(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
**04 October 2018 (04.10.2018)**

WIPO | PCT

(10) **International Publication Number**
**WO 2018/177540 A1**

(51) **International Patent Classification:**
*H02J 3/00* (2006.01)

(21) **International Application Number:** PCT/EP2017/057721

(22) **International Filing Date:** 31 March 2017 (31.03.2017)

(25) **Filing Language:** English

(26) **Publication Language:** English

(71) **Applicant: SIEMENS AKTIENGESELLSCHAFT** [DE/DE]; Werner-von-Siemens-Straße 1, 80333 München (DE).

(72) **Inventors: KRISHNAN, Ganesh Ayyappan**; 182/D, Cauveri Nilaya, 2nd Main, 3rd B Cross, Domlur Layout, Bangalore, Karnataka 560071 (IN). **RAJASEKARAN, Vijayaganesh**; #280, 24th Main, 5th Cross, Agara, Bangalore, Karnataka 560071 (IN). **A, Murugan**; T4, Vintage Roase Apartment, Munireddy Layout, Mahadevpura, Bangalore, Karnataka 560048 (IN).

(74) **Agent: PATENT ATTORNEYS WILHELM & BECK**; Prinzenstr. 13, 80639 Munich (DE).

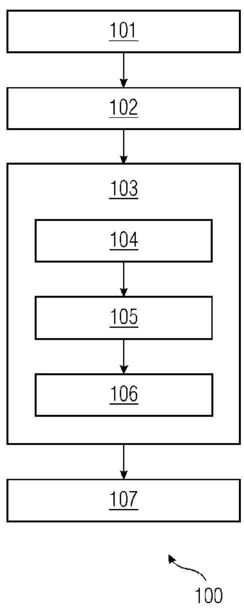
(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

**Published:**
— *with international search report (Art. 21(3))*

(54) **Title:** SYSTEM, METHOD AND A COMPUTER PROGRAM PRODUCT FOR AN IMPROVED FAULT ANALYSIS IN AN ELECTRICAL POWER SYSTEM

FIG 1A




(57) **Abstract:** System,method and a computer program product for analyzing power network data of an electrical power system. A method (100), a power network data analysis system (200), and a computer program product for analyzing power network data of an electrical power system (400) are provided. The power network data analysis system (200) obtains the power network data representing one or more parameters of electrical power being carried on the electrical power system (400), detects a power event on the electrical power system (400) from the power network data, determines a cause of the power event based on the power network data by employing a power network data analysis logic, and generates a recommendation associated with the power event for the electrical power system (400) based on the cause of the power event. The power network data analysis logic comprises determining a type of the power event based on power quality data and protection device data obtained from the power network data, identifying a location of the power event based on the power quality data, and analyzing the power event based on the power network data, the type of the power event, and/or the location of the power event.

WO 2018/177540 A1

Description

System, method and a computer program product for an improved fault analysis in an electrical power system

The present invention relates to fault analysis in an electrical power system. Furthermore, the present invention relates to a method, a power network data analysis system, and a computer program product for analyzing power network data of an electrical power system.

A conventional electrical power generating facility supplies electrical power to consumers over a vast and expansive power distribution grid containing many interconnected power line networks. The power line networks are of various sizes and convey low, medium or high voltage electric power to the consumers. Power quality of the electric power conveyed is typically defined as the power network's ability to supply a clean and stable power supply to the loads connected thereto. In other words, power quality ideally provides a power supply that is always available, is noise-free, and is always within acceptable voltage and frequency tolerance limits. Moreover, power quality determines fitness quotient of the electrical power conveyed to consumer equipment. Without sufficient power quality, the consumer equipment may malfunction, fail prematurely or cease to operate. There are several causes for decrease in power quality, for example, a shared infrastructure among customers, harmonics arising due to integration of micro grids and/or distributed generation, etc.

Power quality issues largely include any deviation from normal operation of a voltage source. Power quality issues include high-speed events such as voltage impulses or transients, high frequency noise, voltage swells and sags, or a total power loss. Electrical equipments of various types, facing power quality issues are typically affected in different ways. By analyzing the electrical power and evaluating the electrical equipment or load of the electrical equipment, it can be determined whether a power quality issue exists or not. Thus, power quality issue could also be looked at as a compatibility problem of the electrical equipment connected to the grid, that is, the electrical equipment's compatibility with events happening on the grid. Such problems are typically resolved by improving the power quality or making the equipment tougher. However, making equipment tougher often results in an increased cost of the equipment. Therefore, addressing the power quality issues is a preferred alternative not only from point of view of equipment life but also from point of view of an overall health of the grid.

In order to maintain acceptable levels of power quality and system reliability, analysis of faults and power quality issues based on the events is performed. However such analysis typically involves scrutinizing humungous data recorded by intelligent electronic devices (IEDs) placed in various substations. Such data is typically analyzed by power engineers via multiple tools in order to establish correlation between an event and a failure of equipment. Conventional power quality analysis tools automatically read disturbance files and record the power quality data captured by IEDs via periodic polling of the IEDs. However, the IEDs typically provide a large number of disturbance files per event, which the power engineers have to look into and identify appropriate disturbance files thereby making the analysis process tedious and time consuming. Moreover, identification of an appropriate disturbance file for analysis is largely based on competency of the power engineers thereby leading to possibility of false conclusions in the analysis due to human errors. Furthermore, determining whether the power quality disturbance occurred first or a fault occurred first is a cumbersome process which requires substation wide analysis. Thus, conventional analysis of power quality lacks efficiency and fails to provide a full-proof and in depth analysis of the disturbances occurring on the grid.

Therefore, it is an object of the present invention to provide a method, system and a computer program product for analyzing power network data of an electrical power system, with maximum accuracy in a time effective and a cost effective way.

The method, system and computer program product according to the present invention achieve the aforementioned object by employing a power network data analysis logic for determining a cause of a power event that has occurred on the electrical power system. According to the present invention, a method of analyzing power network data of an electrical power system is provided. As used herein, "electrical power system" refers to a network of electrical components comprising, for example, power generation equipment, power distribution equipment, power network protection equipment such as circuit breakers, relays, disconnectors, switchgears, etc., connected via power lines for generation, transmission and distribution of power therewithin from a power generation facility to a power consumption facitiy. Also, used herein, "power network data" refers to data obtained in real time and/or in non-real time from geographically distinct points spread over a wide area of an electrical power system. According to a preferred embodiment of the present invention, the power network data is substation wide power network data. According to an embodiment of the present invention, the power network data is a time stamped data comprising, for example, phasor measurements of data streams collected from various geographically distinct points. In a preferred embodiment according to the present invention, the power network data is a measured data and/or a computed data obtained from a plurality of power system data sources comprising, for example, control areas, protection devices, transmission facilities, utilities, regional reliability control centers, EMS/SCADA systems, non-power grid data sources, etc. According to a preferred embodiment of the present invention, the power network data is stored in a power system database. The power network data may be obtained periodically or continuously.

The power network data comprises power quality data, protection device data associated with a plurality of protection devices in the electrical power system, power event data, and topology data. As used herein, "power quality data" refers to data measured by the power quality devices in the electrical power system. The power quality data comprises, for example, harmonic distortion, flicker, unbalance voltage, individual harmonics, individual voltage and current values, etc., of a feeder. As used herein, "protection device data" refers to configuration data associated with the protection devices, for example, threshold value settings such as a trip level for a protection relay. As used herein, "power event data" refers to data associated with a power network event, for example, a time of occurrence of the power event, a sequence of occurrences of a plurality of power events, etc. The power events comprise deviation from a standard steady state operation that are significant from a fault analysis perspective and comprise, for example, load variations, power quality variations, faults such as short circuit faults, phase faults, earth faults, etc. As used herein, "topology data" refers to data associated with one or more substations in the electrical power system. The topology data comprises, for example, details of the electrical components such as power lines, buses, circuit breakers, switches, relays, transformers, as well as the loads such as motors, drives, capacitors, panelboards, etc., that enable to monitor load variation of the electrical power system. The topology data is monitored continuously and is obtained, for example, from configuration files, bay controller units, etc.

The method, according to the present invention, comprises obtaining the power network data representing one or more parameters of electrical power being carried on the electrical power system. The parameters comprising, for example, voltage and current values measured, for example, by various electrical measurement or sensing devices, at various points in the electrical power system. The parameters are related to, for example, quality of the electrical power, data associated with various electrical components supporting the electrical power being carried, data associated with the load being supplied, etc. The parameters comprise, for example, voltage, current, power, phase angles, frequency, harmonics, linear and nonlinear load values, etc., and may be measured and/or computed for each feeder and/or for each electrical component connected in the electrical power system.

The method, according to the present invention, comprises detecting a power event on the electrical power system from the power network data. The power event comprises a momentary event occurring on the electrical power system. As used herein "momentary event" refers to an abrupt deviation from a steady state operation that occurs for a short time period such as momentary overvoltage, a transient fault, etc. The power event is detected by defining a threshold limit for a plurality of power network data values obtained. For example, if a root-mean-square (RMS) current in one or more phases on an electrical power system exceeds a predetermined threshold level, this could indicate presence of a fault current which exceeds normal system load thereby qualifying as a power event. Other types of thresholds comprise, for example, a limit on allowable deviation of a measured quantity from its estimated nominal value, matching observed data to templates representative of certain kinds of failures or incipient failures. In a preferred embodiment, according to the present invention, the power event data is data associated with the power event, which is measured or computed, before and after occurrence of the power event for predefined time duration. Since the method, according to the present invention, precludes manual analysis of power network data, advantageously, the predefined time duration can be set in such way so as to capture and detect each of the momentary events.

The method, according to the present invention, comprises determining a cause of the power event based on the power network data. The cause of the power event comprises a load variation or a fault occurrence in the electrical power system. The cause of the power event is determined by employing power network data analysis logic. The power network data analysis logic comprises determining a type of the power event based on power quality data and protection device data obtained from the power network data. The type of the power event comprises a fault indication in the electrical power system and/or an aberration in quality of the electrical power being carried in the electrical power system. In order to determine, the type of the power event, a time of occurrence of the power event is obtained from the power event data. Using the time of occurrence of the power event, the power quality data and the protection device data, associated with the time of occurrence of the power event, is extracted from the power system database storing the power network data. Using the extracted power quality data and the protection device data, the type of the power event is determined. For example, on occurrence of a voltage swell or a voltage sag observed from the power quality data and on tripping of a protection device observed from the protection device data, a type of the power event is identified to be a combination type power event, which is, fault indication and aberration in power quality.

The power network data analysis logic comprises identifying a location of the power event based on the power quality data. The location of the power event comprises a load side power event and/or a source side power event. In order to identify, the location of the power event, voltage and current values are obtained from the power quality data. Based on the changes in the voltage and current, for example, when voltage dips and current increases at same instant or voltage increases and current dips at the same instant, then the power event is identified to be a load side power event. Whereas, if the voltage and the current both dip at the same instant then the power event is identified to be a source side power event.

The power network data analysis logic comprises analyzing the power event based on the power network data, the type of power event, and/or the location of the power event. The analysis of the power event comprises determining a cause of the power event, that is, a load variation or a fault occurrence in the electrical power system. In order to analyze the power event, the power quality data, the power event data, the protection device data and the topology data are extracted from the power network data. For example, for a combination type of the power event comprising a fault indication and a power quality aberration, a time of occurrence of each type of the power events is obtained from the power event data and a sequence of occurrence of each type of the power events is computed. If the aberration in power quality is found to be occurring before the fault indication, then using the power quality data and the topology data as well as the type of the power event, for example, a load side power event, a cause of the power event is determined. In an embodiment, the protection device data is also analyzed post analyzing the power quality data to determine cause of the power event. If the fault indication is found to occur before the power quality aberration, then using the protection device data and the topology data along with the type of the power event, a cause of the power event is determined. In an embodiment, the power quality data is analyzed after analyzing the protection device data to determine cause of the power event.

The method, according to the present invention, comprises generating a recommendation associated with the power event for the electrical power system based on the cause of the power event. The recommendation comprises one or more of a health status indication of one or more parts of the electrical power system, a replacement indication of one or more parts of the electrical power system, and a calibration indication of one or more parts of the electrical power system. As used herein, "health status" refers to an overall state of operational accuracy of a part of the electrical power system. The health status comprises, for example, whether an electrical component such as a protection device is operating as per its normal operating state, whether it has failed, whether it has had a malfunction, or whether its availability is affected or is expected to be affected following a power quality event or due to its aging factor. The health status is determined based on the cause of the power event and may include time of first observance and severity of any kind of error or contingency of the protection device. For an example, when a total harmonic distortion for a feeder has increased and the type of power event is a power quality aberration only then the health status may indicate a preventive warning about a circuit breaker in the feeder that could potentially trip. Advantageously, the health status is generated based on number of times a power event has occurred in a particular section of the electrical power system, that is, if a power event has happened for a number of times beyond a predefined threshold limit set for a particular feeder then the health status is generated indicating a preventive warning. The recommendation may further comprise a replacement indication for a part of the electrical power system if the health status of the part has been affected for a specific duration of time. The recommendation may further comprise calibration indication for a part such as a sensor, if the health status of the part comprises malfunction indication.

According to the present invention, also disclosed herein is a power network data analysis system for analyzing power network data of an electrical power system. The power network data analysis system comprises a non-transitory computer readable storage medium storing computer program instructions defined by modules of the power network data analysis system and at least one processor communicatively coupled to the non-transitory computer readable storage medium, executing the defined computer program instructions. The modules of the power network data analysis system comprise a data obtaining module, an event detection module, a cause determination module, and a recommendation generation module. The data obtaining module is configured to obtain the power network data representing one or more parameters of electrical power being carried on the electrical power system. The event detection module module is configured to detect a power event on the electrical power system from the power network data. The cause determination module is configured to determine a cause of the power event based on the power network data. The recommendation generation module is configured to generate a recommendation associated with the power event for the electrical power system based on the cause of the power event.

The cause determination module comprises modules configured to employ power network data analysis logic. The modules of the cause determination module comprise a type determination module configured to determine a type of the power event based on power quality data and protection device data obtained from the power network data, a location identification module configured to identify a location of the power event based on the power quality data, and an event analysis module configured to analyze the power event based on one or more of the power network data, the type of the power event, and the location of the power event.

According to the present invention, also disclosed herein, is a computer program product comprising a non-transitory computer readable storage medium storing computer program codes that comprise instructions executable by at least one processor for performing the method of analyzing power network data of an electrical power system, disclosed above.

The above-mentioned and other features of the invention will now be addressed with reference to the accompanying drawings of the present invention. The illustrated embodiments are intended to illustrate, but not limit the invention.

The present invention is further described hereinafter with reference to illustrated embodiments shown in the accompanying drawings, in which:

FIGS 1A-1D are process flowcharts illustrating a method of analyzing power network data of an electrical power system.

FIG 2 illustrates a power network data analysis system for analyzing power network data of an electrical power system.

FIG 3 is a block diagram illustrating architecture of a computer system employed by the power network data analysis system illustrated in FIG 2 for analyzing power network data of an electrical power system.

FIGS 4A-4B illustrate an electrical power system comprising linear and nonlinear loads.

FIGS 5A-5B illustrate graphical waveforms during operation of a protection device in the electrical power system illustrated in FIGS 4A-4B.

FIGS 6-7 illustrate screenshots of a graphical user interface provided by the power network data analysis system illustrated in FIG 2, for rendering recommendations generated by the power network data analysis system based on a cause of occurrence of a power event in the electrical power system illustrated in FIGS 4A-4B.

Various embodiments are described with reference to the drawings, wherein like reference numerals are used to refer to like elements throughout. In the following description, for the purpose of explanation, numerous specific details are set forth in order to provide thorough understanding of one or more embodiments of the present invention. It may be evident that such embodiments may be practiced without these specific details.

FIGS 1A-1D are process flowcharts illustrating a method 100 of analyzing power network data of an electrical power system. In a preferred embodiment, according to the present invention, the method disclosed herein employs a power network data analysis system illustrated in FIG 2, comprising at least one processor configured to execute computer program instructions for analyzing power network data of an electrical power system. As illustrated in FIG 1A, the step 101 of the method disclosed herein comprises obtaining the power network data representing one or more parameters of electrical power being carried on the electrical power system. The power network data comprises power quality data, protection device data associated with a plurality of protection devices in the electrical power system, power event data, and topology data. The power network data is a measured data and/or a computed data. The power network data is substation wide power network data. The power network data is obtained, for example, from each of the feeders of a substation via various sensing and measurement devices coupled to the feeders, such as, transducers, surge protection devices, fault sensing devices, power analyzers, etc. The power network data is stored in a power system database.

The step 102 of the method disclosed herein, comprises detecting a power event on the electrical power system from the power network data. The power event comprises a momentary event occurring on the electrical power system. For detection of the power event, the power network data is periodically screened through and any deviation of any of the parameters from their steady state operation is detected to be a power event. The power events are also stored in the power system database along with the power network data obtained during the time period in which the power event has occurred.

The step 103 of the method disclosed herein, comprises determining a cause of the power event based on the power network data. The cause of the power event comprises a load variation and/or a fault occurrence in the electrical power system. For determining a cause of the power event, the method disclosed herein employs power network data analysis logic. The step 104 of the method disclosed herein, comprises the power network data analysis logic determining a type of the power event based on power quality data and protection device data obtained from the power network data. The type of the power event comprises a fault indication in the electrical power system and/or an aberration in quality of the electrical power being carried in the electrical power system. Thus, the type of the power event can comprise a combination event wherein the power event comprises an occurrence of a fault prior to or post occurrence of an aberration of power quality of the electrical power. The step 105 of the method disclosed herein, comprises the power network data analysis logic identifying a location of the power event based on the power quality data. The location of the power event comprises a load side power event and/or a source side power event. The step 106 of the method disclosed herein, comprises the power network data analysis logic analyzing the power event based on the power network data, the type of the power event, and/or the location of the power event. Each of the steps 104, 105 and 106 of the power network data analysis logic are disclosed in detail in the descriptions of the FIGS 1B-1D.

At step 107, the method disclosed herein comprises generating a recommendation associated with the power event for the electrical power system based on the cause of the power event. The recommendation comprises a health status indication of one or more parts of the electrical power system, a replacement indication of one or more parts of the electrical power system, and/or a calibration indication of one or more parts of the electrical power system.

FIG 1B is a process flowchart illustrating the step 104 of the power network data analysis logic employed by the method disclosed in FIG 1A comprising, determining a type of the power event. At step 104A, the power network data analysis logic comprises extracting the power event data from the power network data, for example, by retrieving the power network data from the power system database. Alternatively at step 104A, the power network data analysis logic comprises obtaining the power event data from the power system database. At step 104B, the power network data analysis logic comprises obtaining a time of occurrence of the power event from the extracted power event data. At step 104C, the power network data analysis logic comprises extracting power quality data and protection device data from the power network data based on the time of occurrence of the power event. The power quality data and the protection device data are extracted for a predefined time window around the time of occurrence of the power event. The time window comprises, for example, 50 seconds before and after an instant at which the power event has occurred as per the obtained time of occurrence. At step 104D, the power network data analysis logic comprises analyzing the power quality data and the protection device data. The power quality data is analyzed to determine presence of an aberration in power quality based on deviation in values of parameters such as total harmonic distortion, flicker, unbalance voltage, unbalance current, individual harmonics, etc., from their standard steady state values. Similarly the protection device data is analyzed to determine whether any of the protection devices in the electrical power system have tripped during the time of occurrence of the power event based on their threshold limits. Thus, the power network data analysis logic provides an indication of whether an aberration in power quality is observed and/or a fault indication via tripping of a protection device has been observed in the electrical power system corresponding to the power event detected.

FIG 1C is a process flowchart illustrating the step 105 of the power network data analysis logic employed by the method disclosed in FIG 1A comprising, identifying a location of the power event. At step 105A, the power network data analysis logic comprises extracting voltage values from the power quality data associated with the time of occurrence of the power event. The voltage values are for one or more feeders in a substation of the electrical power system. At step 105B, the power network data analysis logic comprises extracting current values from the power quality data associated with the time of occurrence of the power event. The current values are for one or more feeders in a substation of the electrical power system. At step 105C, the power network data analysis logic comprises verifying whether the voltage values and the current values are simultaneously increasing or decreasing at the same time instant. If yes, then at step 105D, the power network data analysis logic comprises identifying the location of the power event to be a source side power event and if not, then at step 105E, the power network data analysis logic comprises identifying the location of the power event to be a load side power event. Each of the steps 104A-104D illustrated in FIG 1B and the steps 105A-105E disclosed herein, are performed by the power network data analysis logic for each power event detected by the method disclosed herein in the electrical power system.

FIG 1D is a process flowchart illustrating the step 106 of the power network data analysis logic employed by the method disclosed in FIG 1A comprising, analyzing the power event. At step 106A, the power network data analysis logic comprises verifying whether the type of event determined is a combination event, that is, a fault indication prior to or post occurrence of an aberration of power quality of the electrical power. If no, that is, the power event comprises aberration of power quality but no fault occurrence indication then, at step 106B, based on the location of the power event identified, the cause of the power event is determined to be a load side, that is, a facility side load variation such as abrupt change in a load or a source side, that is, a utility side event such supply line variation. If yes, that is, the power event comprises an indication of an occurrence of a fault prior to or post occurrence of an aberration of power quality of the electrical power then, at step 106C, the power network data analysis logic comprises extracting topology data from the power network data. At step 106D, the power network data analysis logic comprises obtaining a sequence of occurrence of each of the power events based on the time of occurrence of the power events detected. At step 106E, the power network data analysis logic comprises verifying whether the aberration in power quality happened prior to indication of an occurrence of the fault. If yes, then at step 106F, the topology data and power quality data are analyzed along with the location of power event in order to determine whether the cause of the power event is load variation or an actual fault occurrence. Post analysis of the topology data and the power quality data, the protection device data is also analyzed for determining cause of the power event. If no, then at step 106G, the topology data and the protection device data are analyzed along with the location of power event in order to determine whether the cause of the power event is load variation or an actual fault occurrence. Post analysis of the topology data and the protection device data, the power quality data is also analyzed for determining cause of the power event.

FIG 2 illustrates a power network data analysis system (PNDAS) for analyzing power network data of an electrical power system. The PNDAS 200, according to the present invention, is installed on and accessible by a user device, for example, a personal computing device, a workstation, a client device, a network enabled computing device, any other suitable computing equipment, and combinations of multiple pieces of computing equipment. In a preferred embodiment, according to the present invention, the PNDAS 200 is downloadable and usable on the user device. In another embodiment according to the present invention, the PNDAS 200 is configured as a web based platform, for example, a website hosted on a server or a network of servers. In another embodiment according to the present invention, the PNDAS 200 is implemented in the cloud computing environment. The PNDAS 200 is developed, for example, using Google App engine cloud infrastructure of Google Inc., Amazon Web Services® of Amazon Technologies, Inc., the Amazon elastic compute cloud EC2® web service of Amazon Technologies, Inc., the Google® Cloud platform of Google Inc., the Microsoft® Cloud platform of Microsoft Corporation, etc. In an embodiment, the PNDAS 200 is configured as a cloud computing based platform implemented as a service for analyzing power network data of an electrical power system.

The power network data analysis system (PNDAS) 200 disclosed herein comprises a non-transitory computer readable storage medium and at least one processor communicatively coupled to the non-transitory computer readable storage medium. As used herein, "non-transitory computer readable storage medium" refers to all computer readable media, for example, non-volatile media, volatile media, and transmission media except for a transitory, propagating signal. The non-transitory computer readable storage medium is configured to store computer program instructions defined by modules, for example, 201, 202, 203, 204, etc., of the PNDAS 200. The processor is configured to execute the defined computer program instructions. As illustrated in FIG 2, the PNDAS 200 comprises a graphical user interface (GUI) 205. A user using the user device can access the PNDAS 200 via the GUI 205. The GUI 205 is, for example, an online web interface, a web based downloadable application interface such as Microsoft® Windows® application, etc. The PNDAS 200 further comprises a data obtaining module 201, an event detection module 202, a cause determination module 203, and a recommendation generation module 204.

The data obtaining module 201 obtains the power network data representing one or more parameters of electrical power being carried on the electrical power system. The data obtaining module 201 is in operable communication with a plurality of measurement and sensing devices mounted at various geographical points in a substation 207. The data obtaining module 201 computes power network data based on the data received from these devices in the substation 207. In an embodiment, according to the present invention, the data obtaining module 201 is in operable communication with a central database 209 comprising, for example, a database storing data at a substation control center. In an embodiment, according to the present invention, the data obtaining module 201 is in communication with the measurement and/or sensing devices of the substation 207 and the central database 209 via a communication network 208. The communication network is, for example, a wired network, a wireless network, or a network formed from any combination of these networks. The communication network is, for example, a plant bus, a field bus, a communication bus, etc. via which a plurality of measurement and/or sensing devices of the substation 207 communicate with the data obtaining module 201. The data obtaining module 201 stores the power network data in a power system database 206. The power system database 206 is, for example, a structured query language (SQL) data store or a not only SQL (NoSQL) data store. In an embodiment, according to the present invention, the power system database 202, can also be a location on a file system directly accessible by the PNDAS 200. In another embodiment according to the present invention, the power system database 202, is configured as cloud based database implemented in a cloud computing environment, where computing resources are delivered as a service over the communication network 208. As used herein, "cloud computing environment" refers to a processing environment comprising configurable computing physical and logical resources, for example, networks, servers, storage, applications, services, etc., and data distributed over the communication network 208, for example, the internet. The cloud computing environment provides on-demand network access to a shared pool of the configurable computing physical and logical resources.

The event detection module 202 detects a power event on the electrical power system from the power network data. The cause determination module 203 determines a cause of the power event based on the power network data wherein the cause of the power event comprises one or more of a load variation and a fault occurrence in the electrical power system. The cause determination module comprises modules 203A, 203B, and 203C that employ the power network data analysis logic disclosed in the detailed description of FIGS 1A-1D. The cause determination module 203 further comprises a type determination module 203A, a location identification module 203B and an event analysis module 203C. The type determination module 203A determines a type of the power event based on power quality data and protection device data obtained from the power network data. The location identification module 203B identifies a location of the power event based on the power quality data. The event analysis module 203C analyzes the power event based the power network data, the type of the power event, and/or the location of the power event. The recommendation generation module 204 generates a recommendation associated with the power event for the electrical power system based on the cause of the power event.

FIG 3 is a block diagram illustrating architecture of a computer system 300 employed by the power network data analysis system (PNDAS) 200 illustrated in FIG 2, for analyzing power network data of an electrical power system. The PNDAS 200 employs the architecture of the computer system 300 illustrated in FIG 3. The computer system 300 is programmable using a high level computer programming language. The computer system 300 may be implemented using programmed and purposeful hardware. As illustrated in FIG 3, the computer system 300 comprises a processor 301, a non-transitory computer readable storage medium such as a memory unit 302 for storing programs and data, an input/output (I/O) controller 303, a network interface 304, a data bus 305, a display unit 306, input devices 307, a fixed media drive 308 such as a hard drive, a removable media drive 309 for receiving removable media, output devices 310, etc. The processor 301 refers to any one of microprocessors, central processing unit (CPU) devices, finite state machines, microcontrollers, digital signal processors, an application specific integrated circuit (ASIC), a field-programmable gate array (FPGA), etc., or any combination thereof, capable of executing computer programs or a series of commands, instructions, or state transitions. The processor 301 may also be implemented as a processor set comprising, for example, a general purpose microprocessor and a math or graphics co-processor. The processor 301 is selected, for example, from the Intel® processors, Advanced Micro Devices (AMD®) processors, International Business Machines (IBM®) processors, etc. The PNDAS 200 disclosed herein is not limited to a computer system 300 employing a processor 301. The computer system 300 may also employ a controller or a microcontroller. The processor 301 executes the modules, for example, 201, 202, 203, 204, etc., of the PNDAS 200.

The memory unit 302 is used for storing programs, applications, and data. For example, the data obtaining module 201, the event detection module 202, the cause determination module 203, the recommendation generation module 204, etc., of the PNDAS 200 are stored in the memory unit 302 of the computer system 300. The memory unit 302 is, for example, a random access memory (RAM) or another type of dynamic storage device that stores information and instructions for execution by the processor 301. The memory unit 302 also stores temporary variables and other intermediate information used during execution of the instructions by the processor 301. The computer system 300 further comprises a read only memory (ROM) or another type of static storage device that stores static information and instructions for the processor

301. The I/O controller 303 controls input actions and output actions performed by the power network data analysis system (PNDAS) 200.

The network interface 304 enables connection of the computer system 300 to the communication network 208. For example, the power network data analysis system (PNDAS) 200 connects to the communication network 208 via the network interface 304. In an embodiment, the network interface 304 is provided as an interface card also referred to as a line card. The network interface 304 comprises, for example, interfaces using serial protocols, interfaces using parallel protocols, and Ethernet communication interfaces, interfaces based on wireless communications technology such as satellite technology, radio frequency (RF) technology, near field communication, etc. The data bus 305 permits communications between the modules, for example, 201, 202, 203, 204, etc., of PNDAS 200.

The display unit 306, via the graphical user interface (GUI) 205, displays information such as a recommendation report generated by the recommendation generation module 204, user interface elements such as text fields, buttons, windows, etc. The display unit 306 comprises, for example, a liquid crystal display, a plasma display, an organic light emitting diode (OLED) based display, etc. The input devices 307 are used for inputting data into the computer system 300. The input devices 307 are, for example, a keyboard such as an alphanumeric keyboard, a touch sensitive display device, and/or any device capable of sensing a tactile input.

Computer applications and programs are used for operating the computer system 300. The programs are loaded onto the fixed media drive 308 and into the memory unit 302 of the computer system 300 via the removable media drive 309. In an embodiment, the computer applications and programs may be loaded directly via the communication network 208. Computer applications and programs are executed by double clicking a related icon displayed on the display unit 306 using one of the input devices 307. The output devices 310 output the results of operations performed by the power network data analysis system (PNDAS) 200. For example, the PNDAS 200 provides graphical representation of the recommendation reports generated by the recommendation generation module 204, using the output devices 310. The graphical representation comprises, for example, topology view of the substation 207 and recommendation to indicate status of the electrical components or replace or calibrate the electrical components in the substation 207.

The processor 301 executes an operating system, for example, the Linux® operating system, the Unix® operating system, any version of the Microsoft® Windows® operating system, the Mac OS of Apple Inc., the IBM® OS/2, etc. The computer system 300 employs the operating system for performing multiple tasks. The operating system is responsible for management and coordination of activities and sharing of resources of the computer system 300. The operating system further manages security of the computer system 300, peripheral devices connected to the computer system 300, and network connections. The operating system employed on the computer system 300 recognizes, for example, inputs provided by the users using one of the input devices 307, the output display, files, and directories stored locally on the fixed media drive 308. The operating system on the computer system 300 executes different programs using the processor 301. The processor 301 and the operating system together define a computer platform for which application programs in high level programming languages are written.

The processor 301 of the computer system 300 employed by the power network data analysis system (PNDAS) 200 retrieves instructions defined by the data obtaining module 201, the event detection module 202, the cause determination module 203, the recommendation generation module 204, etc., of the PNDAS 200 for performing respective functions disclosed in the detailed description of FIG 2. The processor 301 retrieves instructions for executing the modules, for example, 201, 202, 203, 204, etc., of the PNDAS 200 from the memory unit 302. A program counter determines the location of the instructions in the memory unit 302. The program counter stores a number that identifies the current position in the program of each of the modules, for example, 201, 202, 203, 204, etc., of the PNDAS 200. The instructions fetched by the processor 301 from the memory unit 302 after being processed are decoded. The instructions are stored in an instruction register in the processor 301. After processing and decoding, the processor 301 executes the instructions, thereby performing one or more processes defined by those instructions.

At the time of execution, the instructions stored in the instruction register are examined to determine the operations to be performed. The processor 301 then performs the specified operations. The operations comprise arithmetic operations and logic operations. The operating system performs multiple routines for performing a number of tasks required to assign the input devices 307, the output devices 310, and memory for execution of the modules, for example, 201, 202, 203, 204, etc., of the power network data analysis system (PNDAS) 200. The tasks performed by the operating system comprise, for example, assigning memory to the modules, for example, 201, 202, 203, 204, etc., of the PNDAS 200, and to data used by the PNDAS 200, moving data between the memory unit 302 and disk units, and handling input/output operations. The operating system performs the tasks on request by the operations and after performing the tasks, the operating system transfers the execution control back to the processor 301. The processor 301 continues the execution to obtain one or more outputs. The outputs of the execution of the modules, for example, 201, 202, 203, 204, etc., of the PNDAS 200 are displayed to the user on the GUI 205.

For purposes of illustration, the detailed description refers to the power network data analysis system (PNDAS) 200 being run locally on the computer system 300; however the scope of the present invention is not limited to the PNDAS 200 being run locally on the computer system 300 via the operating system and the processor 301, but may be extended to run remotely over the communication network 208 by employing a web browser and a remote server, a handheld device, or other electronic devices. One or more portions of the computer system 300 may be distributed across one or more computer systems (not shown) coupled to the communication network 208.

Disclosed herein is also a computer program product comprising a non-transitory computer readable storage medium that stores computer program codes comprising instructions executable by at least one processor 301 for analyzing power network data of an electrical power system, as disclosed in the present invention. The computer program product comprises a first computer program code for obtaining the power network data representing one or more parameters of electrical power being carried on the electrical power system; a second computer program code for detecting a power event on the electrical power system from the power network data; a third computer program code for determining a cause of the power event based on the power network data; and a fourth computer program code for generating a recommendation associated with the power event for the electrical power system based on the cause of the power event.

The third computer program code comprises a fifth computer program code, a sixth computer program code, and a seventh computer program code for employing the power network data analysis logic disclosed in the detailed description of the FIGS 1A-1D. The fifth computer program code determines a type of the power event based on power quality data and protection device data obtained from the power network data. The sixth computer program code identifies a location of the power event based on the power quality data. The seventh computer program code analyzes the power event based on the power network data, the type of the power event, and/or the location of the power event.

In an embodiment, a single piece of computer program code comprising computer executable instructions performs one or more steps of the method according to the present invention, for analyzing power network data of an electrical power system. The computer program codes comprising computer executable instructions are embodied on the non-transitory computer readable storage medium. The processor 301 of the computer system 300 retrieves these computer executable instructions and executes them. When the computer executable instructions are executed by the processor 301, the computer executable instructions cause the processor 301 to perform the steps of the method for analyzing power network data of an electrical power system.

FIGS 4A-7 illustrate an example of a power event that comprises a fault occurrence as well as an aberration in the power quality, wherein, the fault occurrence is being triggered as a result of the aberration in the power quality.

FIGS 4A-4B illustrate an electrical power system 400 comprising linear and nonlinear loads 405. The electrical power system 400 comprises a power line 401 to which a transformer 402 and a circuit breaker 403 are connected. The circuit breaker 403 connects and disconnects a busbar 404 to the power line 401. Also, connected to the busbar 404 are the linear and nonlinear loads 405, comprising, for example, a motor, an illumination device such as a cluster of lamps, etc. As illustrated in FIG 4A, harmonics generated due to nonlinear loads tend to move in the direction of the source, that is, the power line 401 from the load 405 due to a low impedance path offered by the power line. As illustrated in FIG 4B, when a capacitor 405A is connected to the busbar 404, the harmonics tend to move towards the capacitor not only from the load side but also from the source side. Due to this flow of harmonics, the circuit breaker 403 tends to overload due to excess harmonics.

FIGS 5A-5B illustrate graphical waveforms during operation of a protection device, that is, the circuit breaker 403 in the electrical power system 400, illustrated in FIGS 4A-4B. The total root mean square (RMS) current waveform 501 represents a total harmonic distortion current including fundamental and harmonics. The waveform 502 represents the fundamental component of the current. The circuit breaker 403 is overloaded due to excess flow of harmonics as disclosed in the detailed description of FIGS 4A-4B. Due to an overload condition, the circuit breaker 403 either malfunctions, that is, fails to trip even when the fundamental value, as indicated by the fundamental waveform 502, is higher than the threshold trip value set 503, as illustrated in FIG 5A, or the circuit breaker 403 trips erroneously despite of the fundamental value, as indicated by the fundamental waveform 502, being lower than the threshold trip value set 503, as illustrated in FIG 5B. As illustrated in FIG 5A, the circuit breaker 403 malfunctions because the presence of harmonics, as indicated by the total RMS current waveform 501, reduces the peak value of the fundamental waveform 502. As illustrated in FIG 5B, the circuit breaker 403 trips erroneously because the presence of harmonics, as indicated by the total RMS current waveform 501, increases the peak value of the fundamental waveform 502.

FIGS 6-7 illustrate screenshots of a graphical user interface (GUI) 205 provided by the power network data analysis system (PNDAS) 200, as disclosed in the detailed description of FIG 2, for rendering recommendations generated by the PNDAS 200 based on a cause of occurrence of a power event in the electrical power system 400 illustrated in FIGS 4A-4B. In order to generate the recommendations, the PNDAS 200, obtains the power network data and detects the power event, that is, aberration in power quality due to an increased amount of harmonics distortion as well as fault occurrence indication, for example, due to erroneous tripping of the circuit breaker 403. The type of such a power event is identified to be a combination power event including fault occurrence indication post an aberration in the power quality. Based on the type of the power event identified, the PNDAS 200 determines whether the power event occurred at the load side or the source side. In this example, it is observed from the power quality data that the voltage and the current values are following an inverse trend with respect to one another at a given time instant, that is, the voltage increases while the current dips. Therefore, the PNDAS 200 identifies the power event to be at the load side. To determine a cause of the power event, the PNDAS 200 further analyzes the power event based on the power quality data and the topology data as the power quality aberration has happened before the fault occurrence indication. The PNDAS 200 obtains the power quality data. The power quality data recorded during a fault occurrence, comprises a comparison of a current measured by the power quality device, for example, the circuit breaker 403, as a fundamental and the total root mean square (RMS) values including the harmonics and fundamental. The PNDAS 200 further obtains from the protection device data, threshold trip levels of the circuit breaker 403 and compares the peak value of the fundamental with the threshold trip levels and determines the cause to be an erroneous tripping of the circuit breaker 403 due to increased harmonics that resulted in the peak value of the fundamental overshooting the threshold trip level. Thus, the cause of the power event is determined to be an actual aberration in power quality due to load variation in the electrical power system 400.

As illustrated in FIG 6, the power network data analysis system (PNDAS) 200 generates a graphical representation 600 of a health status indication as a recommendation indicating the operating status of each of the electrical components in the electrical power system 400. As a result of the continuous increase in the harmonics and the associated root mean square (RMS) value, the PNDAS 200 can generate a warning or an unhealthy status indication at the power line 401 or at the bus bar 404 to provide a preventive indication of a fault that could occur. The health status can also be indicated via a topology view.

As illustrated in FIG 7, the power network data analysis system (PNDAS) 200 generates a graphical representation 700 illustrating a recommendation report comprising the cause of the power event determined to be total harmonic distortion followed by a recommendation stating replacement of the capacitor 405A to a passive filter or an active filter or to calibrate the load linear and the nonlinear load 405 in a way so as to increase percentage of linear load on the busbar 404. The recommendation report can also include age of the capacitor 405A indicating deterioration in its reactive power rating, based on the power quality data obtained, that is, the reactive power value of the capacitor 405A and based on the topology data, that is, position of the capacitor 405A in the electrical power system 400. The recommendation report can also include indication of a life of a protection device, that is, the circuit breaker 403 based on the protection device data indicating maximum number of switching available as per the manufacturer’s data sheet and the actual number of switching obtained as a part of the protection device data. Thus, the PNDAS 200 generates recommendations comprising an overall health status indication, replacement indication, and calibration indication of the electrical components in the electrical power system 400.

Consider an example, where a power event detected on an electrical power system is of a type of a combination event including an aberration in power quality post a fault occurrence indication. The fault occurrence indication comprises a line to ground fault followed by a voltage swell in two of the phases and a voltage dip in one of the phases occurring at different time instants, in a three phase balance load electrical power system. The power network data analysis system (PNDAS) 200 analyzes such a power event at individual phase level. Since the fault occurrence indication is prior to the aberration in power quality, the PNDAS analyzes the protection device data associated with each of the phases and the topology data of the electrical power system to determine whether the root cause of the power event is load variation or a fault. Based on the protection device data and the topology data, the PNDAS 200 determines the fault to be a line to ground fault occurring on one of the phases and further based on the power quality data the PNDAS 200 determines that due to a line to ground fault on one of the phases the voltage dipped in that phase however, due to balance condition in the remaining phases, a voltage swell was observed in each of the remaining phases. Thus, the PNDAS 200 determines the cause of the power event to be an actual fault occurrence at the source side due to simultaneous dip in current followed by voltage at a given time instant, and the aberration in power quality is found to be not resulting from load variation. In this case, the PNDAS 200 generates a recommendation stating that the aberration in power quality is due to a fault that could be transient or permanent in nature. Therefore, please please rectify the fault to reconnect the load.

Consider another example, where a power event detected on an electrical power system is a sheer aberration in power quality without any fault occurrence indication. In this example, the aberration in power quality is a voltage swell due to switching on of a capacitor bank in a load section with minimal inductive load. In this example, the power network data analysis system (PNDAS) 200 identifies the location of the power event to be a load side event as along with the voltage swell the current is observed to dip from the power quality data. The PNDAS 200 thereby determines the cause of the power event to be a load variation at the load side of the electrical power system and generates a recommendation to switch off the capacitor bank, replace the capacitor bank with an automatic power factor correction facilitated capacitor, or switch on an inductive load that balances the capacitive load in the electrical power system.

It will be readily apparent that the various methods, algorithms, and computer programs disclosed herein may be implemented on computer readable media appropriately programmed for computing devices. As used herein, "computer readable media" refers to non-transitory computer readable media that participate in providing data, for example, instructions that may be read by a computer, a processor or a similar device. Non-transitory computer readable media comprise all computer readable media, for example, non-volatile media, volatile media, and transmission media, except for a transitory, propagating signal.

The computer programs that implement the methods and algorithms disclosed herein may be stored and transmitted using a variety of media, for example, the computer readable media in a number of manners. In an embodiment, hard-wired circuitry or custom hardware may be used in place of, or in combination with, software instructions for implementation of the processes of various embodiments. Therefore, the embodiments are not limited to any specific combination of hardware and software. In general, the computer program codes comprising computer executable instructions may be implemented in any programming language. The computer program codes or software programs may be stored on or in one or more mediums as object code. Various aspects of the method and system disclosed herein may be implemented in a non-programmed environment comprising documents created, for example, in a hypertext markup language (HTML), an extensible markup language (XML), or other format that render aspects of a graphical user interface (GUI) or perform other functions, when viewed in a visual area or a window of a browser program. Various aspects of the method and system disclosed herein may be implemented as programmed elements, or non-programmed elements, or any suitable combination thereof. The computer program product disclosed herein comprises one or more computer program codes for implementing the processes of various embodiments.

Where databases are described such as the power system database 206, it will be understood by one of ordinary skill in the art that (i) alternative database structures to those described may be readily employed, and (ii) other memory structures besides databases may be readily employed. Any illustrations or descriptions of any sample databases disclosed herein are illustrative arrangements for stored representations of information. Any number of other arrangements may be employed besides those suggested by tables illustrated in the drawings or elsewhere. Similarly, any illustrated entries of the databases represent exemplary information only; one of ordinary skill in the art will understand that the number and content of the entries can be different from those disclosed herein. Further, despite any depiction of the databases as tables, other formats including relational databases, object-based models, and/or distributed databases may be used to store and manipulate the data types disclosed herein. Likewise, object methods or behaviors of a database can be used to implement various processes such as those disclosed herein. In addition, the databases may, in a known manner, be stored locally or remotely from a device that accesses data in such a database. In embodiments where there are multiple databases in the system, the databases may be integrated to communicate with each other for enabling simultaneous updates of data linked across the databases, when there are any updates to the data in one of the databases.

The present invention can be configured to work in a network environment comprising one or more computers that are in communication with one or more devices via a network. The computers may communicate with the devices directly or indirectly, via a wired medium or a wireless medium such as the Internet, a local area network (LAN), a wide area network (WAN) or the Ethernet, a token ring, or via any appropriate communications mediums or combination of communications mediums. Each of the devices comprises processors, some examples of which are disclosed above, that are adapted to communicate with the computers. In an embodiment, each of the computers is equipped with a network communication device, for example, a network interface card, a modem, or other network connection device suitable for connecting to a network. Each of the computers and the devices executes an operating system, some examples of which are disclosed above. While the operating system may differ depending on the type of computer, the operating system will continue to provide the appropriate communications protocols to establish communication links with the network. Any number and type of machines may be in communication with the computers.

The present invention is not limited to a particular computer system platform, processor, operating system, or network. One or more aspects of the present invention may be distributed among one or more computer systems, for example, servers configured to provide one or more services to one or more client computers, or to perform a complete task in a distributed system. For example, one or more aspects of the present invention may be performed on a client-server system that comprises components distributed among one or more server systems that perform multiple functions according to various embodiments. These components comprise, for example, executable, intermediate, or interpreted code, which communicate over a network using a communication protocol. The present invention is not limited to be executable on any particular system or group of systems, and is not limited to any particular distributed architecture, network, or communication protocol.

The foregoing examples have been provided merely for the purpose of explanation and are in no way to be construed as limiting of the present invention disclosed herein. While the invention has been described with reference to various embodiments, it is understood that the words, which have been used herein, are words of description and illustration, rather than words of limitation. Further, although the invention has been described herein with reference to particular means, materials, and embodiments, the invention is not intended to be limited to the particulars disclosed herein; rather, the invention extends to all functionally equivalent structures, methods and uses, such as are within the scope of the appended claims. Those skilled in the art, having the benefit of the teachings of this specification, may affect numerous modifications thereto and changes may be made without departing from the scope and spirit of the invention in its aspects.

List of reference numerals

200 power network data analysis system

201 data obtaining module

202 event detection module

203 cause determination module

203A type determination module

203B location identification module

203C event analysis module

204 recommendation generation module

205 graphical user interface (GUI)

206 power system database

207 substation

208 communication network

209 central database

300 computer system

301 processor

302 memory unit

303 I/O controller

304 network interface

305 data bus

306 display unit

307 input devices

308 fixed media drive

309 removable media drive

310 output devices

400 electrical power system

401 power line

402 transformer

403 circuit breaker

404 busbar

405 load (linear and/or non linear)

405A capacitor

501 current waveform

502 fundamental waveform

503 threshold trip value

600 graphical representation of a health status recommendation

700 graphical representation of a recommendation report

Claims:

1. A method (100) of analyzing power network data of an electrical power system (400), said method comprising:

- obtaining said power network data representing one or more parameters of electrical power being carried on the electrical power system (400);
- detecting a power event on the electrical power system (400) from said power network data;
- determining a cause of the power event based on said power network data; and
- generating a recommendation associated with the power event for the electrical power system (400) based on the cause of the power event;

characterized in that:

- the cause of the power event is determined by employing a power network data analysis logic.

2. The method (100) according to claim 1, wherein said power network data comprises power quality data, protection device data associated with a plurality of protection devices (402, 403) in the electrical power system (400), power event data, and topology data, and wherein said power network data is one or more of a measured data and a computed data.

3. The method (100) according to any one of the previous claims, wherein said power network data is substation (207) wide power network data.

4. The method (100) according to claim 1, wherein the power event comprises a momentary event occurring on the electrical power system (400).

5. The method (100) according to claim 1, wherein the cause of the power event comprises one or more of a load variation and a fault occurrence in the electrical power system (400).

6. The method (100) according to claim 1, wherein the power network data analysis logic comprises:

- determining a type of the power event based on power quality data and protection device data obtained from the power network data;
- identifying a location of the power event based on the power quality data; and
- analyzing the power event based on one or more of the power network data, the type of the power event, and the location of the power event.

7. The method (100) according to claim 6, wherein the type of the power event comprises one or more of a fault indication in the electrical power system (400) and an aberration in quality of the electrical power being carried in the electrical power system (400).

8. The method (100) according to claim 6, wherein the location of the power event comprises one or more of a load side power event and a source side power event.

9. The method (100) according to claim 1, wherein the recommendation comprises one or more of a health status indication of one or more parts of the electrical power system

(400), a replacement indication of one or more parts of the electrical power system (400), and a calibration indication of one or more parts of the electrical power system (400).

10. A power network data analysis system (200) for analyzing power network data of an electrical power system (400), said power network data analysis system (400) comprising:

a non-transitory computer readable storage medium (302) storing computer program instructions defined by modules (201, 202, 203, and 204) of said power network data analysis system (400);

at least one processor (301) communicatively coupled to said non-transitory computer readable storage medium (302), said at least one processor (301) executing said defined computer program instructions; and

said modules (201, 202, 203, and 204) of said power network data analysis system (400) comprising:

- a data obtaining module (201) configured to obtain said power network data representing one or more parameters of electrical power being carried on the electrical power system (400), wherein said power network data comprises power quality data, protection device data associated with a plurality of protection devices in the electrical power system (400), power event data, and topology data, and wherein said power network data is one or more of a measured data and a computed data, and wherein said power network data is substation (207) wide power network data;
- an event detection module (202) configured to detect a power event on the electrical power system (400) from said

power network data, wherein the power event comprises a momentary event occurring on the electrical power system (400);

- a cause determination module (203) configured to determine a cause of the power event based on said power network data, wherein the cause of the power event comprises one or more of a load variation and a fault occurrence in the electrical power system (400); and
- a recommendation generation module (204) configured to generate a recommendation associated with the power event for the electrical power system (400) based on the cause of the power event, wherein the recommendation comprises one or more of a health status indication of one or more parts of the electrical power system (400), a replacement indication of one or more parts of the electrical power system (400), and a calibration indication of one or more parts of the electrical power system (400);

characterized in that:

- the cause determination module (203) comprises modules (203A, 203B, and 203C) configured to employ a power network data analysis logic.

11. The power network data analysis system (201) according to claim 10, wherein said modules (203A, 203B, and 203C) of said cause determination module (203) comprising:

- a type determination module (203A) configured to determine a type of the power event based on power quality data and protection device data obtained from the power network data, wherein the type of the power event comprises one or more of a fault indication in the electrical power system

(400) and an aberration in quality of the electrical power being carried in the electrical power system (400);

- a location identification module (203B) configured to identify a location of the power event based on the power quality data, wherein the location of the power event comprises one or more of a load side power event and a source side power event; and
- an event analysis module (203C) configured to analyze the power event based on one or more of the power network data, the type of the power event, and the location of the power event.

12. A computer program product comprising a non-transitory computer readable storage medium (302), said non-transitory computer readable storage medium (302) storing computer program codes that comprise instructions executable by at least one processor (301), said computer program codes comprising:

- a first computer program code for obtaining power network data representing one or more parameters of electrical power being carried on the electrical power system (400), wherein said power network data comprises power quality data, protection device data associated with a plurality of protection devices in the electrical power system (400), power event data, and topology data, and wherein said power network data is one or more of a measured data and a computed data, and wherein said power network data is substation (207) wide power network data;
- a second computer program code for detecting a power event on the electrical power system (400) from said power

network data, wherein the power event comprises a momentary event occurring on the electrical power system (400);

- a third computer program code for determining a cause of the power event based on said power network data, wherein the cause of the power event comprises one or more of a load variation and a fault occurrence in the electrical power system (400); and
- a fourth computer program code for generating a recommendation associated with the power event for the electrical power system (400) based on the cause of the power event, wherein the recommendation comprises one or more of a health status indication of one or more parts of the electrical power system (400), a replacement indication of one or more parts of the electrical power system (400), and a calibration indication of one or more parts of the electrical power system (400);

characterized in that:

- said third computer program code comprising computer program codes for employing a power network data analysis logic.

13. The computer program product according to claim 12, wherein said computer program codes of said third computer program code comprising:

- a fifth computer program code for determining a type of the power event based on power quality data and protection device data obtained from the power network data, wherein the type of the power event comprises one or more of a fault indication in the electrical power system (400) and an aberration in quality of the electrical power being carried in the electrical power system (400);

- a sixth computer program code for identifying a location of the power event based on the power quality data, wherein the location of the power event comprises one or more of a load side power event and a source side power event; and
- a seventh computer program code for analyzing the power event based on one or more of the power network data, the type of the power event, and the location of the power event.

FIG 1A

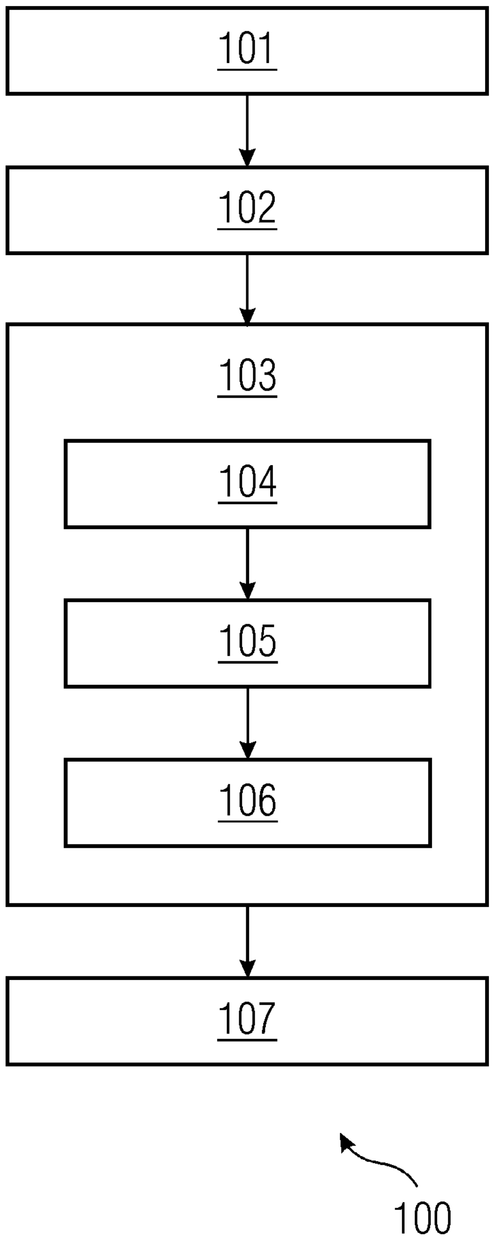


FIG 1B

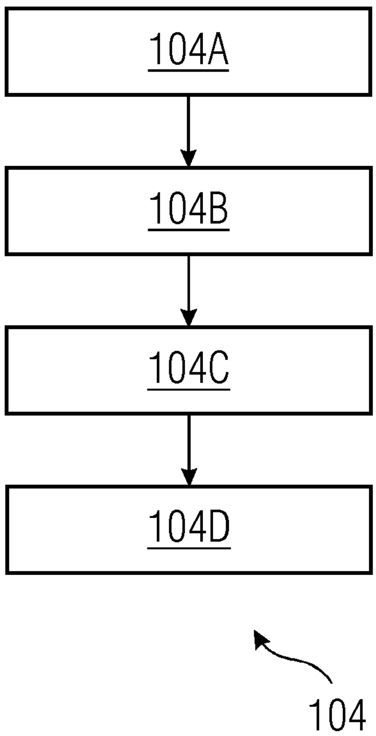



FIG 1C

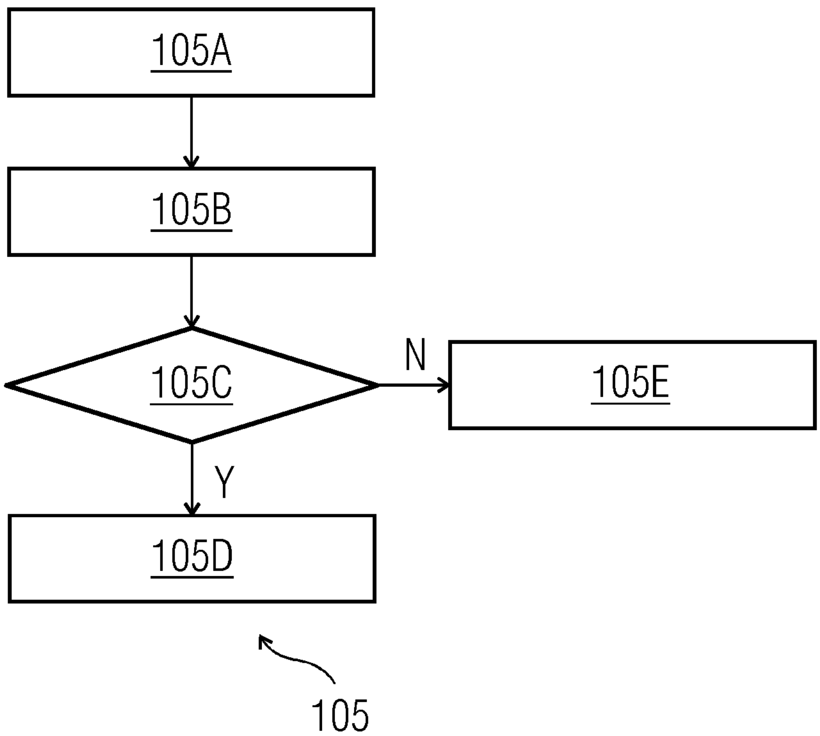


FIG 1D

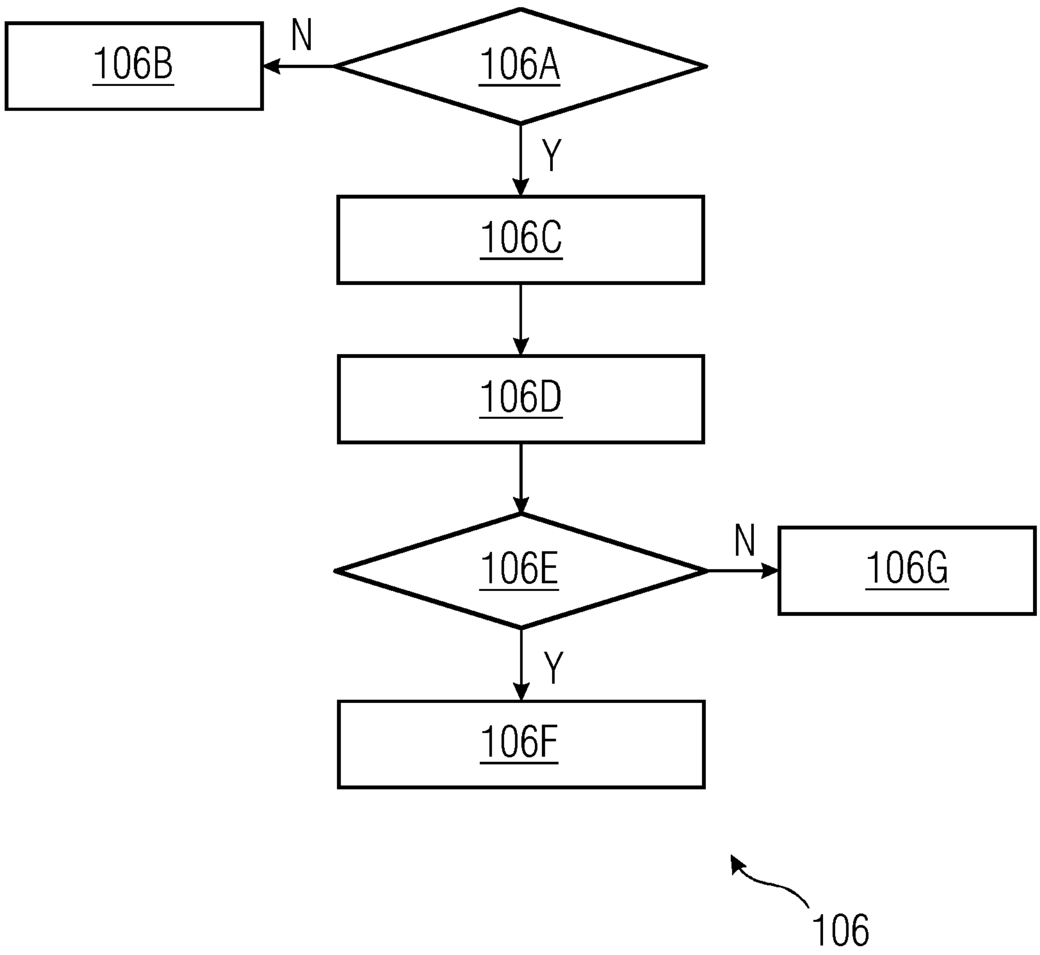


FIG 2

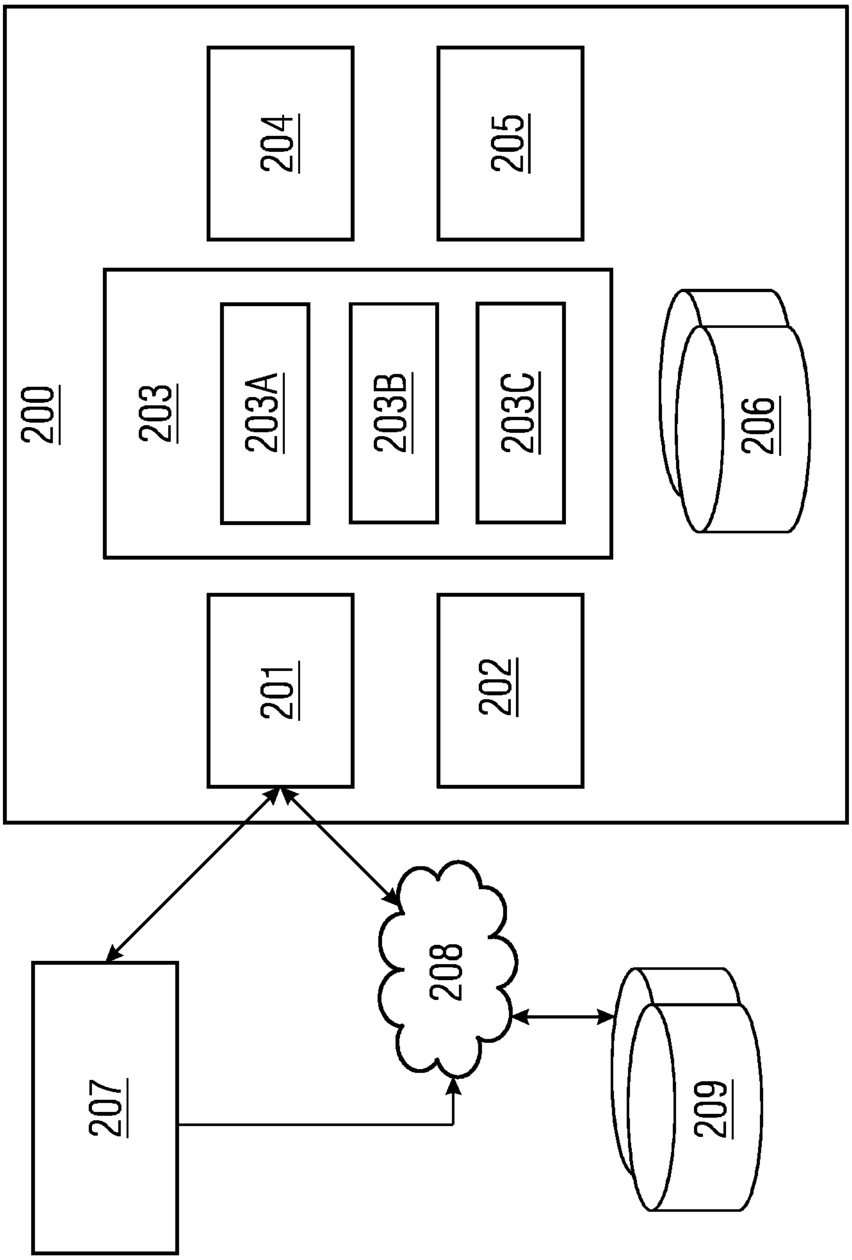


FIG 3

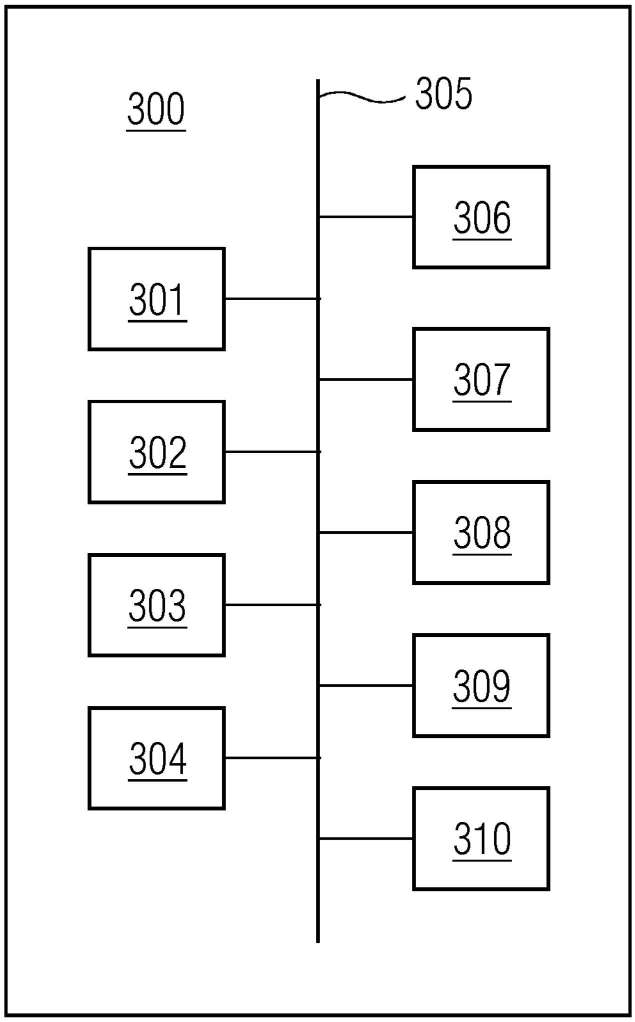


FIG 4A

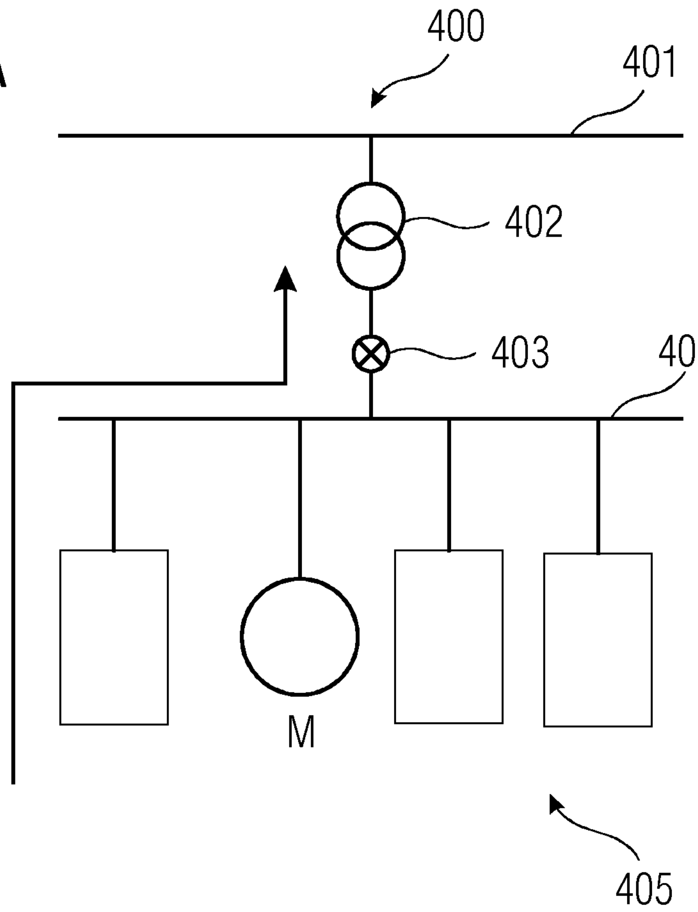



FIG 4B

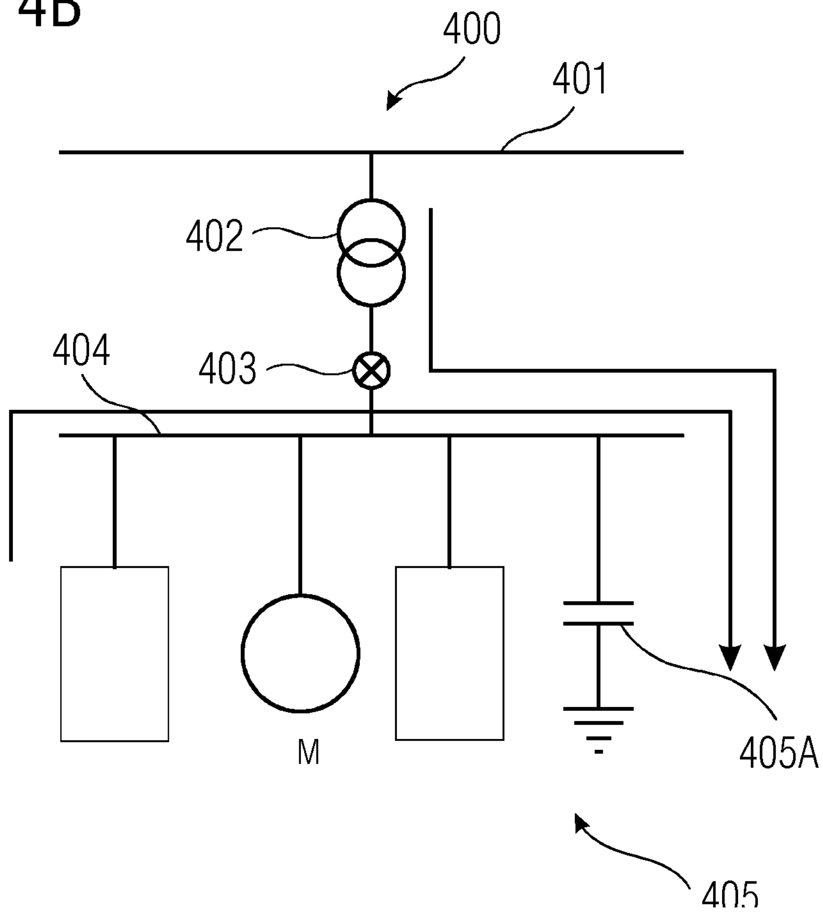


FIG 5A

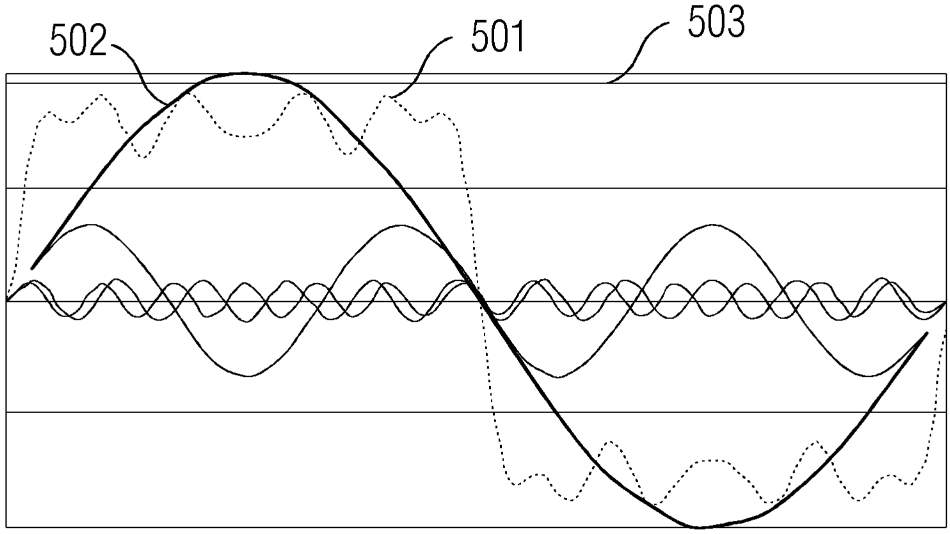



FIG 5B

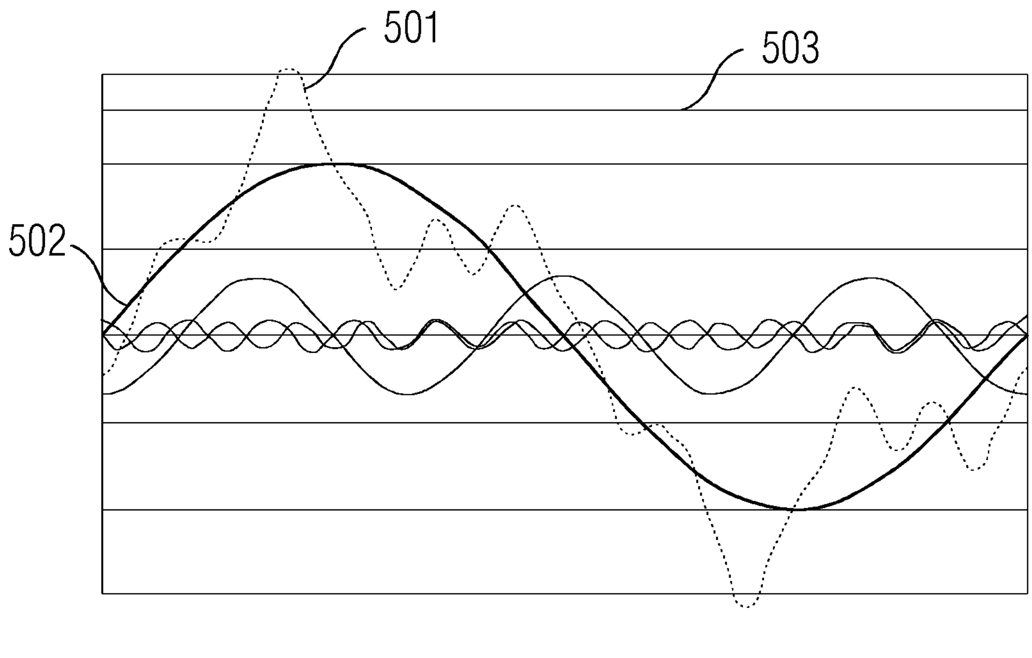


FIG 6

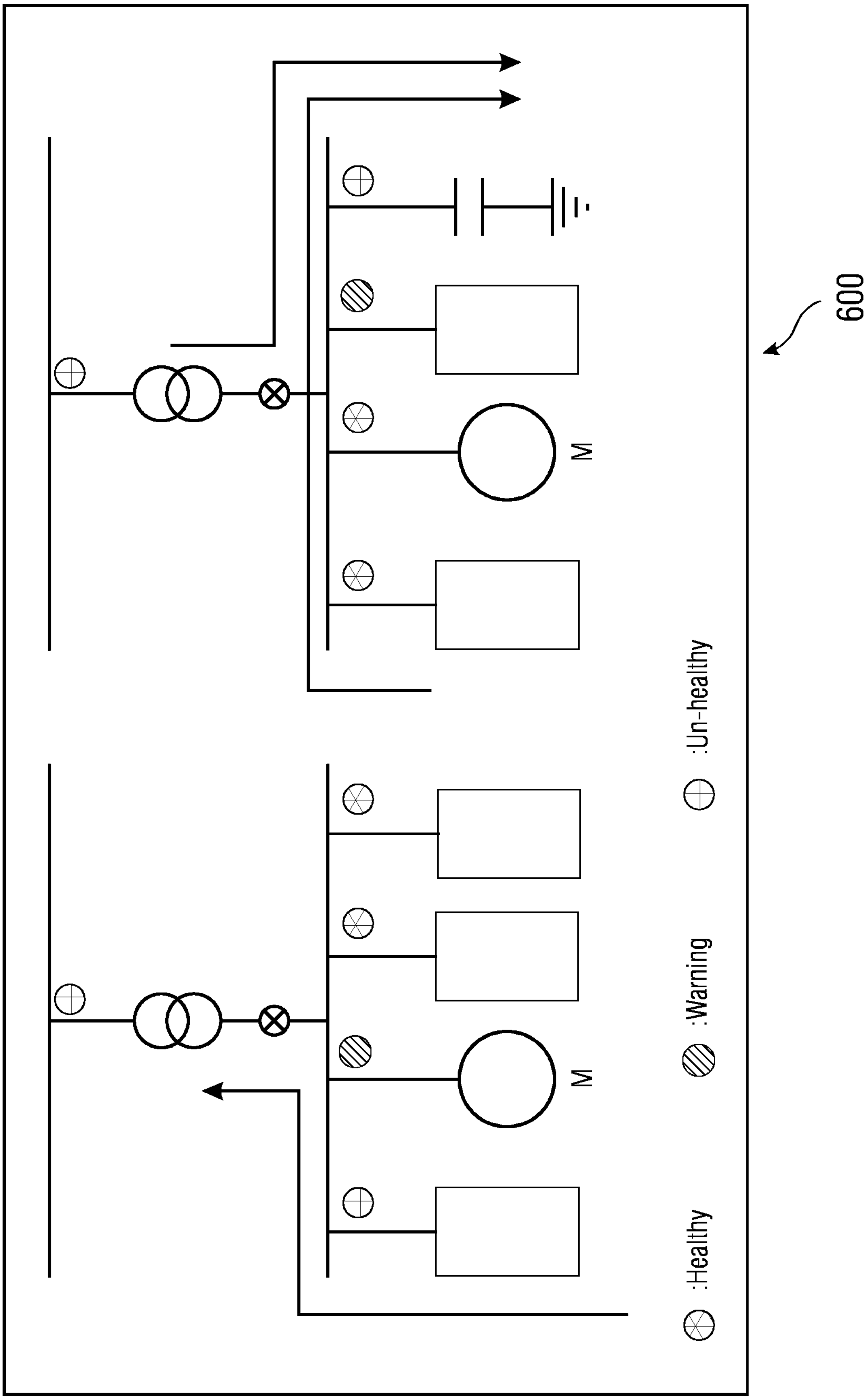


FIG 7

700

# RECOMMENDATION REPORT

Grid Code: XXXXXXXXX
Trigger: xxxxxxxxxxxx
Topology path: xxxxxxxxxxxx

Begin: 09/06/2016 10:30:02.020
Duration: 00:00:10.000
Extreme value: 97.4%
Limit: <98.0%
Involved Phases: XXX
Classification: FR with PQ violation (FR triggered by PQ violation)

SOE: <List of SOE detail_Pre and post PQ event list_based on the configuration>

| | |
|---|---|
| 1 | 10:30 :20.020 09-06-2016_THD Violation |
| 2 | 10:30 :20.020 09-06-2016_PQ Event |
| 3 | 10:30 :20.021 09-06-2016_Fault Record_Current |
| 4 | 10:30 :20.022 09-06-2016_Fault Record_Current |

Cause: THD I

Description:

THDI exceeds threshold limit (violated) in the feeder xxxNo.xxx.
-Due to Non linear load on load side caused the sudden increase in THD I
-Bare Capacitor is connected in the adjacent feeder, and it may boost up the harmonics further due to the resonance condition.

Solution:

1. Change the bare capacitor to passive filter (detuned or turned)or active filter
(or)
2. Change the Feeder arrangement in the bus (in such a way that Linear load percentage will be more than Non linear loads)

# INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/057721

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. H02J3/00
ADD.

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)
H02J

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)

EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | WO 2007/070255 A2 (VIRGINIA TECH INTELL PROP [US]; GARNDER ROBERT MATTHEW [US]; ZHONG ZHI) 21 June 2007 (2007-06-21)<br>paragraph [0008] - paragraph [0012]<br>paragraph [0056] - paragraph [0082]<br>----- | 1-13 |
| X | US 2007/239373 A1 (NASLE ADIB [US]) 11 October 2007 (2007-10-11)<br>paragraph [0101] - paragraph [0138]; figures 9-12<br>paragraph [0203] - paragraph [0233]<br>paragraph [0238] - paragraph [0244]; figure 19<br>----- | 1-13 |
| X | US 2006/235574 A1 (LAPINSKI STERLING [US] ET AL) 19 October 2006 (2006-10-19)<br>paragraph [0012]<br>paragraph [0022] - paragraph [0046]<br>paragraph [0047]; figure 5<br>----- | 1-13 |

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

☒ See patent family annex.

* 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 |
|---|---|
| 15 November 2017 | 23/11/2017 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016 | Gatzert, C |

1

# INTERNATIONAL SEARCH REPORT

**Information on patent family members**

International application No
PCT/EP2017/057721

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| WO 2007070255 A2 | 21-06-2007 | AU 2006324395 A1 | 21-06-2007 |
| | | CA 2634583 A1 | 21-06-2007 |
| | | EP 1969692 A2 | 17-09-2008 |
| | | US 2007150114 A1 | 28-06-2007 |
| | | US 2009198383 A1 | 06-08-2009 |
| | | WO 2007070255 A2 | 21-06-2007 |
| US 2007239373 A1 | 11-10-2007 | US 2007239373 A1 | 11-10-2007 |
| | | US 2015248617 A1 | 03-09-2015 |
| US 2006235574 A1 | 19-10-2006 | AU 2005330673 A1 | 26-10-2006 |
| | | CA 2604475 A1 | 26-10-2006 |
| | | EP 1875322 A1 | 09-01-2008 |
| | | JP 5425978 B2 | 26-02-2014 |
| | | JP 2008537468 A | 11-09-2008 |
| | | JP 2012239378 A | 06-12-2012 |
| | | US 2006235574 A1 | 19-10-2006 |
| | | WO 2006112839 A1 | 26-10-2006 |