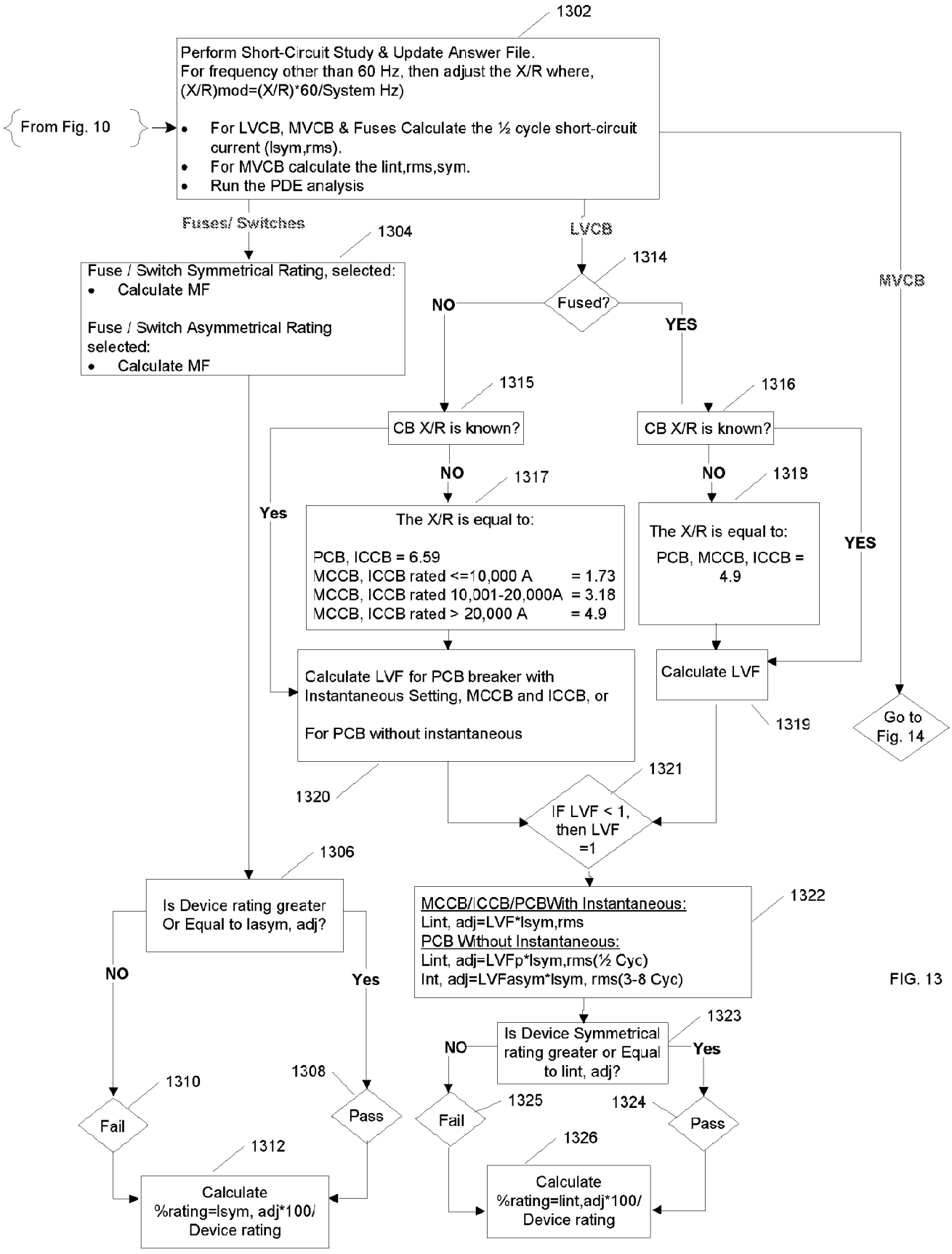

1302
Perform Short-Circuit Study & Update Answer File.
For frequency other than 60 Hz, then adjust the X/R where,
(X/R)mod=(X/R)*60/System Hz)
From Fig. 10
For LVCB, MVCB & Fuses Calculate the ½ cycle short-circuit current (Isym,rms).
For MVCB calculate the Iint,rms,sym.
Run the PDE analysis
Fuses/ Switches
LVCB
MVCB
1304
Fuse / Switch Symmetrical Rating, selected:
Calculate MF
Fuse / Switch Asymmetrical Rating selected:
Calculate MF
1314
Fused?
NO
YES
1315
CB X/R is known?
1316
CB X/R is known?
NO
1317
NO
1318
Yes
The X/R is equal to:
PCB, ICCB = 6.59
MCCB, ICCB rated <=10,000 A = 1.73
MCCB, ICCB rated 10,001-20,000A = 3.18
MCCB, ICCB rated > 20,000 A = 4.9
The X/R is equal to:
PCB, MCCB, ICCB = 4.9
YES
Calculate LVF for PCB breaker with Instantaneous Setting, MCCB and ICCB, or
For PCB without instantaneous
Calculate LVF
1319
Go to Fig. 14
1320
1321
IF LVF < 1, then LVF =1
1306
Is Device rating greater Or Equal to Isym, adj?
MCCB/ICCB/PCBWith Instantaneous:
Iint, adj=LVF*Isym,rms
PCB Without Instantaneous:
Iint, adj=LVFp*Isym,rms(½ Cyc)
Int, adj=LVFasym*Isym, rms(3-8 Cyc)
1322
NO
Yes
1323
Is Device Symmetrical rating greater or Equal to Iint, adj?
NO
Yes
1308
1310
Pass
Fail
1325
1324
Pass
Fail
1312
1326
Calculate %rating=Isym, adj*100/ Device rating
Calculate %rating=Iint,adj*100/ Device rating

FIG. 13

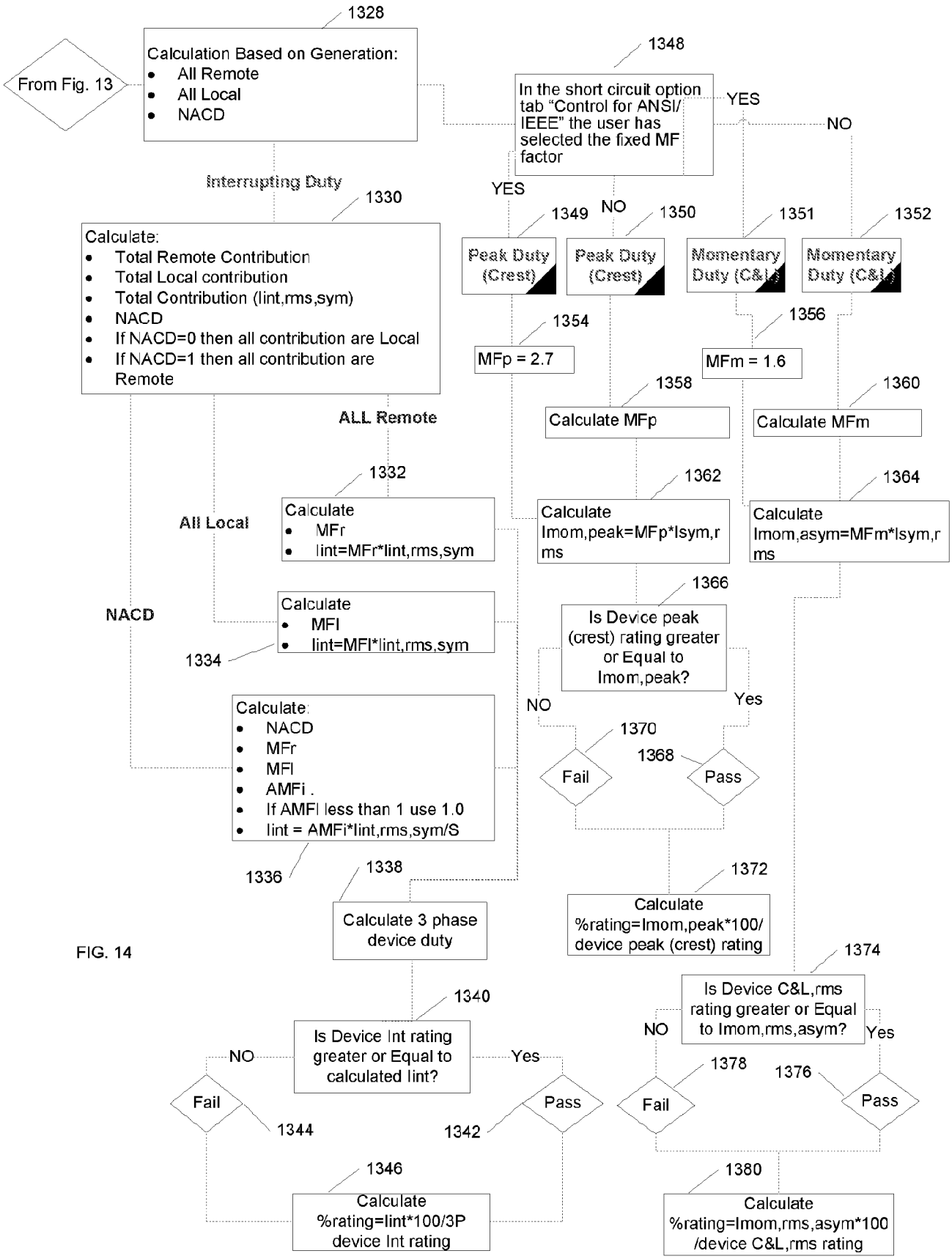

From Fig. 13
1328
Calculation Based on Generation:
All Remote
All Local
NACD
Interrupting Duty
1330
Calculate:
Total Remote Contribution
Total Local contribution
Total Contribution (Iint,rms,sym)
NACD
If NACD=0 then all contribution are Local
If NACD=1 then all contribution are Remote
ALL Remote
All Local
NACD
1332
Calculate
MFr
Iint=MFr*Iint,rms,sym
Calculate
MFI
Iint=MFI*Iint,rms,sym
1334
Calculate:
NACD
MFr
MFI
AMFi .
If AMFI less than 1 use 1.0
Iint = AMFi*Iint,rms,sym/S
1336
1338
Calculate 3 phase device duty
1340
Is Device Int rating greater or Equal to calculated Iint?
NO
Yes
Fail
Pass
1344
1342
1346
Calculate %rating=Iint*100/3P device Int rating
1348
In the short circuit option tab "Control for ANSI/ IEEE" the user has selected the fixed MF factor
YES
NO
YES
NO
1349
1350
1351
1352
Peak Duty (Crest)
Peak Duty (Crest)
Momentary Duty (C&L)
Momentary Duty (C&L)
1354
MFp = 2.7
1356
MFm = 1.6
1358
Calculate MFp
1360
Calculate MFm
1362
Calculate Imom,peak=MFp*Isym,rms
1364
Calculate Imom,asym=MFm*Isym,rms
1366
Is Device peak (crest) rating greater or Equal to Imom,peak?
NO
Yes
1370
1368
Fail
Pass
1372
Calculate %rating=Imom,peak*100/ device peak (crest) rating
1374
Is Device C&L,rms rating greater or Equal to Imom,rms,asym?
NO
Yes
1378
1376
Fail
Pass
1380
Calculate %rating=Imom,rms,asym*100 /device C&L,rms rating

FIG. 14

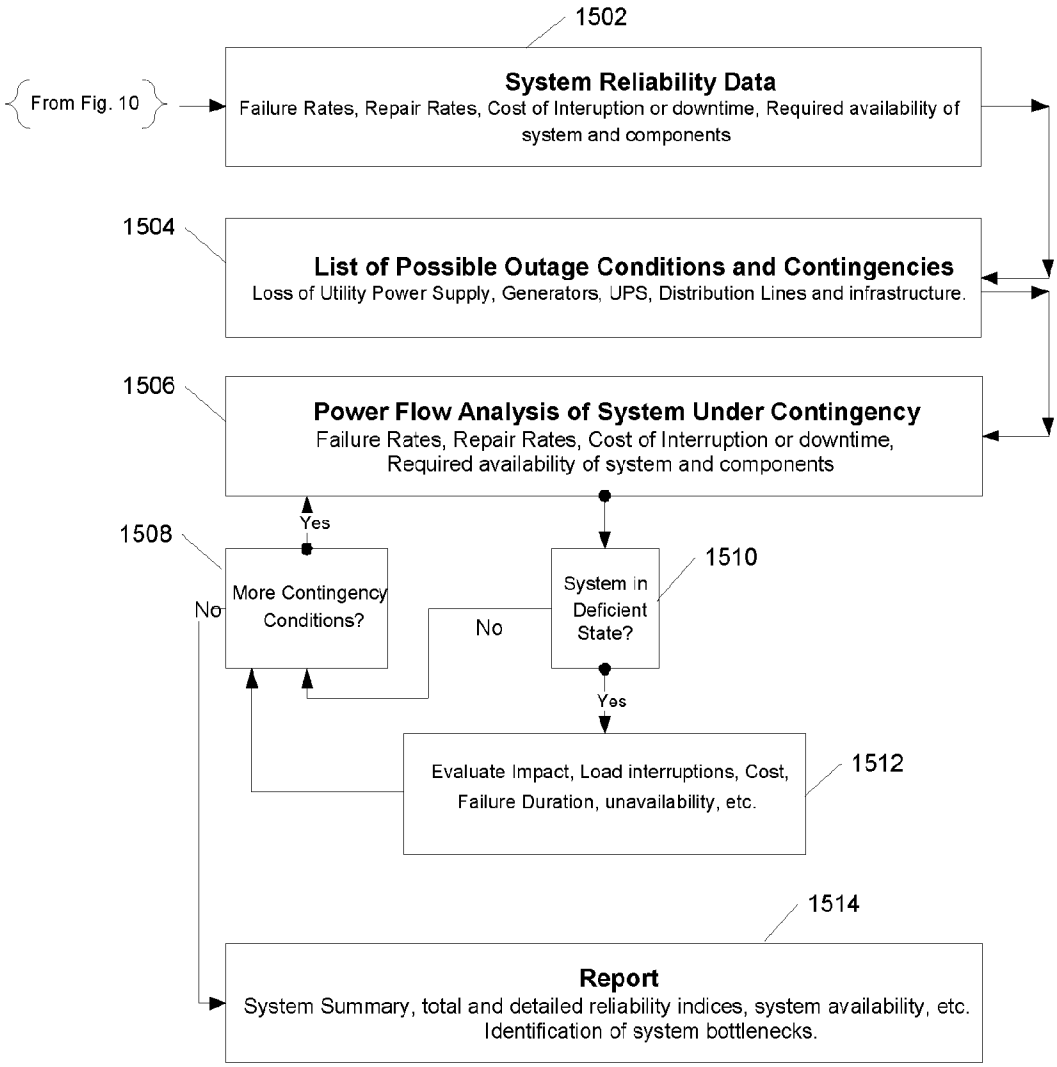

1502
System Reliability Data
Failure Rates, Repair Rates, Cost of Interuption or downtime, Required availability of system and components
From Fig. 10
1504
List of Possible Outage Conditions and Contingencies
Loss of Utility Power Supply, Generators, UPS, Distribution Lines and infrastructure.
1506
Power Flow Analysis of System Under Contingency
Failure Rates, Repair Rates, Cost of Interruption or downtime, Required availability of system and components
Yes
1508
More Contingency Conditions?
No
No
System in Deficient State?
1510
Yes
Evaluate Impact, Load interruptions, Cost, Failure Duration, unavailability, etc.
1512
1514
Report
System Summary, total and detailed reliability indices, system availability, etc. Identification of system bottlenecks.

FIG. 15

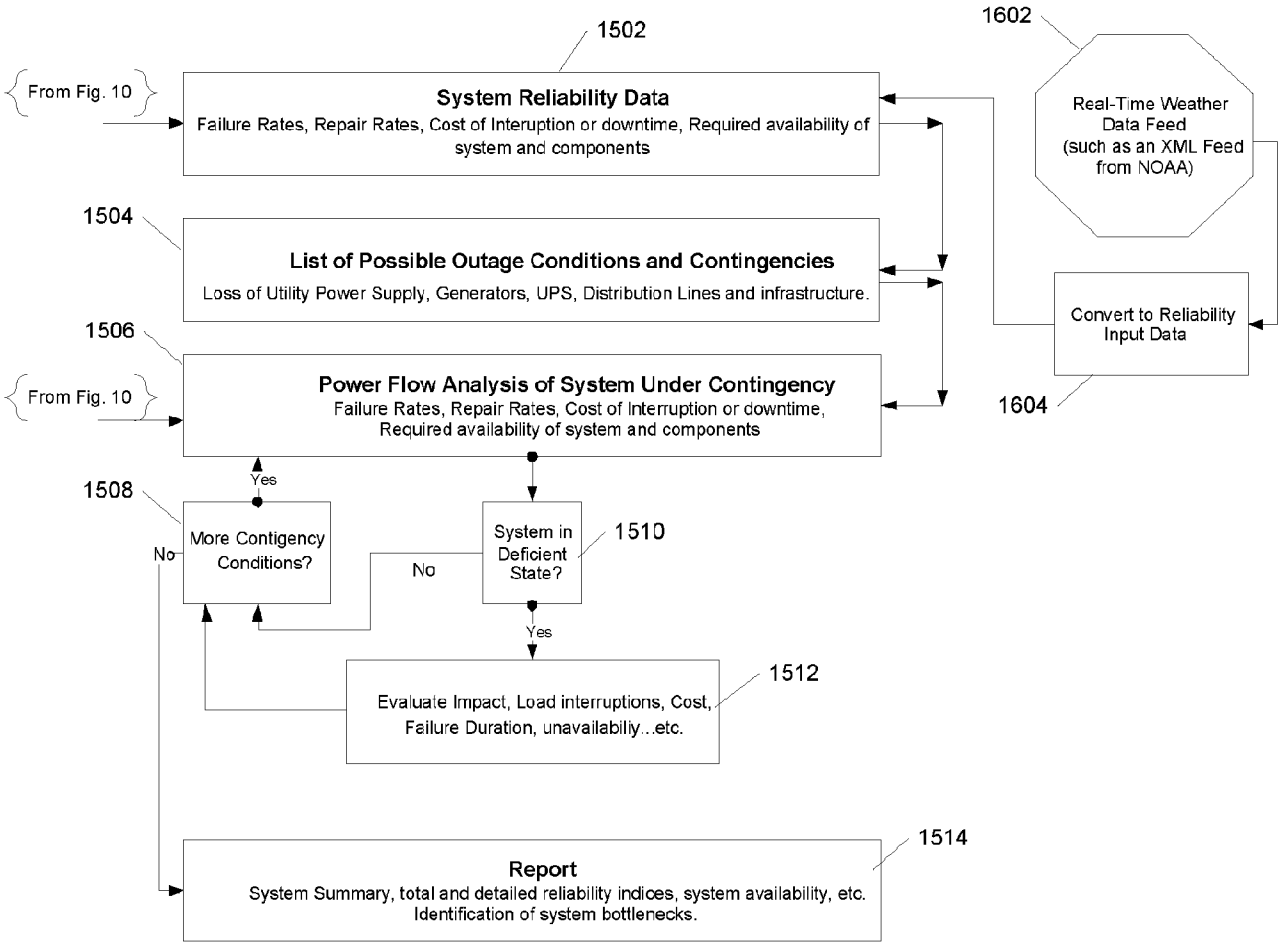

1502
1602
From Fig. 10
System Reliability Data
Failure Rates, Repair Rates, Cost of Interuption or downtime, Required availability of system and components
Real-Time Weather Data Feed (such as an XML Feed from NOAA)
1504
List of Possible Outage Conditions and Contingencies
Loss of Utility Power Supply, Generators, UPS, Distribution Lines and infrastructure.
Convert to Reliability Input Data
1506
From Fig. 10
Power Flow Analysis of System Under Contingency
Failure Rates, Repair Rates, Cost of Interruption or downtime, Required availability of system and components
1604
Yes
1508
More Contigency Conditions?
No
System in Deficient State?
No
1510
Yes
1512
Evaluate Impact, Load interruptions, Cost, Failure Duration, unavailabiliy...etc.
1514
Report
System Summary, total and detailed reliability indices, system availability, etc.
Identification of system bottlenecks.

FIG. 16

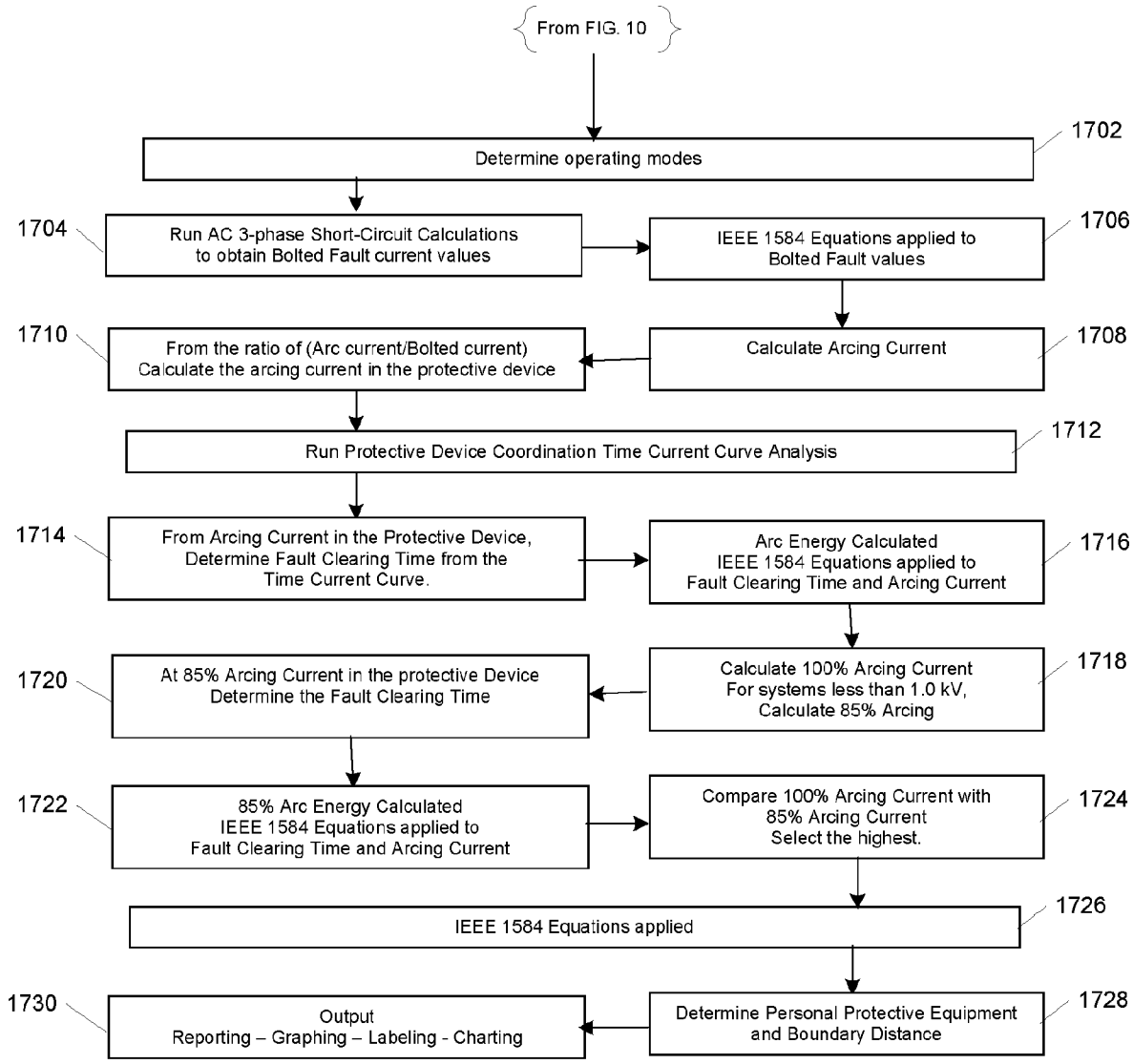

From FIG. 10
Determine operating modes
1702
1704
Run AC 3-phase Short-Circuit Calculations to obtain Bolted Fault current values
IEEE 1584 Equations applied to Bolted Fault values
1706
1710
From the ratio of (Arc current/Bolted current) Calculate the arcing current in the protective device
Calculate Arcing Current
1708
Run Protective Device Coordination Time Current Curve Analysis
1712
1714
From Arcing Current in the Protective Device, Determine Fault Clearing Time from the Time Current Curve.
Arc Energy Calculated IEEE 1584 Equations applied to Fault Clearing Time and Arcing Current
1716
1720
At 85% Arcing Current in the protective Device Determine the Fault Clearing Time
Calculate 100% Arcing Current For systems less than 1.0 kV, Calculate 85% Arcing
1718
1722
85% Arc Energy Calculated IEEE 1584 Equations applied to Fault Clearing Time and Arcing Current
Compare 100% Arcing Current with 85% Arcing Current Select the highest.
1724
IEEE 1584 Equations applied
1726
1730
Output Reporting – Graphing – Labeling - Charting
Determine Personal Protective Equipment and Boundary Distance
1728

FIG. 17

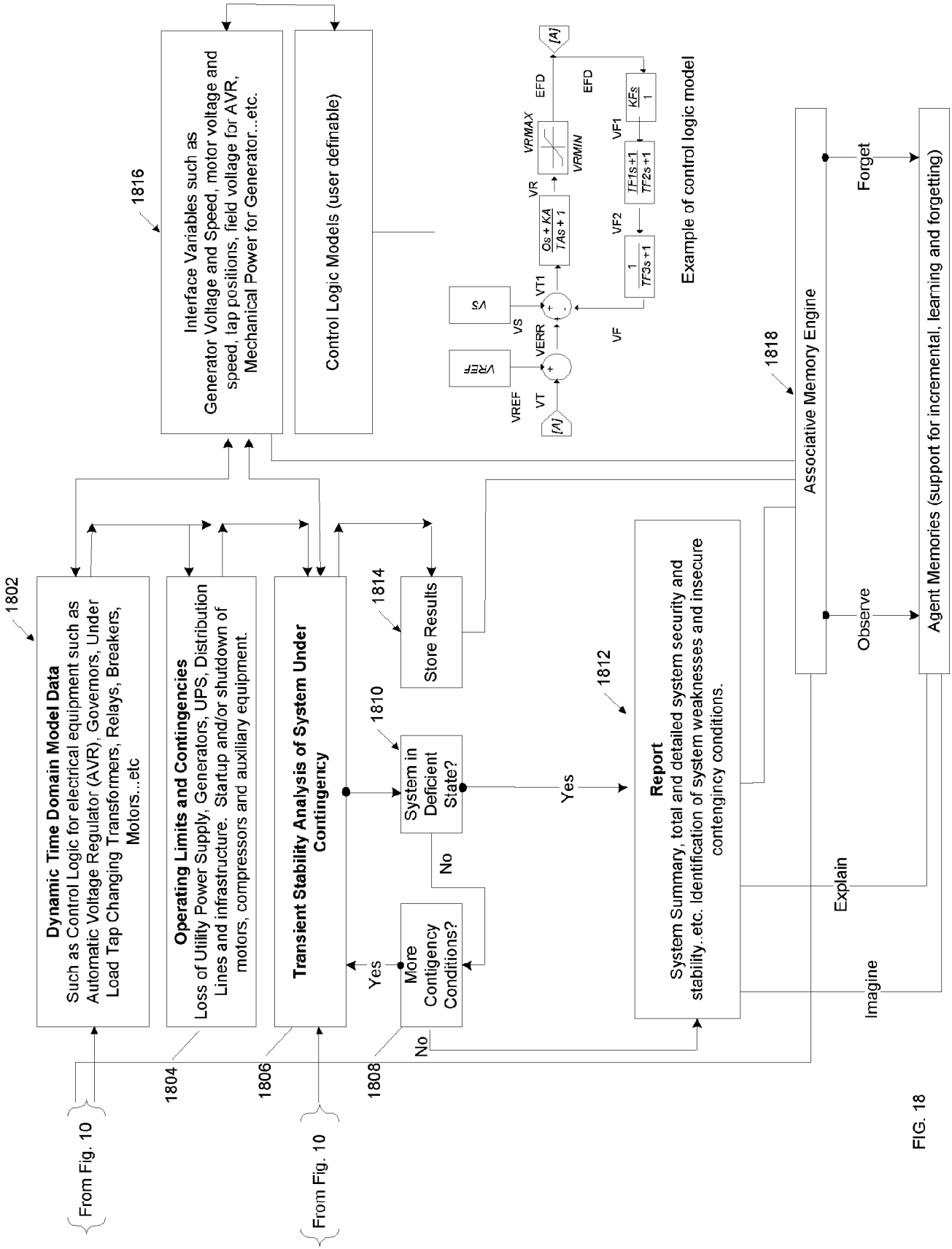

From Fig. 10
1802
Dynamic Time Domain Model Data
Such as Control Logic for electrical equipment such as Automatic Voltage Regulator (AVR), Governors, Under Load Tap Changing Transformers, Relays, Breakers, Motors...etc
1804
Operating Limits and Contingencies
Loss of Utility Power Supply, Generators, UPS, Distribution Lines and infrastructure. Startup and/or shutdown of motors, compressors and auxiliary equipment.
1806
From Fig. 10
Transient Stability Analysis of System Under Contingency
1808
More Contigency Conditions?
Yes
No
1810
System in Deficient State?
No
Yes
1812
Report
System Summary, total and detailed system security and stability..etc. Identification of system weaknesses and insecure contengincy conditions.
1814
Store Results
1816
Interface Variables such as Generator Voltage and Speed, motor voltage and speed, tap positions, field voltage for AVR, Mechanical Power for Generator...etc.
Control Logic Models (user definable)
VREF
VS
VERR
VT1
VR
VRMAX
VRMIN
EFD
VF
VF1
VF2
Example of control logic model
1818
Associative Memory Engine
Observe
Explain
Imagine
Forget
Agent Memories (support for incremental, learning and forgetting)

FIG. 18

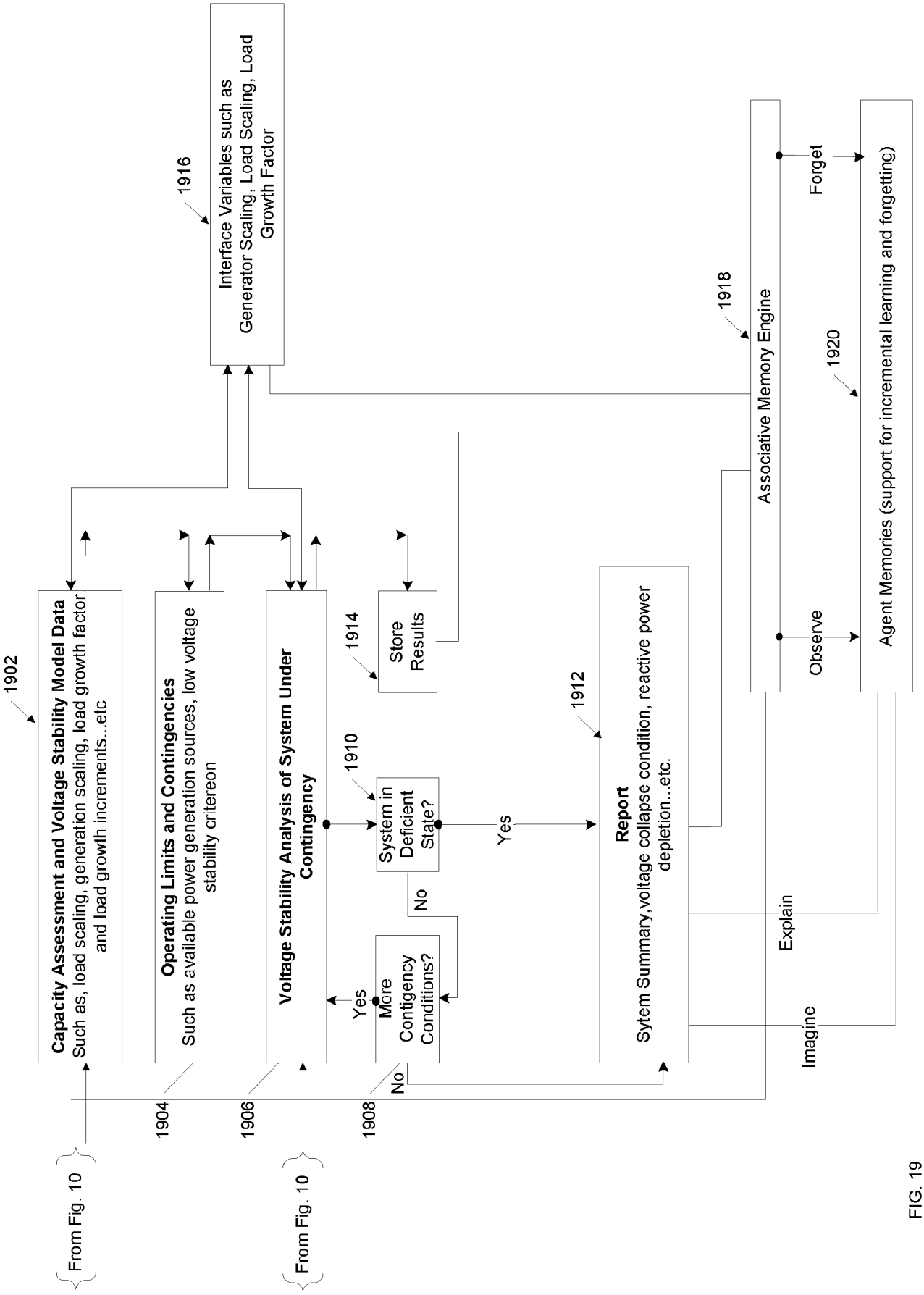

1916
Interface Variables such as Generator Scaling, Load Scaling, Load Growth Factor
1902
Capacity Assessment and Voltage Stability Model Data
Such as, load scaling, generation scaling, load growth factor and load growth increments...etc
Operating Limits and Contingencies
Such as available power generation sources, low voltage stability critereon
Voltage Stability Analysis of System Under Contingency
1914
Store Results
1910
System in Deficient State?
Yes
No
More Contigency Conditions?
Yes
No
1912
Report
Sytem Summary,voltage collapse condition, reactive power depletion...etc.
1918
Associative Memory Engine
Forget
1920
Observe
Agent Memories (support for incremental learning and forgetting)
Explain
Imagine
1904
1906
1908
From Fig. 10
From Fig. 10

FIG. 19

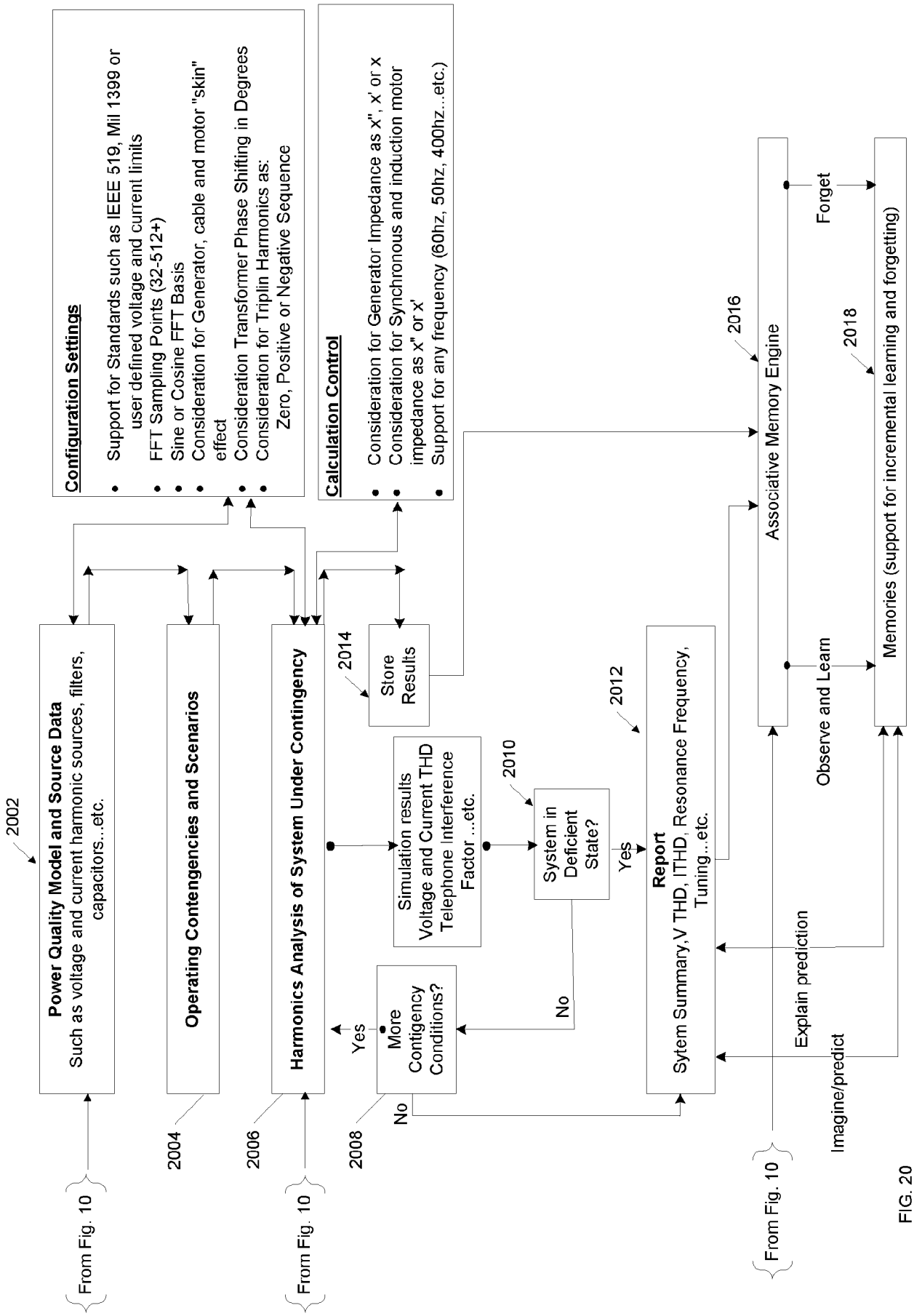

Configuration Settings
Support for Standards such as IEEE 519, Mil 1399 or user defined voltage and current limits
FFT Sampling Points (32-512+)
Sine or Cosine FFT Basis
Consideration for Generator, cable and motor "skin" effect
Consideration Transformer Phase Shifting in Degrees
Consideration for Triplin Harmonics as: Zero, Positive or Negative Sequence
Calculation Control
Consideration for Generator Impedance as x", x' or x
Consideration for Synchronous and induction motor impedance as x" or x'
Support for any frequency (60hz, 50hz, 400hz...etc.)
2002
Power Quality Model and Source Data
Such as voltage and current harmonic sources, filters, capacitors...etc.
2004
Operating Contengencies and Scenarios
2006
Harmonics Analysis of System Under Contingency
2008
More Contigency Conditions?
Yes
No
Simulation results Voltage and Current THD Telephone Interference Factor ...etc.
2010
System in Deficient State?
No
Yes
2012
Report
Sytem Summary,V THD, ITHD, Resonance Frequency, Tuning...etc.
2014
Store Results
2016
Associative Memory Engine
2018
Memories (support for incremental learning and forgetting)
Forget
Observe and Learn
Explain prediction
Imagine/predict
From Fig. 10
From Fig. 10
From Fig. 10

FIG. 20

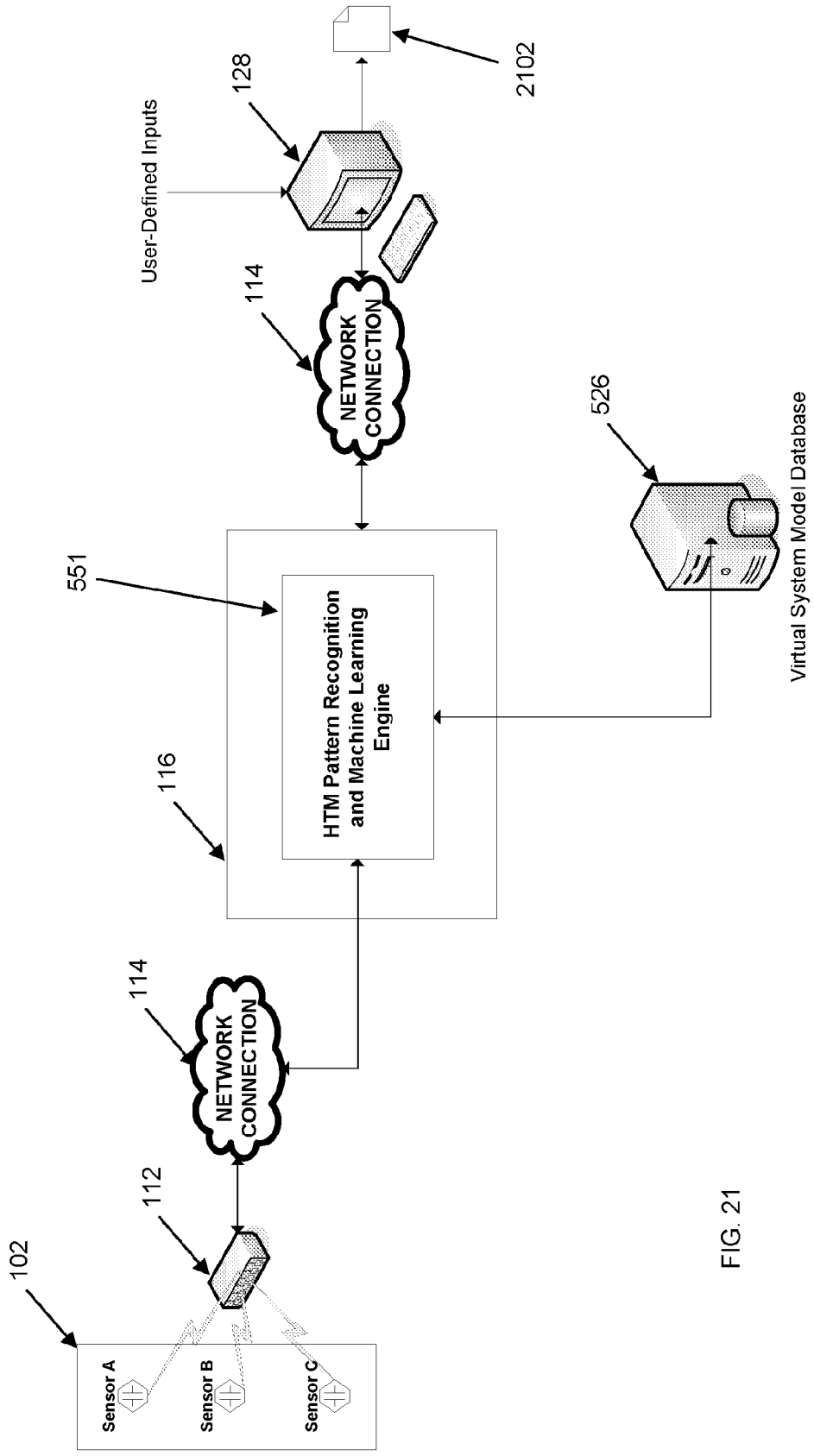

2102
128
User-Defined Inputs
114
NETWORK CONNECTION
526
Virtual System Model Database
551
HTM Pattern Recognition and Machine Learning Engine
116
114
NETWORK CONNECTION
112
102
Sensor A
Sensor B
Sensor C

FIG. 21

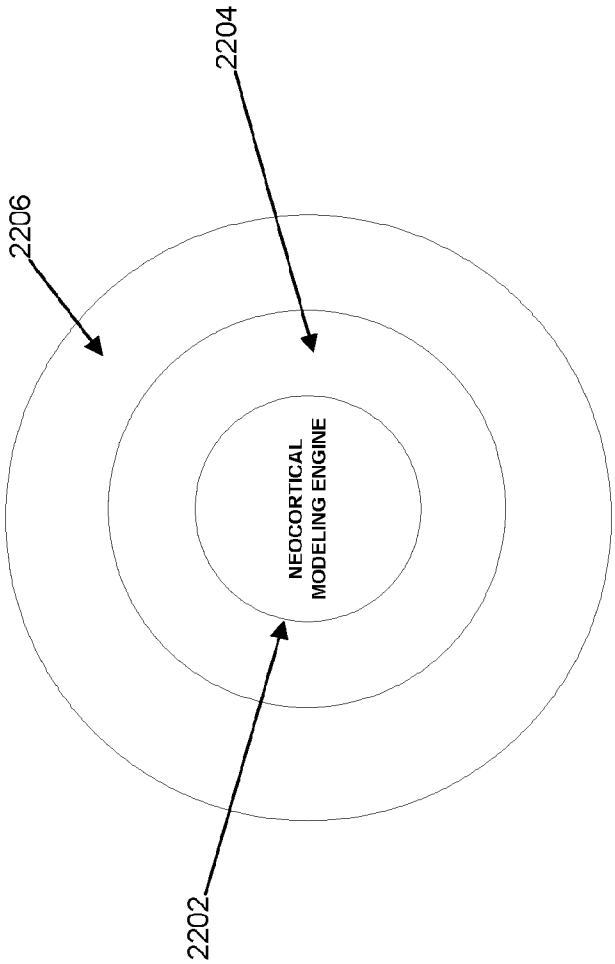


FIG. 22

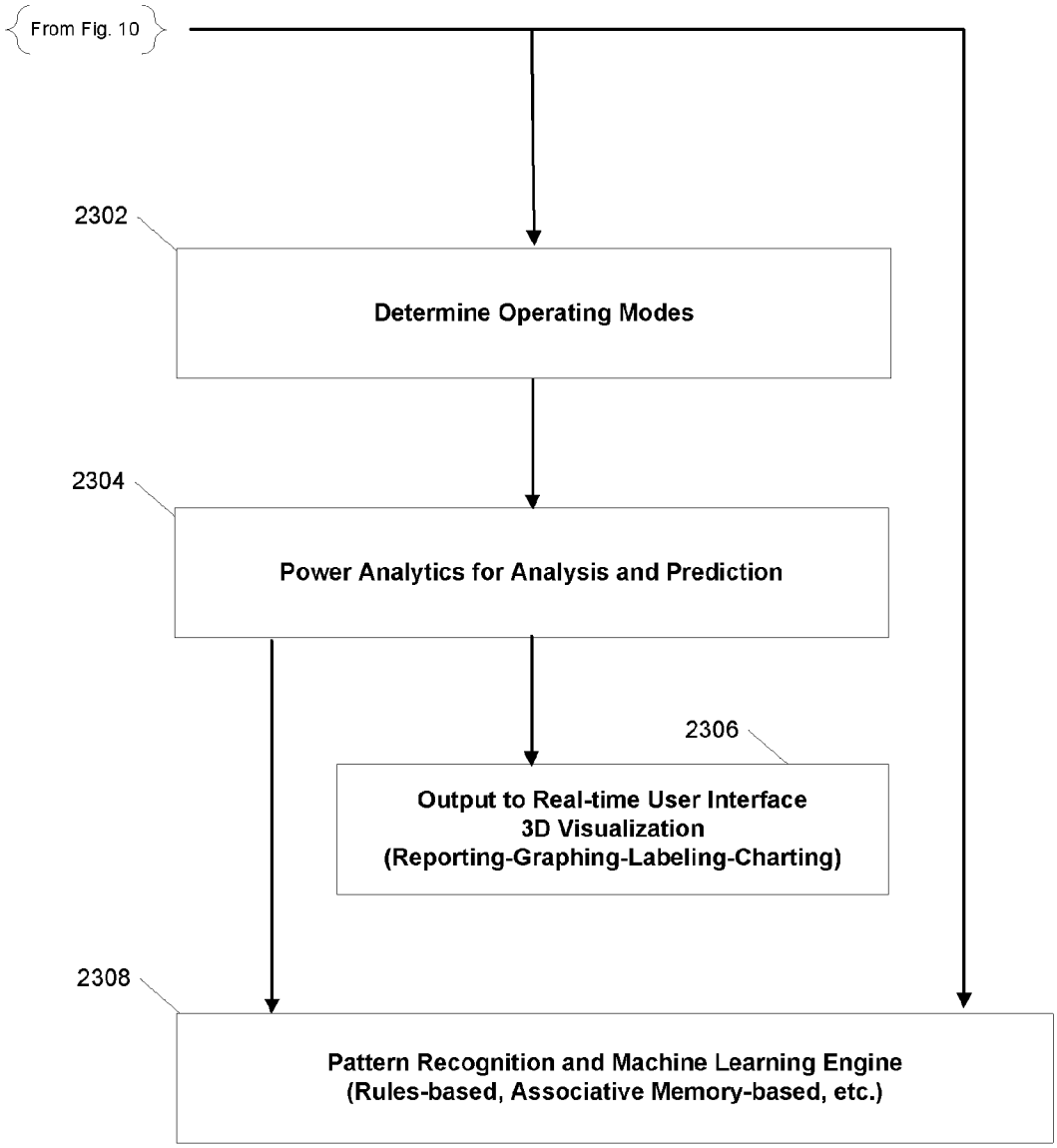

From Fig. 10
2302
Determine Operating Modes
2304
Power Analytics for Analysis and Prediction
2306
Output to Real-time User Interface
3D Visualization
(Reporting-Graphing-Labeling-Charting)
2308
Pattern Recognition and Machine Learning Engine
(Rules-based, Associative Memory-based, etc.)

FIG. 23

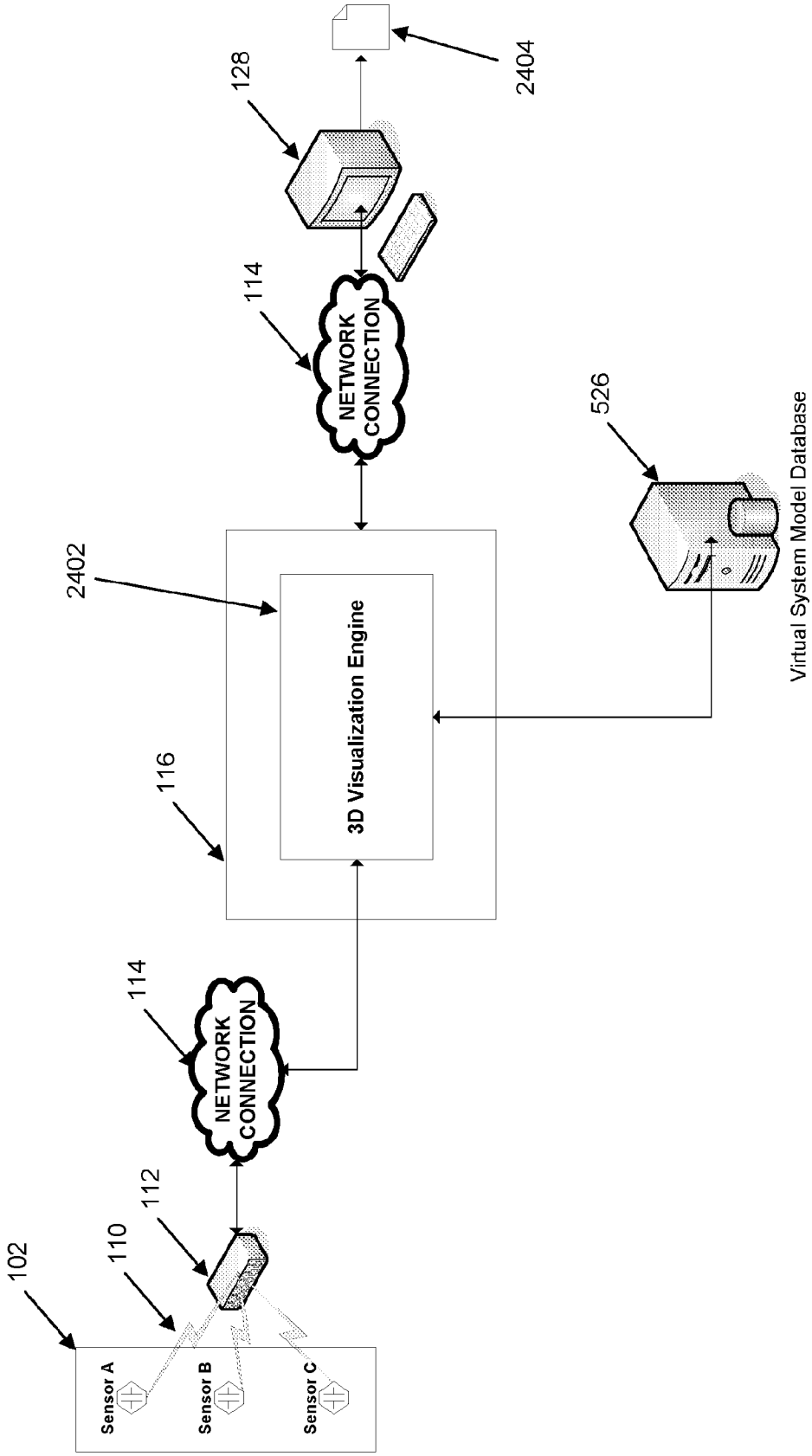

102
110
112
114
NETWORK CONNECTION
116
3D Visualization Engine
2402
526
Virtual System Model Database
114
NETWORK CONNECTION
128
2404
Sensor A
Sensor B
Sensor C

FIG. 24

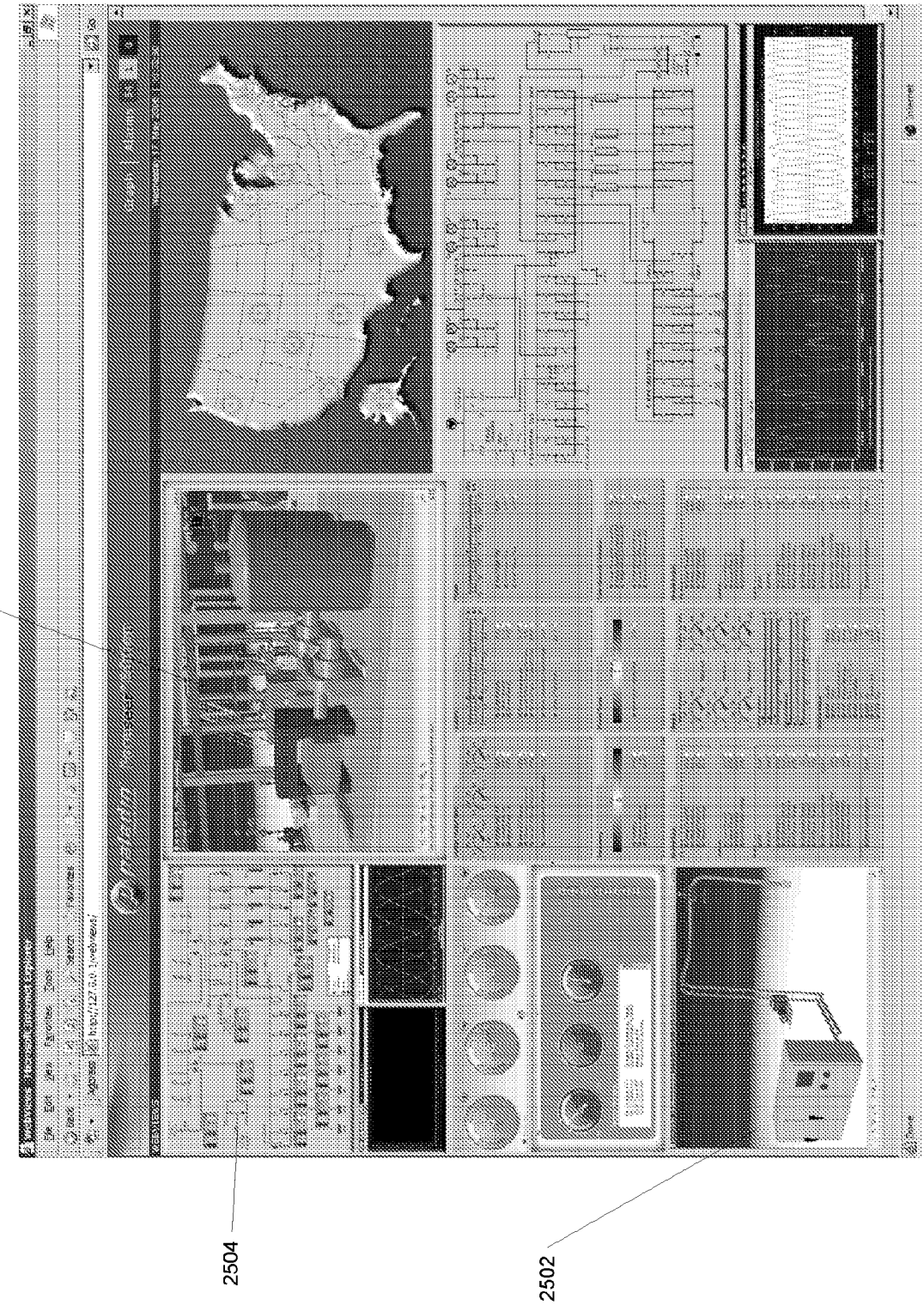


FIG. 25

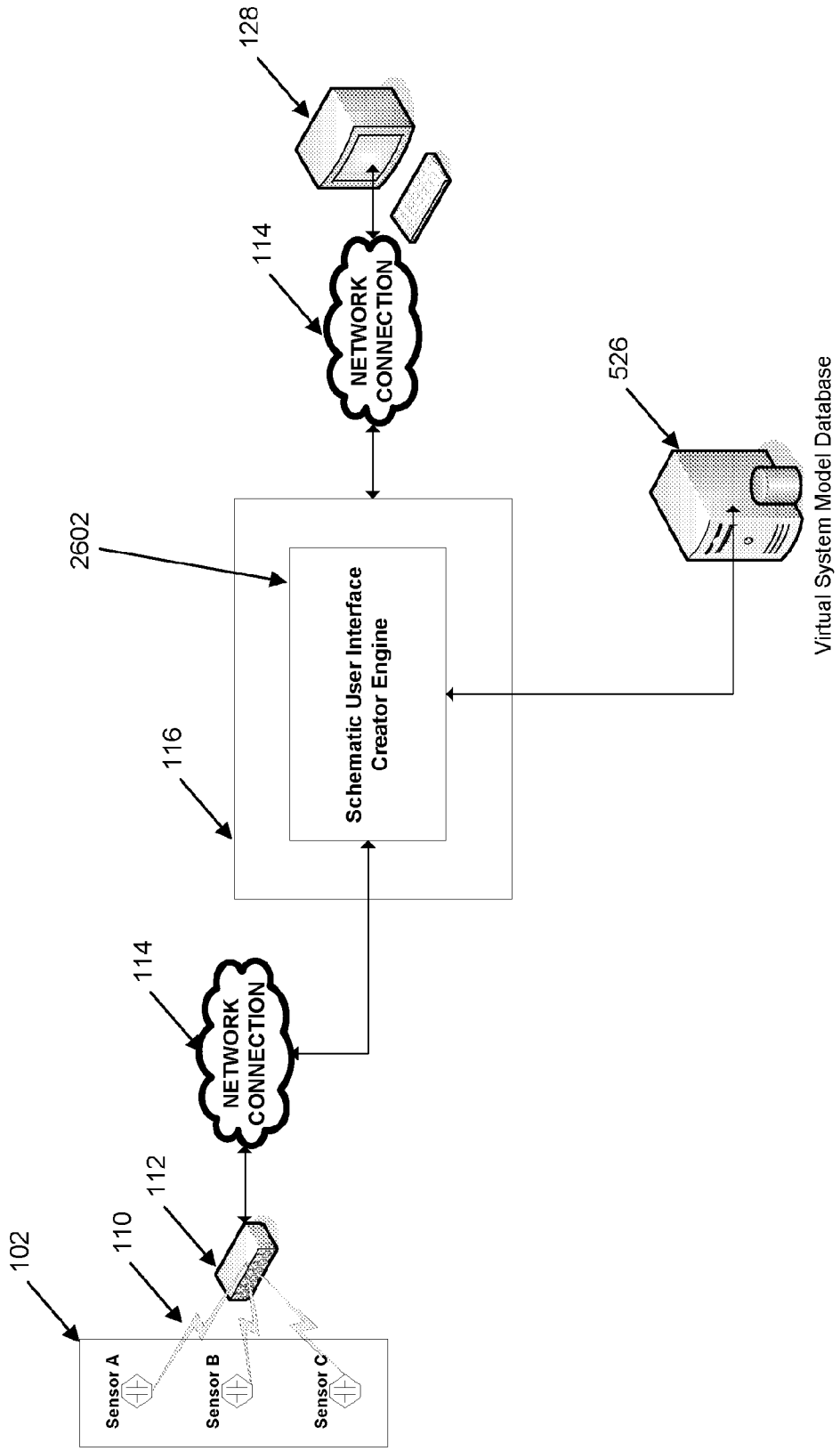

128
114
NETWORK CONNECTION
526
Virtual System Model Database
2602
Schematic User Interface Creator Engine
116
114
NETWORK CONNECTION
112
110
102
Sensor A
Sensor B
Sensor C

FIG. 26

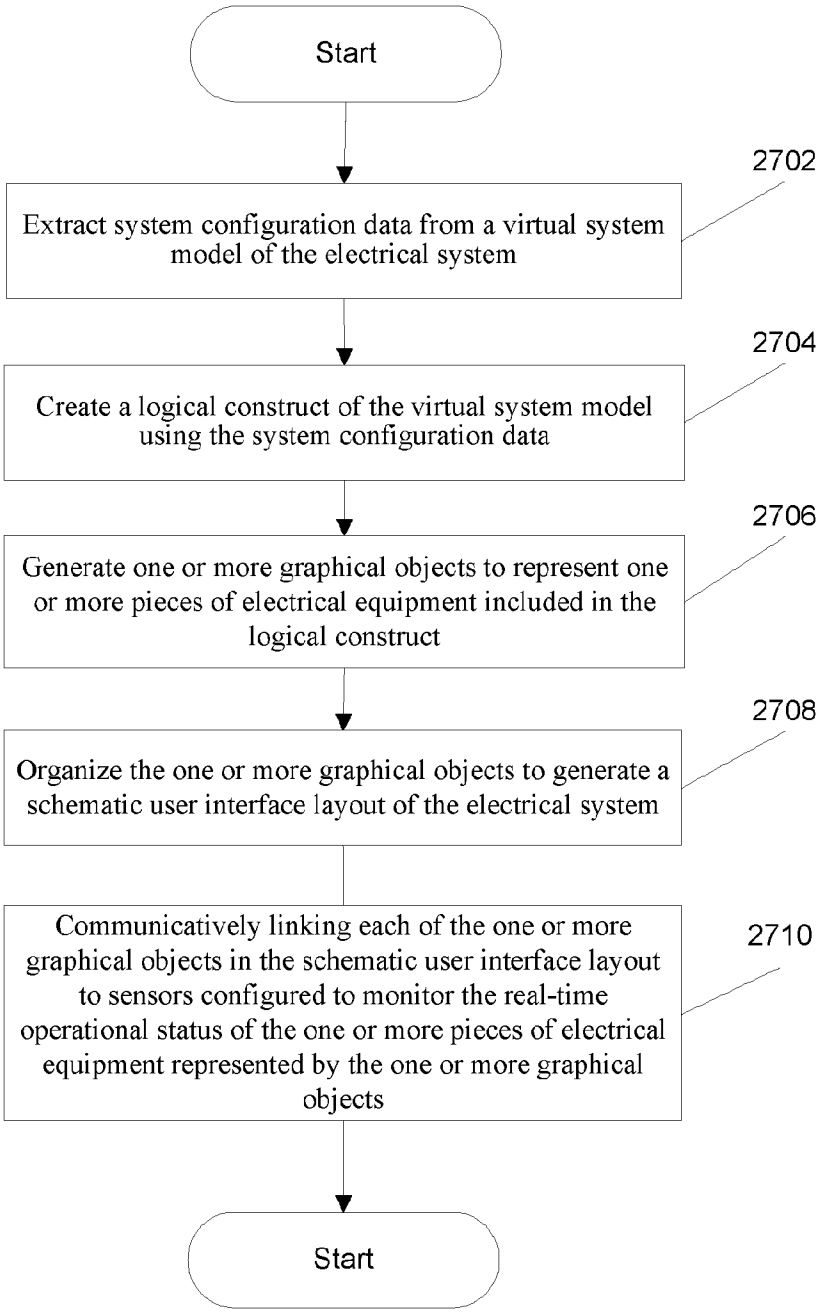

Start
2702
Extract system configuration data from a virtual system model of the electrical system
2704
Create a logical construct of the virtual system model using the system configuration data
2706
Generate one or more graphical objects to represent one or more pieces of electrical equipment included in the logical construct
2708
Organize the one or more graphical objects to generate a schematic user interface layout of the electrical system
2710
Communicatively linking each of the one or more graphical objects in the schematic user interface layout to sensors configured to monitor the real-time operational status of the one or more pieces of electrical equipment represented by the one or more graphical objects
Start

FIG. 27

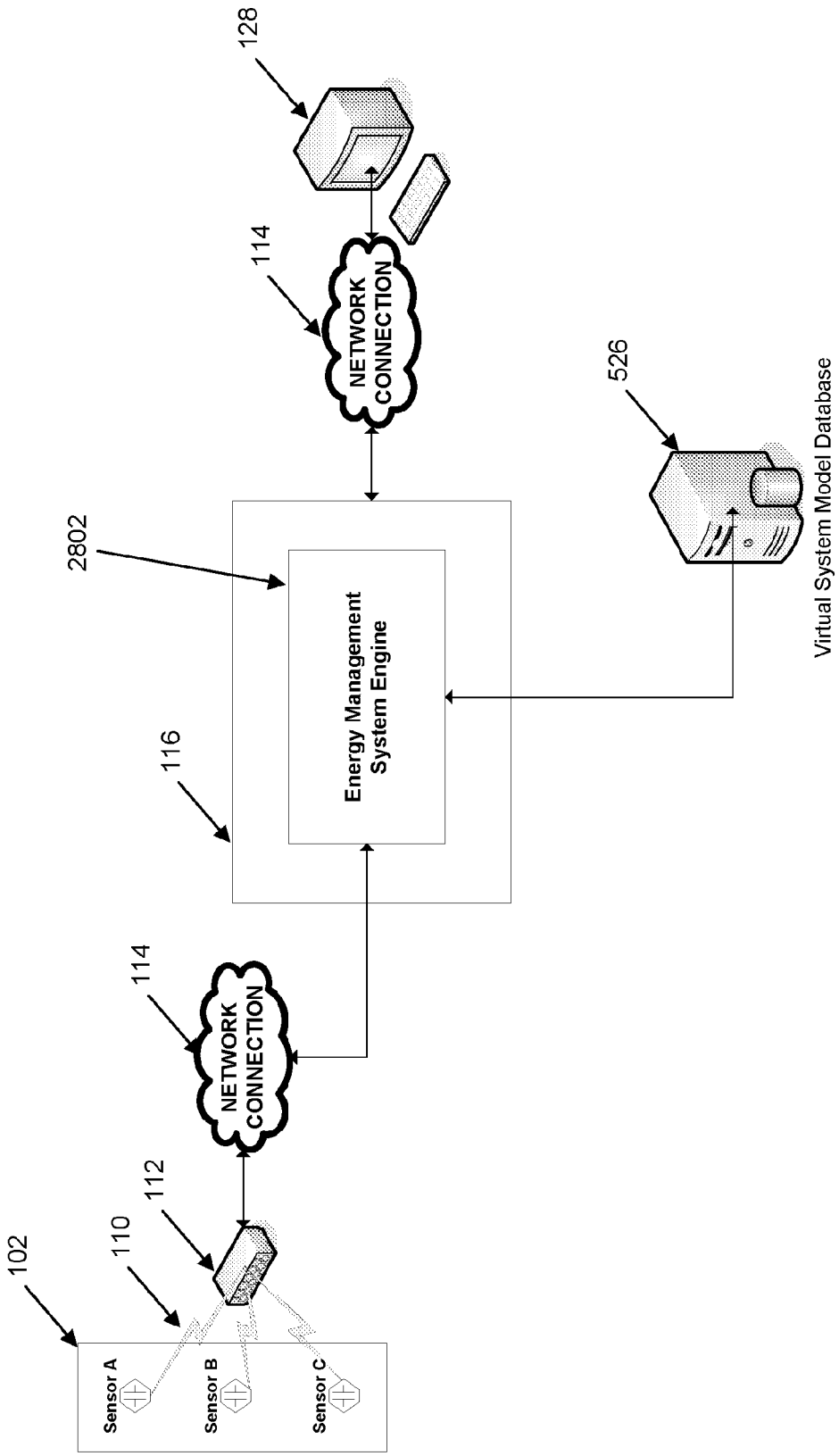

128
114
NETWORK CONNECTION
526
Virtual System Model Database
2802
Energy Management System Engine
116
114
NETWORK CONNECTION
112
110
102
Sensor A
Sensor B
Sensor C

FIG. 28

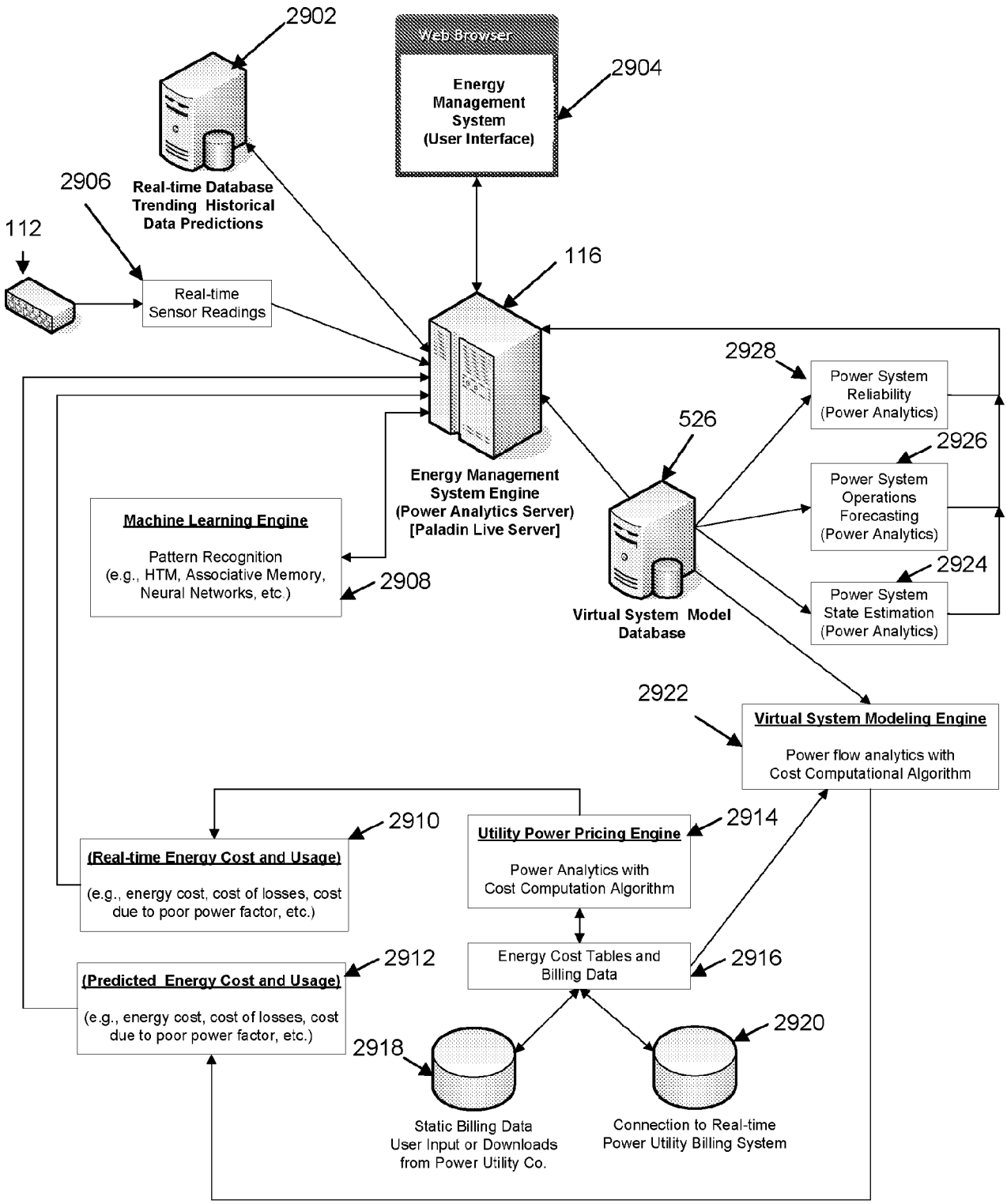

2902
Web Browser
Energy Management System (User Interface)
2904
2906
Real-time Database Trending Historical Data Predictions
112
Real-time Sensor Readings
116
2928
Power System Reliability (Power Analytics)
526
2926
Power System Operations Forecasting (Power Analytics)
Energy Management System Engine (Power Analytics Server) [Paladin Live Server]
Machine Learning Engine
Pattern Recognition (e.g., HTM, Associative Memory, Neural Networks, etc.)
2908
2924
Power System State Estimation (Power Analytics)
Virtual System Model Database
2922
Virtual System Modeling Engine
Power flow analytics with Cost Computational Algorithm
2910
(Real-time Energy Cost and Usage)
(e.g., energy cost, cost of losses, cost due to poor power factor, etc.)
2914
Utility Power Pricing Engine
Power Analytics with Cost Computation Algorithm
2912
(Predicted Energy Cost and Usage)
(e.g., energy cost, cost of losses, cost due to poor power factor, etc.)
Energy Cost Tables and Billing Data
2916
2918
2920
Static Billing Data User Input or Downloads from Power Utility Co.
Connection to Real-time Power Utility Billing System

FIG. 29

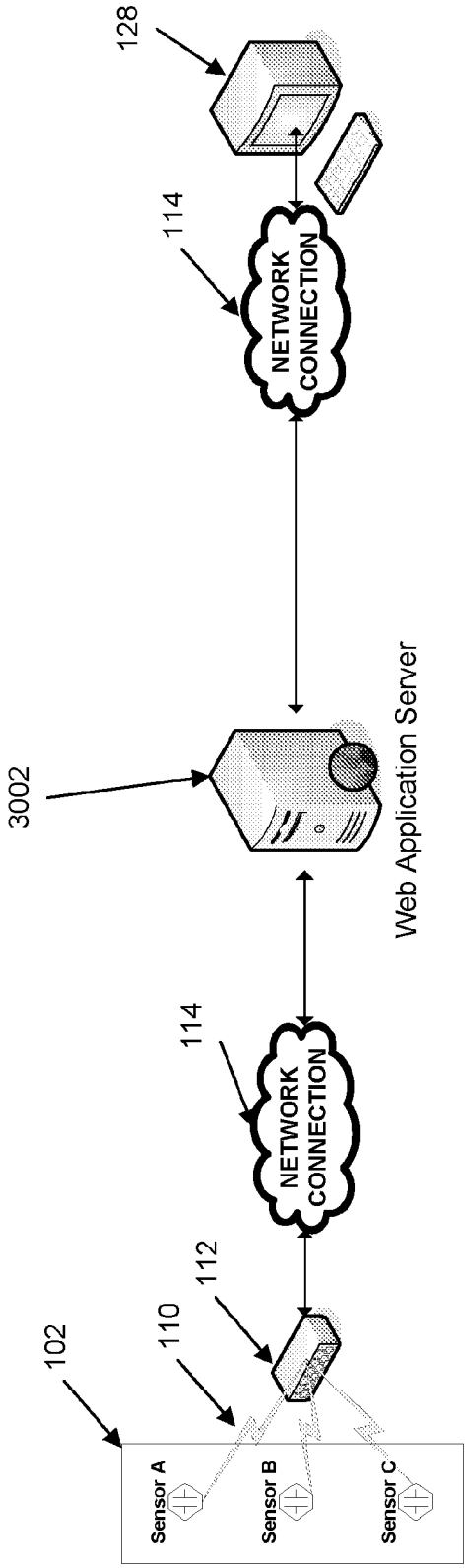

128
114
NETWORK CONNECTION
3002
Web Application Server
114
NETWORK CONNECTION
112
110
102
Sensor A
Sensor B
Sensor C

FIG. 30

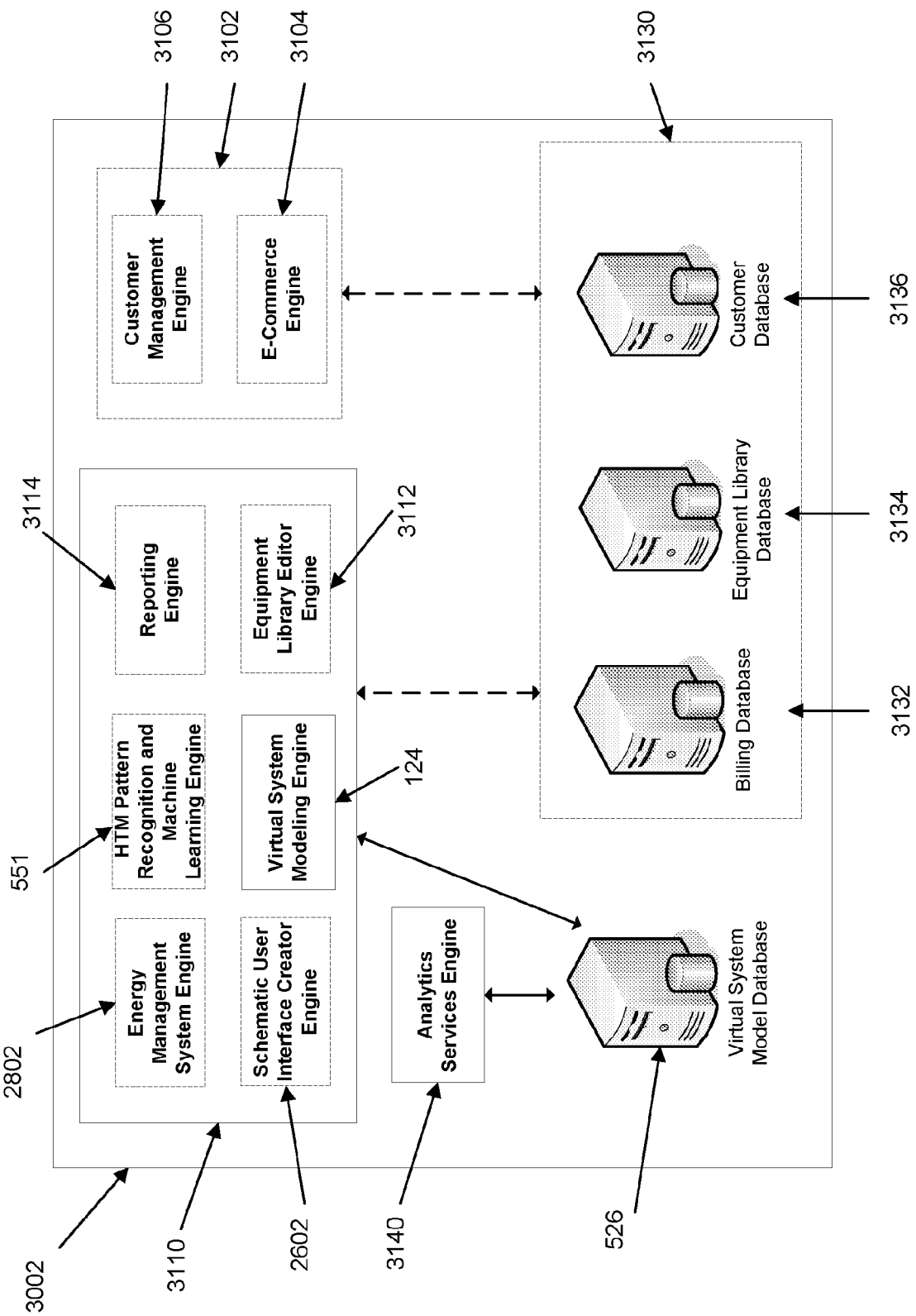

3106
3102
3104
3130
Customer Management Engine
E-Commerce Engine
Customer Database
3136
3114
Reporting Engine
Equipment Library Editor Engine
3112
Equipment Library Database
3134
HTM Pattern Recognition and Machine Learning Engine
Virtual System Modeling Engine
124
Billing Database
3132
551
Energy Management System Engine
Schematic User Interface Creator Engine
Analytics Services Engine
Virtual System Model Database
2802
3002
3110
2602
3140
526

FIG. 31

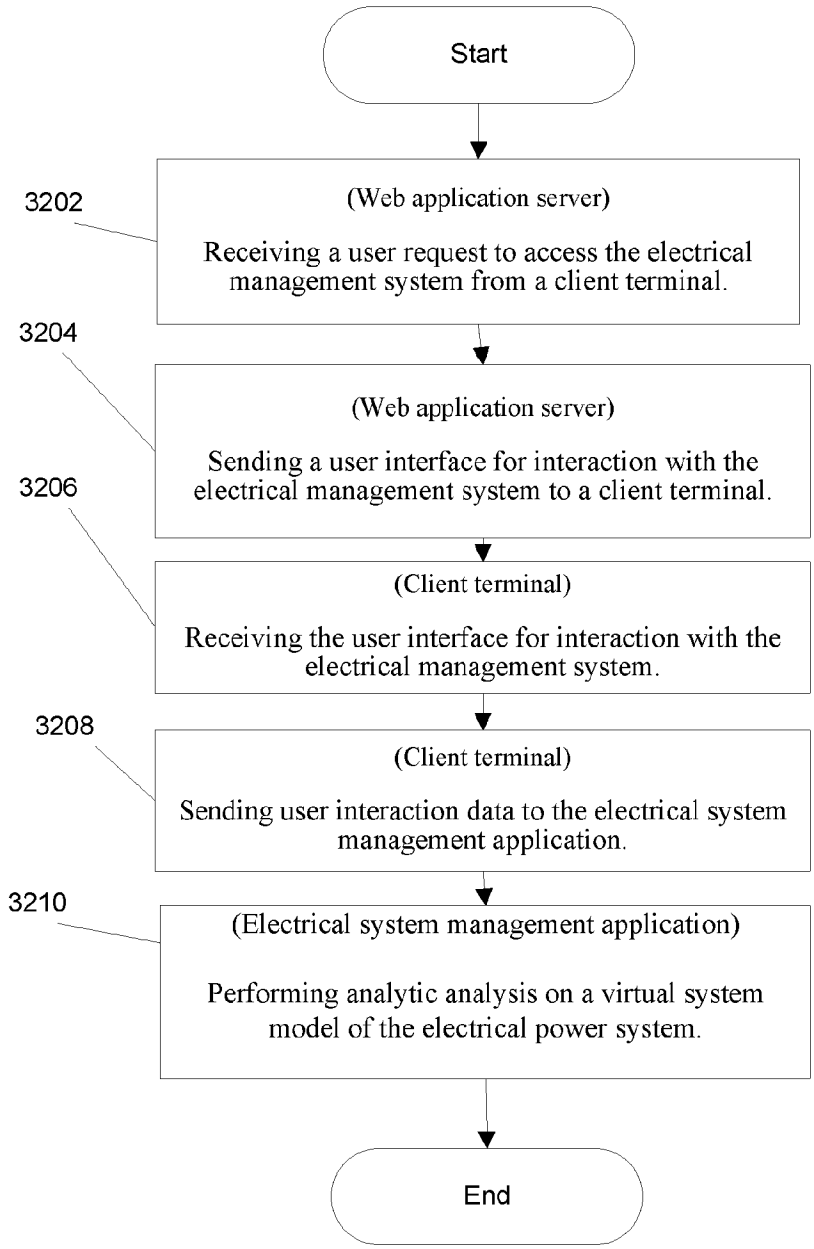

Start
3202
(Web application server)
Receiving a user request to access the electrical management system from a client terminal.
3204
(Web application server)
Sending a user interface for interaction with the electrical management system to a client terminal.
3206
(Client terminal)
Receiving the user interface for interaction with the electrical management system.
3208
(Client terminal)
Sending user interaction data to the electrical system management application.
3210
(Electrical system management application)
Performing analytic analysis on a virtual system model of the electrical power system.
End

FIG. 32

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2008/079218

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - G06F 17/50 (2008.04)
USPC - 703/14
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - G06F 17/50 (2008.04)
USPC - 703/14

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
MicroPatent

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y	US 2007/0192078 A1 (NASLE et al) 16 August 2007 (16.08.2007) entire document	1-2, 4-8, 10-12, 14-17 --- 3, 9, 13, 18
Y	WO 2007/084784 A2 (GHANI) 26 July 2007 (26.07.2007) entire document	3, 9, 13, 18
A	US 2005/0156715 A1 (ZOU et al) 21 July 2005 (21.07.2005) entire document	1-18

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
05 December 2008	22 DEC 2008
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774