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(54) **SYSTEMS AND METHODS FOR REAL-TIME DC MICROGRID POWER ANALYTICS FOR MISSION-CRITICAL POWER SYSTEMS**

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(52) **U.S. Cl.**

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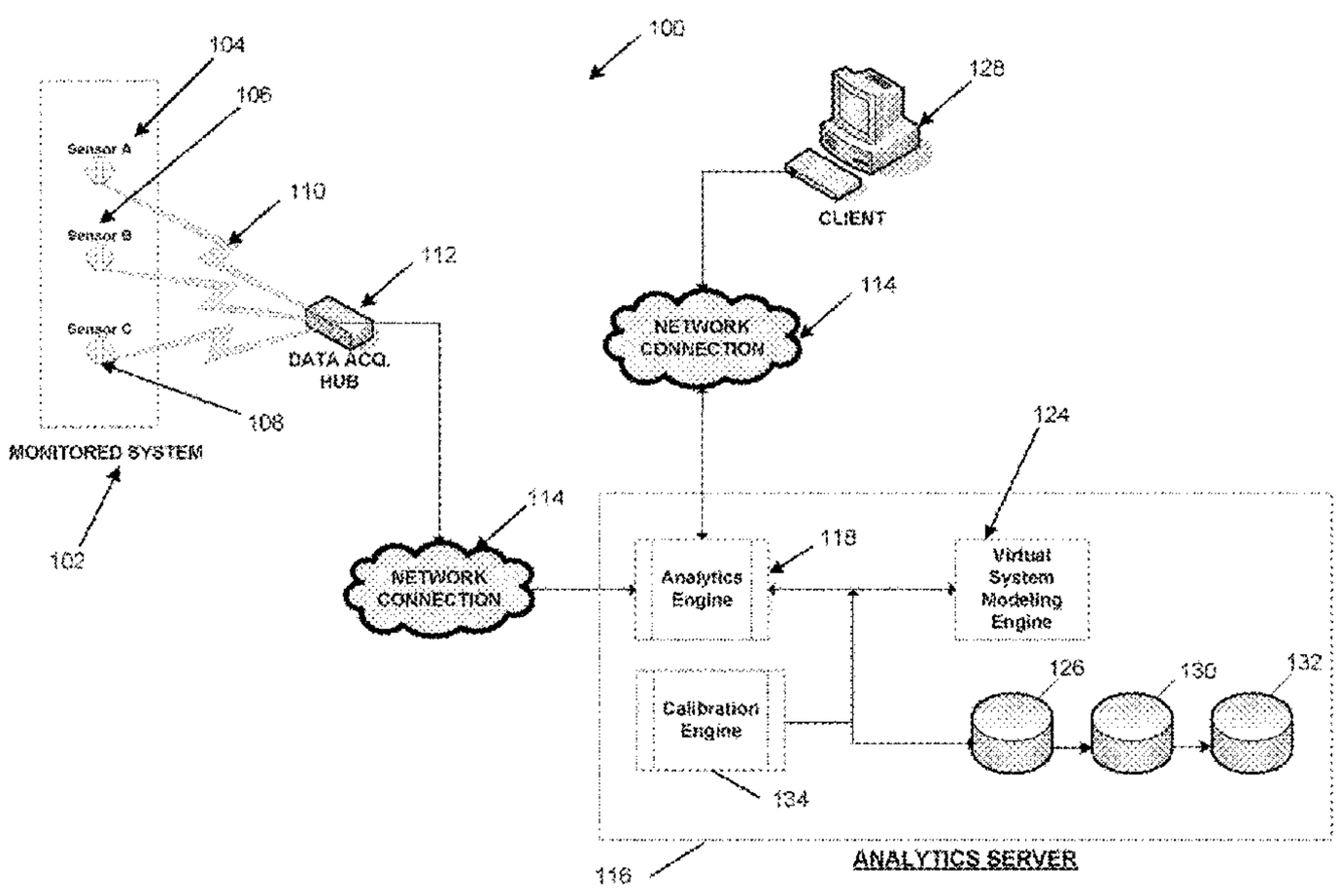
(57) **ABSTRACT**

Systems and methods for performing power analytics on a microgrid. In an embodiment, predicted data is generated for the microgrid utilizing a virtual system model of the microgrid, which comprises a virtual representation of a topology of the microgrid. Real-time data is received via a portal from at least one external data source. If the difference between the real-time data and the predicted data exceeds a threshold, a calibration and synchronization operation is initiated to update the virtual system model in real-time. Power analytics may be performed on the virtual system model to generate analytical data, which can be returned via the portal.



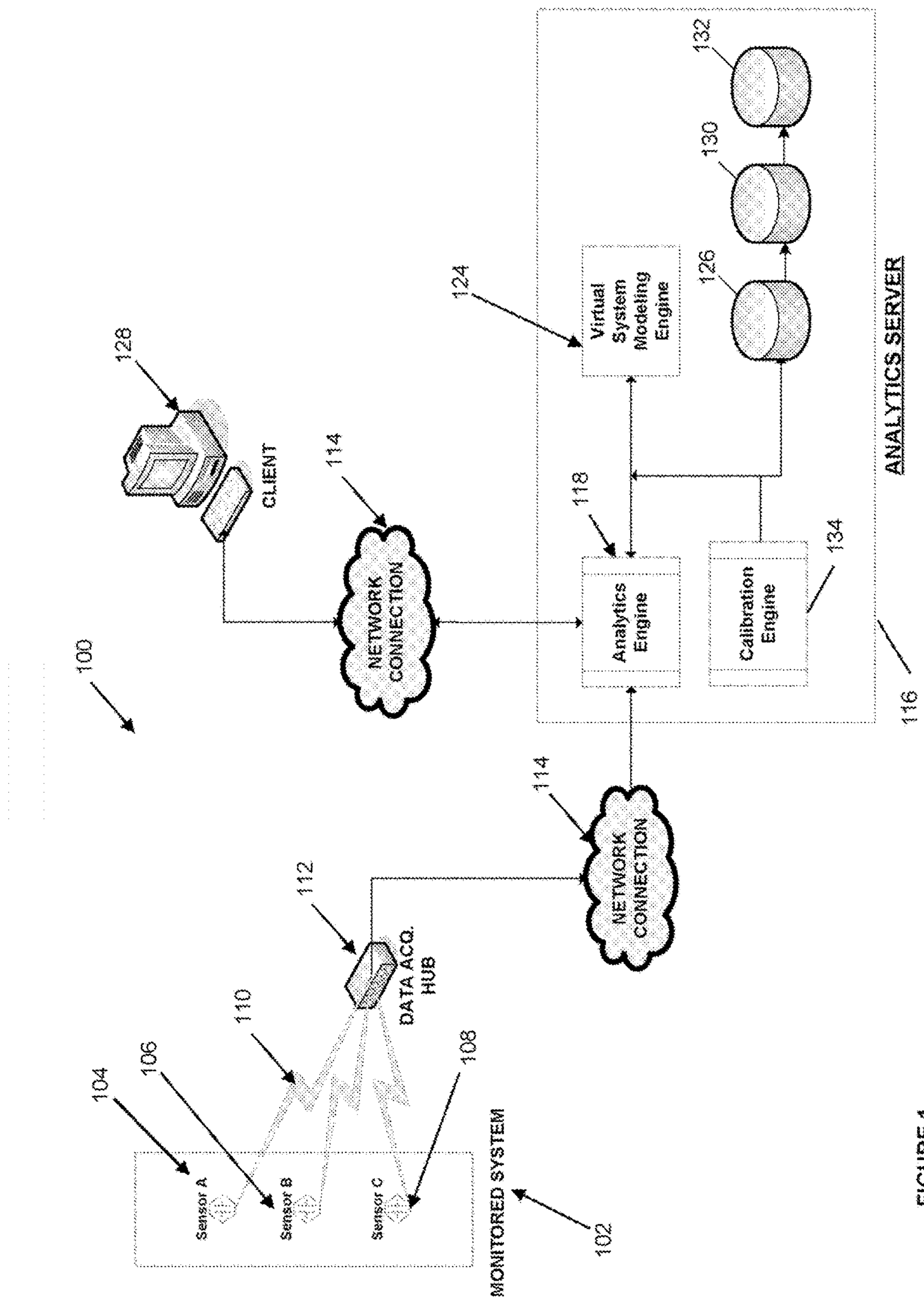

100
128
CLIENT
114
NETWORK CONNECTION
124
Virtual System Modeling Engine
126
130
132
118
Analytics Engine
Calibration Engine
134
ANALYTICS SERVER
116
114
NETWORK CONNECTION
112
DATA ACQ. HUB
110
104
106
108
Sensor A
Sensor B
Sensor C
MONITORED SYSTEM
102

FIGURE 1

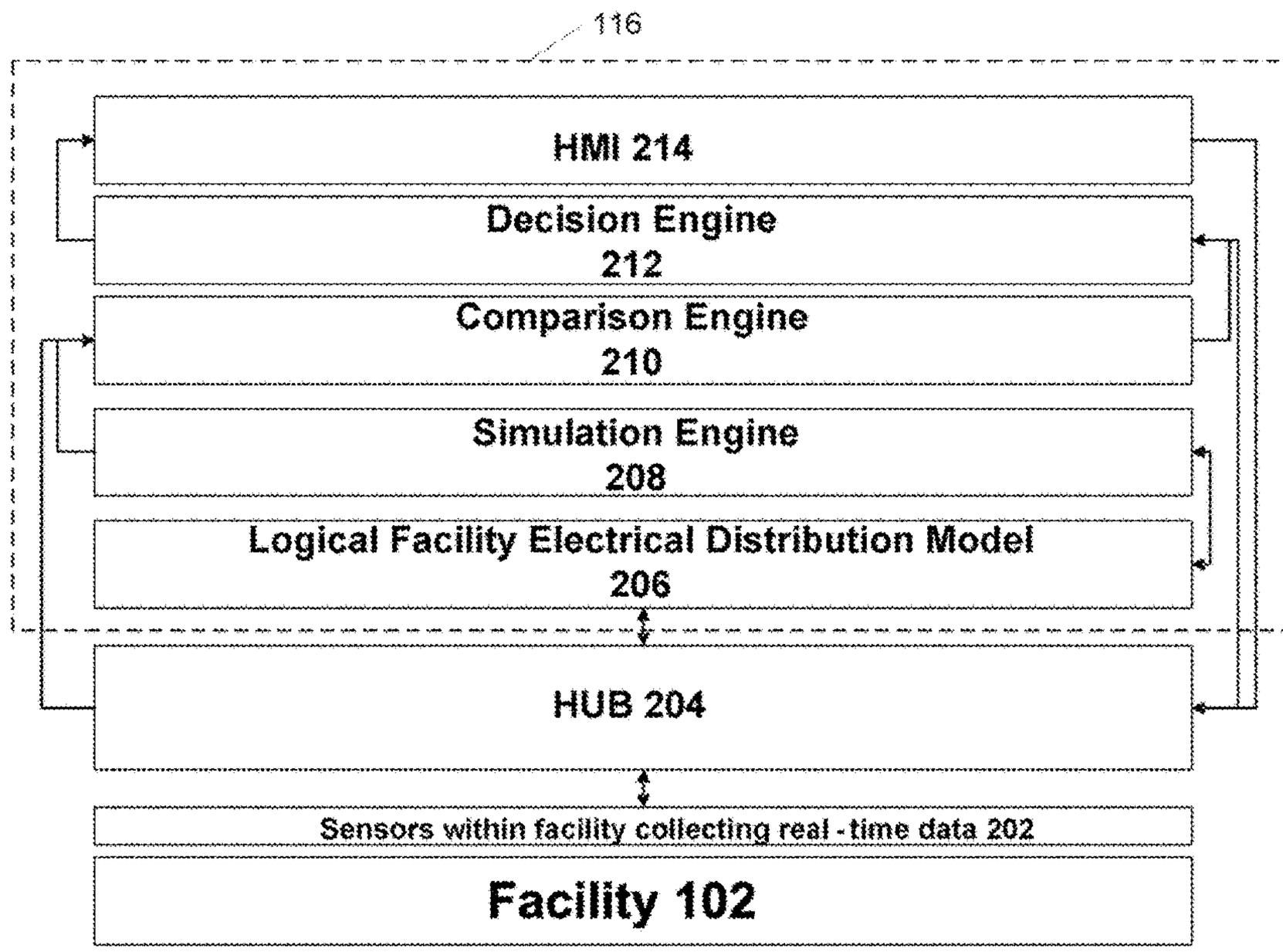

116
HMI 214
Decision Engine
212
Comparison Engine
210
Simulation Engine
208
Logical Facility Electrical Distribution Model
206
HUB 204
Sensors within facility collecting real - time data 202
Facility 102

FIGURE 2

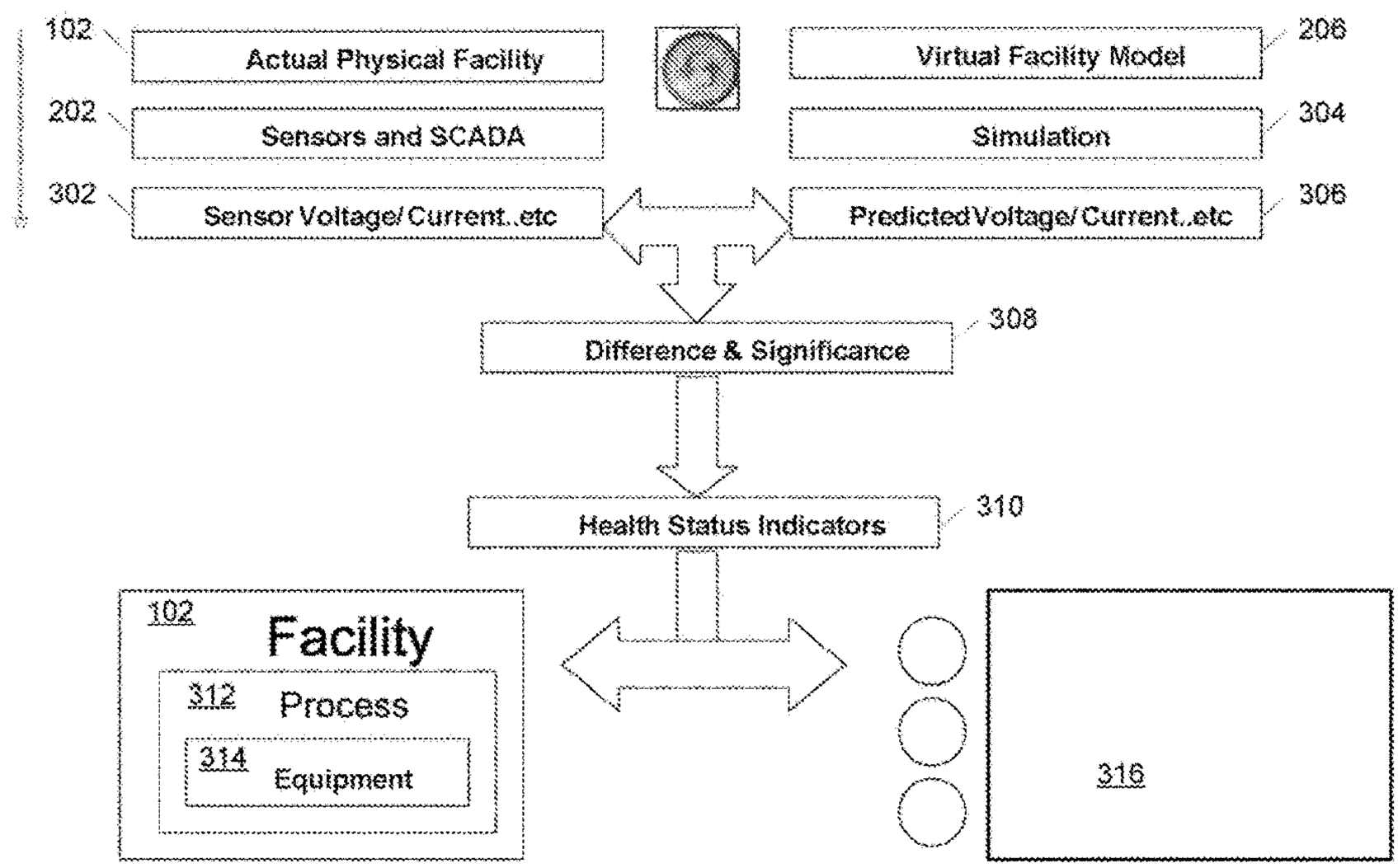

102
Actual Physical Facility
202
Sensors and SCADA
302
Sensor Voltage/Current..etc
Virtual Facility Model
206
Simulation
304
PredictedVoltage/Current..etc
306
Difference & Significance
308
Health Status Indicators
310
102
Facility
312
Process
314
Equipment
316

FIGURE 3

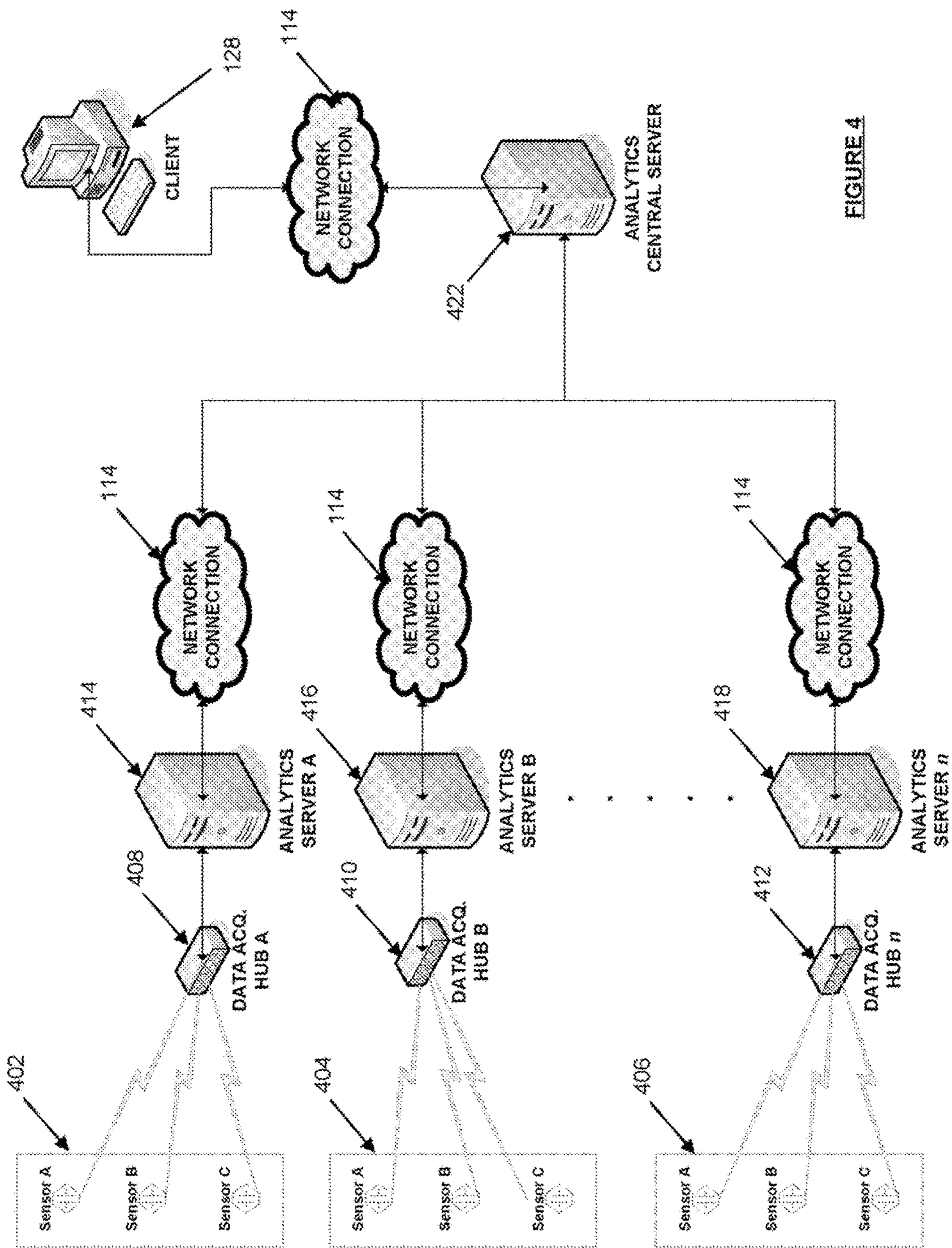

CLIENT
128
114
NETWORK CONNECTION
ANALYTICS CENTRAL SERVER
422
114
NETWORK CONNECTION
414
ANALYTICS SERVER A
408
DATA ACQ. HUB A
402
Sensor A
Sensor B
Sensor C
114
NETWORK CONNECTION
416
ANALYTICS SERVER B
410
DATA ACQ. HUB B
404
Sensor A
Sensor B
Sensor C
114
NETWORK CONNECTION
418
ANALYTICS SERVER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

FIGURE 4

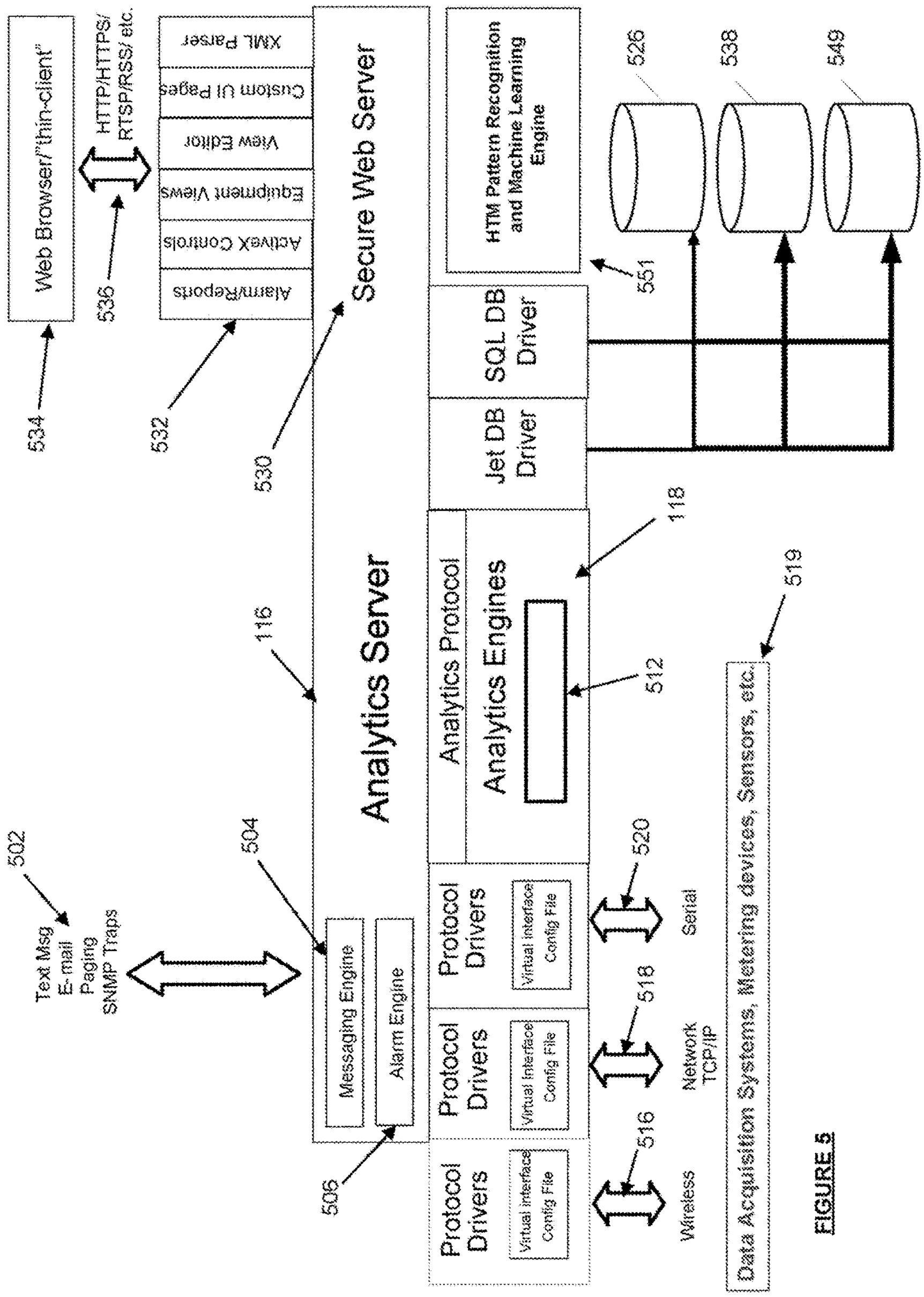

Web Browser/"thin-client"
HTTP/HTTPS/
RTSP/RSS/ etc.
536
534
Alarm/Reports
ActiveX Controls
Equipment Views
View Editor
Custom UI Pages
XML Parser
532
Secure Web Server
530
HTM Pattern Recognition and Machine Learning Engine
551
526
538
549
SQL DB Driver
Jet DB Driver
118
Analytics Protocol
Analytics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

FIGURE 5

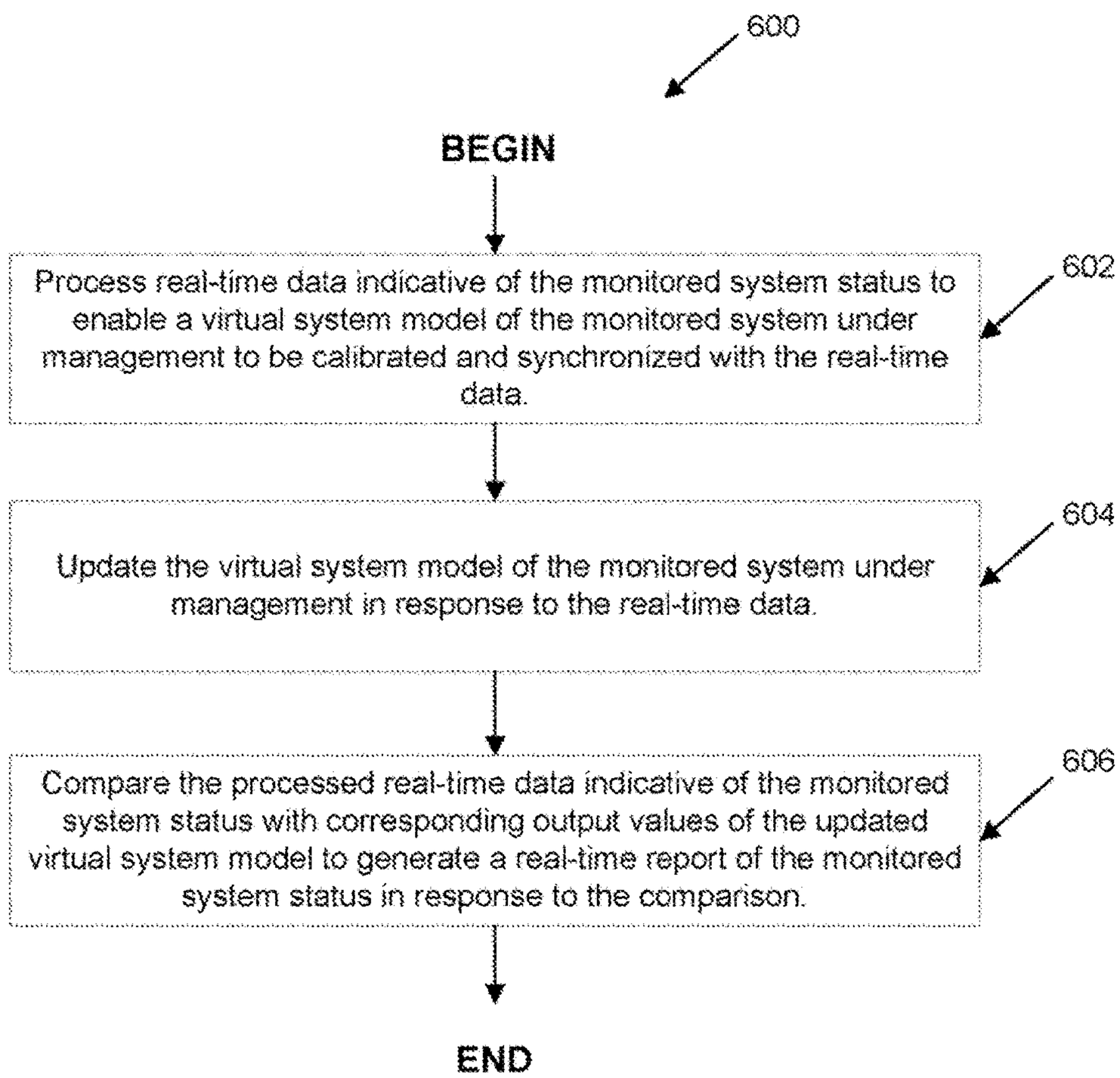

600
BEGIN
Process real-time data indicative of the monitored system status to enable a virtual system model of the monitored system under management to be calibrated and synchronized with the real-time data.
602
Update the virtual system model of the monitored system under management in response to the 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

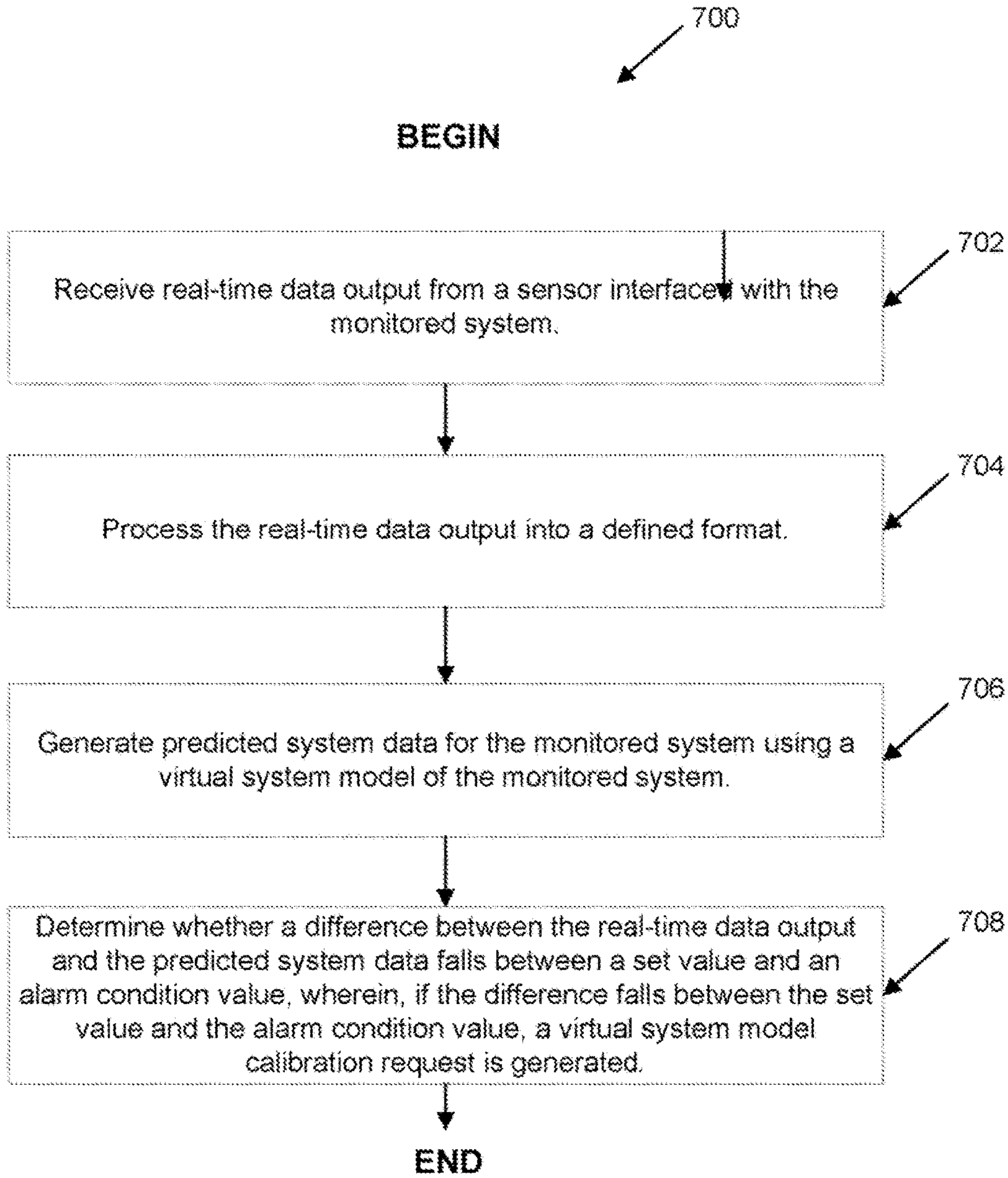

700
BEGIN
Receive real-time data output from a sensor interfaced with the monitored system.
702
Process the real-time data output into a defined format.
704
Generate predicted system data for the monitored system using a virtual system model of the monitored system.
706
Determine whether a difference 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

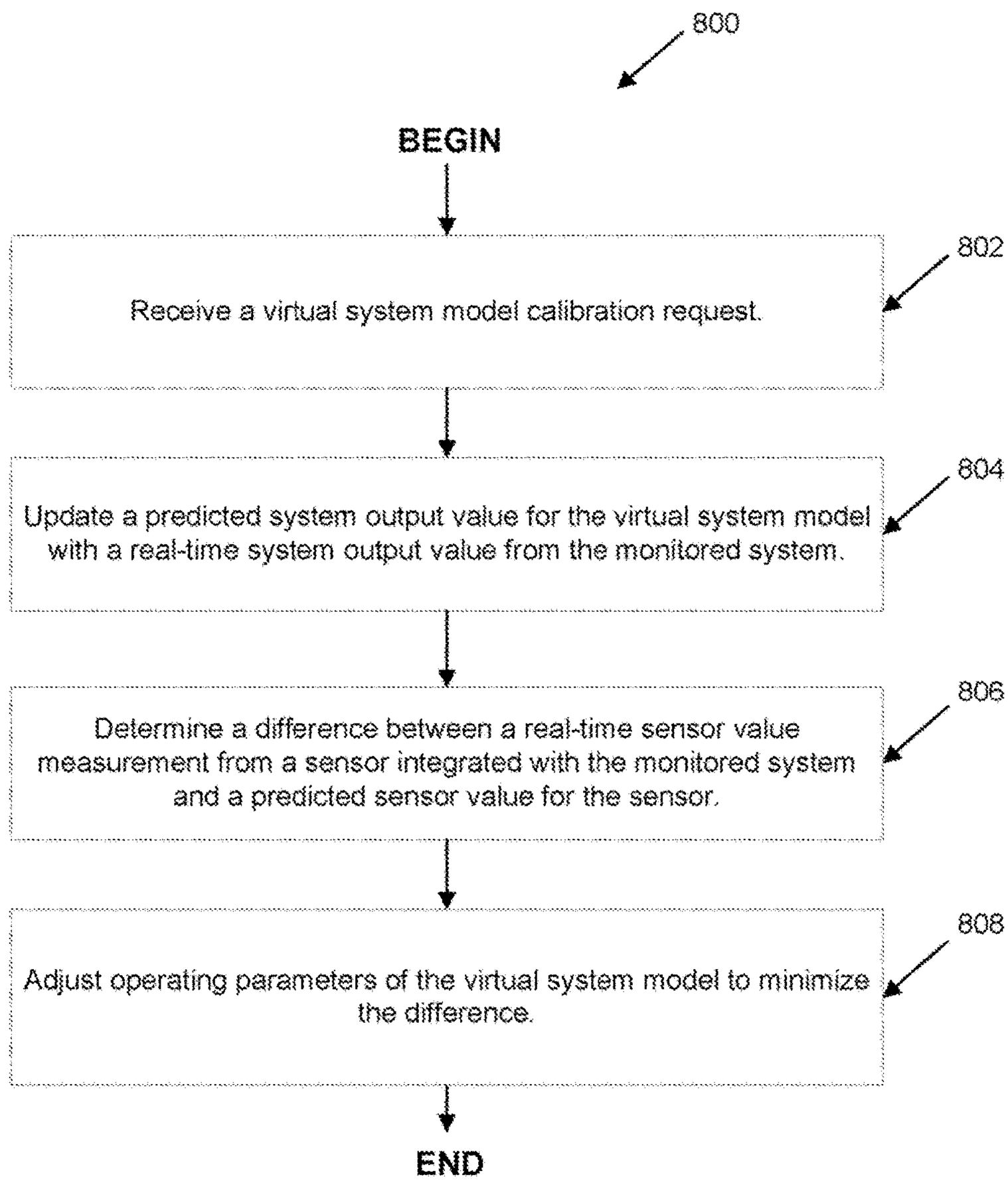

800
BEGIN
802
Receive a virtual system model calibration request.
804
Update a predicted system output value for the virtual system model with a real-time system output value from the monitored system.
806
Determine a difference between a real-time sensor value measurement from a sensor integrated with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

FIGURE 8

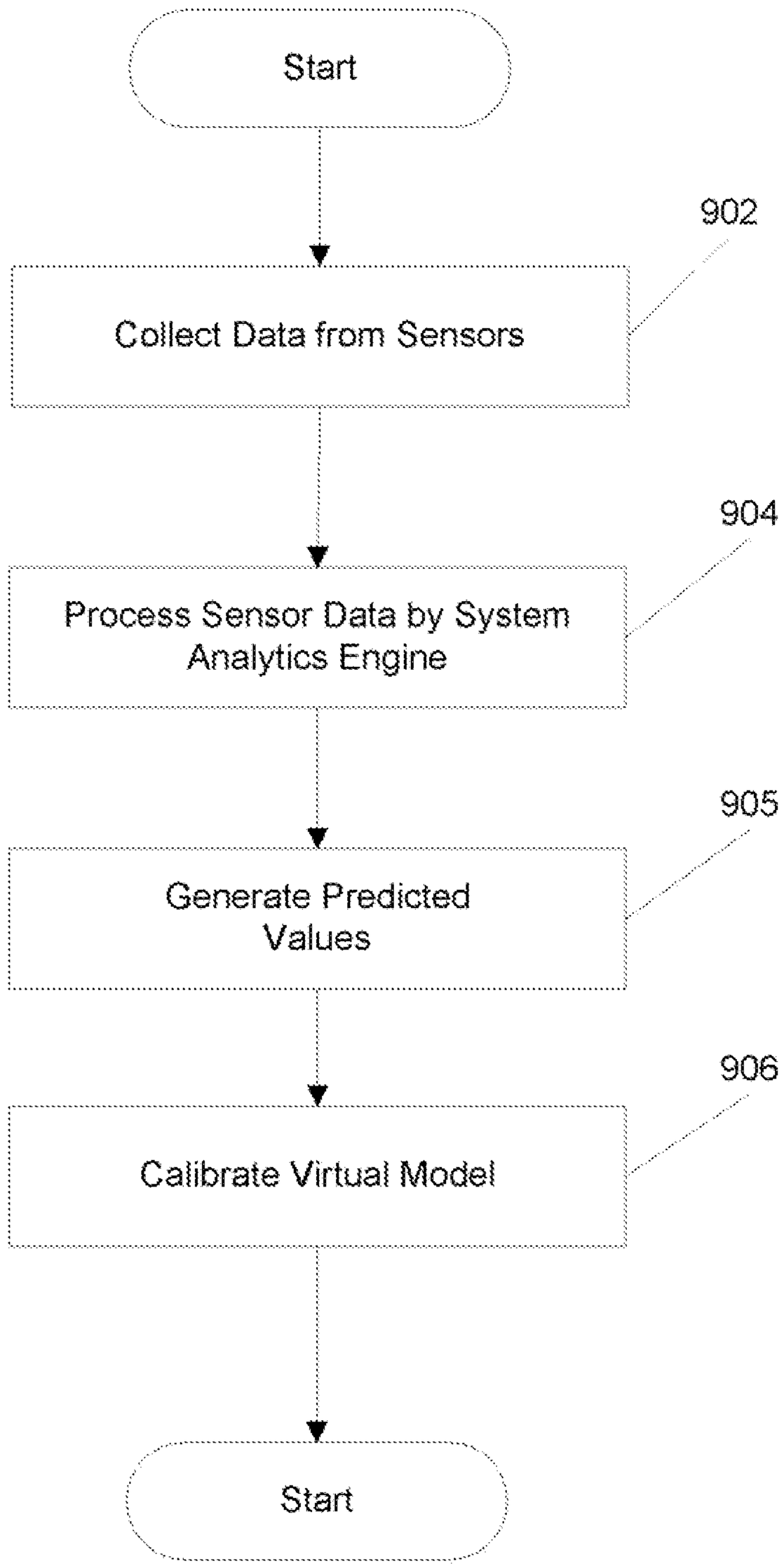

Start
902
Collect Data from Sensors
904
Process Sensor Data by System Analytics Engine
905
Generate Predicted Values
906
Calibrate Virtual Model
Start

Figure 9

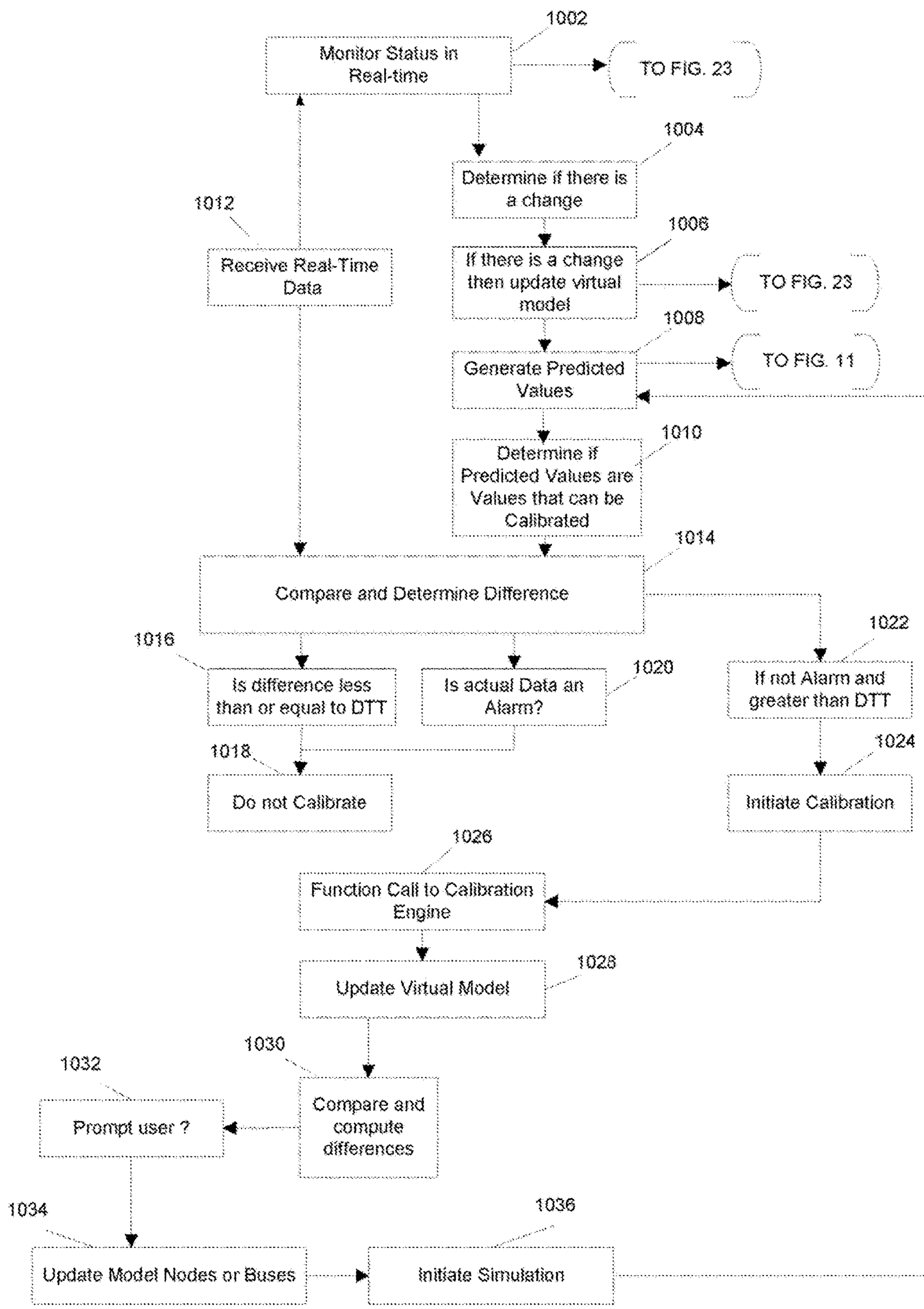

1002
Monitor Status in Real-time
TO FIG. 23
1004
Determine if there is a change
1012
Receive Real-Time Data
1006
If there is a change then update virtual model
TO FIG. 23
1008
Generate Predicted Values
TO FIG. 11
1010
Determine if Predicted Values are Values that can be Calibrated
1014
Compare and Determine 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

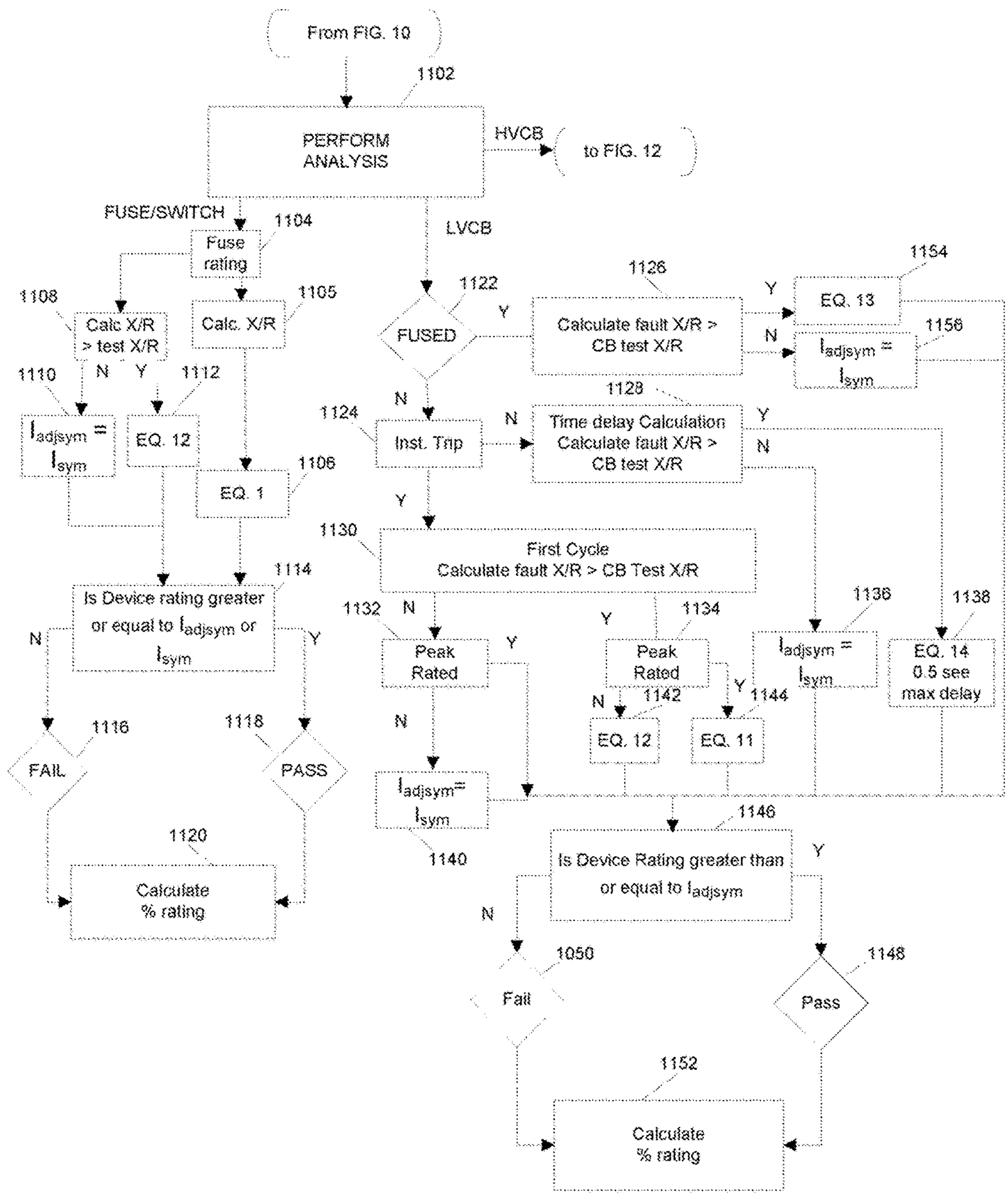

From FIG. 10
1102
PERFORM ANALYSIS
HVCB
to FIG. 12
FUSE/SWITCH
1104
Fuse rating
LVCB
1108
Calc X/R > test X/R
1105
Calc. X/R
1122
FUSED
1126
Calculate fault X/R > CB test X/R
1154
EQ. 13
1156
I_{adjsym} = I_{sym}
1110
I_{adjsym} = I_{sym}
1112
EQ. 12
1124
Inst. Trip
1128
Time delay Calculation Calculate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

FIG. 11

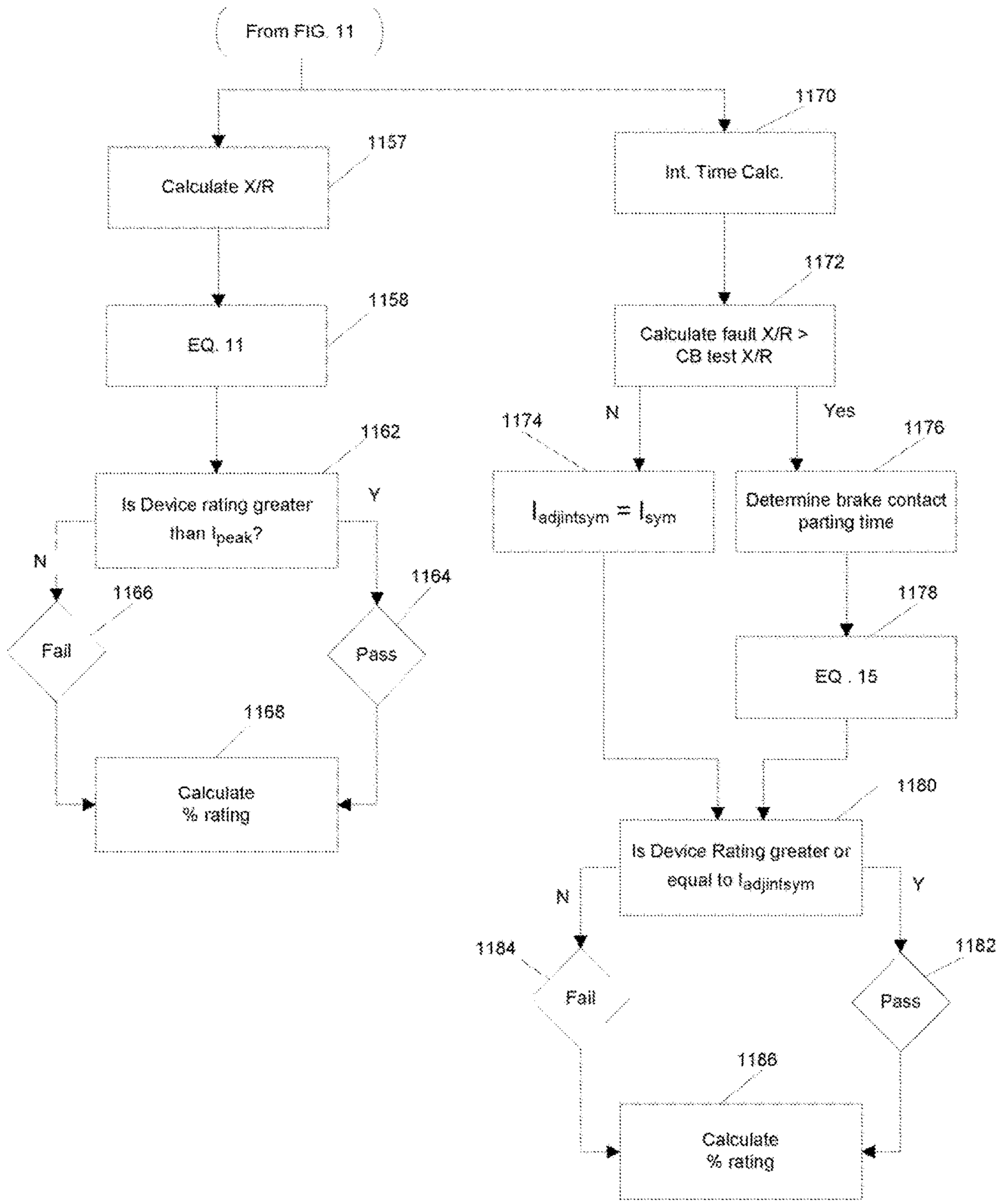

From FIG. 11
1157
Calculate X/R
1158
EQ. 11
1162
Is Device rating greater than I_{peak}?
N
Y
1166
Fail
1164
Pass
1168
Calculate % rating
1170
Int. Time Calc.
1172
Calculate fault X/R > CB test X/R
N
Yes
1174
$I_{adjintsym} = I_{sym}$
1176
Determine brake contact parting time
1178
EQ . 15
1180
Is Device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

FIG. 12

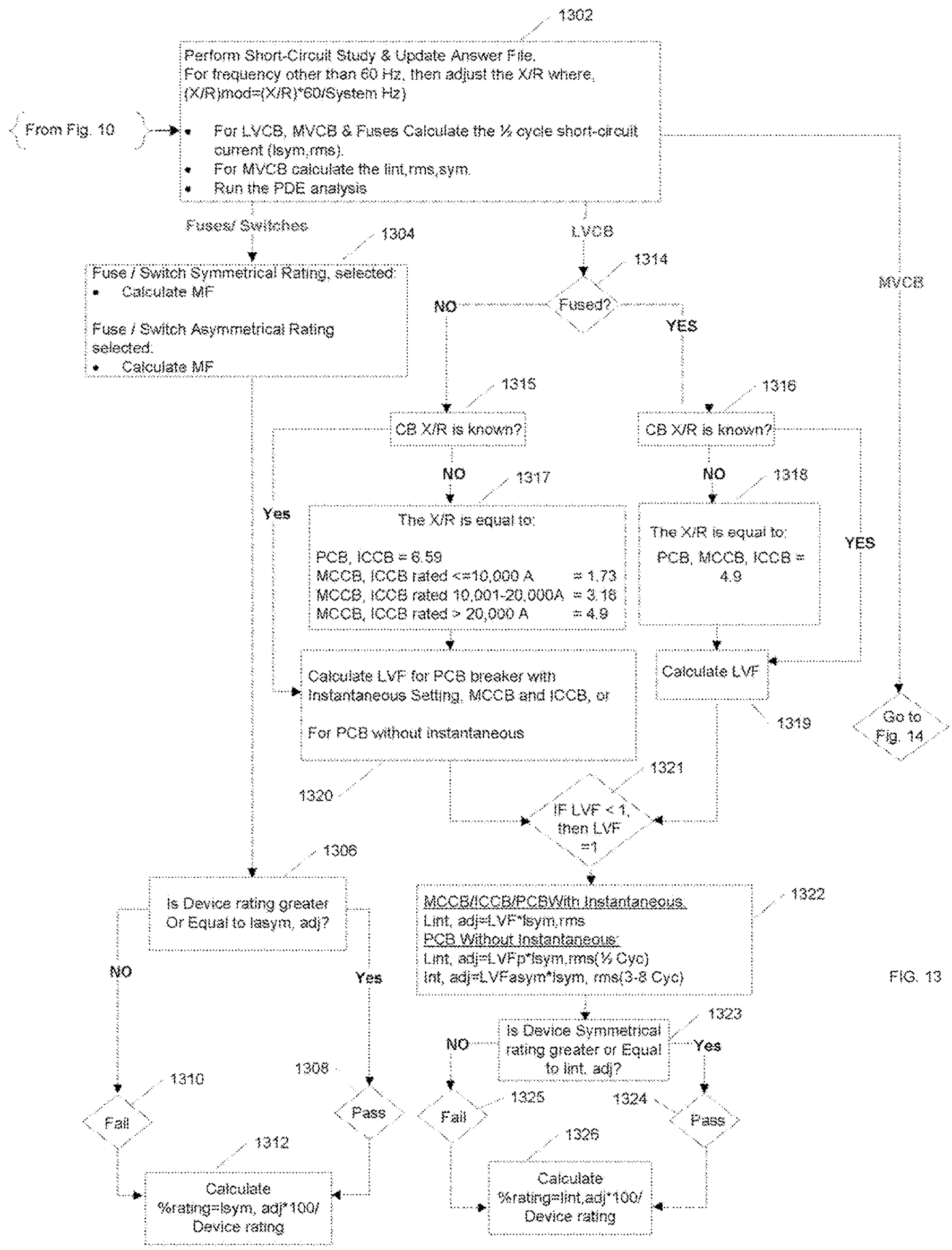

1302
Perform Short-Circuit Study & Update Answer File.
For frequency other than 60 Hz, then adjust the X/R where,
(X/R)mod=(X/R)*60/System Hz)
From Fig. 10
For LVCB, MVCB & Fuses Calculate the ½ cycle short-circuit current (Isym,rms).
For MVCB calculate the Iint,rms,sym.
Run the PDE analysis
Fuses/ Switches
LVCB
MVCB
1304
Fuse / Switch Symmetrical Rating, selected:
Calculate MF
Fuse / Switch Asymmetrical Rating selected:
Calculate MF
1314
Fused?
NO
YES
1315
1316
CB X/R is known?
CB X/R is known?
NO
NO
1317
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 = 3.16
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 Iasym, adj?
MCCB/ICCB/PCBWith Instantaneous:
Iint, adj=LVF*Isym,rms
PCB Without Instantaneous:
Iint, adj=LVFp*Isym,rms(½ Cyc)
Iint, 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
Fail
Pass
1325
1324
Fail
Pass
1312
1326
Calculate %rating=Isym, adj*100/ Device rating
Calculate %rating=Iint,adj*100/ Device rating

FIG. 13

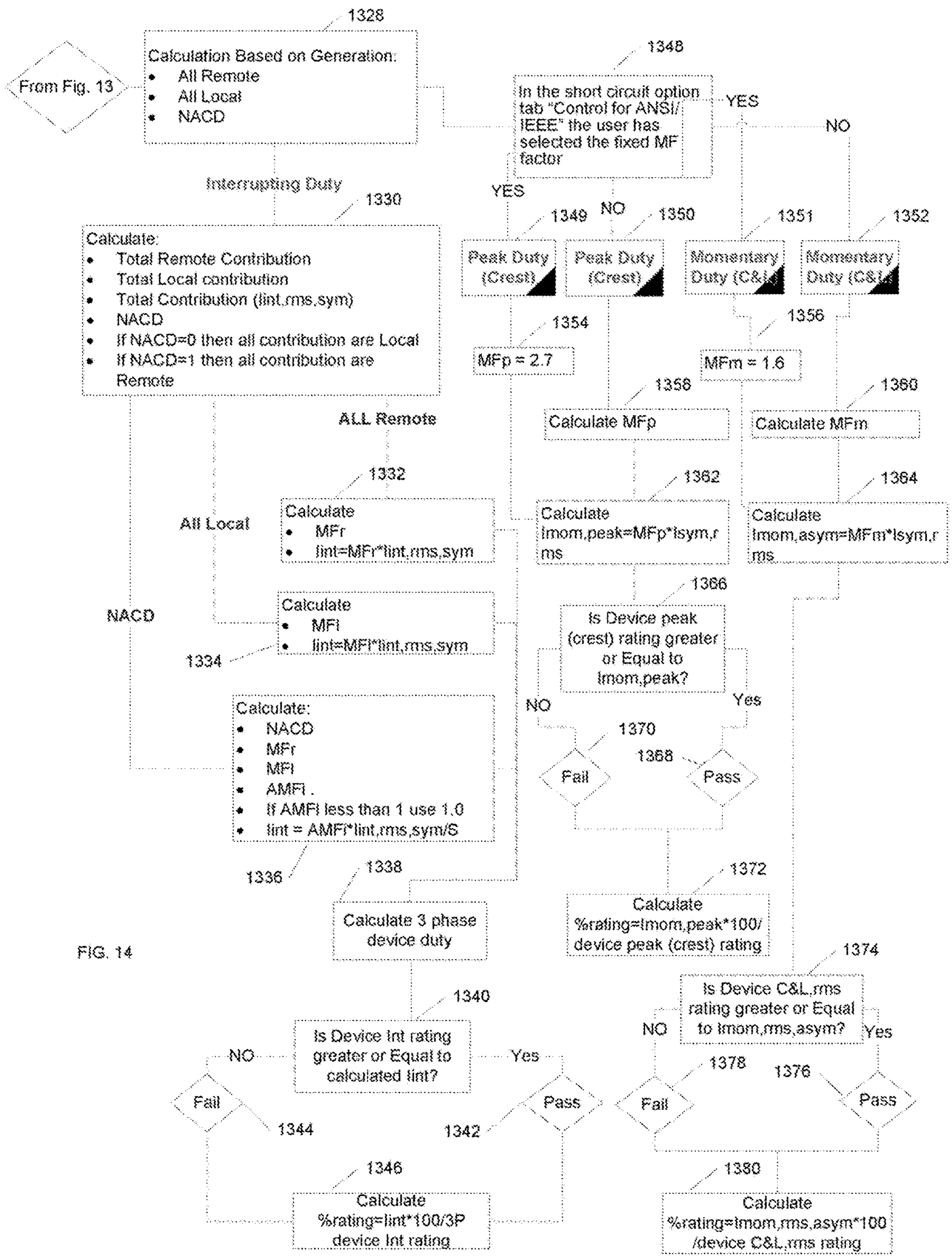

1328
From Fig. 13
Calculation Based on Generation:
All Remote
All Local
NACD
1348
In the short circuit option tab "Control for ANSI/IEEE" the user has selected the fixed MF factor
YES
NO
Interrupting Duty
1330
YES
NO
1349
1350
1351
1352
Calculate:
Total Remote Contribution
Total Local contribution
Total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

FIG. 14

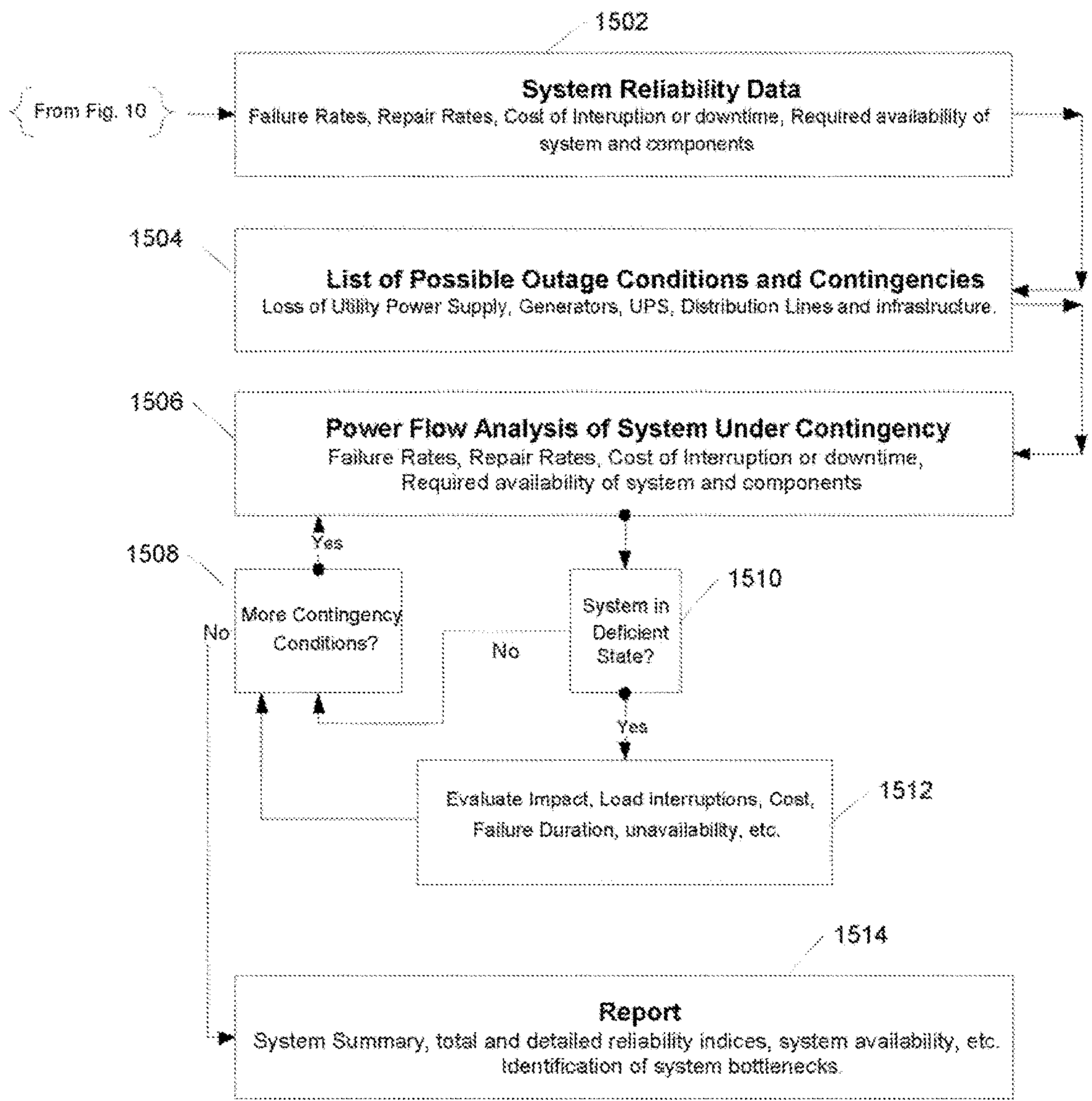

1502
From Fig. 10
System Reliability Data
Failure Rates, Repair Rates, Cost of Interuption or downtime, Required availability of system and components
1504
List of Possible Outage Conditions and Contingencies
Loss of Utility Power Supply, Generators, UPS, Distribution Lines and infrastructure.
1506
Power 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
1510
System in Deficient State?
No
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

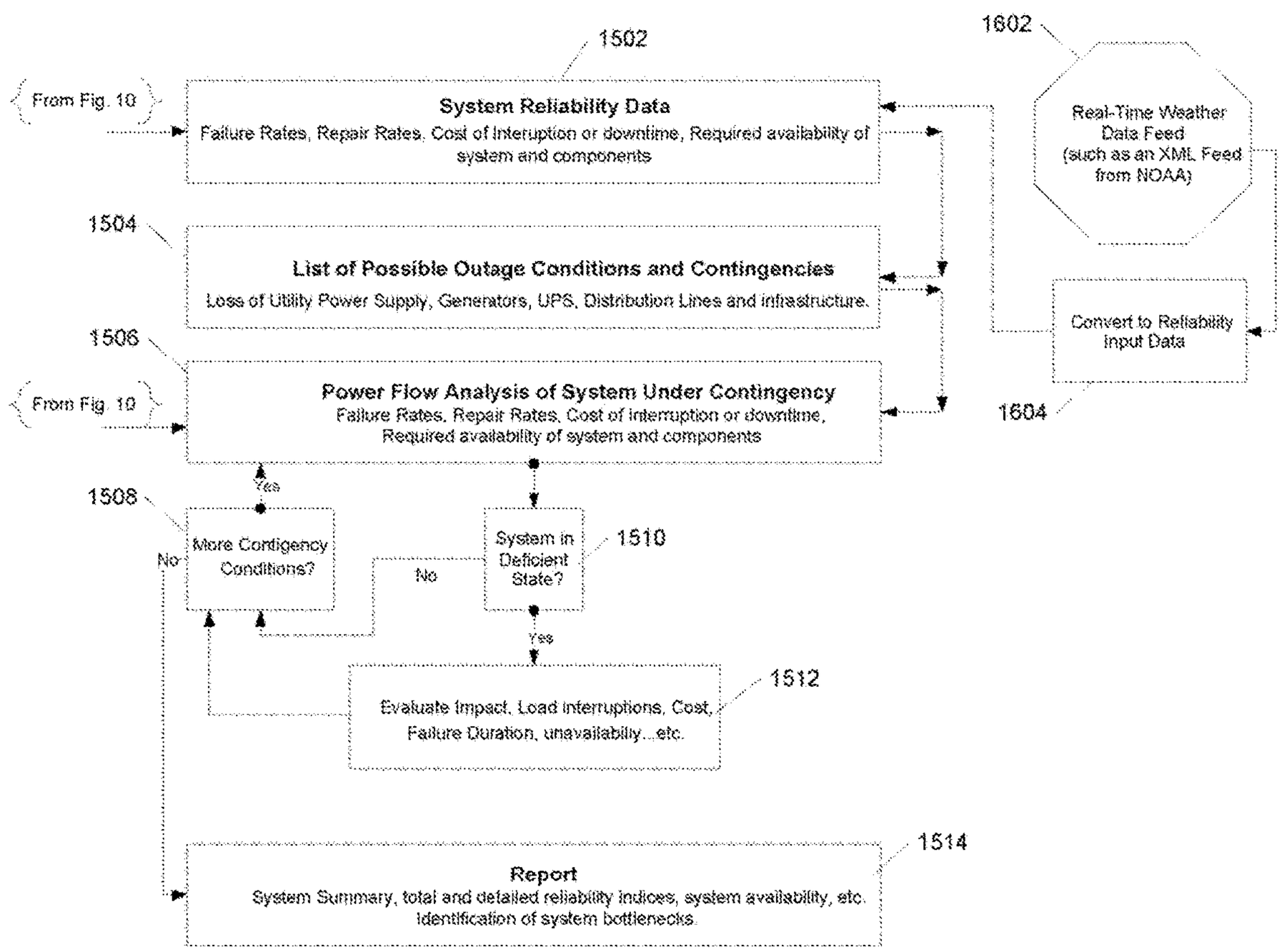

1502
From Fig. 10
System Reliability Data
Failure Rates, Repair Rates, Cost of Interuption or downtime, Required availability of system and components
1602
Real-Time Weather Data Feed (such as an XML Feed from NOAA)
1504
List of Possible Outage Conditions and Contingencies
Loss of Utility Power Supply, 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?
1510
No
Yes
1512
Evaluate Impact, Load Interruptions, Cost, Failure Duration, unavailability...etc.
1514
Report
System Summary, total and detailed reliability indices, system availability, etc. Identification of system bottlenecks.

FIG. 16

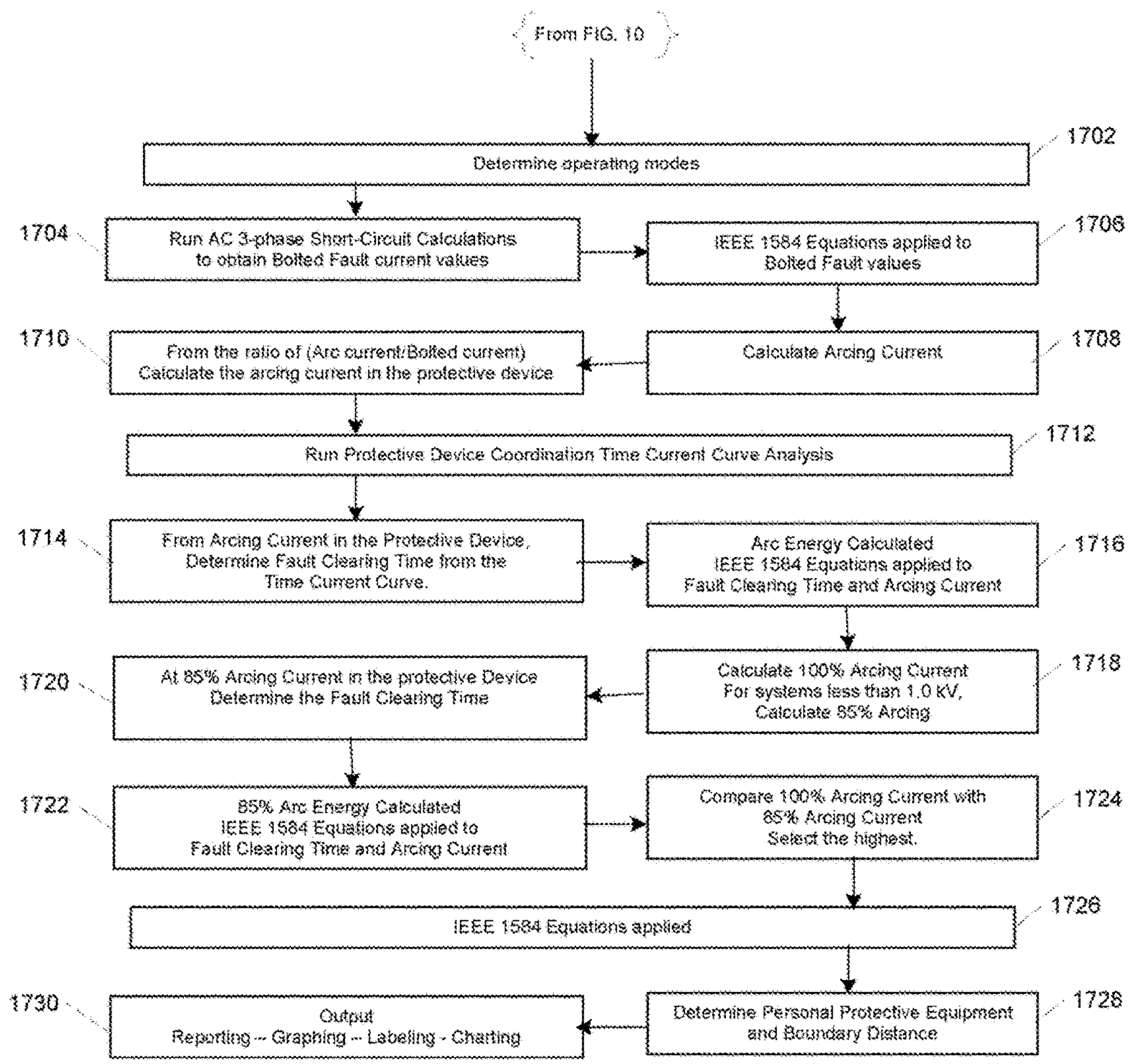

From FIG. 10
1702
Determine operating modes
1704
Run AC 3-phase Short-Circuit Calculations to obtain Bolted Fault current values
IEEE 1584 Equations applied to Bolted Fault values
1706
1710
From the ratio of (Arc current/Bolted current) Calculate the arcing current in the protective device
Calculate 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

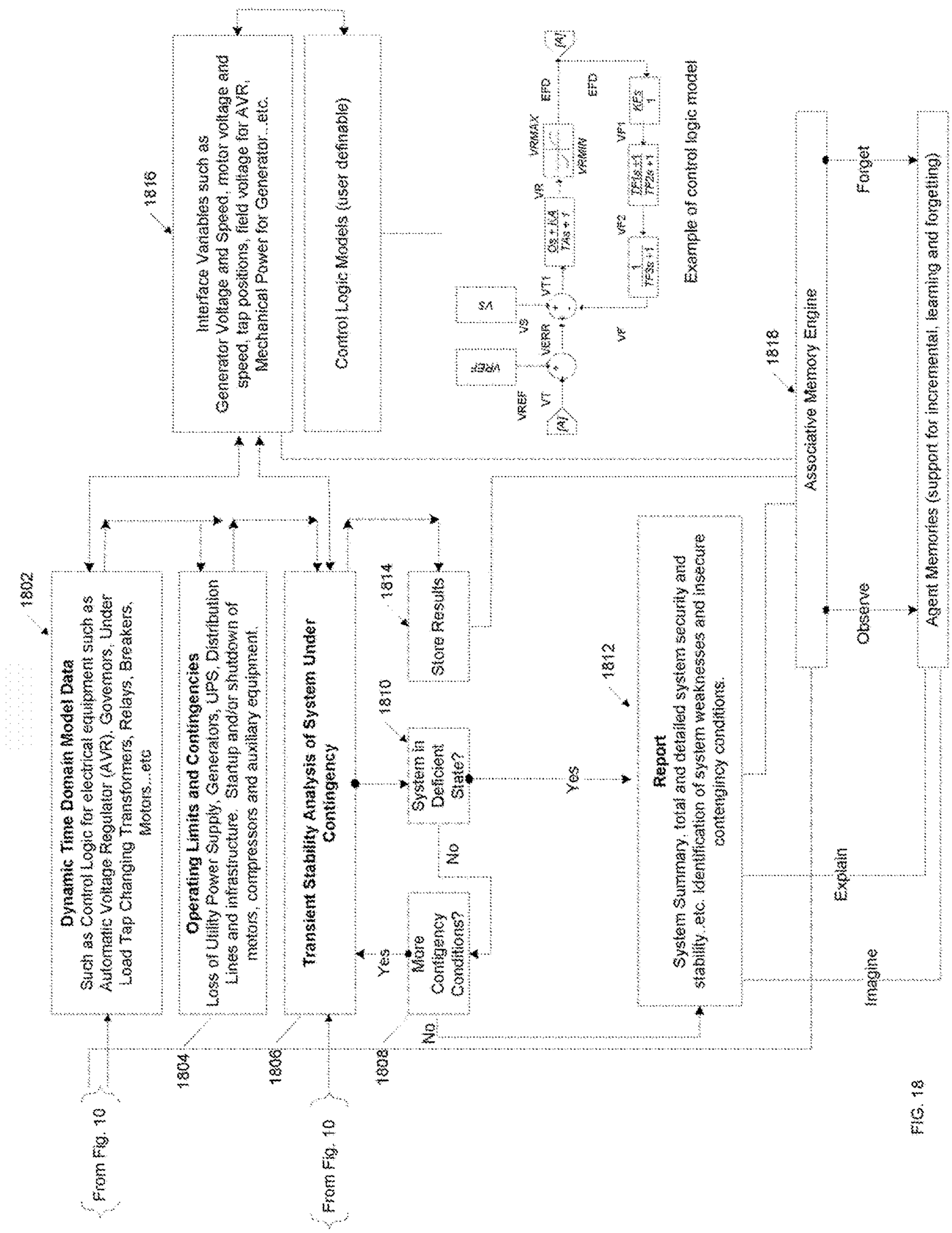

1816
Interface Variables such as Generator Voltage and Speed, motor voltage and speed, tap positions, field voltage for AVR, Mechanical Power for Generator...etc.
Control Logic Models (user definable)
Example of control logic model
1818
Associative Memory Engine
Forget
Observe
Agent Memories (support for incremental, learning and forgetting)
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
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.
Transient Stability Analysis of System Under Contingency
1814
Store Results
1810
System in Deficient State?
Yes
No
1812
Report
System Summary, total and detailed system security and stability..etc. Identification of system weaknesses and insecure contenginicy conditions.
More Contigency Conditions?
Yes
No
Explain
Imagine
1804
1806
1808
From Fig. 10
From Fig. 10

FIG. 18

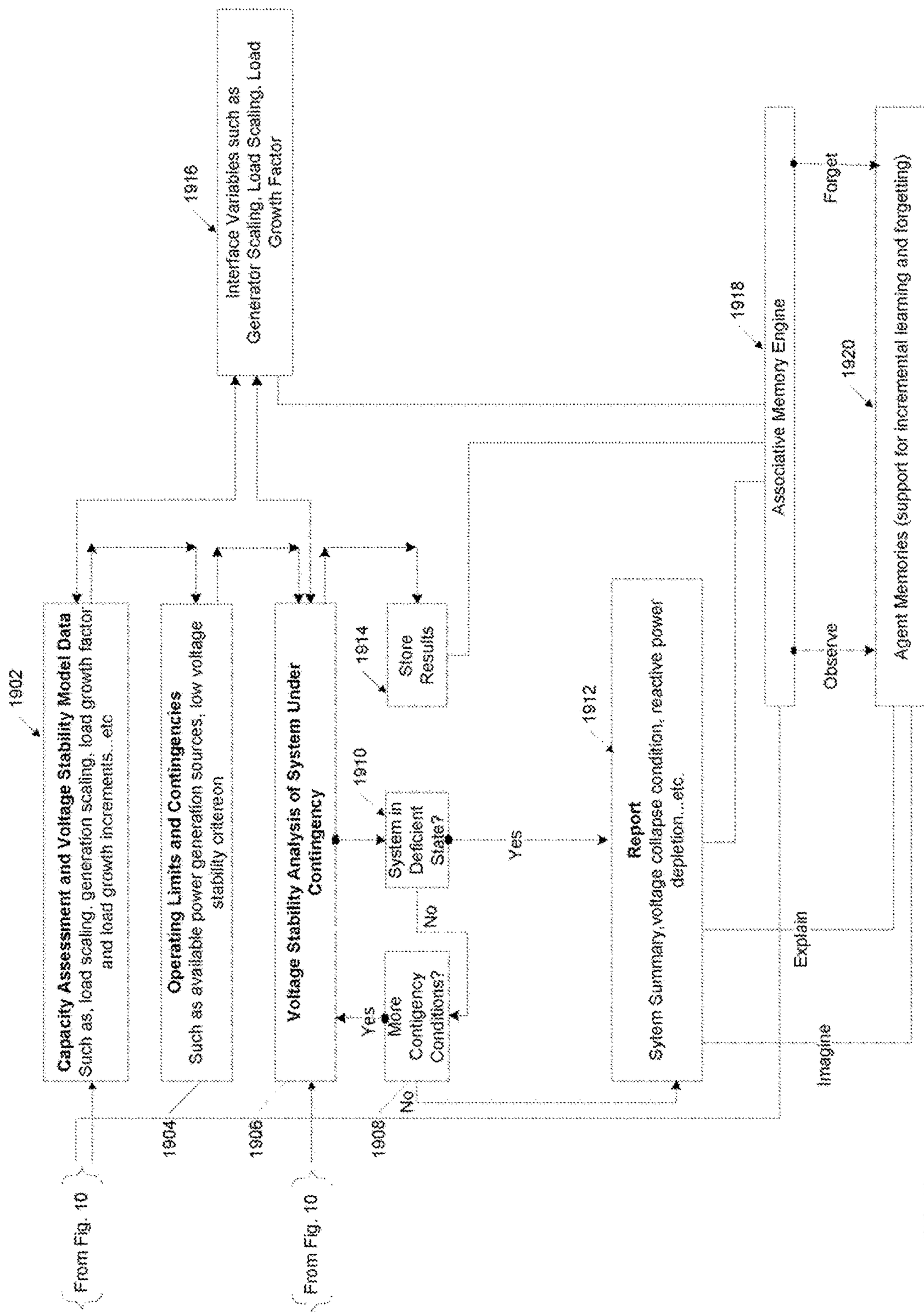

1916
Interface Variables such as Generator Scaling, Load Scaling, Load Growth Factor
1902
Capacity Assessment and Voltage Stability Model Data
Such as, load scaling, generation scaling, load growth factor and load growth increments...etc
1904
Operating Limits and Contingencies
Such as available power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

FIG. 19

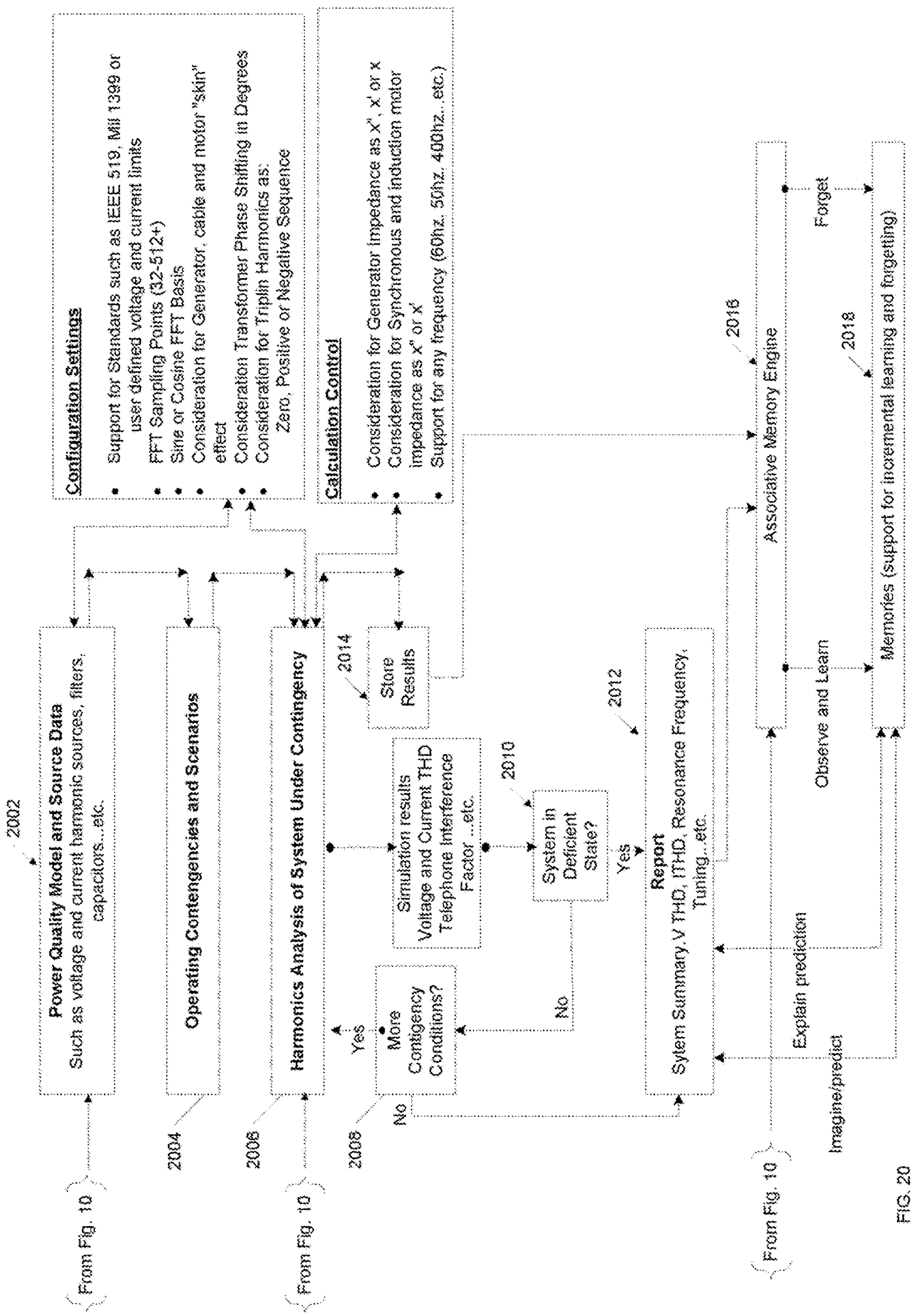

From Fig. 10
2002
Power Quality Model and Source Data
Such as voltage and current harmonic sources, filters, capacitors...etc.
Configuration Settings
Support for Standards such as IEEE 519, Mil 1399 or user defined voltage and current limits
FFT Sampling Points (32-512+)
Sine or Cosine FFT Basis
Consideration for Generator, cable and motor "skin" effect
Consideration Transformer Phase Shifting in Degrees
Consideration for Triplin Harmonics as: Zero, Positive or Negative Sequence
2004
Operating Contengencies and Scenarios
2006
Harmonics Analysis of System Under Contingency
From Fig. 10
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.)
2008
More Contigency Conditions?
Yes
No
2014
Store Results
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.
2016
Associative Memory Engine
Forget
2018
Memories (support for incremental learning and forgetting)
Observe and Learn
Explain prediction
Imagine/predict
From Fig. 10

FIG. 20

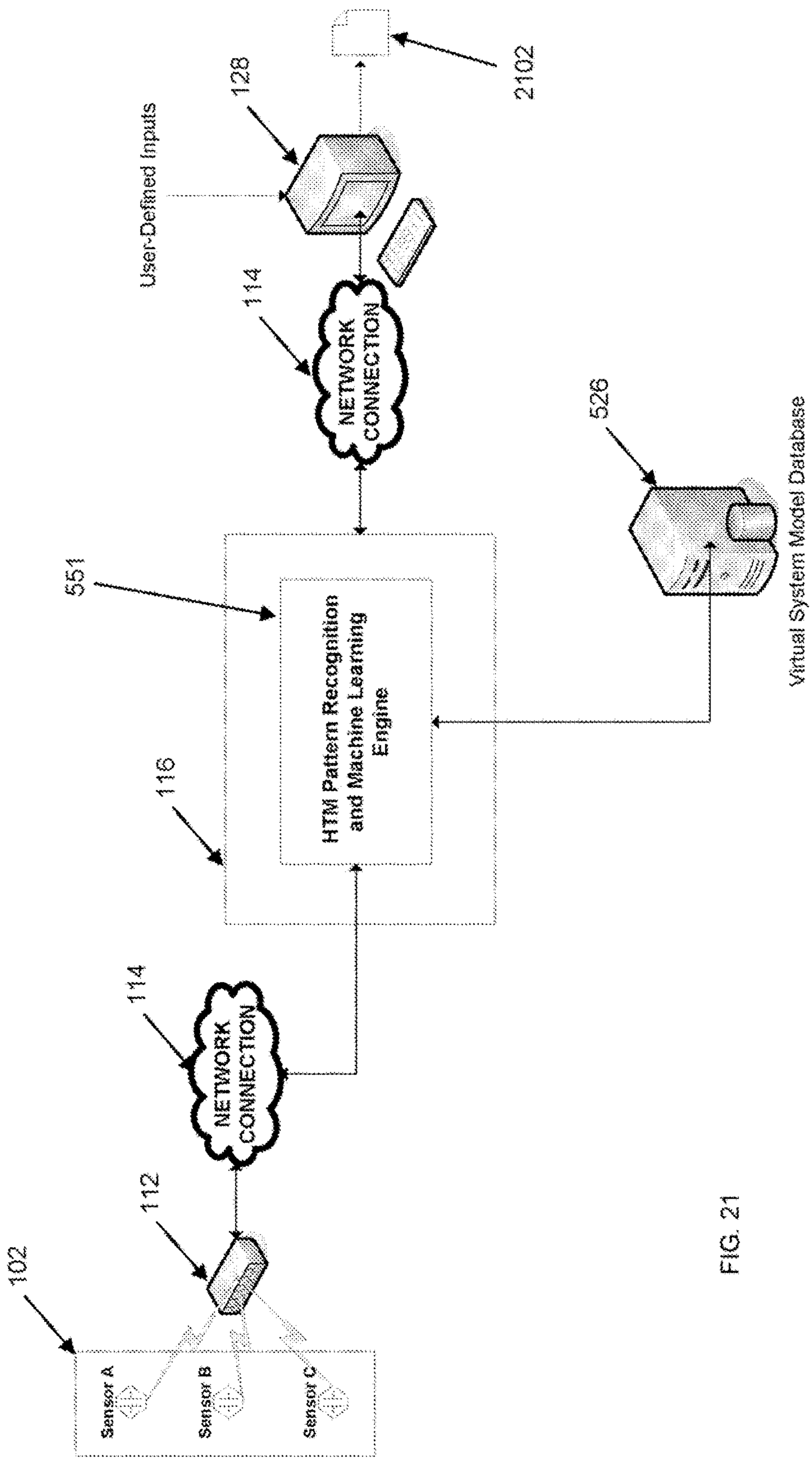

102
Sensor A
Sensor B
Sensor C
112
114
NETWORK CONNECTION
116
551
HTM Pattern Recognition and Machine Learning Engine
114
NETWORK CONNECTION
526
Virtual System Model Database
128
User-Defined Inputs
2102

FIG. 21

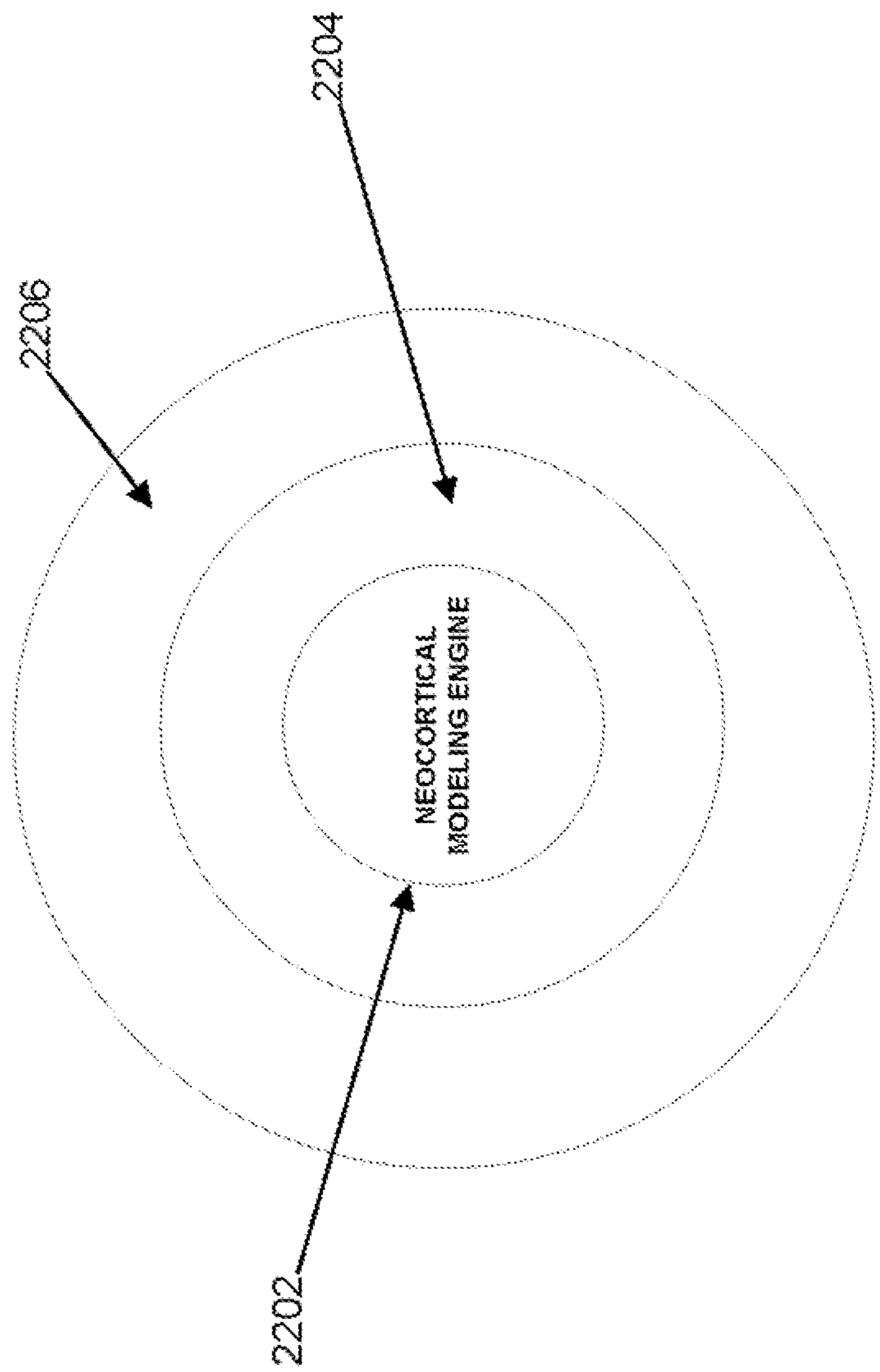


FIG. 22

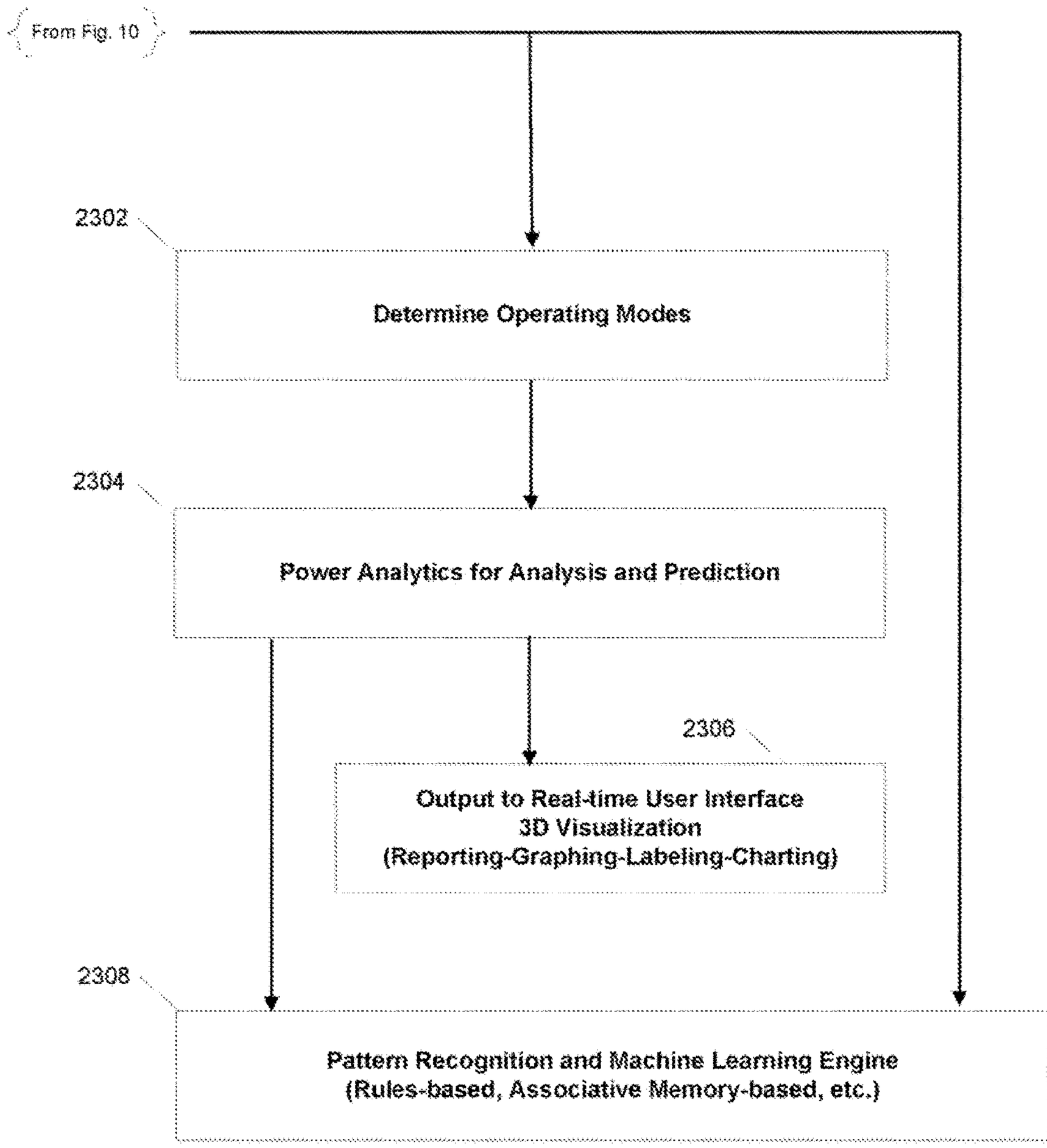

From Fig. 10
2302
Determine Operating Modes
2304
Power Analytics for Analysis and Prediction
2306
Output to Real-time User Interface
3D Visualization
(Reporting-Graphing-Labeling-Charting)
2308
Pattern Recognition and Machine Learning Engine
(Rules-based, Associative Memory-based, etc.)

FIG. 23

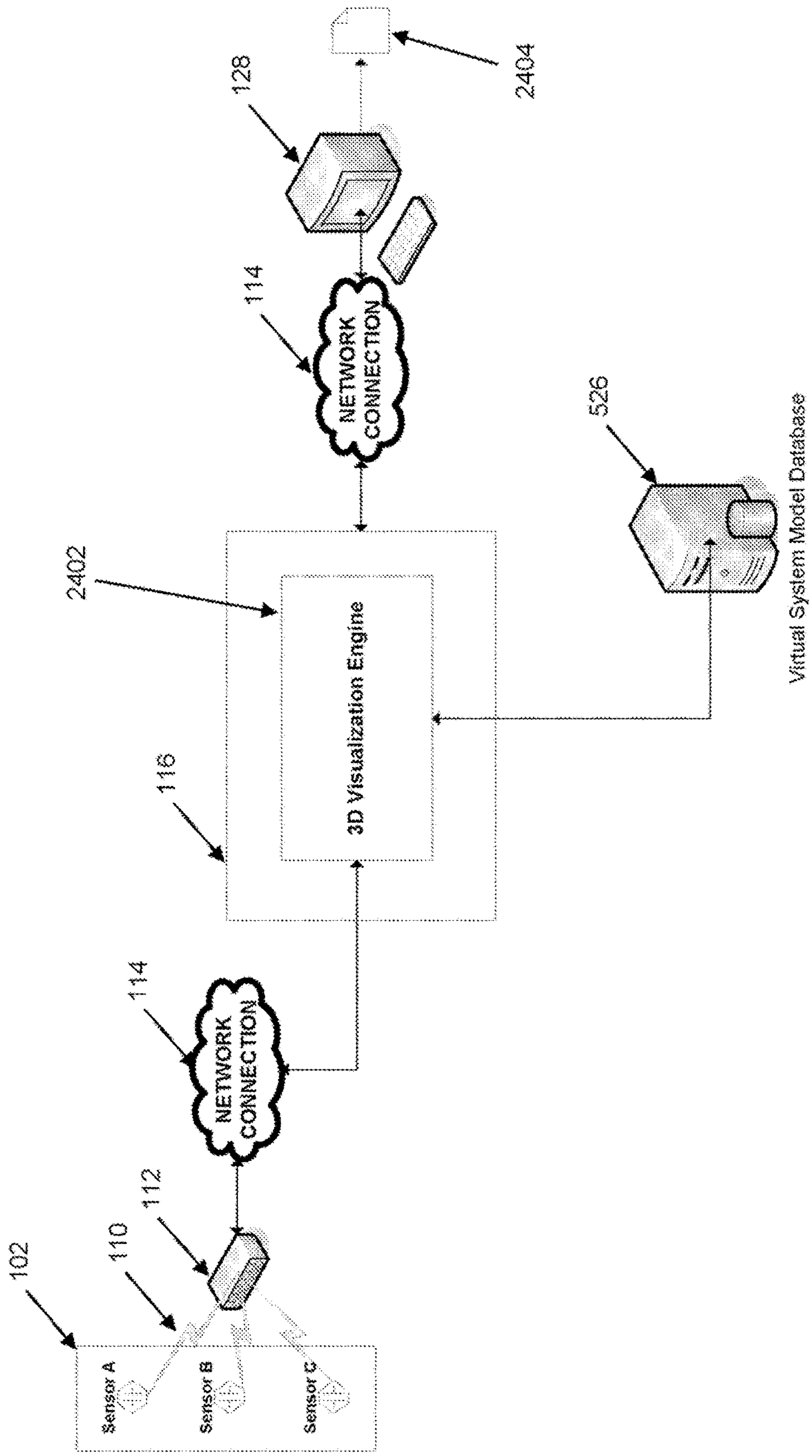

102
Sensor A
Sensor B
Sensor C
110
112
114
NETWORK CONNECTION
2402
116
3D Visualization Engine
114
NETWORK CONNECTION
128
2404
526
Virtual System Model Database

FIG. 24

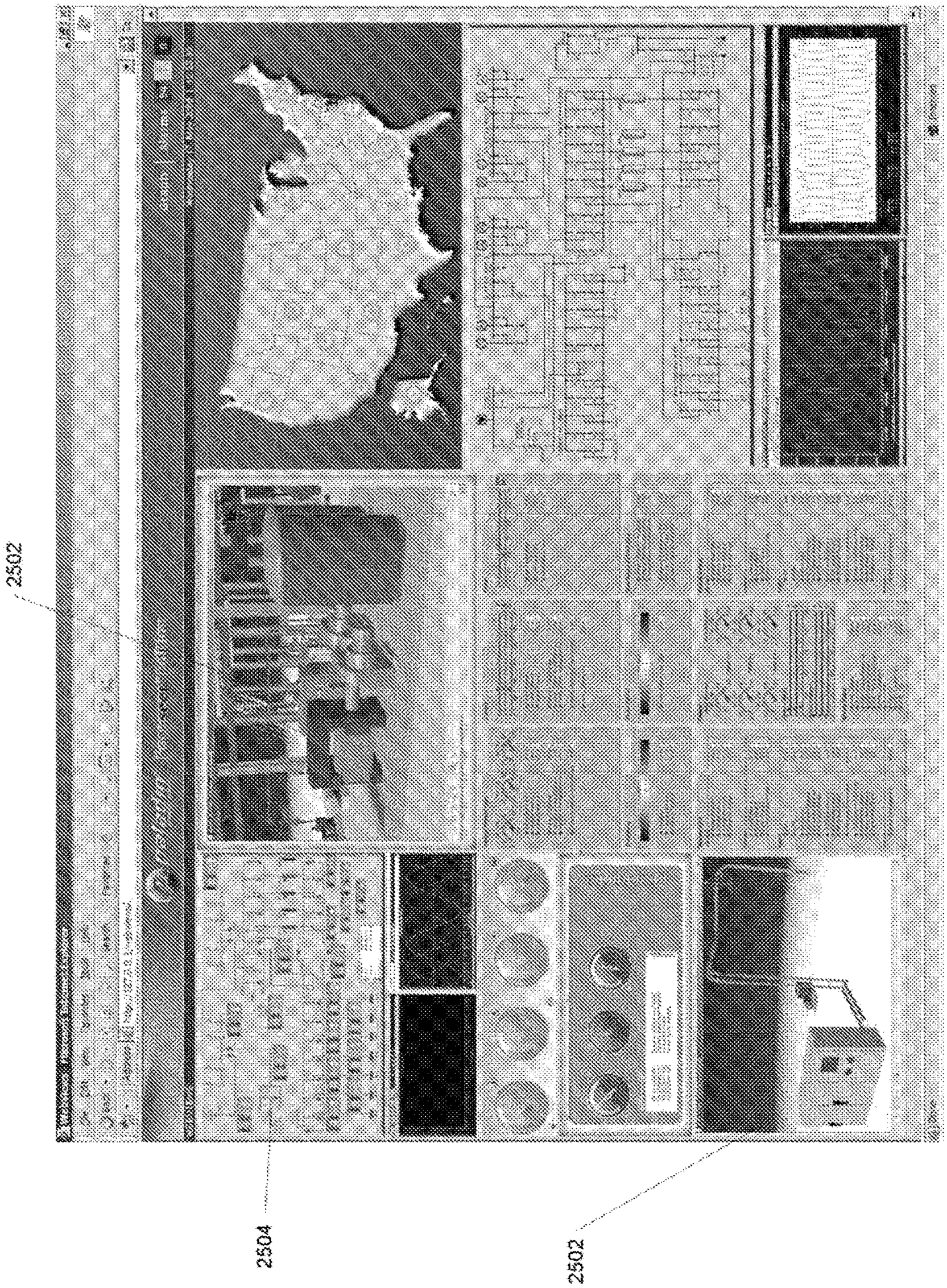


FIG. 25

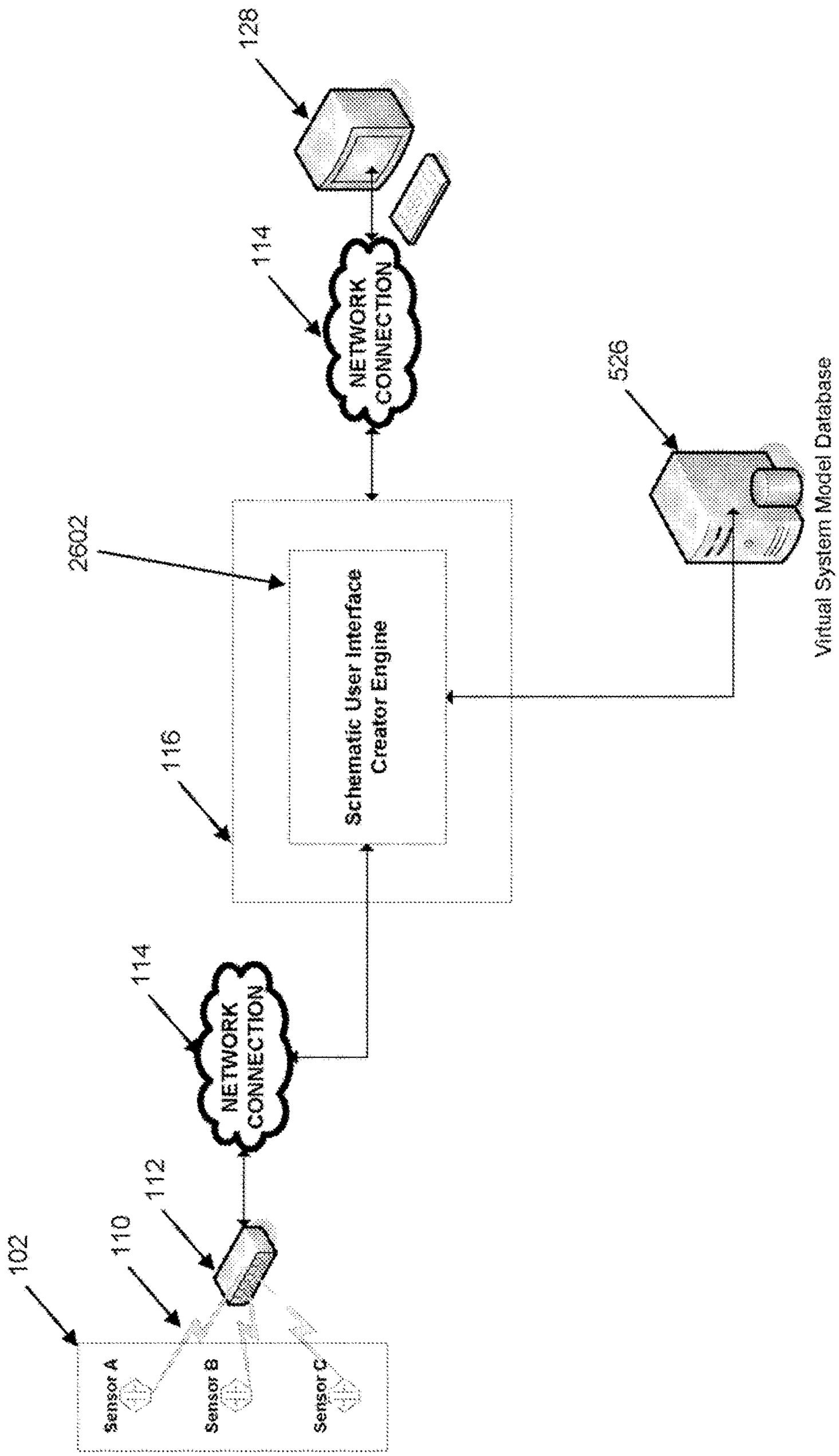

128
114
NETWORK CONNECTION
526
Virtual System Model Database
2602
Schematic User Interface Creator Engine
116
114
NETWORK CONNECTION
112
110
102
Sensor A
Sensor B
Sensor C

FIG. 26

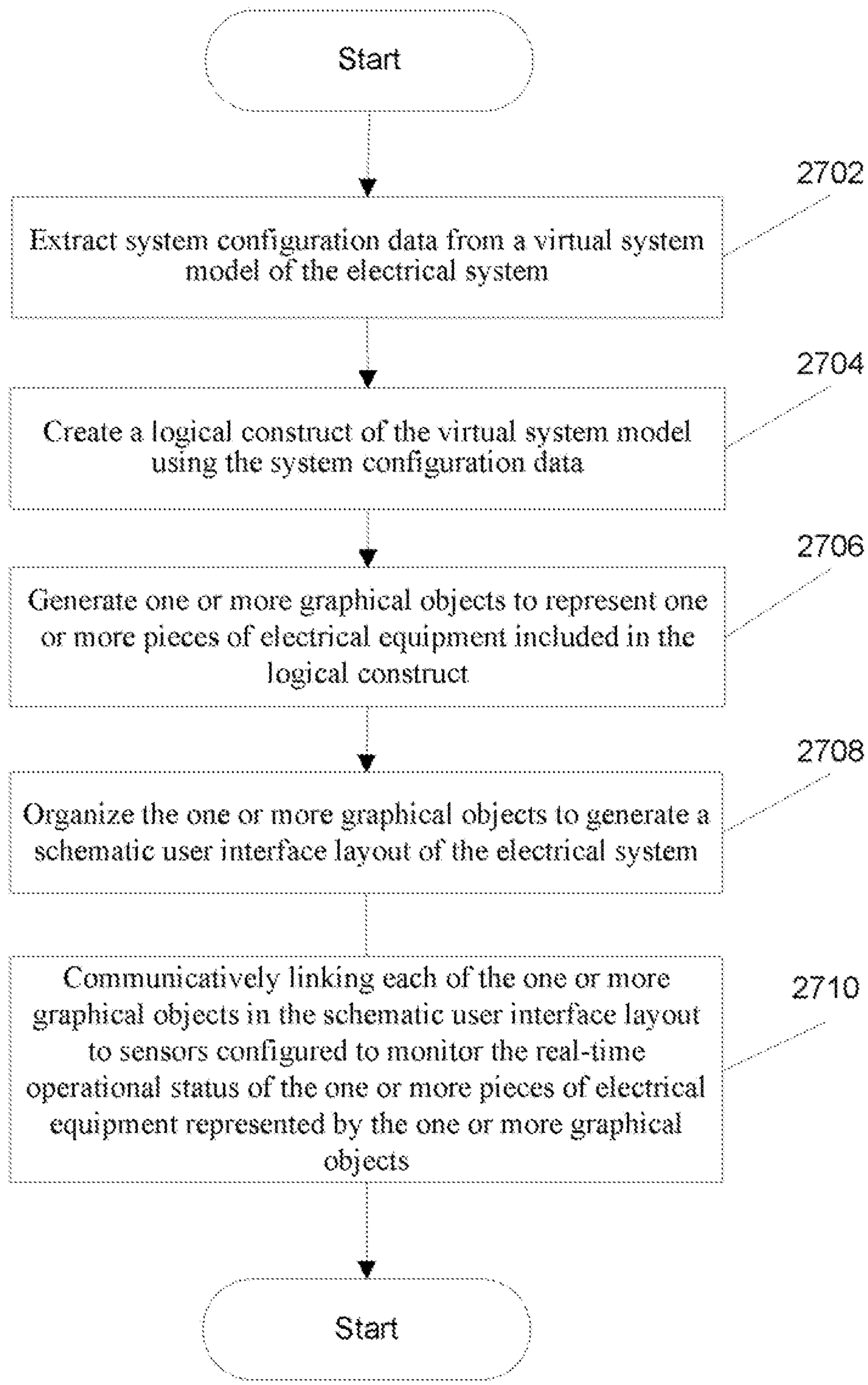

Start
2702
Extract system configuration data from a virtual system model of the electrical system
2704
Create a logical construct of the virtual system model using the system configuration data
2706
Generate one or more graphical objects to represent one or more pieces of electrical equipment included 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

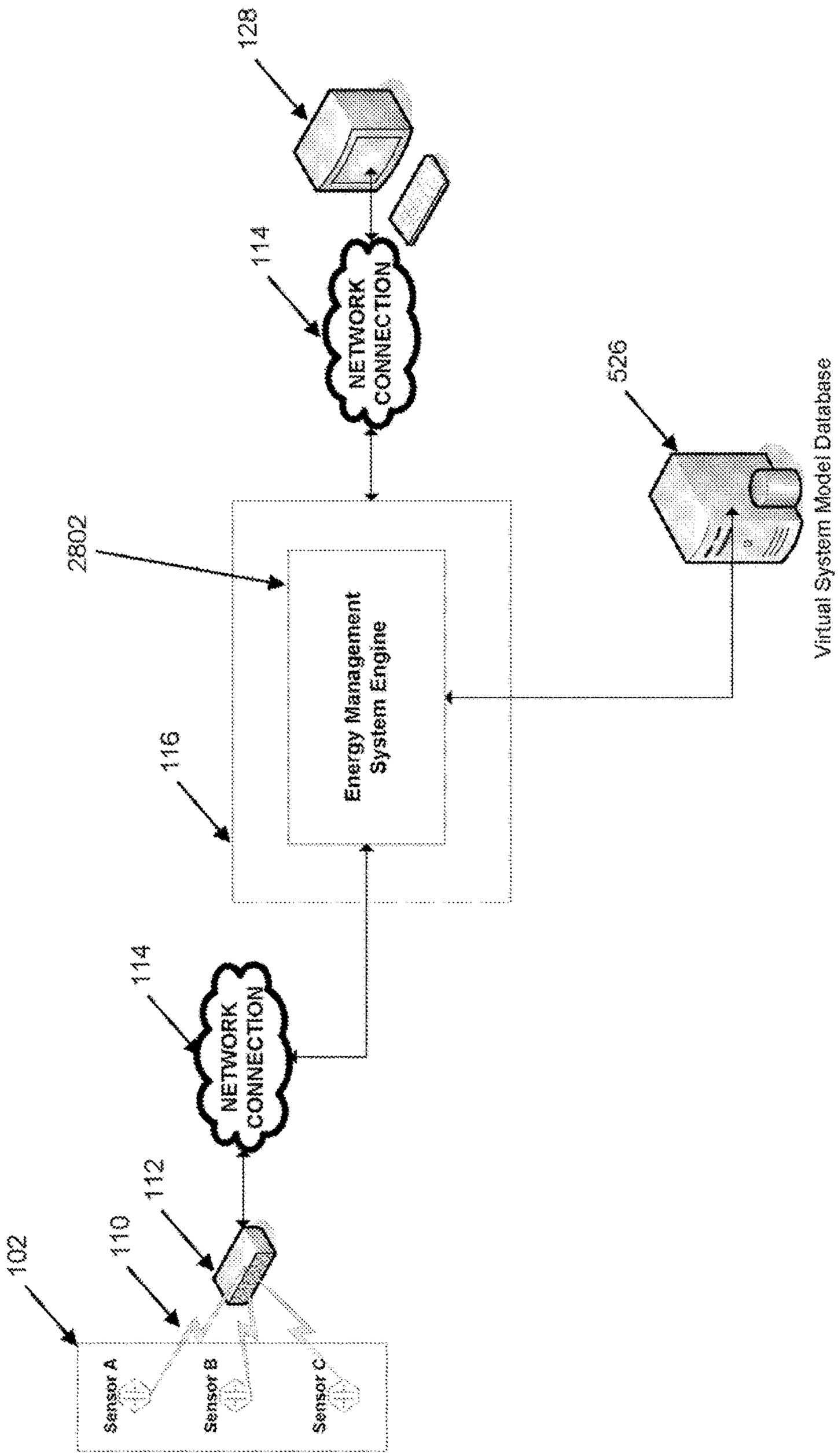

128
114
NETWORK CONNECTION
526
Virtual System Model Database
2802
Energy Management System Engine
116
114
NETWORK CONNECTION
112
110
102
Sensor A
Sensor B
Sensor C

FIG. 28

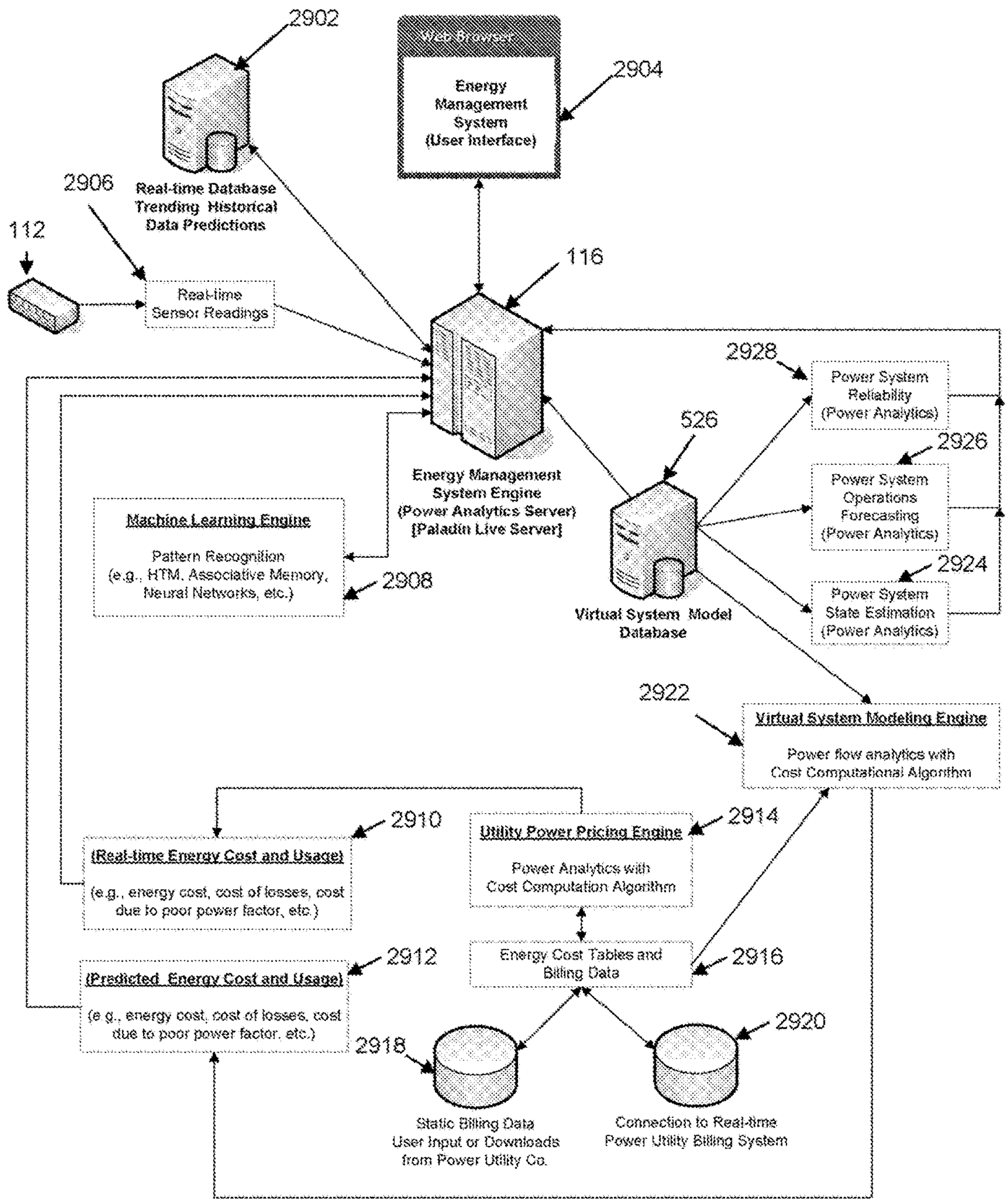

2902
Web Browser
Energy Management System (User Interface)
2904
2906
Real-time Database Trending Historical Data Predictions
112
Real-time Sensor Readings
116
2928
Power System Reliability (Power Analytics)
526
2926
Power System Operations Forecasting (Power Analytics)
Energy Management System Engine (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
2914
(Real-time Energy Cost and Usage)
(e.g., energy cost, cost of losses, cost due to poor power factor, etc.)
Utility Power Pricing Engine
Power Analytics with Cost Computation Algorithm
2912
Energy Cost Tables and Billing Data
2916
(Predicted Energy Cost and Usage)
(e.g., energy cost, cost of losses, cost due to poor power factor, etc.)
2920
2918
Static Billing Data User Input or Downloads from Power Utility Co.
Connection to Real-time Power Utility Billing System

FIG. 29

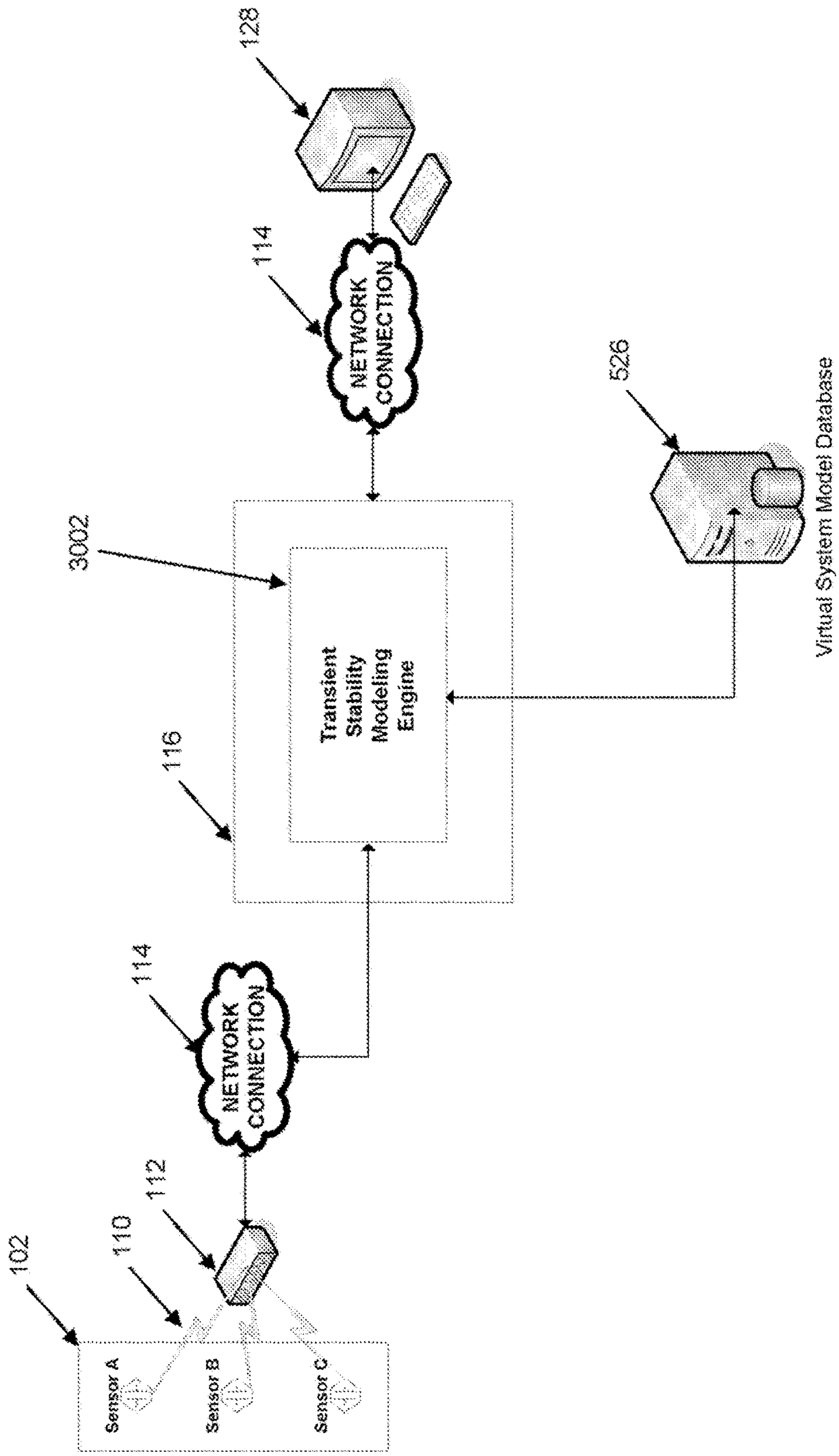

128
114
NETWORK CONNECTION
526
Virtual System Model Database
3002
Transient Stability Modeling Engine
116
114
NETWORK CONNECTION
112
110
102
Sensor A
Sensor B
Sensor C

FIG. 30

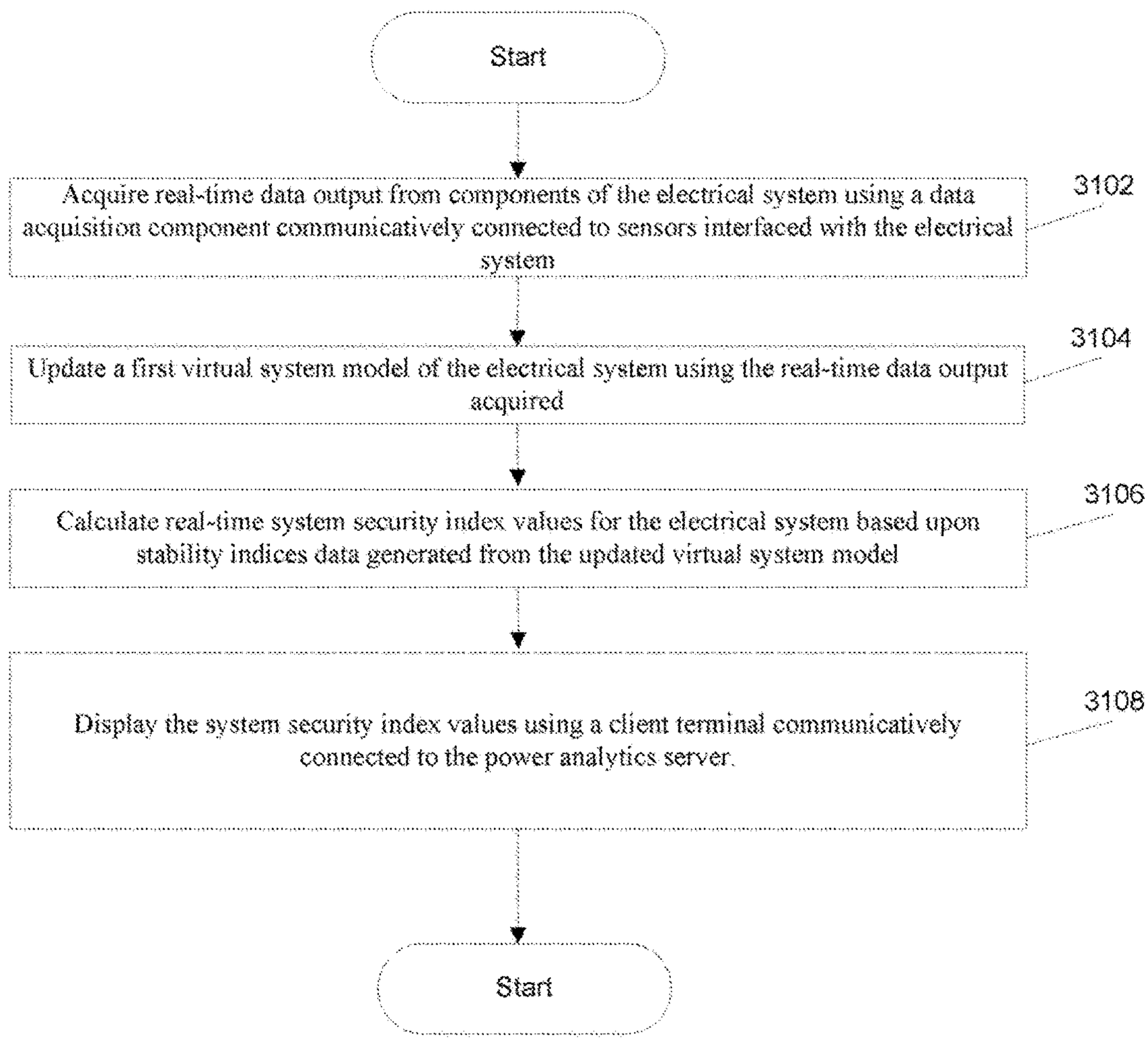

Start
Acquire real-time data output from components of the electrical system using a data acquisition component communicatively connected to sensors interfaced with the electrical system
3102
Update a first virtual system model of the electrical system using the real-time data output acquired
3104
Calculate real-time system security index values for the electrical system based upon stability indices data generated from the updated virtual system model
3106
Display the system security index values using a client terminal communicatively connected to the power analytics server.
3108
Start

FIG. 31

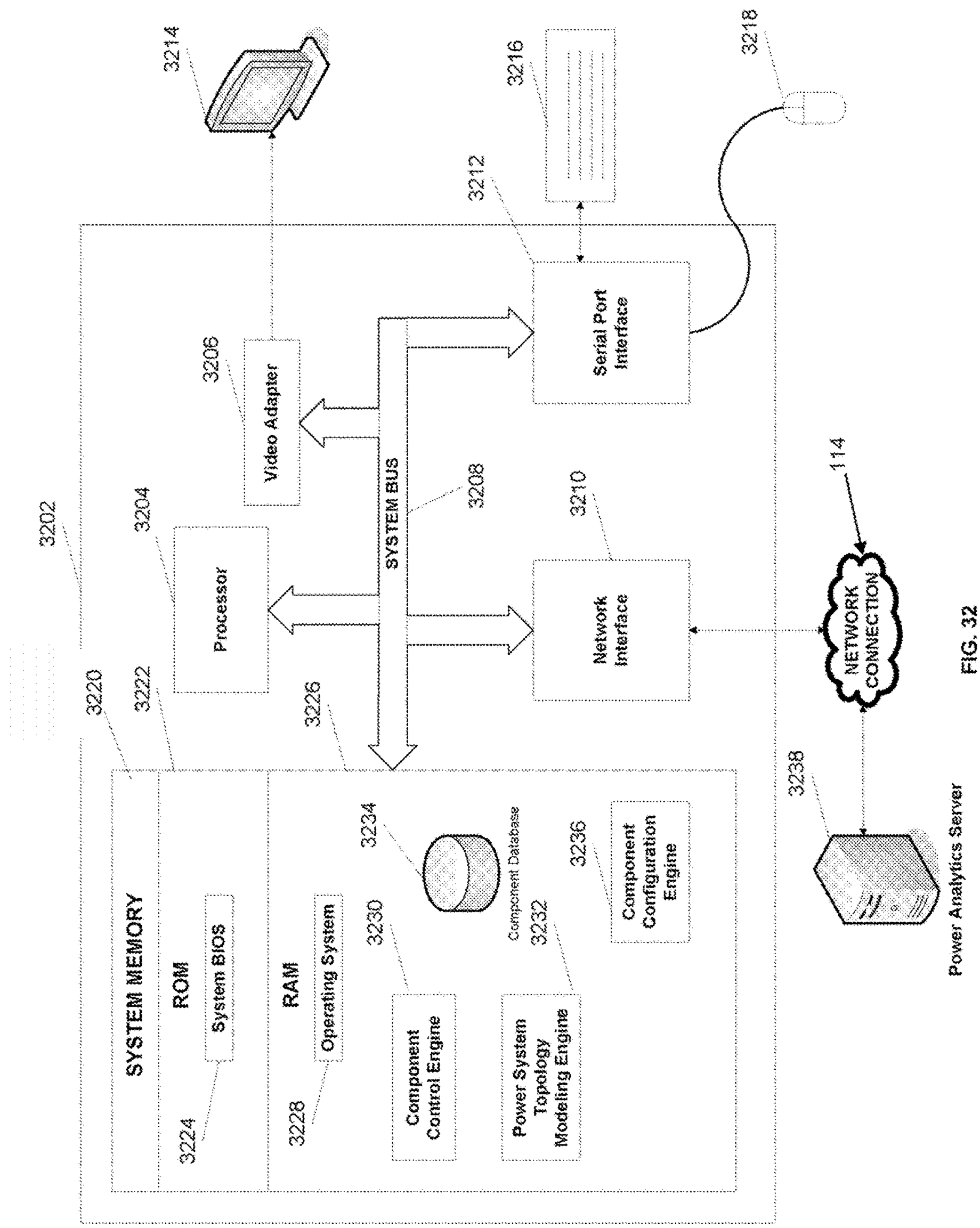

3214
3216
3218
3212
Serial Port Interface
3206
Video Adapter
SYSTEM BUS
3208
3210
Network Interface
114
NETWORK CONNECTION
3202
3204
Processor
3220
3222
3226
SYSTEM MEMORY
ROM
System BIOS
3224
RAM
Operating System
3228
3234
Component Database
3230
Component Control Engine
3232
Power System Topology Modeling Engine
3236
Component Configuration Engine
3238
Power Analytics Server

FIG. 32

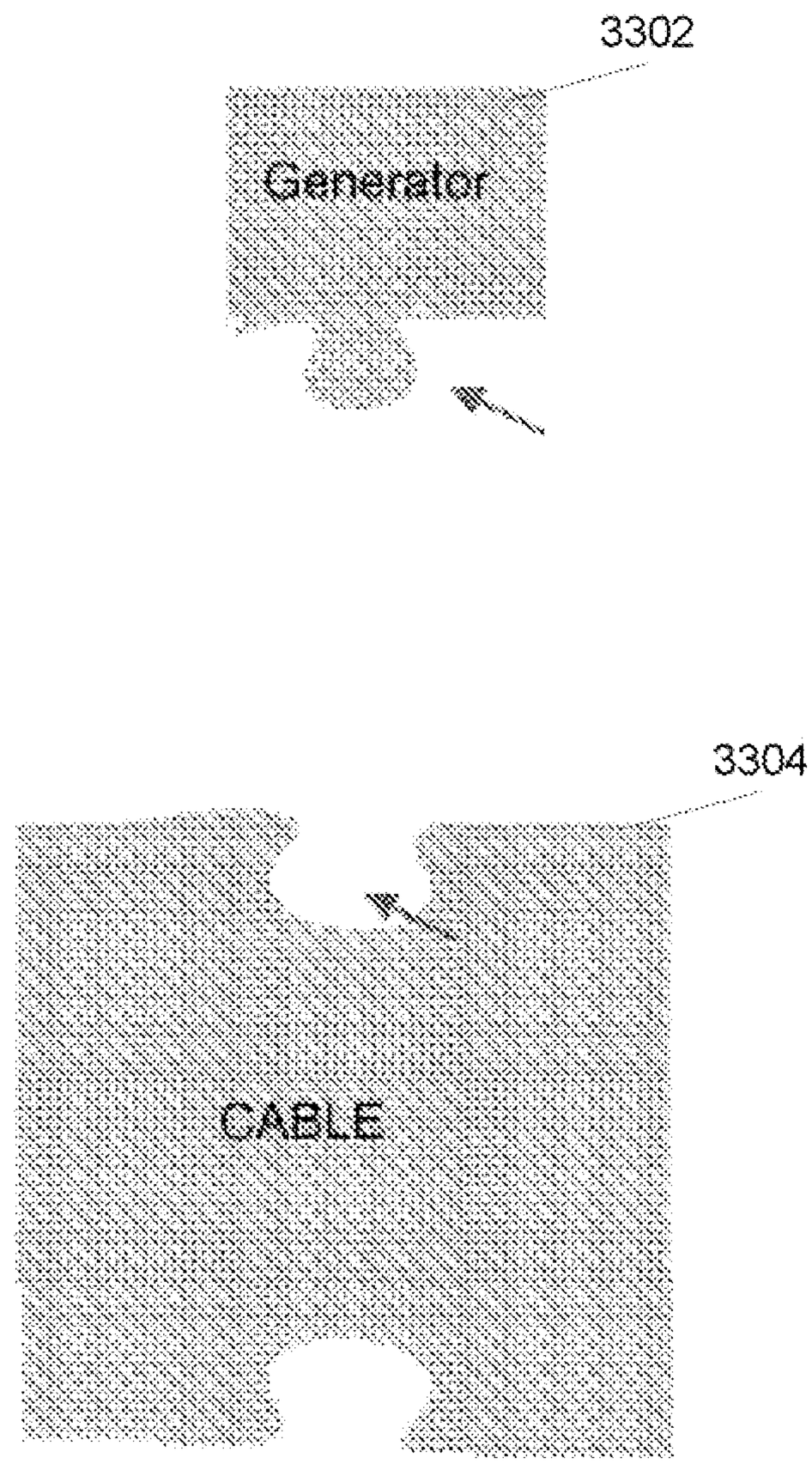


FIG. 33

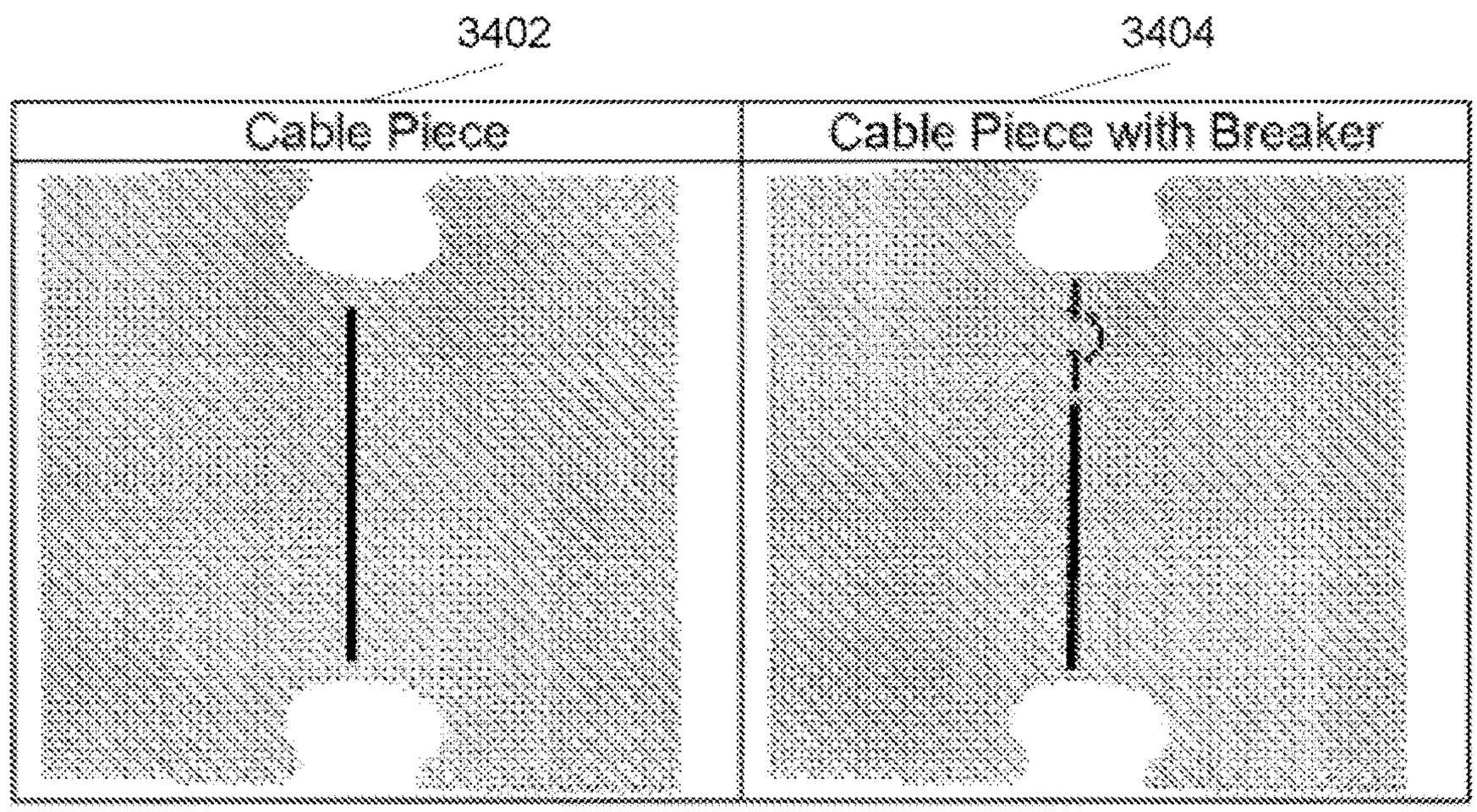


FIG. 34

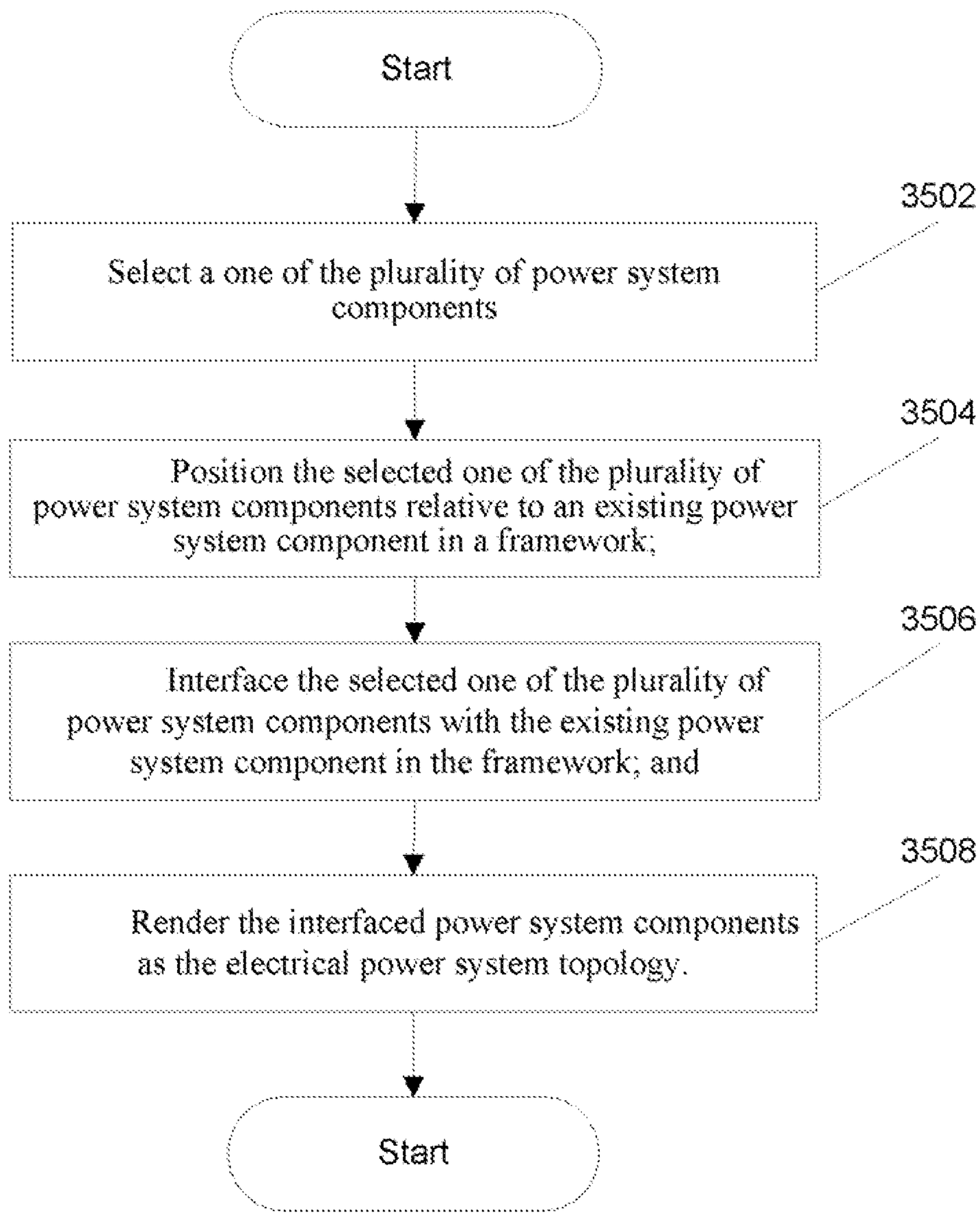

Start
3502
Select a one of the plurality of power system components
3504
Position the selected one of the plurality of power system components relative to an existing power system component in a framework;
3506
Interface the selected one of the plurality of power system components with the existing power system component in the framework; and
3508
Render the interfaced power system components as the electrical power system topology.
Start

FIG. 35

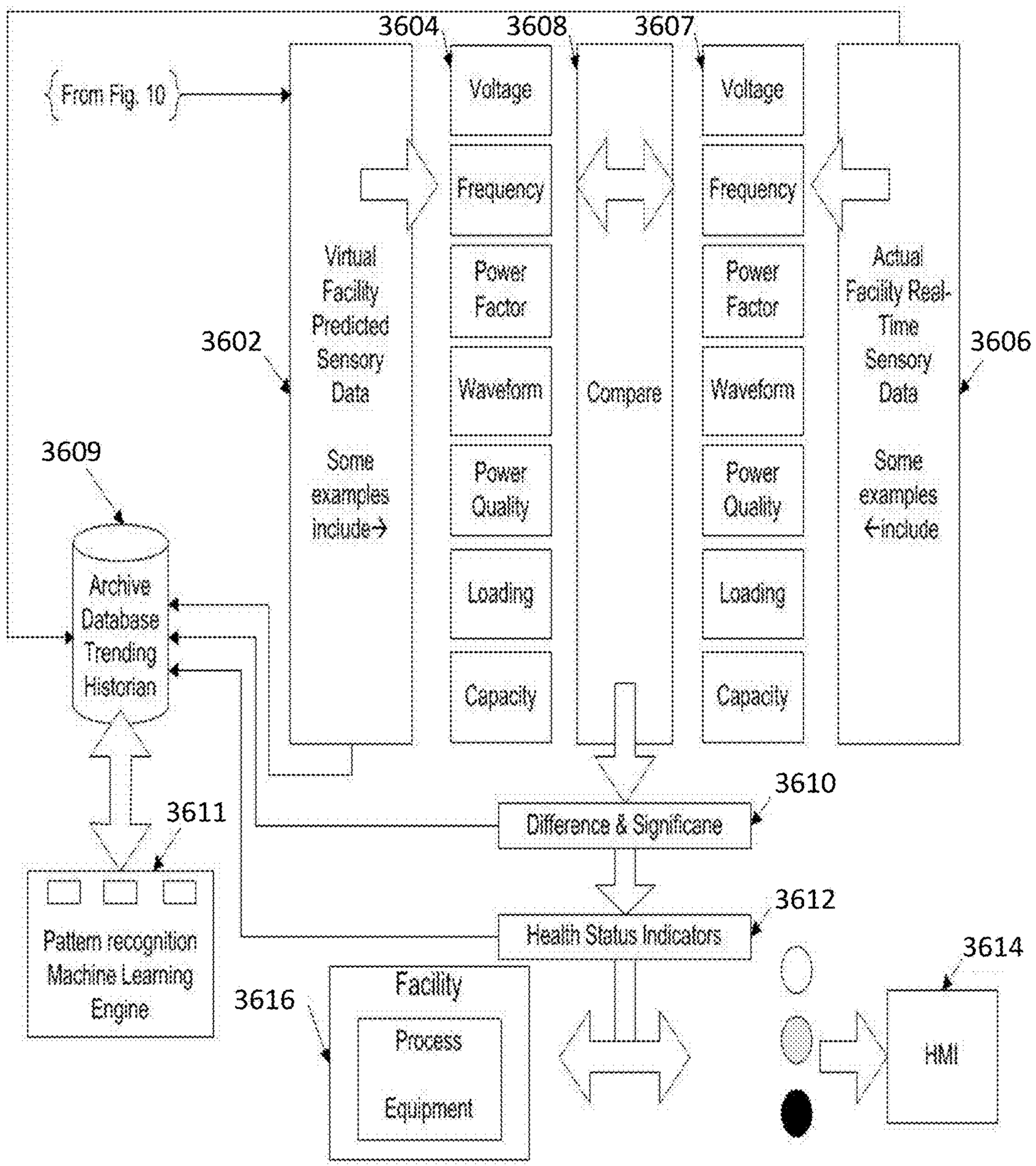

3604
3608
3607
From Fig. 10
Voltage
Frequency
Power Factor
Waveform
Power Quality
Loading
Capacity
Voltage
Frequency
Power Factor
Waveform
Power Quality
Loading
Capacity
Virtual Facility Predicted Sensory Data
Some examples include→
Compare
Actual Facility Real-Time Sensory Data
Some examples ←include
3602
3606
3609
Archive Database Trending Historian
3610
Difference & Significane
3611
Pattern recognition Machine Learning Engine
3612
Health Status Indicators
3614
3616
Facility
Process
Equipment
HMI

FIG. 36

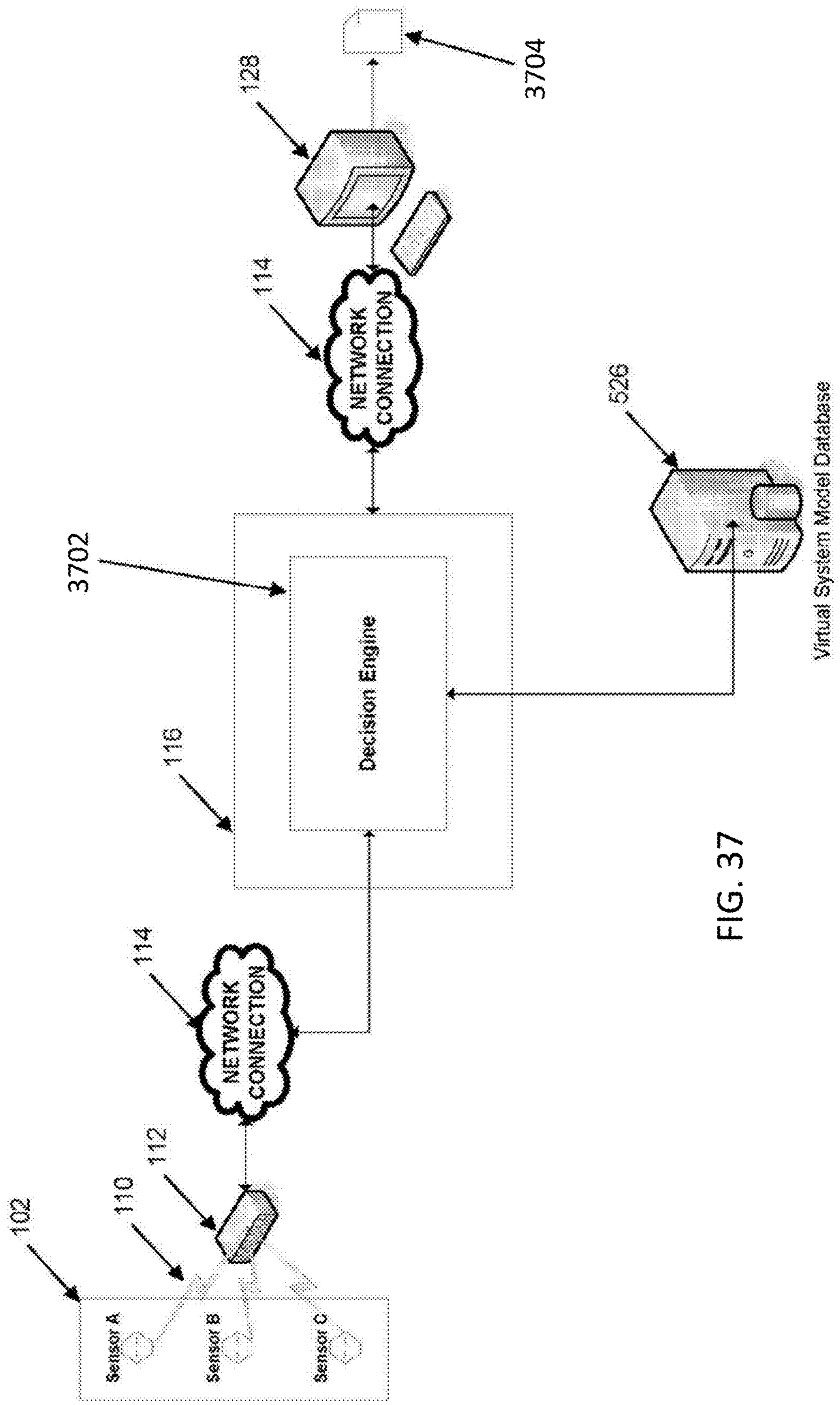
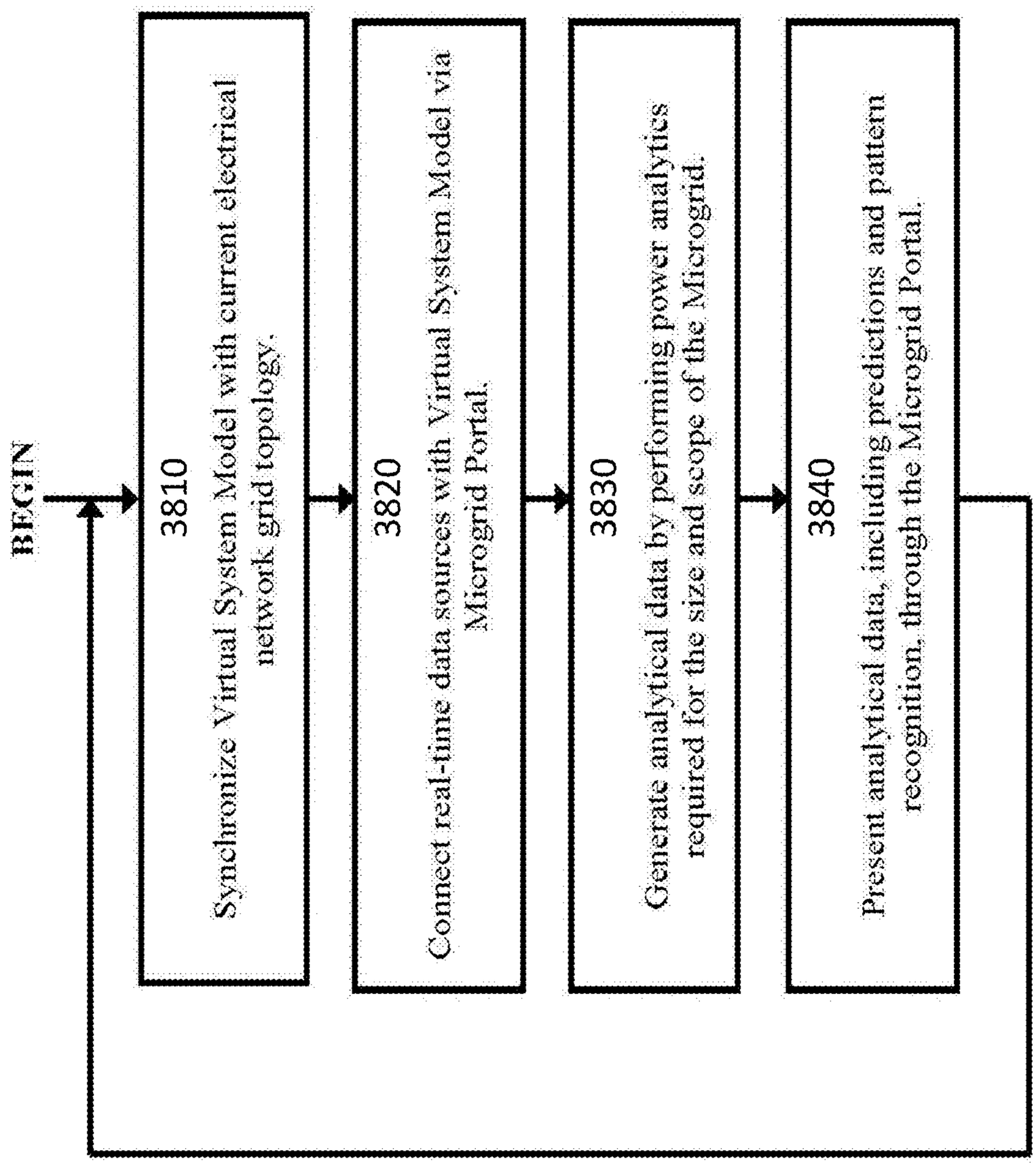

102
Sensor A
Sensor B
Sensor C
110
112
114
NETWORK CONNECTION
3702
116
Decision Engine
114
NETWORK CONNECTION
128
3704
526
Virtual System Model Database

FIG. 37

FIG. 38


BEGIN
3810
Synchronize Virtual System Model with current electrical network grid topology.
3820
Connect real-time data sources with Virtual System Model via Microgrid Portal.
3830
Generate analytical data by performing power analytics required for the size and scope of the Microgrid.
3840
Present analytical data, including predictions and pattern recognition, through the Microgrid Portal.

SYSTEMS AND METHODS FOR REAL-TIME DC MICROGRID POWER ANALYTICS FOR MISSION-CRITICAL POWER SYSTEMS

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application is related to and claims priority from the following U.S. patent applications. This application is a Continuation-In-Part of U.S. patent application Ser. No. 14/597,499 filed Jan. 15, 2015, which is a continuation of U.S. patent application Ser. No. 13/358,376 filed Jan. 25, 2012, and claims priority to U.S. Provisional Patent App. No. 61/436,073, filed on Jan. 25, 2011. This application is also a Continuation-In-Part of U.S. patent application Ser. No. 15/068,105 filed Mar. 11, 2016, which is a continuation of U.S. application Ser. No. 14/810,451 filed Jul. 27, 2015, which is a continuation of U.S. application Ser. No. 12/237,948 filed Sep. 25, 2008, which claims priority under 35 U.S.C. §119(e) of U.S. Provisional Application No. 60/975,063 filed Sep. 25, 2007. U.S. patent application Ser. No. 12/237,948 is also a Continuation-In-Part of U.S. patent application Ser. No. 12/236,030 filed Sep. 23, 2008, which claims priority under the benefit under 35 U.S.C. §119(e) of U.S. Provisional Application No. 60/974,649 filed Sep. 24, 2007. U.S. patent application Ser. No. 12/236,030 is also a Continuation-In-Part of U.S. application Ser. No. 12/121,552 filed May 15, 2008, which claims priority under the benefit under 35 U.S.C. §119(e) of U.S. Provisional Application No. 60/938,324 filed May 16, 2007. U.S. patent application Ser. No. 12/121,552 is also a Continuation-In-Part of U.S. application Ser. No. 11/777,121 filed Jul. 12, 2007, which claims priority under the benefit under 35 U.S.C. §119(e) of U.S. Provisional Application No. 60/807,795 filed Jul. 19, 2006. U.S. application Ser. No. 11/777,121 is also a Continuation-In-Part of U.S. application Ser. No. 11/734,709 filed Apr. 12, 2007, which claims priority under the benefit under 35 U.S.C. §119(e) of U.S. Provisional Application No. 60/792,175 filed Apr. 12, 2006. U.S. application Ser. No. 11/734,709 is also a Continuation-In-Part of U.S. application Ser. No. 11/717,378 filed Mar. 12, 2007, which claims priority under the benefit under 35 U.S.C. §119(e) of U.S. Provisional Application No. 60/782,329 filed Mar. 10, 2006 and U.S. Provisional Application No. 60/806,215 filed Jun. 29, 2006. U.S. application Ser. No. 11/717,378 is also a Continuation-In-Part of U.S. application Ser. No. 11/674,994 filed Feb. 14, 2007, which claims priority under the benefit under 35 U.S.C. §119(e) of U.S. Provisional Application No. 60/773,560 filed Feb. 14, 2006. The disclosures of the above identified applications are incorporated herein by reference as if set forth in full.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates generally to computer modeling and management of systems and, more particularly, to power analytics techniques using a real-time system model of a direct current (DC) microgrid for mission-critical power systems.

[0004] 2. Background of the Invention

[0005] 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.

[0006] 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 to DC microgrids, e.g., for real-time operational monitoring and management of the microgrid. 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.

[0007] 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.

[0008] 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.

[0009] 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.

[0010] Moreover, the ability to predict, and understand the health and stability of an electrical network (the capability of a power system to maintain stability and/or recover from events and disturbances without violating system opera-

tional constraints) in both static and in real-time, is important in order to insure that the power distribution system can meet the power demands and maintain sufficient active and reactive power reserves to hand the ongoing changes in demand and disturbances to the system due to various contingencies. Traditional transient stability programs are capable of accurately computing the trajectories of power system quantities, such as voltages, frequencies, power flow, etc., following disturbances. However, programs leave the understanding of these trajectories, i.e., severity of these disturbances, and their relevance to the power system security Largely to an engineer's judgment.

[0011] Conventional approaches to modeling complex network topologies, their interconnectivity, interdependencies and relationships are limited to the application of diagrammatic sketches, computer aided design (CAD), or other forms of design technologies that require extensive training and know-how by the user in order to design realistic and error free networks, such as electrical one-line diagrams for power system simulation. As such, there is a need for novel methods that provide intuitive modeling paradigms that reduce the need for end user training or know-how for properly modeling, connecting and defining electrical power transmission, or distribution networks.

[0012] Also for example, current technology often overburdens users with thousands of pieces of information per second from sensory data points that are distributed throughout the monitored electrical power system facility. Therefore, it is nearly impossible for facility operators, managers and technicians to digest and understand all the sensory data to formulate an accurate understanding of their relevance to the overall status and health of their mission critical power system operations.

[0013] DC has significant advantages over alternating current (AC) in generation, distribution, and storage. These advantages are of particular importance in a complex Smart Grid, and in particular, for a microgrid. However, existing technology is primarily focused on the more traditional AC in the context of microgrids. Mixed technologies (i.e., both AC and DC) are not currently well understood. Current standards create islands of data which do not have the ability to incorporate advanced and/or new power system modeling and analytics methods. This hinders the overall acceptance and adoption of microgrid systems, especially those comprising DC or mixed technologies.

[0014] Currently, no solution exists for performing real-time power analytics on a DC microgrid for mission-critical power systems.

SUMMARY OF THE INVENTION

[0015] Systems and methods for modeling a topology of an electrical power system are disclosed.

[0016] In one aspect, the system for modeling a topology of an electrical power system can include a processor, a memory, a display device, and an input device. The memory device can be coupled to the processor and configured to maintain a component database, a component control engine, and a power system topology modeling engine. The display device can be coupled to the processor and configured for displaying the topology of the electrical power system. The input device can be coupled to the processor and can be operative to select one of the plurality of power system components stored in the component database as a selected component, position the selected component within a framework, and interface the selected component with other selected components within the framework. The processor can be operative to execute instructions within the component control engine to control the position of the selected components within the framework and execute instructions within the power system topology modeling engine to render the topology of the electrical system after the selected components have been positioned.

[0017] In another aspect, a computer implemented method for modeling a topology of an electrical power system can include selecting a one of the plurality of power system components, positioning the selected one of the plurality of power system components relative to an existing power system component in a framework, interfacing the selected one of the plurality of power system components with the existing power system component in the framework, and rendering the interfaced power system components as the electrical power system topology.

[0018] Accordingly, a system for performing power analytics on a microgrid is disclosed. In an embodiment, the system comprises: a modeling engine that generates predicted data for a microgrid utilizing a virtual system model of the microgrid, the virtual system model comprising a virtual representation of a topology of the microgrid; an analytics engine that monitors real-time data and the predicted data, initiates a calibration and synchronization operation to update the virtual system model in real-time when a difference between the real-time data and the predicted data exceeds a threshold, and generates analytical data by performing power analytics on the virtual system model; and a portal that receives the real-time data from at least one external data source and provides the generated analytical data to a recipient.

[0019] In addition, a method for performing power analytics on a microgrid is disclosed. In an embodiment, the method comprises: generating predicted data for a microgrid utilizing a virtual system model of the microgrid, the virtual system model comprising a virtual representation of a topology of the microgrid; receiving real-time data from at least one external data source; initiating a calibration and synchronization operation to update the virtual system model in real-time when a difference between the real-time data and the predicted data exceeds a threshold; generating analytical data by performing power analytics on the virtual system model; and providing the generated analytical data to a recipient.

[0020] These and other features, aspects, and embodiments of the invention are described below in the section entitled "Detailed Description."

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] 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:

[0022] FIG. **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.

[0023] FIG. **2** is a diagram illustrating a detailed view of an analytics server included in the system of FIG. **1**.

[0024] FIG. **3** is a diagram illustrating how the system of FIG. **1** operates to synchronize the operating parameters between a physical facility and a virtual system model of the facility.

[0025] FIG. **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.

[0026] FIG. **5** is a block diagram that shows the configuration details of the system illustrated in FIG. **1**, in accordance with one embodiment.

[0027] FIG. **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.

[0028] FIG. **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.

[0029] FIG. **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.

[0030] FIG. **9** is a flow chart illustrating an example method for updating the virtual model, in accordance with one embodiment.

[0031] FIG. **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.

[0032] FIG. **11** is a flowchart illustrating an example process for determining the protective capabilities of the protective devices being monitored, in accordance with one embodiment.

[0033] FIG. **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.

[0034] FIG. **13** is a flowchart illustrating an example process for determining the protective capabilities of the protective devices being monitored, in accordance with another embodiment.

[0035] FIG. **14** is a diagram illustrating a process for evaluating the withstand capabilities of a MVCB, in accordance with one embodiment.

[0036] FIG. **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.

[0037] FIG. **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.

[0038] FIG. **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.

[0039] FIG. **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.

[0040] FIG. **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.

[0041] FIG. **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.

[0042] FIG. **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.

[0043] FIG. **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.

[0044] FIG. **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.

[0045] FIG. **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.

[0046] FIG. **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.

[0047] FIG. **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.

[0048] FIG. **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.

[0049] FIG. **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.

[0050] FIG. **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.

[0051] FIG. **30** is a diagram illustrating how the Energy Management System Engine works in conjunction with the other elements of the analytics system to provide indexing of the stability and reliability of an electrical power system, in accordance with one embodiment.

[0052] FIG. **31** is an example process for real-time stability indexing of an electrical system, in accordance with one embodiment.

[0053] FIG. **32** is a diagram illustrating a system (computing environment) for implementing a method for modeling a topology of an electrical power system, in accordance with one embodiment.

[0054] FIG. **33** is a depiction of node and branch type network component pieces, in accordance with one embodiment.

[0055] FIG. **34** is a depiction of how the customized features on the network component pieces are graphically represented, in accordance with one embodiment.

[0056] FIG. **35** is an example process for modeling a topology of an electrical power system, in accordance with one embodiment.

[0057] FIG. **36** is an example process for alarm filtering and management of real-time sensory data from a monitored electrical system, in accordance with one embodiment.

[0058] FIG. **37** is a diagram illustrating how the Decision Engine works in conjunction with the other elements of the analytics system to intelligently filter and manage real-time sensory data, in accordance with one embodiment.

[0059] FIG. **38** is a high-level flow chart illustrating an example process for performing power analytics using a real-time system model of a microgrid.

DETAILED DESCRIPTION

[0060] Systems and methods for filtering and interpreting real-time sensory data from 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.

[0061] 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, etc.).

[0062] 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.).

[0063] FIG. **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.

[0064] 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.

[0065] Continuing with FIG. **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**.

[0066] 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.

[0067] Still with FIG. **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**.

[0068] 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 (CATS), 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**.

[0069] 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.

[0070] As shown in FIG. **1**, 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**.

[0071] FIG. **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 configured to provide real-time data to server **116** as well as alarming, sensing and control featured for facility **102**.

[0072] 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**. 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.

[0073] 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.

[0074] 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.

[0075] 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.

[0076] 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.

[0077] 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.

[0078] 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.

[0079] 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.

[0080] 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**.

[0081] Referring back to FIG. **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.

[0082] 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**.

[0083] 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**.

[0084] Continuing with FIG. **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

[0085] 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.

[0086] 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.

[0087] 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.

[0088] 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.

[0089] 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.

[0090] 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 FIG. **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**.

[0091] FIG. **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**.

[0092] 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**.

[0093] 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.

[0094] 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**.

[0095] 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 CATS, 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.

[0096] 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.

[0097] FIG. **5** is a block diagram that shows the configuration details of analytics server **116** illustrated in FIG. **1** in more detail. It should be understood that the configuration details in FIG. **5** are merely one embodiment of the items described for FIG. **1**, and it should be understood that alternate configurations and arrangements of components could also provide the functionality described herein.

[0098] The analytics server **116** includes a variety of components. In the FIG. **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.

[0099] 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**.

[0100] Continuing with FIG. **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.

[0101] 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.

[0102] 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.

[0103] 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**.

[0104] For example, a user can access information from server **116** using thin client **534**. For example, reports can be generated 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 from anywhere and anytime.

[0105] Continuing with FIG. **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.

[0106] FIG. **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.

[0107] 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.

[0108] 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.

[0109] 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.

[0110] FIG. **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.

[0111] 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.

[0112] 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.

[0113] 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.

[0114] FIG. **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.

[0115] 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.

[0116] 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.

[0117] 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.

[0118] 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.

[0119] 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.

[0120] At a high level, this process can be illustrated with the aid of FIG. **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.

[0121] 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**.

[0122] 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.

[0123] 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.

[0124] 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.

[0125] FIGS. **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. FIG. **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.

[0126] 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**.

[0127] 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**.

[0128] 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.

[0129] 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**.

[0130] FIG. **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 FIG. **11** is not dependent on a particular standard being used.

[0131] 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 FIGS. **10-12**.

[0132] 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.

[0133] 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 FIG. **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.

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

[0134] 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:

[0135] PCB, ICCB=6.59

[0136] MCCB, ICCB rated <=10,000 A=1.73

[0137] MCCB, ICCB rated 10,001-20,000 A=3.18

[0138] MCCB, ICCB rated >20,000 A=4.9

[0139] 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 (Iadjsym).

Eq 12:

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

[0140] If the calculated X/R is not greater than the fuse test X/R then I_{adisym} can be set equal to Tarn 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

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

[0141] If it is determined in step **1114** that the device rating is not greater than or equal to Iadjsym, then it can be determined that the device as failed in step **1116**. The percent rating can still be calculating in step **1120**.

[0142] 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_{adisym} can be set equal to Ism in step **1140**. In step **1146**, it can be determined if the device rating is greater or equal to Iadjsym, or to I_{peak} as appropriate, for the LVCB.

[0143] 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 Iadjsym 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**.

[0144] 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 Iadjsym can be determined using equation 12. If the LVCB is peak rated, then I_{peak} can be determined using equation 11.

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

[0145] It can then be determined if the device rating is greater than or equal to I_{adisym} 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

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

[0146] 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 I_{sym} in step **1136**. If the calculated fault at X/R is greater than the circuit breaker test X/R, then $I_{adjsymdelay}$ can be calculated in step **1138** using the following equation with, e.g., a 0.5 second maximum delay:

Eq 14:

$$I_{ADJSYM\ DELAY} = I_{SYM\ DELAY}\left\{\frac{\sqrt{1 + 2e^{-60\ pl(CALC\ X/R)}}}{\sqrt{1 + 2e^{-60\ pl(TEST\ X/R)}}}\right\}$$

[0147] 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**.

[0148] 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 Iadjsym can be calculated in step **1154** using the following equation:

Eq 13:

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

[0149] If the calculated fault X/R is not greater than the circuit breaker test X/R, then Iadjsym can be set equal to Lyn, in step **1156**. It can then be determined if the device rating is greater than or equal to Iadjsym 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**.

[0150] FIG. **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:

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

[0151] 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;

[0152] 50 Hz Test X/R=13.7

[0153] 60 Hz Test X/R=16.7

[0154] (DC Time contant=0.45 ms)

[0155] If the fault X/R is not greater than the circuit breaker test X/R then $I_{adjintsym}$ can be set equal to Lyn, 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**.

Eq 15:

$$I_{\substack{ADJINT\\SYM}} = I_{\substack{INT\\SYM}}\left\{\frac{\sqrt{1+2e^{-4\ pf*tl(CALC\ \ X/R)}}}{\sqrt{1+2e^{-4\ pf*tl(TEST\ \ X/R)}}}\right\}$$

[0156] 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:

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

[0157] FIG. **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 60 hz, the protective device X/R can be modified as follows:

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

[0158] 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 Iadjsym. In step **1306**, it can be determined if the device rating is greater than or equal to $I_{adjasym}$ or Iadjsym. 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:

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

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

[0159] 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:

[0160] PCB, ICCB=6.59

[0161] MCCB, ICCB rated <=10,000 A=1.73

[0162] MCCB, ICCB rated 10,001-20,000 A=3.18

[0163] MCCB, ICCB rated >20,000 A=4.9

[0164] 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**.

[0165] 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:

[0166] MCCB/ICCB/PCB with Instantaneous:

$$I_{int,adj}=\text{LVF}*I_{sym,rms}$$

[0167] PCB without Instantaneous:

$$I_{int,adj}=\text{LVF}p*I_{sym,rms}(\tfrac{1}{2}\ \text{Cyc})$$

$$I_{int,adj}=\text{LVF}_{asym}*I_{sym,rms}(3\text{-}8\ \text{Cyc})$$

[0168] 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:

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

[0169] FIG. **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 ($I_{intnnssym}$), 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.

[0170] If all the contributions are remote, then in step **1332** the remote MF (MFr) can be calculated and Tint can be calculated using the following:

$$I_{int}=\text{MF}r*I_{intrmssym}$$

[0171] If all the inputs are local, then MF**1** can be calculated and I_{int} can be calculated using the following:

$$I_{int}=\text{MF}l*I_{intrmssym}$$

[0172] 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. lint can then be calculated using the following:

$$I_{int}=\text{AMF}l*I_{intrmssym}/S.$$

[0173] 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:

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

[0174] 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:

$$I_{mompeak}=\mathrm{MF}p*I_{symrms}.$$

[0175] 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:

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

[0176] 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:

$$I_{momsym}=\mathrm{MF}m*I_{symrms}.$$

[0177] 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:

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

[0178] 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.

[0179] 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.

[0180] FIG. **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.

[0181] 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.

[0182] 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.

[0183] 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.

[0184] 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.

[0185] 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.

[0186] 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.

[0187] Various load models can be used in the process of FIG. **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).

[0188] 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 FIG. **15** and indices can be associated with these factors. For example, FIG. **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**.

[0189] 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.

[0190] 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.

[0191] 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.

[0192] 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.

[0193] 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 described 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.

[0194] FIG. **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**.

[0195] 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.

[0196] In step **1718**, the 100% arcing current can be calculated and for systems operating at less than 1 kV 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.

[0197] In other embodiments, using the same or a similar procedure as illustrated in FIG. **17**, the following evaluations can be made in real-time and based on an accurate, e.g., aged, model of the system:

[0198] Arc Flash Exposure based on IEEE 1584;

[0199] Arc Flash Exposure based on NFPA 70E;

[0200] Network-Based Arc Flash Exposure on AC Systems/Single Branch Case;

[0201] Network-Based Arc Flash Exposure on AC Systems/Multiple Branch Cases;

[0202] Network Arc Flash Exposure on DC Networks;

[0203] Exposure Simulation at Switchgear Box, MCC Box, Open Area and Cable Grounded and Ungrounded;

[0204] Calculate and Select Controlling Branch(s) for Simulation of Arc Flash;

[0205] Test Selected Clothing;

[0206] Calculate Clothing Required;

[0207] Calculate Safe Zone with Regard to User Defined Clothing Category;

[0208] Simulated Art Heat Exposure at User Selected locations;

[0209] User Defined Fault Cycle for 3-Phase and Controlling Branches;

[0210] User Defined Distance for Subject;

[0211] 100% and 85% Arcing Current;

[0212] 100% and 85% Protective Device Time;

[0213] Protective Device Setting Impact on Arc Exposure Energy;

[0214] User Defined Label Sizes;

[0215] Attach Labels to One-Line Diagram for User Review;

[0216] Plot Energy for Each Bus;

[0217] Write Results into Excel;

[0218] View and Print Graphic Label for User Selected Bus(s); and

[0219] Work permit.

[0220] 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.

[0221] FIG. **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.

[0222] 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 described 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.

[0223] 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:

[0224] 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.

[0225] 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).

[0226] 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.

[0227] For AVR and Excitation Systems: There are a number of models ranging from 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.

[0228] 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.

[0229] 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.

[0230] 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.

[0231] 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.)

[0232] 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 require 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.

[0233] 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.

[0234] Some examples of contingency events include but are not limited to:

[0235] Application/removal of three-phase fault.

[0236] Application/removal of phase-to-ground fault

[0237] Application/removal of phase-phase-ground fault.

[0238] Application/removal of phase-phase fault.

[0239] Branch Addition.

[0240] Branch Tripping

[0241] Starting Induction Motor.

[0242] Stopping Induction Motor

[0243] Shunt Tripping.

[0244] Shunt Addition (Capacitor and/or Induction)

[0245] Generator Tripping.

[0246] SVC Tripping.

[0247] Impact Loading (Load Changing Mechanical Torque on Induction Machine.

[0248] With this option it is actually possible to turn an induction motor to an induction generator)

[0249] Loss of Utility Power Supply/Generators/UPS/Distribution Lines/System Infrastructure Load Shedding

[0250] 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.

[0251] 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.

[0252] 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.

[0253] The results of real-time simulations performed in accordance with FIG. **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**.

[0254] The process of FIG. **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 shed-

ding 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.

[0255] FIG. **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.

[0256] 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.

[0257] 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

[0258] 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.

[0259] 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.

[0260] 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.

[0261] 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.

[0262] 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.

[0263] 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.

[0264] The results of real-time simulations performed in accordance with FIG. **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**.

[0265] 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.

[0266] Thus, the process of FIG. **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.

[0267] FIG. **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.

[0268] 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.

[0269] 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.

[0270] 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.

[0271] 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 described 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.

[0272] 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.

[0273] 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.

[0274] Continuing with FIG. **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:

[0275] Wave-shape Distortions/Oscillations data

[0276] Parallel and Series Resonant Condition data

[0277] 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.

[0278] 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.

[0279] 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.)

[0280] 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.

[0281] The results of real-time simulations performed in accordance with FIG. **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**.

[0282] Thus, the process of FIG. **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).

[0283] FIG. **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.

[0284] 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.

[0285] 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**.

[0286] 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.

[0287] Continuing with FIG. **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**.

[0288] 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.

[0289] 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.

[0290] 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.

[0291] 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.

[0292] 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.

[0293] FIG. **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.

[0294] FIG. **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.

[0295] 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.

[0296] Some examples of contingency events include but are not limited to:

- **[0297]** Application/removal of three-phase fault
- **[0298]** Application/removal of phase-to-ground fault
- **[0299]** Application/removal of phase-phase-ground fault
- **[0300]** Application/removal of phase-phase fault
- **[0301]** Branch Addition Branch Tripping
- **[0302]** Starting Induction Motor
- **[0303]** Stopping Induction Motor Shunt Tripping
- **[0304]** Shunt Addition (Capacitor and/or induction) Generator Tripping
- **[0305]** SVC Tripping
- **[0306]** 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)
- **[0307]** Loss of Utility Power Supply/Generators/UPS/Distribution Lines/System
- **[0308]** Infrastructure
- **[0309]** Load Shedding

[0310] 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.

[0311] Continuing with FIG. **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.

[0312] 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.

[0313] 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:

- **[0314]** Power System Health and Performance
  - **[0315]** 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

[0316] Incorporation of performance and behavioral specifications for all the equipment and components that comprise the electrical system into a real-time management environment

[0317] System Reliability and Availability

[0318] As a function of different system, process and load point reliability indices

[0319] Implementation of different technological solutions to achieve reliability centered maintenance targets and goals

[0320] Power System Capacity levels

[0321] As-designed total power capacity of the power system.

[0322] How much of the total power capacity remains or is available (ability of the electrical system to maintain availability of its total power capacity)

[0323] Present utilized power capacity.

[0324] Power System Strength and Resilience

[0325] Dynamic stability predictions across all contingency events

[0326] Determination of protection system stress and withstand status

[0327] Determination of system security and stability

[0328] 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.

[0329] Continuing with FIG. **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**.

[0330] 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 FIG. **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 FIG. **25**.

[0331] 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 a 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.

[0332] FIG. **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.

[0333] 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**.

[0334] Continuing with FIG. **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**.

[0335] FIG. **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.

[0336] Given the complexity of modem 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.

[0337] 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.

[0338] 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. They may also relate to the virtual model database and model based predictions. For example, the predictions can be indicative of the real-time Carbon Footprint, Power Usage Effectiveness, and infrastructure power efficiency, or 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.

[0339] 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**.

[0340] Continuing with FIG. **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 sche-

matic 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.

[0341] FIG. **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.

[0342] 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.).

[0343] 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.

[0344] 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.

[0345] 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.

[0346] 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 digraph layout format. It should be appreciated that the self-executing algorithm can follow any format as long as each of the one or 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.

[0347] 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.

[0348] In step **2710**, communicatively linking each of the one or more graphical objects m the schematic user interface layout to channels, database tags, or sensors configured to monitor the operational status of one or more pieces of electrical equipment represented by the one or more graphical objects including virtual system model status, analysis and simulation results. This can be accomplished by intelligently **1** inking 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."

[0349] 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 virtual model or 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 ani-

mated in response to the monitored real-time data of and/or predicted values for the electrical system during operation.

[0350] FIG. **28** is a diagram illustrating how the Energy Management System Engine works in conjunction with the other elements of the analytics system to provide indexing of the stability and reliability of an electrical power 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.

[0351] 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.

[0352] 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 regard ing 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.

[0353] 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.

[0354] 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.

[0355] 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**.

[0356] 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.

[0357] 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**.

[0358] Continuing with FIG. **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.

[0359] FIG. **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**.

[0360] In one embodiment, the connection is a "hardwire" physical connection. For example, the power analytics server **116** can be communicatively connected (via Category 5 (CATS), 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 802.11big 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.

[0361] Still with FIG. **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 FIG. **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.

[0362] 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).

[0363] 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.).

[0364] Continuing with FIG. **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).

[0365] 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:

[0366] Active Power (kW)

[0367] Reactive Power (kVAR)

[0368] Power Factor (%)

[0369] Humidity (%)

[0370] Temperature (° F.)

[0371] Total Cost of Energy ($)

[0372] Total Penalty Cost Due to Poor Power Factor ($)

[0373] Frequency (Hz)

[0374] Voltage (p.u.)

[0375] Cost of Losses ($)

[0376] 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 S (CATS), fiber optic or equivalent cabling) to a data server (not shown) that is communicatively connected (via CATS, fiber optic or equivalent cabling) through the Internet and to the analytics server **116**. The analytics server **116** being also communicatively connected with the Internet (via CATS, 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**.

[0377] 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.

[0378] FIG. **30** is a diagram illustrating how the Transient Stability Modeling Engine works in conjunction with the other elements of the analytics system to intelligently predict and understand an electrical system's ability to maintain stability and/or recover from events and disturbances without violating system operational constraints, in accordance with one embodiment. Conventional transient stability modeling programs/engines, such as those offered by a majority of power system analysis software vendors, are capable of accurately computing the trajectories of power system quantities (e.g., voltages, frequencies, power flows, etc.) following disturbances, while leaving the comprehension of these trajectories (i.e., severity of these disturbances) and their relevance to power system security largely to the judgment of engineers.

[0379] That is, a conventional transient stability modeling program/engine only presents a user (i.e., electrical system owner, administrator, and/or operator) with a view of how the trajectories of the various operational power parameters of an electrical power system are impacted after a disturbance, but, fails to give any interpretive indicia of how well the overall security and stability of the power system improves after the disturbance.

[0380] The ability to predict (i.e., compute) an electrical power system security (and stability) index, in static and real-time, via a model (i.e., virtual system model) of the electrical power system that can age and synchronize itself in real-time with the electrical power system's actual operating conditions is critical in obtaining accurate predictions of the system's ability to handle disturbances to the system due to various contingencies. Without operational conditions synchronization, 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. In one embodiment, the power system security (and stability) index may be a combination of the transient stability values of multiple operational indices associated with the power system. For example, the power system security (and stability) index may be determined from a voltage stability index, a frequency stability index, and an angular (transient) stability index.

[0381] According to one embodiment, trajectories are quickly and accurately computed to provide an overall system security index by assigning an index score between 0 to 100. For example, a system security index of 100 may indicate that the power system is fully secure and stable following a disturbance or plurality of disturbances. A system security index of 0 may indicate that the power system is insecure and unstable, and unable to recover and maintain stability following a disturbance or plurality of disturbances. Thus, by combining various security indices, an overall system security index may be determined to provide a complete understanding of the relevance of different disturbances to the power system in order to provide a real-time understanding of the security and stability of the power system.

[0382] The Angular Stability Index (ASI) is computed, for example, using a heuristic method for each individual subsystem (island) of the complete power system. The ASI for the complete power system is determined to be the smallest index of each of the individual the sub-systems. Accordingly, the ASI can be no higher than the smallest index of the sub-systems.

[0383] The Frequency Stability Index (FSI) may be defined, for example, as a maximum time duration for which the frequency excursion, i.e., rise/drop, violates a predefined frequency threshold.

[0384] The Voltage Stability Index (VSI) may be defined, for example, as a maximum time duration for which a voltage excursion, i.e., rise/drop, violates a predefined voltage threshold.

[0385] The System Security Index (SSI) is an overall system security index of the complete power system and may be defined, for example, as an algorithmic calculation of the ASI, FSI, and VSI, wherein the algorithmic calculation may include a multiplication of each of the ASI, FSI, and VSI. Based upon the result of the algorithmic calculation, the security of the power system may be declared. As an example, in order for the power system to be declared secure, each of the ASI, FSI, and VSI should be greater than 0, or greater than a predetermined acceptable threshold value.

[0386] Once the power system undergoes a disturbance or a plurality of disturbances, the security of the power system may be quickly and accurately assessed based upon the SSI. Moreover, the SSI also provide s a real-time indication as to the ability of the power system to recover from the disturbance or plurality of disturbances.

[0387] System input data provided by various power system components allows for the determination of the SSI. For example, the system input data includes information regarding interconnections, interdependencies and dynamic behavior of the power system in order to compute trajectories, indexes, and the SSI. As an example, system static component (non-rotating equipment) input data and rotating equipment input data may comprise the system input data.

[0388] System static components may include static elements, such as transformers, cables, overhead power transmission lines, and reactors. These static elements are presumed to display no operational/functional changes during the time duration in which the transient disturbance takes place. For example, the time duration for the transient disturbance may range, for example, from a few cycles up to a few seconds. The static component input data may be a basis for what is termed the "power flow solution."

[0389] Rotating equipment data may encompass data received from synchronous machines including their associated controls, i.e., exciters, governors, etc., induction machines, and static var compensators. As an example, the synchronous machines may include generators and/or motors. In addition, thermal (round rotor) and hydraulic (salient pole) units may both be simulated either by using a simple model or by a complete two-axis model including damper winding representations. Moreover, as detailed below, other rotating equipment may include:

[0390] For induction machines, which may include motors and/or generators, a complete two-axis model may be used. In addition, it may be possible to model the induction machines by providing test curves (current, power factor, and torque as a function of speed), wherein no electrical dynamics modeling is necessary for the torque as a function of speed curve;

[0391] For doubly-fed induction generators that may include the use of wind power generators, voltage and frequency behaviors of the power system networks are likely to be significantly affected;

[0392] For motor operated valves (MOVs), which are commonly used in nuclear power plant auxiliaries' operation, as well as other industrial installations, two modes of operation may be provided. For opening and closing operating modes, wherein each mode includes: (a) start; (b) full speed; (c) unseating; (d) travel; and (e) stall, a user-defined model type for each mode may be provided. For example, the "start" stage may be modeled as a constant current, while the "full speed" stage may be modeled by constant power. The modeling for the opening mode may be the same as modeling for the closing mode;

[0393] For Automatic Voltage Regulator (AVR) and excitation systems, there may be a number of models ranging from rotating, i.e., DC and AC, and analogue to static and digital controls. In addition, a system may offer user-defined modeling capability that can be used to define a new excitation model;

[0394] For governors and turbines, a system may be designed to address current and future technologies including, but not limited to, hydraulic, diesel, gasoline, and combined cycle with mechanical and/or digital governors;

[0395] For relays, a system may be designed to address current and future technologies including under frequency, under voltage, over current, and impedance types;

[0396] For Static Var Compensators (SVCs), a system may be designed to address current and future technologies including a number of solid-state (thyristor) controlled SVCs or even the saturable reactor type SVCs;

[0397] For Fault Isolation Units (FIUs), also known as Current Limiting Devices (CLDs), a system may be designed to address current and future technologies, wherein a device is installed between a power source and loads to limit the magnitude of fault currents that may occur within loads connected to power distribution networks; and

[0398] For Status Automatic Bus Transfers (SABTs), a system may be designed to address current and future technologies of SABTs, which is a solid-state three-phase, dual position, three-pole switch, consisting of six pairs of silicon controlled rectifiers (SCRs) connected in an AC switch configuration.

[0399] Various events (disturbances) may be supported, either individually or simultaneously, or sequenced in time, including application/removal of three-phase faults, application/removal of phase-to-ground faults, application/removal of phase-phase-ground faults, and application/removal of phase-phase faults. In addition, other events may include branch addition/tripping, starting/stopping induction motors, shunt tripping/addition, and generator/SVC tripping. Moreover, impact loading, which involves changing a load based upon changing mechanical torque on an induction machine, and load shedding may be considered an event. During the impact loading, it may be possible to convert an induction motor into an induction generator.

[0400] According to the one embodiment, the understanding of stability trajectories may be automated, and their relevance to overall power system stability. For example, power system security may no longer be dependent upon the sole judgment of an individual user, but now may be automated.

[0401] According to the one embodiment, a static and real-time stability assessment may be performed using a security index for static simulations that incorporates a security index into a real-time system along with machine learning technologies, such as associative memories, HTM, and on-line/real-time system snap shot capture by a real-time data acquisition platform to perform the real-time system security and strength evaluation.

[0402] According to the one embodiment, an accurately interpretation and prediction of security of an electrical power system includes actual interaction with a power facility that accounts for natural aging effects of hardware components that comprise the total power distribution system and the need for machine learning to understand,

consume, and use non-electrical sensory data in combination with electrical sensory data to identify failure mode patterns for early warnings and predictions.

[0403] In FIG. **30**, the Transient Stability Modeling Engine **3002** 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.

[0404] In addition to being communicatively connected to the data acquisition hub **112** and the client **128**, the Transient Stability Modeling Engine **3002** can also be interfaced with the components of the power analytics server **116**. The components of the electrical system **102** may relate to the static components and rotating equipment, as detailed above. For example, the stability indices data from the components can be indicative of the real-time ability of the electrical system **102** to sustain power demand and maintain sufficient active and reactive power reserve to cope with ongoing changes in demand and system disturbances due to contingencies, operate safely with minimum operating costs while maintaining an adequate level of reliability, and provide an acceptably high level of power quality (maintaining voltage and frequency within tolerable limits) when operating under contingency conditions.

[0405] The Transient Stability Modeling Engine **3002** 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 system security index values of the electrical system **102** to a user (i.e., electrical system **102** owner/system administrator/operator). In one embodiment, the system security index values can be the real-time operational performance of the individual components 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**.

[0406] For example, the Transient Stability Modeling Engine **3002** 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.

[0407] In another example, the Transient Stability Modeling Engine **3002** can be configured to generate a text-based or a graphics-based user interface that conveys real-time operational performance of the electrical system **102** that can include real-time system security index values 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), security and stability (i.e., the predicted ability of the electrical system **102** to withstand a contingency event that results in stress to the electrical system **102**), and availability (e.g., the predicted ability of the electrical system **102** to maintain availability of total power capacity). 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.

[0408] The data acquisition hub **112** can be communicatively connected via data connections **110** to a plurality of sensors that can be embedded with the individual system components 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**.

[0409] Continuing with FIG. **30**, 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.), Transient Stability Modeling Engine **3002** (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 stability data from the various monitored components of the electrical system **102** and the real-time predictions (forecasts) about the health, performance, reliability, security, 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.

[0410] FIG. **31** is an example process for real-time stability indexing of an electrical system, in accordance with one embodiment. In one embodiment, the operational steps that comprise the process are implemented through a transient stability modeling 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 transient stability modeling engine that runs on a separate (network application) server that is communicatively connected to the power analytics server. Just 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.

[0411] The method begins with operation **3102** where real-time data output from components of the electrical system is acquired using a data acquisition component communicatively connected to sensors interfaced with the electrical system in the manner described above with respect to FIGS. **1** and **4**.

[0412] Next, the method moves on to operation **3104** where the virtual system model of the electrical system under management is updated in response to the real-time data output acquired. This may include, but is not limited to, modifying the simulated data output from the first virtual system model, adjusting the logic/processing parameters utilized by the virtual system modeling engine to simulate the operation of the electrical system, adding/subtracting functional elements of the first virtual system model, etc. It should be understood, that any operational parameter of the virtual system modeling engine and/or the first 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.

[0413] In step **3106**, real-time system security index values for the electrical system can be calculated based upon stability indices data generated from the updated virtual system model. In one embodiment, the system security values can be a product of the stability indices data input from at least one of an angular stability index, a frequency index, and a voltage stability index. For example, the system security values can range from 0, which can be indicative of an insecure and unstable electrical system, to 100, which can be indicative of a fully secure and stable electrical system. In addition, the generation of the real-time system security index values can occur after detection of a disturbance event or events, as detailed above, within the electrical system, thereby effectively communicating a real-time indication as to the stability of the electrical system immediately after the disturbance event or events.

[0414] In step **3108**, the system security index values can be displayed using a client terminal communicatively connected to the power analytics server.

[0415] The conventional approach to modeling complex network topologies, their interconnectivity, interdependencies and relationships have been approached through the application of diagrammatic sketches, computer aided design (CAD), or other forms of design technologies that require extensive training and know-how by the user in order to design realistic and error free networks, such as electrical one-line diagrams for power system simulation. As such, novel methods that provide intuitive modeling paradigms that reduce the need for end user training or know-how for properly modeling, connecting and defining electrical power transmission, or distribution networks offer distinct advantages over the conventional approaches.

[0416] One such method can involve the representation of network components (e.g., power sources, power consumers, bus bars, capacitor buses, generators, transformers, cables breakers, switches, etc.) as virtual "jigsaw puzzle" pieces, on a computer, that a user can readily manipulate and join to form a myriad of different power system network topology combinations.

[0417] FIG. **32** is a diagram illustrating a system (computing environment) for implementing a method for modeling a topology of an electrical power system, in accordance with one embodiment. The method can be described in the general context of an application program that runs on an operating system **3228** in conjunction with a computer **3202**. The application program can include code, applets, engines, routines, components, modules, objects, data structure, etc., that can perform particular processing tasks or implement particular abstract data types. As shown herein, the application can be comprised of various functional elements such as a component control engine **3230**, a power system topology modeling engine **3232**, and a component configuration engine **3236**. It should be understood, however, that the application may include more or less engines, components, and/or modules than what is depicted herein FIG. **32**. For example, in certain embodiments, the functionalities of the component control engine **3230**, the power topology modeling engine **3232**, and/or the component configuration engine **3236** can be combined into a single engine element. That is, there is no requirement for the application to be partitioned out into more than one engine element, as long as a single engine element possesses the functional capabilities of the component control engine **3230**, the power system topology modeling engine **3232**, and the component configuration engine **3236**.

[0418] In one embodiment, the computer **3202** is a standalone personal computer. That is, the application is wholly stored and executed by the computer **3202**. In another embodiment, the computer **3202** is a thin-client computing device that is communicatively connected to a thin-client server (i.e., application server) via a network connection **114**. That is, the application can be wholly or partially stored and executed by the thin-client server.

[0419] As shown in FIG. **32**, the system can include a computer **3202**, a display device **3214**, a keyboard **3216**, a

pointing device **3218** (i.e., mouse), and a network connection **114** to a power analytics server **3268**. The computer **3202** can include various hardware components (e.g., processor **3204**, video adapter **3206**, system memory **3220**, network interface **3210**, serial port interface **3212**, etc.) that are communicatively linked together by a system bus **3208**. The system memory **3220** can include read only memory (ROM) **3222** and random access memory (RAM) **3226**. A basic input/output system (BIOS) **3224** is stored in ROM **3222**. The BIOS **3224** can contain basic routines that help to transfer information between elements/subsystems within the computer **3202** during certain computer **3202** operations. A number of program modules, components and/or engines can be temporarily stored in the RAM **3226**, such as an operating system **3228**, a component control engine **3230**, a power system topology modeling engine **3232**, a component configuration engine **3236** and a component database **3234**. In one embodiment, permanent storage for the program modules, components, and/or engines described above can be provided by one or more types of storage media interfaced to the computer **3202** including, but not limited to, a hard disk drive, an optical disk drive, magnetic disk drive, flash memory cards, etc. In another embodiment, permanent storage for the program modules, components, and/or engines can be provided by one or more distributed computing devices (e.g., application servers, database servers, etc.) that are communicatively connected to the computer **3202** via a network connection **114**.

[0420] The operating system **3228**, in conjunction with the system BIOS **3224** and associated device drivers, provides the basic interface between the computer's hardware and software resources, the user, and program modules/components/engines. A user may enter commands and information into the computer **3202** through a keyboard **3216** and/or an input pointing device (i.e., mouse) **3218**. These and other input devices are connected to the processor **3204** via serial port interface **3212** and a system bus **3208**. A monitor **3214** or other type of display device can be connected to the system bus **3208** via a video adapter **3206**.

[0421] As discussed above, the computer **3202** can operate in a networked environment using network connections **114** to one or more remote computing devices. The remote computing devices can be a server (e.g., power analytics server **3238**, application server, database server, etc.), a router, a device, or other common network node. Typically, the remote computer devices can include many of the elements described above with respect to computer **3202**. In one embodiment, the remote computing devices serve as an external memory storage location for the component control engine **3230**, power system topology modeling engine **3232**, the component configuration engine **3236**, and/or the component database **3236**.

[0422] The system shown in FIG. **32** can provide a computing environment for implementing the application program for modeling a topology of an electrical power system. As discussed above, the application program can facilitate the representation of network components as virtual "jigsaw puzzle" pieces that that a user can readily manipulate and join to create different power network topology combinations. Each of these network component pieces are stored in the component database **3234**.

[0423] As depicted in FIGS. **33** and **34**, the components used to define the network can be grouped into unique categories such as nodes and branches. Node type objects **3302** can be depicted as a "male" jigsaw puzzle piece. Examples of node type objects include, but are not limited to, power sources, power consumers, bus bars, capacitor buses, generators, etc. Branch type objects **3304** can be depicted as "female" jigsaw puzzle pieces. Examples of branch type objects include, but are not limited to, transformers, cables, breakers, switches, etc.

[0424] The network component 'jigsaw pieces" (i.e., node and branch type objects) are configured to be fully customizable by the user. That is, the component configuration engine **3236** can be configured to enable a user to modify the various attributes/features of each network component piece (stored in component database **3234**) depending on the requirements of the application. Therefore, each piece can be customized by the user to have multiple male (e.g., busbars, motor control centers, etc.) or female (e.g., 3-winding transformers, automatic transfer switches, etc.) connectors; to include equipment operating modes, characteristics, physics, cost, weight, installation related information; and to contain pictures, text, color coding or some combination thereof to aid in the power system modeling task (therefore, certain pieces can contain a combination of feature symbols that depict additional features such as a fused line with a cable or a circuit breaker with a transformer), etc. For example, in FIG. **34**, a cable piece can be depicted as containing just a fused line **3402** or a fused line with a breaker **3404** together.

[0425] Moreover, the component configuration engine **3236** can be configured to enable users to define multiple branch objects within a single piece. For example, the user can drag and drop a cable piece and define additional equipment such as breakers, switches, fuses at the "from" or "top" end of the piece and the "to" or "bottom" end of the piece. Other combination pieces may include pre-built circuits such as a complete MCC or panel. Furthermore, in certain embodiments, the pieces can have the capability to textually or graphically display simulation, connectivity, or other analytical data. This can be accomplished by communicatively linking the component database **3234** and/or the component configuration engine **3236** to the power analytics server **3238** by way of a network connection **114** to the network interface **3210** of the computer **3202**.

[0426] The component control engine **3230** can be configured to enable a user to "drag," "drop," and/or attach the pieces on a framework (e.g., grid, etc.) that can be rendered by the power system topology modeling engine **3232** on to a display **3214** (connected to the computer **3202** by way of the video adapter **3206**). In one embodiment, the power system topology modeling engine **3202** can be configured to enforce one or more rules that govern how the pieces interact with one another. These rules may include, but are not limited to, allowing only a female piece to be attached to a male piece (or vice versa), providing recommendations as to what the next network component piece in the design of the power system network should be, etc. For example, if a power source piece (node type object) is dragged and dropped on to the framework, the power system topology modeling engine **3202** can be configured to first show a set of valid and/or recommended branch puzzle pieces that are relevant to how the power source piece is typically connected to a power system network. Users will be able to save and re-use the definitions, rules and other customizable options so that the same rule does not have to be re-applied to each similar piece.

[0427] FIG. **35** is an example process for modeling a topology of an electrical power system, in accordance with one embodiment. In step **3502**, one of the plurality of power system components is selected. The power system components can be represented as virtual "jigsaw puzzle" pieces that that a user can readily manipulate and join to create different power network topology combinations. The power system components are stored in a component database and are fully customizable using a component configuration engine.

[0428] In step **3504**, the selected one of the plurality of power system components is positioned relative to an existing power system component in a framework. That is, a component control engine can be utilized by the user to "drag" and "drop" the power system component anywhere within the framework.

[0429] In step **3506**, the selected one of the plurality of power system components can be interfaced with the existing power system component in the framework. As discussed above, the power system topology modeling engine can be configured enforce one or more rules that govern how the pieces interact with one another. These rules may include, but are not limited to, allowing only a female piece to be attached to a male piece (or vice versa), providing recommendations as to what the next network component piece in the design of the power system network should be, etc. For example, if a power source piece (node type object) is dragged and dropped on to the framework, the power system topology modeling engine can be configured to first show a set of valid and/or recommended branch puzzle pieces that are relevant to how the power source piece is typically connected to a power system network.

[0430] In step **3508**, the interfaced power system components are rendered as the electrical power system topology.

[0431] FIG. **23** is an example process for alarm filtering and management of real-time sensory data from a monitored electrical system, in accordance with one embodiment. The complexity of electrical power systems coupled with the many operational conditions that 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.

[0432] The ability to intelligently filter, interpret and analyze dense real-time sensory data streams generated by sensor clusters distributed throughout the monitored electrical facility greatly enhances the ability of facility administrators/technical staff (e.g., operators, owners, managers, technicians, etc.) to quickly understand the health and predicted performance of their power network. This allows them to quickly determine the significance of any deviations detected in the sensory data and take or recommend reconfiguration options in order to prevent potential power disruptions.

[0433] In step **2302**, the power analytics server is configured to simulate the operation of a virtual system model (logical model) of the power facility to generate virtual facility predicted sensory data **2304** for the various sensor clusters distributed throughout the facility. Examples of the types of predicted sensory data **2304** that can be generated by the power analytics server include, but are not limited to power system: voltage, frequency, power factor, harmonics waveform, power quality, loading, capacity, etc. It should be understood that the power analytics server can be configured to generate any type of predicted sensory data **2304** as long as the data parameter type can be simulated using a virtual system model of the facility.

[0434] The simulation can be based on a number of different virtual system model variants of the electrical power system facility. The switch, breaker open/close and equipment on/off status of the actual electrical power system facility is continuously monitored so that the virtual system model representation can be continuously updated to reflect the actual status of the facility. Some examples of virtual system model variants, include but are not limited to: Power Flow Model (used to calculate expected kW, kVAR and power factor values to compare with real-time sensory data), Short Circuit Model (used to calculate maximum and minimum available fault currents for comparison with real-time data and determine stress and withstand capabilities of protective devices integrated with the electrical system), Protection Model (used to determine the proper protection scheme and insure the optimal selective coordination of protective devices integrated with the electrical system), Power Quality Model (used to determine proper voltage and current distortions at any point in the power network for comparison with real-time sensory data), and Dynamic Model (used to predict power system time-domain behavior in view of system control logic and dynamic behavior for comparison with real-time data and also predicting the strength and resilience of the system subjected to various contingency event scenarios). It should be appreciated that these are but just a few examples of virtual system model variants. In practice, the power analytics server can be configured to simulate any virtual system model variant that can be processed by the virtual system modeling engine of the power analytics server.

[0435] In step **2306**, the actual real-time sensory data **2307** (e.g., voltage, frequency, power factor, harmonics waveform, power quality, loading, capacity, etc.) readings can be acquired by sensor clusters that are integrated with various power system equipment/components that are distributed throughout the power facility. These sensor clusters are typically connected to a data acquisition hub that is configured to provide a real-time feed of the actual sensory data **2307** to the power analytics server. The actual real-time sensory data **2307** can be comprised of "live" sensor readings that are continuously updated by sensors that are interfaced with the facility equipment to monitor power system parameters during the operation of the facility. Each piece of facility equipment can be identified by a unique equipment ID that can be cross referenced against a virtual counterpart in the virtual system model of the facility. Therefore, direct comparisons (as depicted in step **2308**) can be made between the actual real-time equipment sensor data **2307** readings from the actual facility and the predicted equipment sensor data **2304** from a virtual system model of the actual facility to determine the overall health and performance of each piece of facility equipment and also the overall power system facility as a whole.

[0436] Both the actual real-time sensory data **2307** feed and the predicted sensory data **2304** feed are communicated directly to an archive database trending historian element **2309** so that the data can be accessed by a pattern recognition machine learning engine **2311** to make various predictions regarding the health, stability and performance of the electrical power system. For example, in one embodiment,

the machine learning engine **2311** can be used to make predictions about the operational reliability of an electrical power system (aspects) 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. Often, the machine learning engine **2311** includes a neocortical model that is encapsulated by a real-time sensory system layer, which is itself encapsulated by an associative memory model layer.

[0437] Continuing with FIG. **36**, in step **3610**, differences between the actual real-time sensory data **3607** and predicted sensory data **3604** are identified by the decision engine component of the power analytics server and their significance determined. That is, the decision engine is configured to compare the actual real-time data **3607** and the predicted sensory data **3604**, and then look for unexpected deviations that are clear indicators (indicia) of real power system health problems and alarm conditions. Typically, only deviations that clearly point to a problem or alarm condition are presented to a user (e.g., operator, owner, manager, technician, etc.) for viewing. However, in situations where both the actual real-time sensory data **3607** and the predicted sensory data **3604** do not deviate from each other, but still clearly point to a problem or alarm condition (e.g., where both sets of data show dangerously low voltage or current readings, etc.), the decision engine is configured to communicate that problem or alarm condition to the user. This operational capability in essence "filters" out all the "noise" in the actual real-time sensory data **3607** stream such that the power system administrative/technical staff can quickly understand the health and predicted performance of their power facility without having to go through scores of data reports to find the real source of a problem.

[0438] In one embodiment, the filtering mechanism of the decision engine uses various statistical techniques such as analysis of variance (ANOVA), f-test, best-fit curve trending (least squares regression), etc., to determine whether deviations spotted during step **3610** are significant deviations or just transient outliers. That is, statistical tools are applied against the actual **3607** and predicted **3604** data readings to determine if they vary from each other in a statistically significant manner. In another embodiment, the filters are configured to be programmable such that a user can set pre-determined data deviation thresholds for each power system operational parameter (e.g., voltage, frequency, power factor, harmonic waveform, power quality, loading, capacity, etc.), that when surpassed, results in the deviation being classified as a significant and clear indicator change in power system health and/or performance. In still another embodiment, the decision engine is configured to work in conjunction with the machine learning engine **3611** to utilize the "historical" actual **3607** and predicted **3604** sensory data readings stored in the archive database trending historian element **3609** to determine whether a power system parameter deviation is significant. That is, the machine learning engine **3611** can look to past sensory data trends (both actual **3607** and predicted data **3604**) and relate them to past power system faults to determine whether deviations between the actual **3607** and predicted **3604** sensory data are clear indicators of a change in power system health and/or performance.

[0439] In step **3612**, the decision engine is configured to take the actual real-time sensory data **3607** readings that were "filtered out" in step **3610** and communicate that information (e.g., alarm condition, sensory data deviations, system health status, system performance status, etc.) to the user via a Human-Machine Interface (HMI) **3614** such as a "thick" or "thin" client display. The facility status information **3616** can be specific to a piece of equipment, a specific process or the facility itself. To enhance the understanding of the information, the HMI **3614** can be configured to present equipment, sub-system, or system status by way of a color indicator scheme for easy visualization of system health and/or performance. The colors can be indicative of the severity of the alarm condition or sensory data deviation. For example, in certain embodiments, green can be representative of the equipment or facility operating at normal, yellow can be indicative of the equipment or facility operating under suspected fault conditions, and red can be indicative of the equipment or facility operating under fault conditions. In one embodiment, the color indicators are overlaid on top of already recognizable diagrams allowing for instantaneous understanding of the power system status to both technical and non-technical users. This allows high-level management along with technical experts to not only explore and understand much greater quantities of data, but, also to grasp the relationships between more variables than is generally possible with technical tabular reports or charts.

[0440] FIG. **37** is a diagram illustrating how the Decision Engine works in conjunction with the other elements of the analytics system to intelligently filter and manage real-time sensory data from an electrical system, in accordance with one embodiment. As depicted herein, the Decision Engine **3702** 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-time operating conditions of the system. This provides a desirable approach to alarm filtering and management of real-time sensory data from sensors distributed throughout an electrical power system.

[0441] The decision engine **3702** is interfaced with 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**.

[0442] Continuing with FIG. **37**, 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.), decision engine (e.g., configuration files, filtering algorithms and parameters, alarm condition 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, filtered and interpreted sensory data from the various components of the electrical system and information relating to the health, performance, reliability and availability of the electrical system can be displayed on a client **128** display panel (i.e., HMI) for viewing by a system administrator or equivalent. In another embodiment, the data may be summarized in a hard copy report **3704**.

[0443] FIG. **38** illustrates a high-level flow chart of an example process for performing real-time power analytics on a DC microgrid. A microgrid is a localized grouping of electricity generation, energy storage, and loads that normally operates connected to a centralized grid or macrogrid. The microgrid may have a single point of common coupling with the macrogrid and may function autonomously from the macrogrid, for example, if disconnected. For instance, a microgrid may represent a college campus, a housing development, etc. A microgrid may comprise one or more local generation resources. A microgrid may operate with small-scale power generation technologies, called distributed energy resource systems (e.g., fuel cells, wind turbines, solar panels, and other energy source), which provide alternatives to or enhancements of traditional electrical power generation systems, such as coal, nuclear, or hydroelectric power plants. Microgrids distribute energy generation, and therefore, can provide a more robust power grid. The opportunity to incorporate multiple sources and uses in the same power network is critical to the operation of microgrids.

[0444] As discussed above, existing systems focus on wholly AC power networks. Existing systems also rely on turnkey structures that are proprietary and frequently isolated from competition with other technologies and infrastructures (including legacy systems). This creates significant barriers to the adoption and wide scale deployment of DC microgrids. This, in turn, creates barriers to the adoption and wide scale deployment of microgrids in general, since the incorporation of DC in medium and high voltage power networks is essential to the rapid deployment and adoption of microgrids across geographies and economic strata.

[0445] With reference to FIG. **38**, in block **3810**, a virtual system model of the microgrid is generated and continuously synchronized with the actual microgrid topology, according to any of the various embodiments described in detail above.

[0446] In block **3820**, real-time data sources communicate with the virtual microgrid model via a portal or interface with the model. In this manner, the hyper-accurate power system model of the microgrid is able to obtain real-time data for analysis based on interactions with numerous data sources. This enables the microgrid to address the broadest possible cross-section of distributed energy management. For instance, real-time data from market pricing technologies may be received via the microgrid portal and used to create or simulate various market-based scenarios, which can then be used as critical input into decisions regarding the use of distributed energy resources within the microgrid.

[0447] In an embodiment, the portal is an abstract interface or API which enables non-proprietary (e.g., open source), as well as proprietary, software systems to interface with the virtual microgrid model. By providing an interface which is open to non-proprietary software systems, the market is better able to determine the best data sources and/or methods of using data sources for analysis and prediction. Such a system can provide real-time modeling and analysis of the microgrid, while incorporating real-time data from various commodity markets and incorporating conditions independent of any specific data acquisition system and independent of the presence of AC and DC power network elements. Thus, a process is disclosed which provides real-time modeling, evaluation, commodity market pricing, and optimization of a microgrid across virtually any digital data source and regardless of whether the microgrid comprises AC or DC network elements. In an embodiment, newly learned lessons and standards can be applied, without compromise, to underlying or legacy data acquisition, process control, and/or supervisory control and data acquisition (SCADA) systems.

[0448] Again with reference to FIG. **38**, in block **3830**, analytical data is generated by performing power analytics using the virtual system model of the microgrid and, in an embodiment, the real-time data acquired in block **3820**. As discussed above, the power analytics used to generate the analytical data may be supplied by open-source software systems, as well as proprietary software systems via the microgrid portal. In block **3840**, the analytical data is then presented through the microgrid portal. The analytical data may include predictions and pattern recognition. Thus, the microgrid portal provides the opportunity for the global management of distributed energy in microgrids. By enabling multiple sources of data and multiple types of data acquisition systems with differing capabilities to access the virtual microgrid model through the microgrid portal, the disclosed systems and methods facilitate broad and rapid deployment of distributed energy systems in mature and developing markets, economies, and geographies. In one embodiment, the microgrid portal is operable to connect at least one data source via at least one data acquisition system and to communicate real-time data from the at least one data source via the at least one data acquisition system to the virtual system model. In another embodiment, the microgrid portal is operable to connect two or more data sources via two or more data acquisition systems and to communicate real-time data from the two or more data sources via the two or more data acquisition systems to the virtual system model.

[0449] 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.

[0450] 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.

[0451] 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.

[0452] 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.

[0453] 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.

What is claimed is:

1. A system for performing power analytics on a microgrid, comprising:

at least one processor, comprising a virtual system modeling engine and analytics engine; and a microgrid portal;

wherein the virtual system modeling engine is operable to generate a virtual system model of the microgrid;

wherein the microgrid portal is operable to connect at least one data source via at least one data acquisition system to the virtual system model and to communicate real-time data from the at least one data source to the virtual system model;

wherein the virtual system model is synchronized with the microgrid topology based on the real-time data;

wherein the analytics engine is operable to generate analytical data by performing power analytics required for a size and a scope and a mission of the microgrid;

wherein the analytical data are presented through the microgrid portal.

2. The system of claim **1**, wherein the microgrid comprises a direct current (DC) network element.

3. The system of claim **1**, wherein the microgrid further comprises an alternating current (AC) network element.

4. The system of claim **1**, wherein the microgrid portal is an abstract interface or an Application Program Interface (API) which enables non-proprietary, as well as proprietary, software systems to interface with the virtual system model of the microgrid.

5. The system of claim **1**, wherein the microgrid portal is operable to connect two or more data sources via two or more data acquisition systems to the virtual system model and to communicate real-time data from the two or more data sources to the virtual system model.

6. The system of claim **1**, wherein predicted data is generated by simulating the virtual system model of the microgrid, and wherein the virtual system model is calibrated in real time when a difference between the real-time data and the predicted data exceeds a threshold.

7. The system of claim **5**, wherein the virtual system model is calibrated in real time when a change in power network topology is detected between the real-time data and the virtual model.

8. The system of claim **1**, wherein the virtual system model is continuously synchronized with the microgrid topology based on the real-time data;

9. The system of claim **1**, wherein the analytical data comprises predictions and pattern recognition.

10. The system of claim **1**, wherein the real-time data are from market pricing technologies.

11. The system of claim **1**, wherein the at least one processor further comprises a decision engine, and wherein the decision engine is operable to filter and interpret real-time data relating to the health, performance, reliability, stability and availability of the microgrid.

12. A method for performing power analytics for a microgrid, comprising:

generating a virtual system model of the microgrid;

connecting at least one real-time data source with the virtual system model of the microgrid via a microgrid port;

synchronizing the virtual system model of the microgrid with the actual microgrid topology based on real-time data from the at least one real-time data source;

generating analytical data by performing real-time power analytics required for a size and a scope and a mission of the microgrid; and

presenting analytical data through the microgrid portal.

13. The method of claim **12**, wherein the microgrid comprises a direct current (DC) network element.

14. The method of claim **12**, wherein the microgrid comprises an alternating current (AC) network element.

15. The method of claim **12**, wherein the microgrid portal is an abstract interface or an Application Program Interface (API) which enables non-proprietary, as well as proprietary, software systems to interface with the virtual system model of the microgrid.

16. The method of claim **12**, further comprising generating predicted data by simulating the virtual system model of the microgrid.

17. The method of claim **16**, further comprising updating the virtual system model in real time when a difference between the real-time data and the predicted data exceeds a

threshold, or when a change in power network topology is detected between the real-time data and the virtual model.

18. The method of claim **12**, wherein the analytical data comprises predictions and pattern recognition.

19. The method of claim **12**, wherein the real-time data are from market pricing technologies.

20. The method of claim **12**, further comprising filtering and interpreting real-time data relating to the health, performance, reliability, stability and availability of the microgrid.

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