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(54) **METHOD AND APPARATUS FOR OPTIMIZING REDUNDANT CRITICAL CONTROL SYSTEMS**

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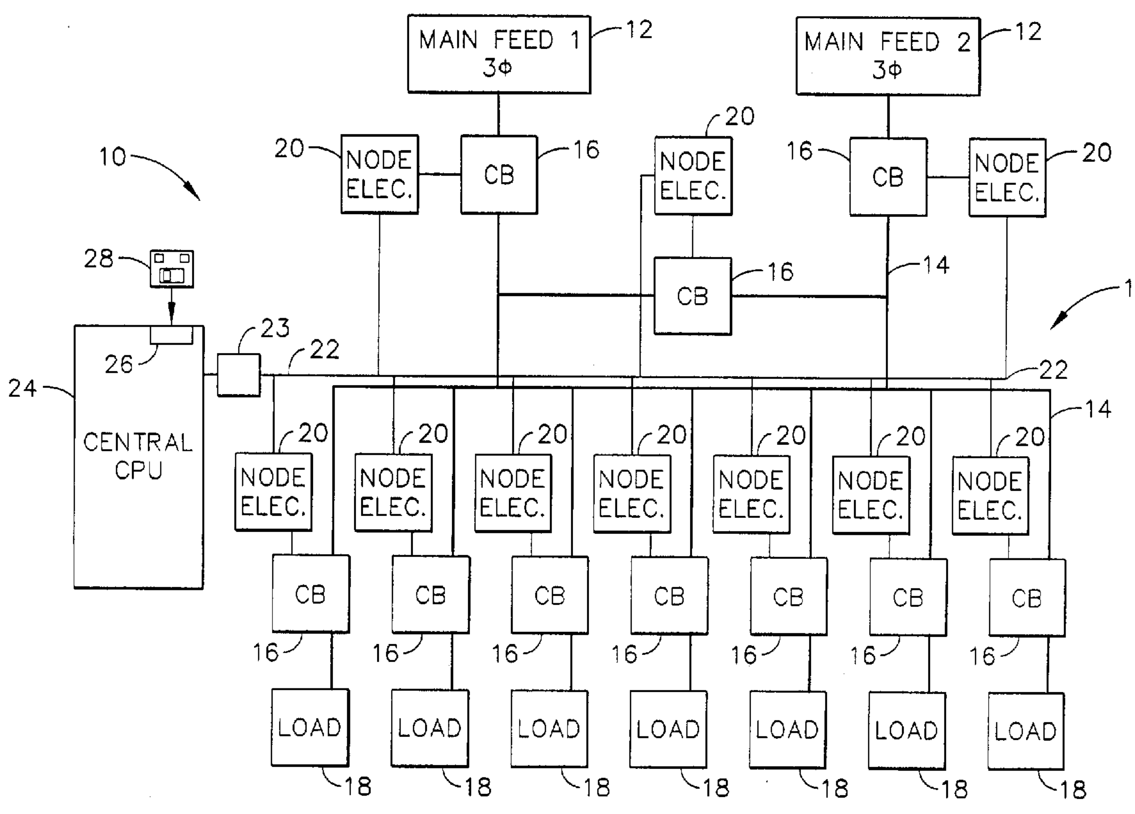
(57) **ABSTRACT**

A method and system for determining a configuration of a redundant critical control system is provided. The method includes receiving power distribution system operating characteristic information, using a computer, determining a plurality of alternative configurations of the power distribution system that are consistent with the operating characteristic information and determining efficiency characteristics of each of the alternative configurations, and selecting a configuration from the plurality of alternative configurations. The system includes a computer system configured to receive power distribution system operating characteristic information, determine a plurality of alternative configurations of the power distribution system that are consistent with the operating characteristic information and determine life-cycle cost characteristics of each of the alternative configurations, and select a configuration from the plurality of alternative configurations.



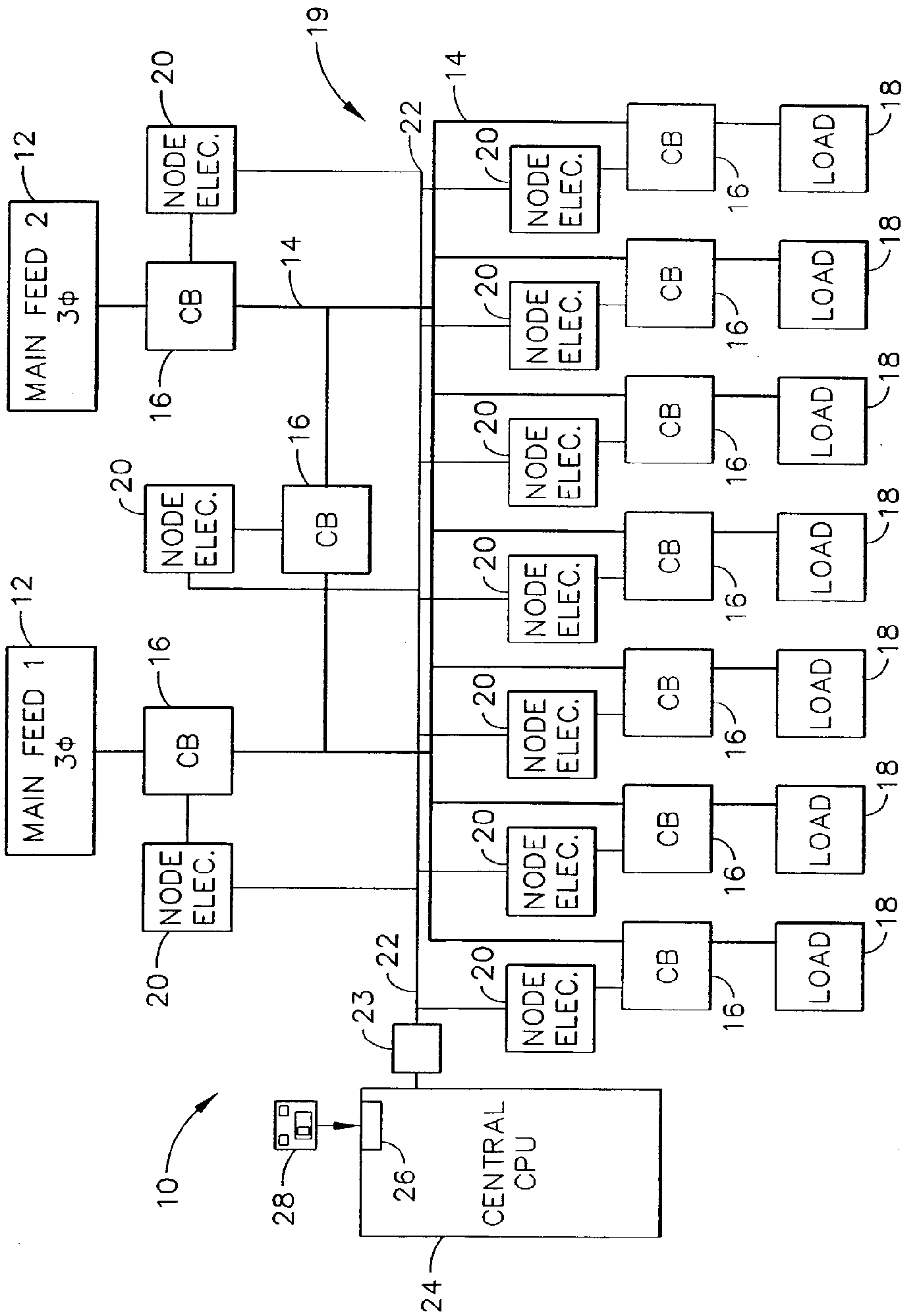

MAIN FEED 2 3φ
MAIN FEED 1 3φ
NODE ELEC.
CB
LOAD
CENTRAL CPU
10
12
14
16
18
19
20
22
23
24
26
28

FIG. 1

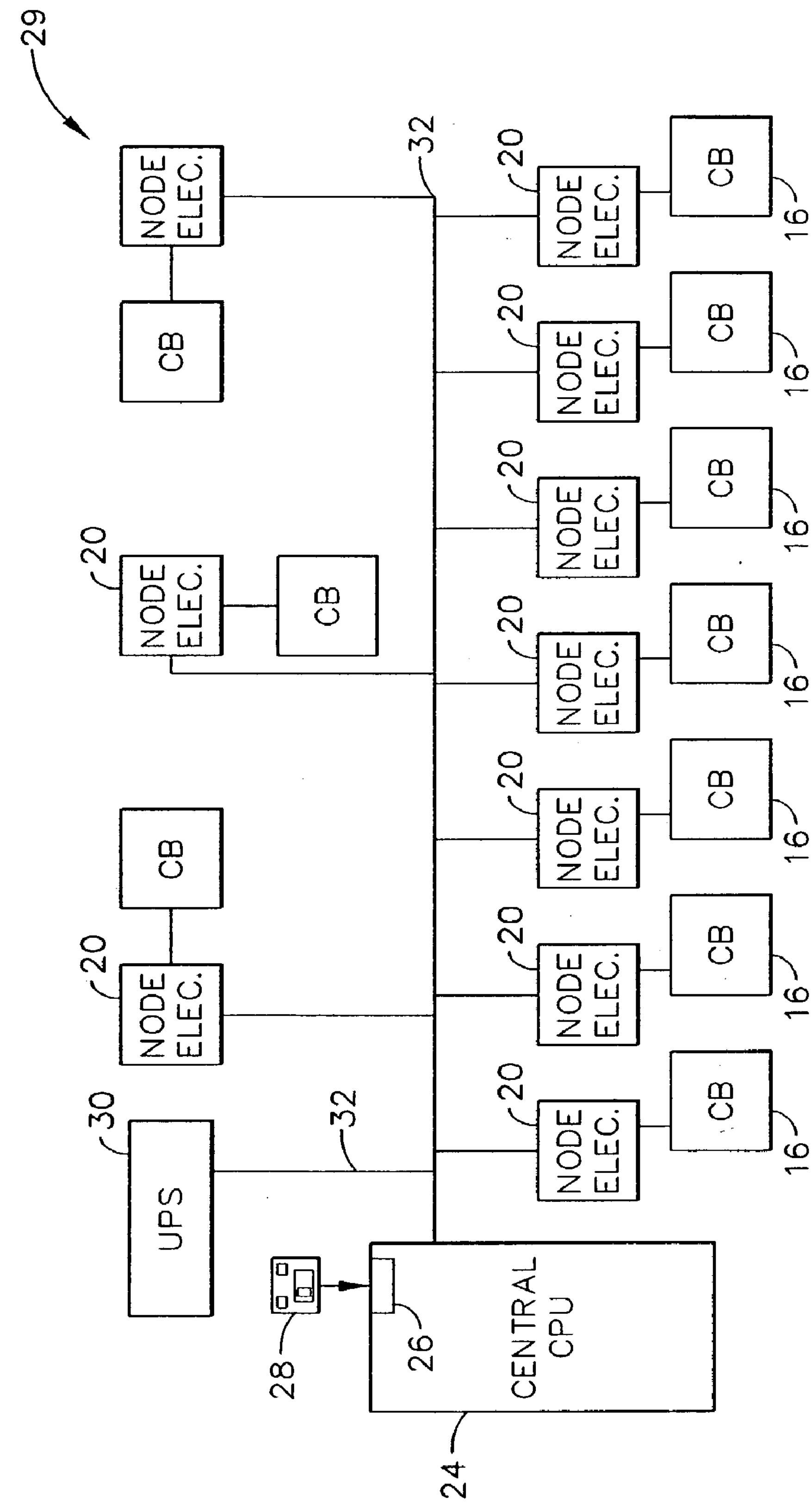


FIG. 2

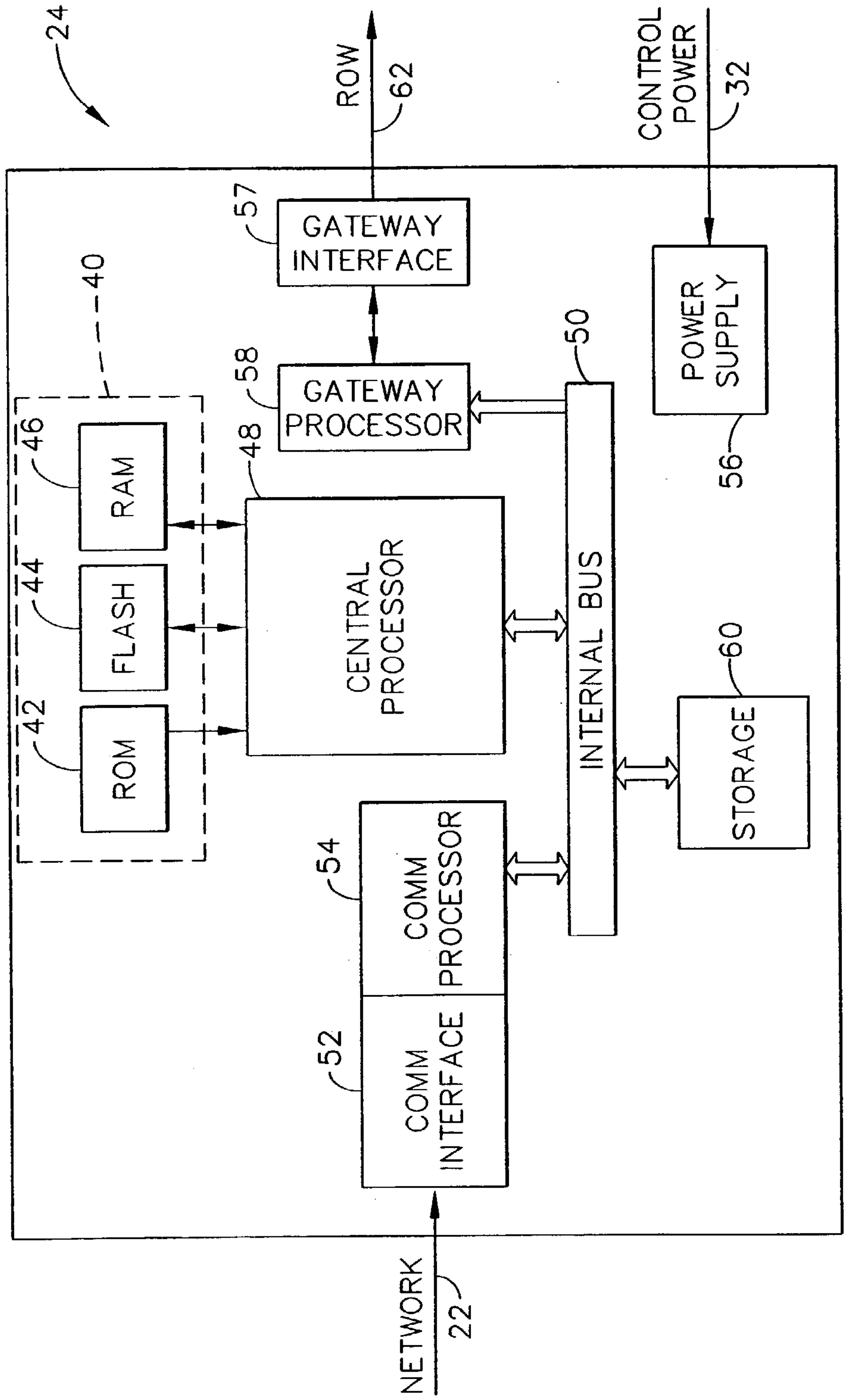

24
ROW
62
CONTROL POWER
32
57
GATEWAY INTERFACE
40
58
GATEWAY PROCESSOR
50
POWER SUPPLY
56
46
RAM
48
44
FLASH
CENTRAL PROCESSOR
INTERNAL BUS
42
ROM
60
STORAGE
54
COMM PROCESSOR
52
COMM INTERFACE
NETWORK
22

FIG. 3

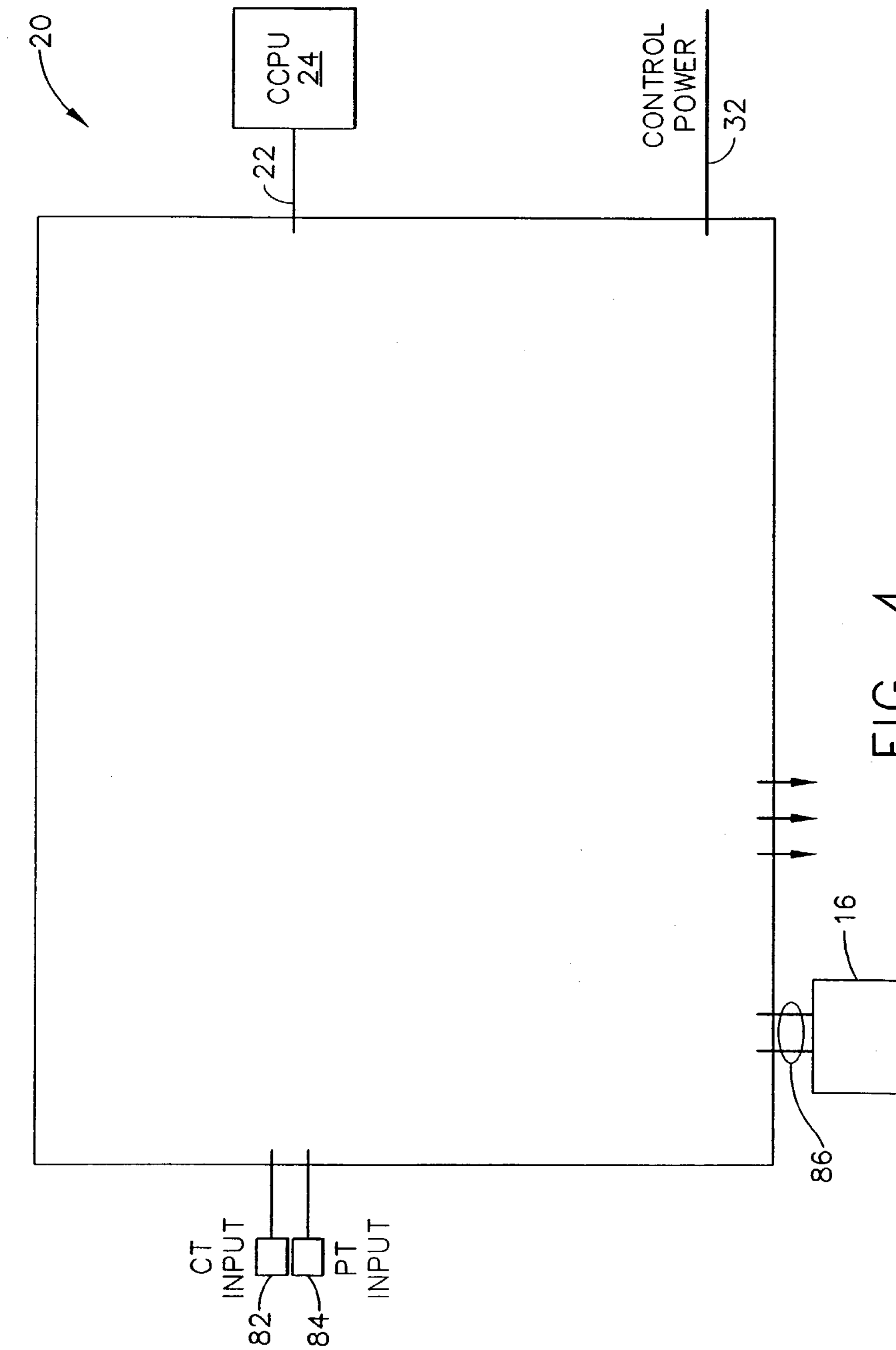


FIG. 4

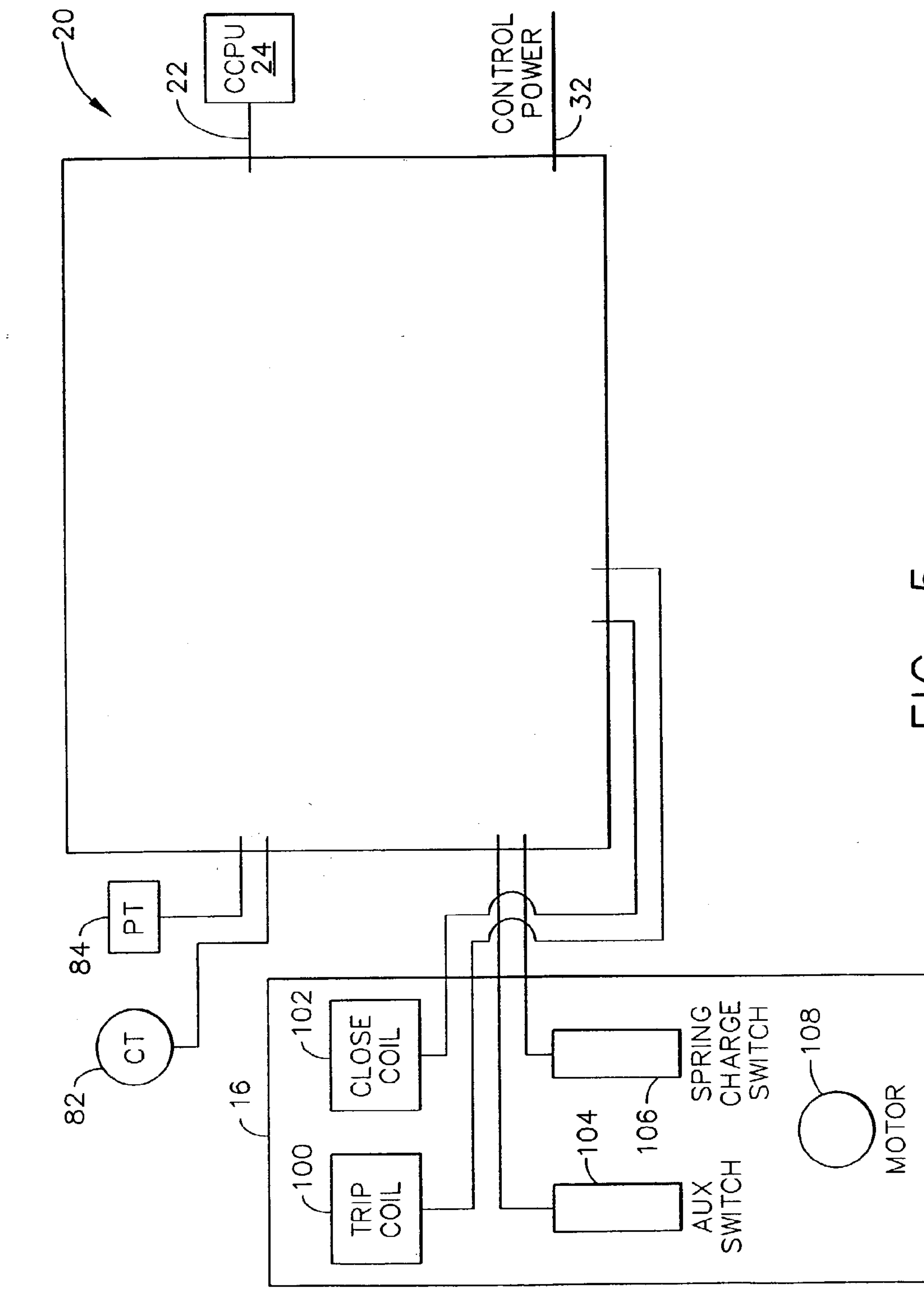

20
CCPU
24
22
CONTROL
POWER
32
PT
84
CT
82
16
CLOSE
COIL
102
TRIP
COIL
100
AUX
SWITCH
104
SPRING
CHARGE
SWITCH
106
MOTOR
108

FIG. 5

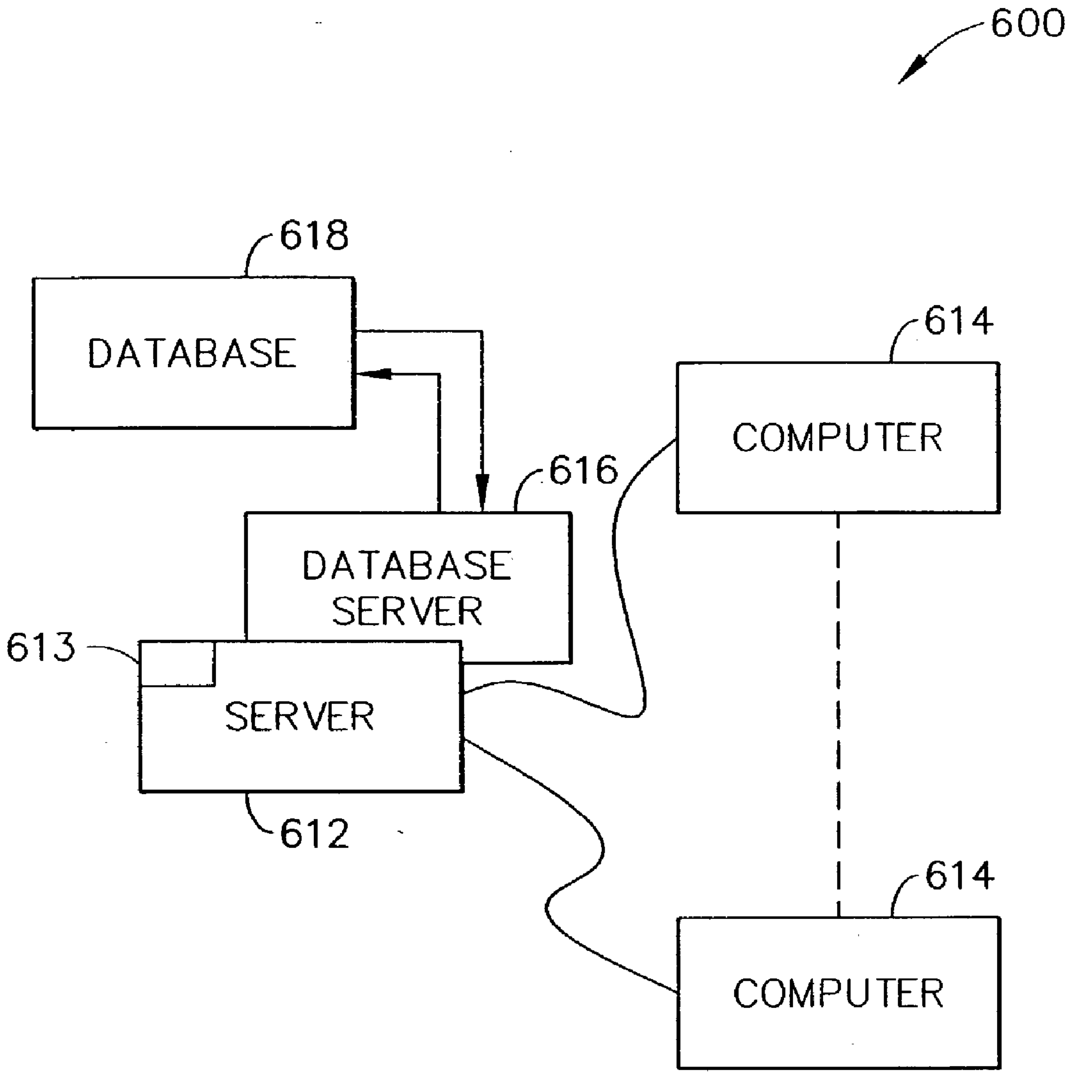

600
618
DATABASE
614
COMPUTER
616
DATABASE SERVER
613
SERVER
612
614
COMPUTER

FIG. 6

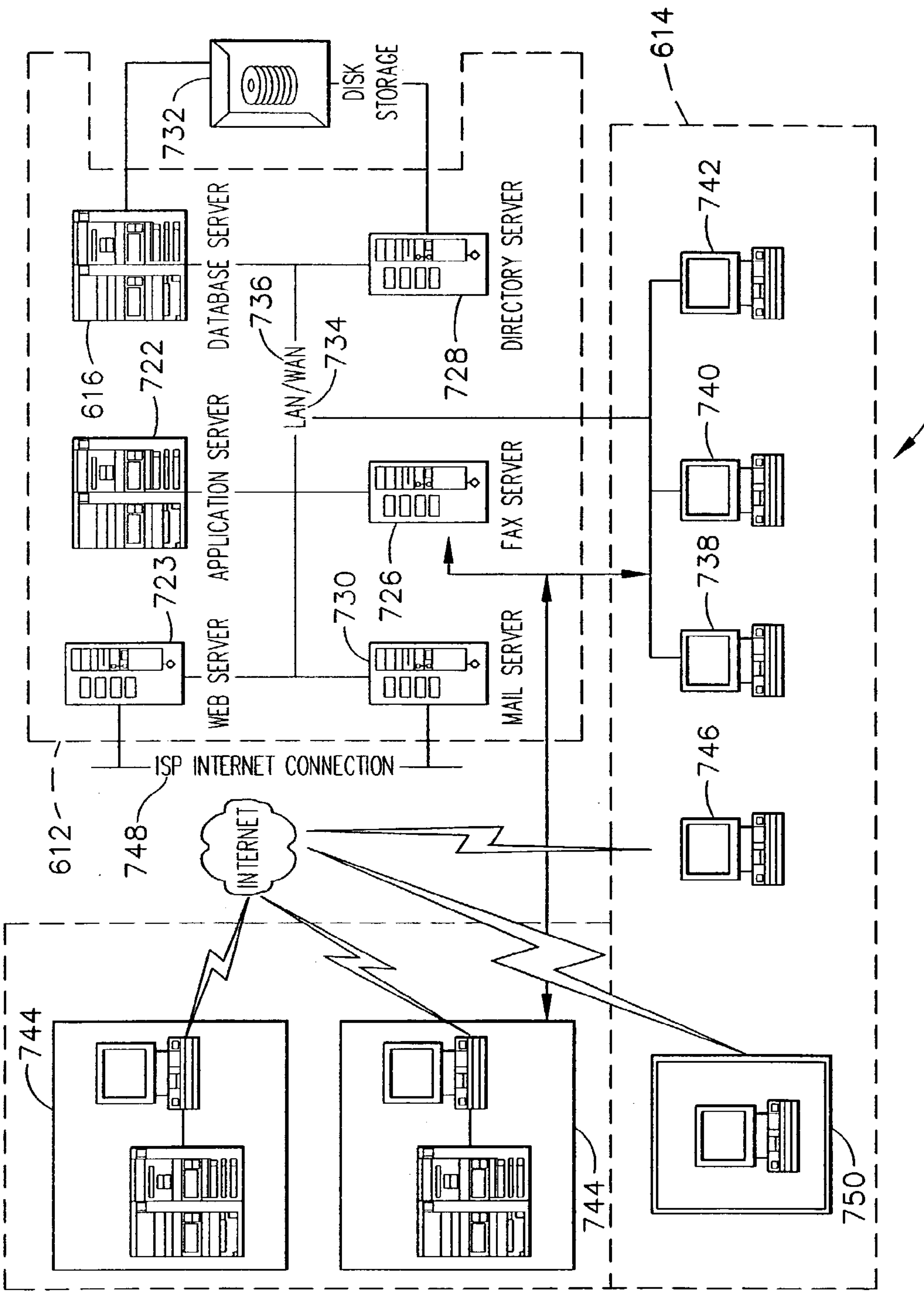

614
732
DISK STORAGE
DATABASE SERVER
616
722
APPLICATION SERVER
736
LAN/WAN
734
728
DIRECTORY SERVER
742
740
738
700
FAX SERVER
726
730
723
WEB SERVER
MAIL SERVER
746
ISP INTERNET CONNECTION
612
748
INTERNET
744
744
750

FIG. 7

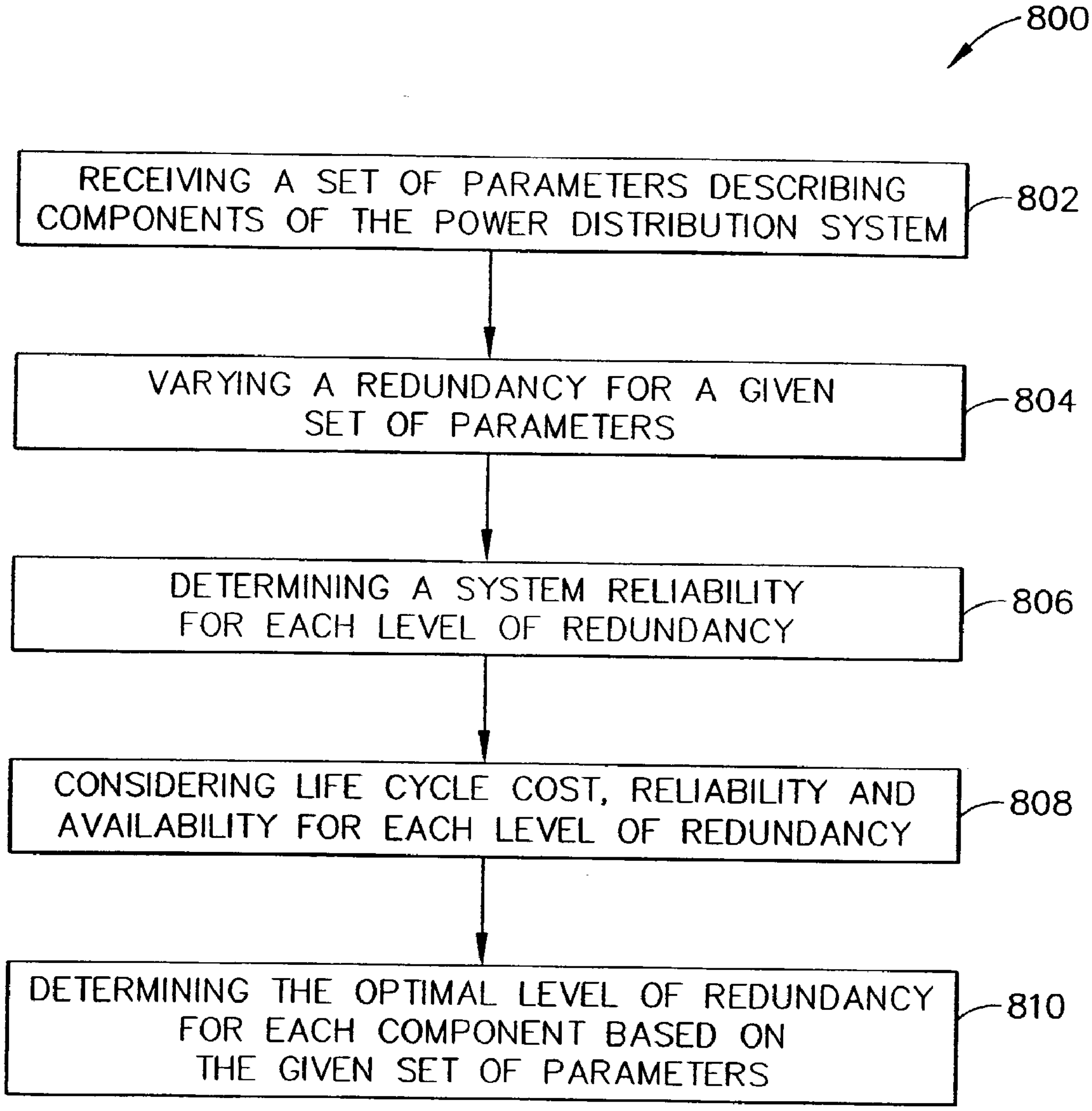

800
RECEIVING A SET OF PARAMETERS DESCRIBING COMPONENTS OF THE POWER DISTRIBUTION SYSTEM
802
VARYING A REDUNDANCY FOR A GIVEN SET OF PARAMETERS
804
DETERMINING A SYSTEM RELIABILITY FOR EACH LEVEL OF REDUNDANCY
806
CONSIDERING LIFE CYCLE COST, RELIABILITY AND AVAILABILITY FOR EACH LEVEL OF REDUNDANCY
808
DETERMINING THE OPTIMAL LEVEL OF REDUNDANCY FOR EACH COMPONENT BASED ON THE GIVEN SET OF PARAMETERS
810

FIG. 8

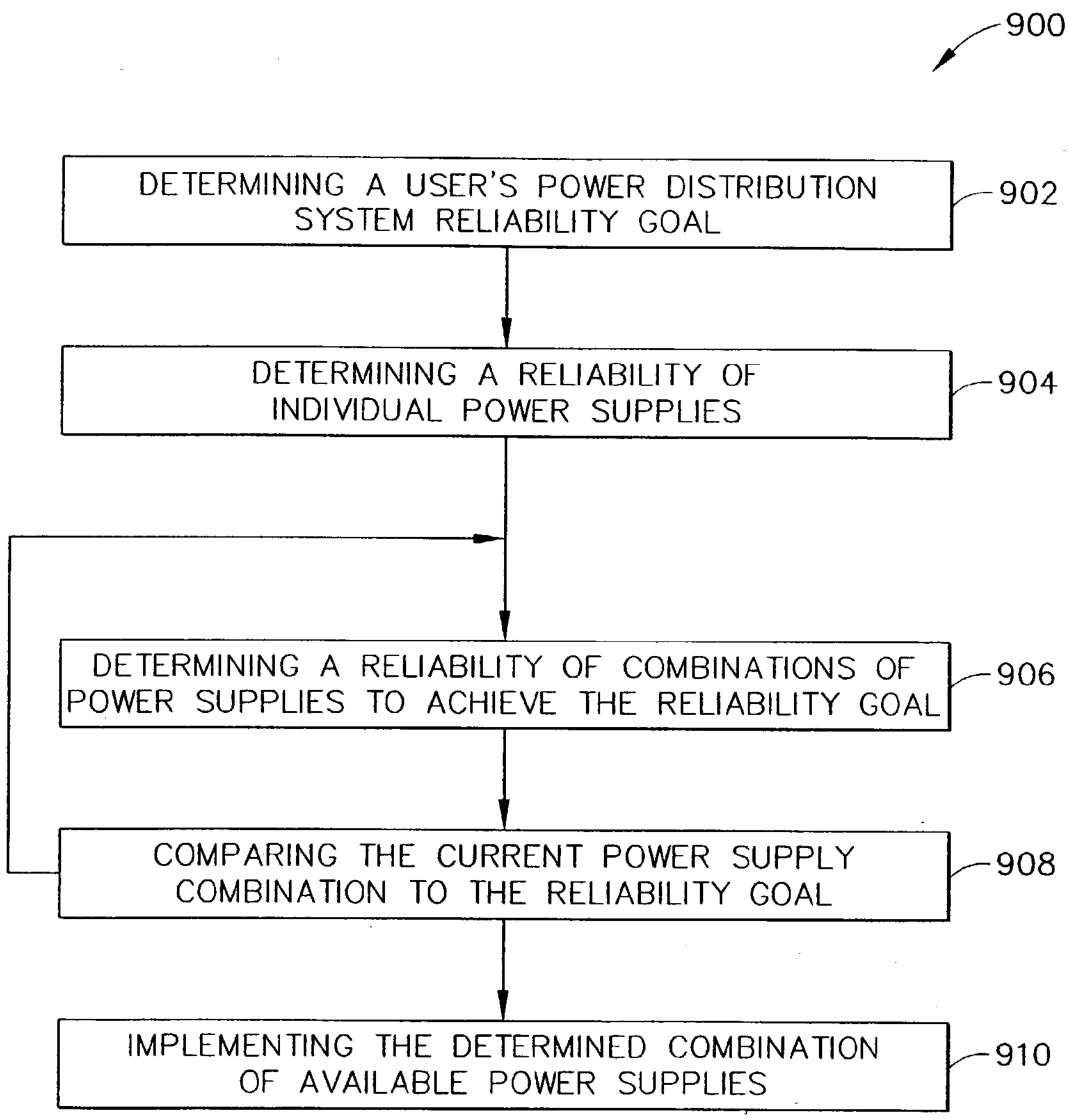

900
DETERMINING A USER'S POWER DISTRIBUTION SYSTEM RELIABILITY GOAL
902
DETERMINING A RELIABILITY OF INDIVIDUAL POWER SUPPLIES
904
DETERMINING A RELIABILITY OF COMBINATIONS OF POWER SUPPLIES TO ACHIEVE THE RELIABILITY GOAL
906
COMPARING THE CURRENT POWER SUPPLY COMBINATION TO THE RELIABILITY GOAL
908
IMPLEMENTING THE DETERMINED COMBINATION OF AVAILABLE POWER SUPPLIES
910

FIG. 9

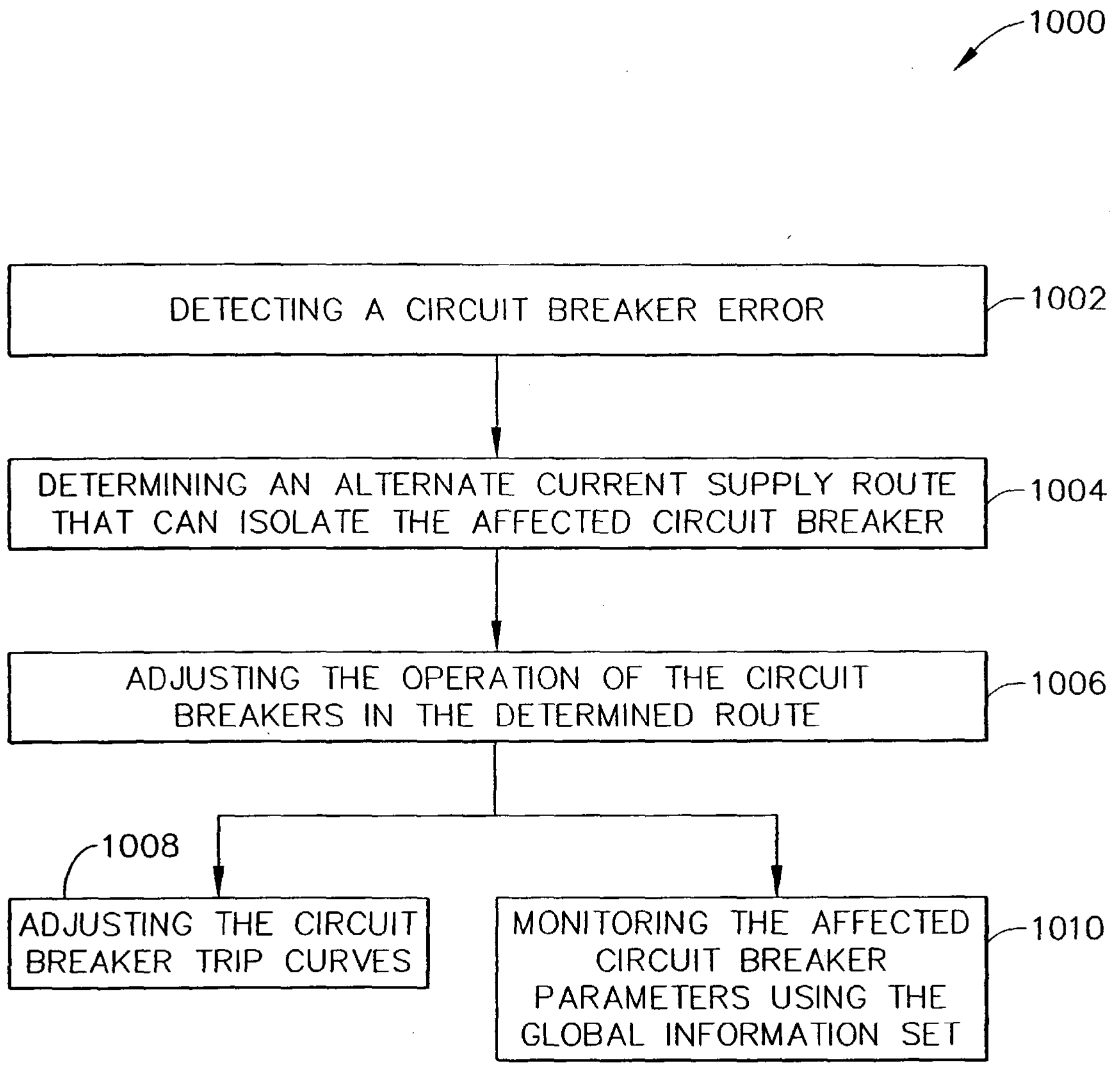

1000
DETECTING A CIRCUIT BREAKER ERROR
1002
DETERMINING AN ALTERNATE CURRENT SUPPLY ROUTE THAT CAN ISOLATE THE AFFECTED CIRCUIT BREAKER
1004
ADJUSTING THE OPERATION OF THE CIRCUIT BREAKERS IN THE DETERMINED ROUTE
1006
1008
ADJUSTING THE CIRCUIT BREAKER TRIP CURVES
MONITORING THE AFFECTED CIRCUIT BREAKER PARAMETERS USING THE GLOBAL INFORMATION SET
1010

FIG. 10

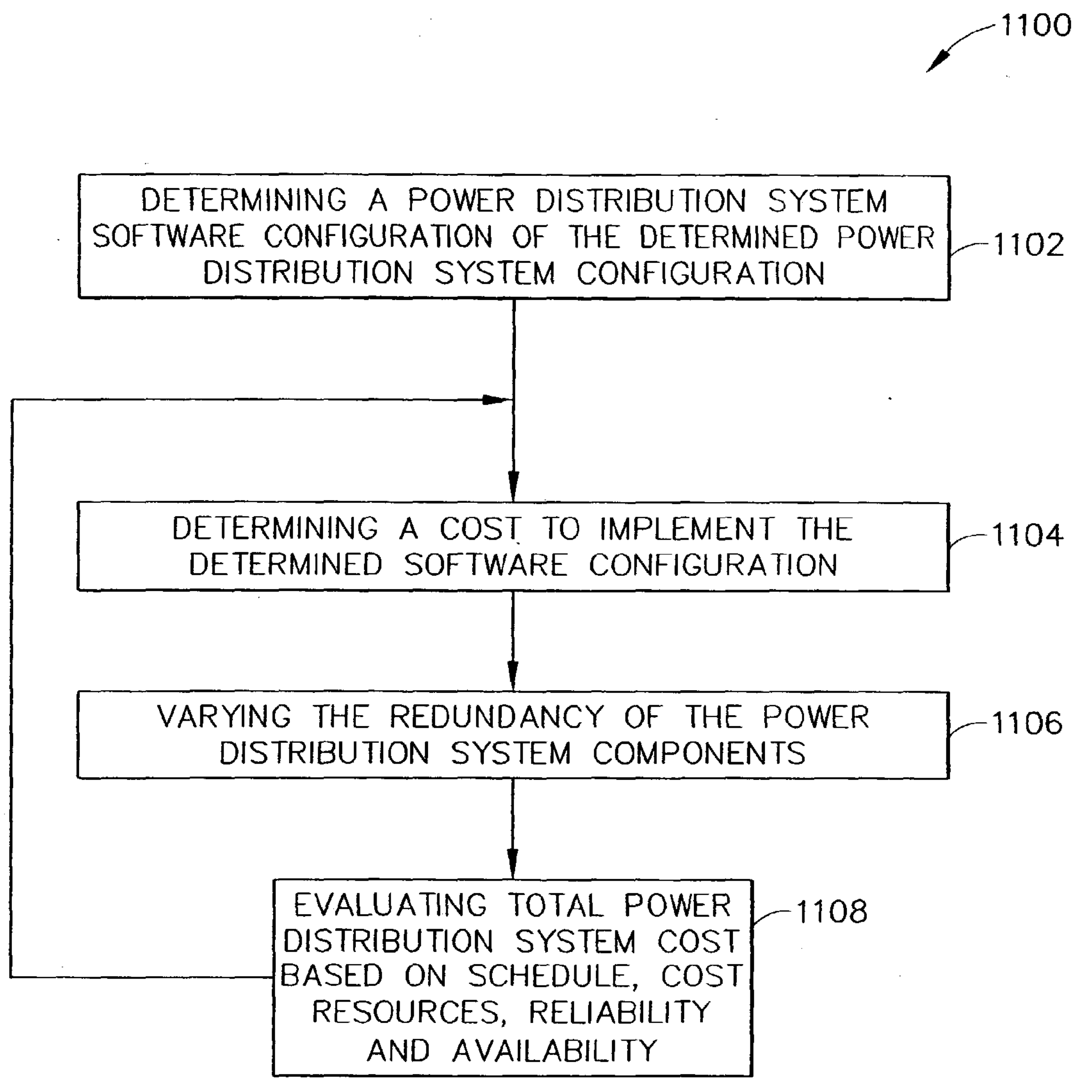

1100
DETERMINING A POWER DISTRIBUTION SYSTEM SOFTWARE CONFIGURATION OF THE DETERMINED POWER DISTRIBUTION SYSTEM CONFIGURATION
1102
DETERMINING A COST TO IMPLEMENT THE DETERMINED SOFTWARE CONFIGURATION
1104
VARYING THE REDUNDANCY OF THE POWER DISTRIBUTION SYSTEM COMPONENTS
1106
EVALUATING TOTAL POWER DISTRIBUTION SYSTEM COST BASED ON SCHEDULE, COST RESOURCES, RELIABILITY AND AVAILABILITY
1108

FIG. 11

METHOD AND APPARATUS FOR OPTIMIZING REDUNDANT CRITICAL CONTROL SYSTEMS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is related to U.S. Patent Application No. 60/359,544 filed on Feb. 25, 2002 for "Integrated Protection, Monitoring, and Control" the content of which is incorporated in its entirety herein by reference. This application is also related to U.S. Patent Application No. 60/438,159 filed on Jan. 6, 2003 for "Single Processor Concept for Protection and Control of Circuit Breakers in Low-Voltage Switchgear" the content of which is incorporated in its entirety herein by reference.

BACKGROUND OF THE INVENTION

[0002] This invention relates generally to electrical switchgear and more particularly, to a method and apparatus for facilitating maximizing a power distribution system reliability and system availability through optimizing power distribution system component redundancy and configuration.

[0003] In an industrial power distribution system, power generated by a power generation company may be supplied to an industrial or commercial facility wherein the power may be distributed throughout the industrial or commercial facility to various equipment such as, for example, motors, welding machinery, computers, heaters, lighting, and other electrical equipment. At least some known power distribution systems include switchgear which facilitates dividing the power into branch circuits which supply power to various portions of the industrial facility. Circuit breakers are provided in each branch circuit to facilitate protecting equipment within the branch circuit. Additionally, circuit breakers in each branch circuit can facilitate minimizing equipment failures since specific loads may be energized or de-energized without affecting other loads, thus creating increased efficiencies, and reduced operating and manufacturing costs. Similar switchgear may also be used within an electric utility transmission system and a plurality of distribution substations, although the switching operations used may be more complex.

[0004] Switchgear typically include multiple devices, other than the power distribution system components, to facilitate providing protection, monitoring, and control of the power distribution system components. For example, at least some known breakers include a plurality of shunt trip circuits, under-voltage relays, trip units, and a plurality of auxiliary switches that close the breaker in the event of an undesired interruption or fluctuation in the power supplied to the power distribution components. Additionally, at least one known power distribution system also includes a monitor device that monitors a performance of the power distribution system, a control device that controls an operation of the power distribution system, and a protection device that initiates a protective response when the protection device is activated.

[0005] In at least some other known power distribution systems, a monitor and control system operates independently of the protective system. For example, a protective device may de-energize a portion of the power distribution system based on its own predetermined operating limits, without the monitoring devices recording the event. The failure of the monitoring system to record the system shutdown may mislead an operator to believe that an over-current condition has not occurred within the power distribution system, and as such, a proper corrective action may not be initiated by the operator. Additionally, a protective device, i.e. a circuit breaker, may open because of an over-current condition in the power distribution system, but the control system may interpret the over-current condition as a loss of power from the power source, rather than a fault condition. As such, the control logic may undesirably attempt to connect the faulted circuit to an alternate source, thereby restoring the over-current condition. In addition to the potential increase in operational defects which may occur using such devices, the use of multiple devices and interconnecting wiring associated with the devices may cause an increase in equipment size, an increase in the complexity of wiring the devices, and/or an increase in a quantity of devices installed.

BRIEF DESCRIPTION OF THE INVENTION

[0006] In one aspect, a method for determining a configuration of a redundant critical control system is provided. The method includes receiving power distribution system operating characteristic information, using a computer, determining a plurality of alternative configurations of the power distribution system that are consistent with the operating characteristic information and determining efficiency characteristics of each of the alternative configurations, and selecting a configuration from the plurality of alternative configurations.

[0007] In another aspect, a computer system for determining a configuration of a redundant critical control system is provided. The computer system is configured to receive power distribution system operating characteristic information, determine a plurality of alternative configurations of the power distribution system that are consistent with the operating characteristic information and determining efficiency characteristics of each of the alternative configurations, and select a configuration from the plurality of alternative configurations.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] **FIG. 1** is an exemplary schematic illustration of a power distribution system;

[0009] **FIG. 2** is an exemplary schematic illustration of a node power system;

[0010] **FIG. 3** is an exemplary schematic illustration of a central control processing unit that may used with the power distribution system shown in **FIG. 1**;

[0011] **FIG. 4** is an exemplary schematic illustration of a node electronic unit that may used with the power distribution system shown in **FIG. 1**;

[0012] **FIG. 5** is an exemplary schematic illustration of a circuit breaker that may used with the power distribution system shown in **FIG. 1**;

[0013] **FIG. 6** is a simplified block diagram of a power distribution system design computer system that may be used with power distribution system **10** shown in **FIG. 1**;

[0014] **FIG. 7** is an expanded version block diagram of an exemplary embodiment of a server architecture of power distribution system design computer system shown in **FIG. 6**;

[0015] **FIG. 8** is a flow chart illustrating an exemplary embodiment of a method for operating power distribution system shown in **FIG. 1**;

[0016] **FIG. 9** is a flow chart illustrating an exemplary embodiment of a method **900** optimizing a reliability of a plurality of control power sources in the power distribution system shown in **FIG. 1**;

[0017] **FIG. 10** is a flow chart illustrating an exemplary embodiment of a method for determining a probability that a power distribution system circuit breaker error will not affect the reliability of the power distribution system shown in **FIG. 1**; and

[0018] **FIG. 11** is a flow chart illustrating an exemplary embodiment of a method for operating power distribution system shown in **FIG. 1**.

DETAILED DESCRIPTION OF THE INVENTION

[0019] **FIG. 1** illustrates an exemplary schematic illustration of a power distribution system **10**, used by an industrial facility for example. In an exemplary embodiment, system **10** includes at least one main feed system **12**, a power distribution bus **14**, a plurality of power circuit switches or interrupters, also referred to herein as a circuit breakers (CB) **16**, and at least one load **18**, such as, but not limited to, motors, welding machinery, computers, heaters, lighting, and/or other electrical equipment.

[0020] In use, power is supplied to a main feed system **12**, i.e. a switchboard for example, from a source (not shown) such as, an electric generator driven by a prime mover locally, or an electric utility source from an electrical substation. The prime mover may be powered from, for example, but not limited to, a turbine, or an internal combustion engine. Power supplied to main feed system **12** is divided into a plurality of branch circuits by a plurality of busbars configured to route the power from a branch feed breaker and a bus-tie breaker to a plurality of load circuit breakers **16** which supply power to various loads **18** in the industrial facility. In addition, circuit breakers **16** are provided in each branch circuit to facilitate protecting equipment, i.e. loads **18**, connected within the respective branch circuit. Additionally, circuit breakers **16** facilitate minimizing equipment failures since specific loads **18** may be energized or de-energized without affecting other loads **18**, thus creating increased efficiencies, and reduced operating and manufacturing costs.

[0021] Power distribution system **10** includes a circuit breaker control protection system **19** that includes a plurality of node electronics units **20** that are each electrically coupled to a digital network **22**. Circuit breaker control protection system **19** also includes at least one central control processing unit (CCPU) **24** that is electrically coupled to digital network **22** via a switch **23** such as, but not limited to, an Ethernet switch **23**. In use, each respective node electronics unit **20** is electrically coupled to a respective circuit breaker **16**, such that CCPU **24** is electrically coupled to each circuit breaker **16** through digital network **22** and through an associated node electronics unit **20**.

[0022] In one embodiment, digital network **22** includes, for example, at least one of a local area network (LAN) or a wide area network (WAN), dial-in-connections, cable modems, and special high-speed ISDN lines. Digital network **22** also includes any device capable of interconnecting to the Internet including a web-based phone, personal digital assistant (PDA), or other web-based connectable equipment.

[0023] In one embodiment, CCPU **24** is a computer and includes a device **26**, for example, a floppy disk drive or CD-ROM drive, to facilitate reading instructions and/or data from a computer-readable medium **28**, such as a floppy disk or CD-ROM. In another embodiment, CCPU **24** executes instructions stored in firmware (not shown). CCPU **24** is programmed to perform functions described herein, but other programmable circuits can likewise be programmed. Accordingly, as used herein, the term computer is not limited to just those integrated circuits referred to in the art as computers, but broadly refers to computers, processors, microcontrollers, microcomputers, programmable logic controllers, application specific integrated circuits, and other programmable circuits. Additionally, although described in a power distribution setting, it is contemplated that the benefits of the invention accrue to all electrical distribution systems including industrial systems such as, for example, but not limited to, an electrical distribution system installed in an office building.

[0024] **FIG. 2** is an exemplary schematic illustration of a node power distribution system **29** that can be used with power distribution system **10** (shown in **FIG. 1**) and more specifically, with circuit breaker control protection system **19** (shown in **FIG. 1**). Node power distribution system **29** includes a power source **30** that is electrically coupled to node electronic units **20** through a node power distribution bus **32**. In an exemplary embodiment, power source **30** is an uninterruptible power supply (UPS). In one embodiment, power source **30** receives power from power distribution system **10** and then distributes this power to node electronic units **20** through node power distribution bus **32**. In an alternative embodiment, power is not supplied to power source **30**, but rather, power source **30** supplies power to node electronic units **20** using an internal power supply, such as, but not limited to, a plurality of batteries (not shown). In another alternate embodiment, node electronic units **20** are powered by secondary current available from current sensor **82** and/or voltage sensor **84**. In this embodiment, circuit breaker control protection system **19** would not include node power distribution system **29**, power source **30**, or node power distribution bus **32**.

[0025] **FIG. 3** is an exemplary schematic illustration of CCPU **24**. CCPU **24** includes at least one memory device **40**, such as, but not limited to, a read only memory (ROM) **42**, a flash memory **44**, and/or a random access memory (RAM) **46**. CCPU **24** also includes a central processor unit (CPU) **48** that is electrically coupled to at least one memory device **40**, as well as an internal bus **50**, a communications interface **52**, and a communications processor **54**. In an exemplary embodiment, CCPU **24** is a printed circuit board and includes a power supply **56** to supply power to a plurality of devices on the printed circuit board.

[0026] Additionally, in an exemplary embodiment, internal bus **50** includes an address bus, a data bus, and a control bus. In use, the address bus is configured to enable CPU **48** to address a plurality of internal memory locations or an input/output port, such as, but not limited to communications interface **52** through communications processor **54**, and a gateway interface **58**, through a gateway processor **56**. The data bus is configured to transmit instructions and/or data between CPU **48** and at least one input/output, and the control bus is configured to transmit signals between the plurality of devices to facilitate ensuring that the devices are operating in synchronization. In the exemplary embodiment, internal bus **50** is a bi-directional bus such that signals can be transmitted in either direction on internal bus **50**. CCPU **24** also includes at least one storage device **60** configured to store a plurality of information transmitted via internal bus **50**.

[**0027**] In use, gateway interface **58** communicates to a remote workstation (not shown) via an Internet link **62** or an Intranet **62**. In the exemplary embodiment, the remote workstation is a personal computer including a web browser. Although a single workstation is described, such functions as described herein can be performed at one of many personal computers coupled to gateway interface **58**. For example, gateway interface **58** may be communicatively coupled to various individuals, including local operators and to third parties, e.g., remote system operators via an ISP Internet connection. The communication in the example embodiment is illustrated as being performed via the Internet, however, any other wide area network (WAN) type communication can be utilized in other embodiments, i.e., the systems and processes are not limited to being practiced via the Internet. In one embodiment, information is received at gateway interface **58** and transmitted to node electronics unit **20** via CCPU **24** and digital network **22**. In another embodiment, information sent from node electronics unit **20** is received at communication interface **52** and transmitted to Internet **62** via gateway interface **58**.

[**0028**] **FIG. 4** is an exemplary schematic illustration of single node electronic unit **20**. In the exemplary embodiment, node electronic unit **20** is a unitary device mounted remotely from CCPU **24** and circuit breaker **16**. In an exemplary embodiment, node electronic unit **20** is separate from, but proximate to circuit breaker **16**. In an exemplary embodiment, node electronic unit **20** is a printed circuit board.

[**0029**] In one embodiment, node electronics unit **20** receives signals input from a plurality of devices, such as, but not limited to, a current sensor **82**, and a voltage sensor **84**, and/or circuit breaker **16**. Status input device **86** receives a plurality of status signals from circuit breaker **16** can include signals related to one or more conditions of the breaker, such as, but not limited to, an auxiliary switch status, and a spring charge switch status. Additionally, node electronics unit **20** sends signals **86** to at least circuit breaker **16** in order to control one or more states of the breaker.

[**0030**] In use, signals input from status input device **86**, current sensor **82**, and voltage sensor **84**, are transmitted to CCPU **24** via node electronics unit **20**, and digital network **22**. Node electronics unit **20** receives the input from status input device **86**, current sensor **82**, and voltage sensor **84**, and packages a digital message that includes the input and additional data relating to a health and status of node electronics unit **20**. The health and status data may include information based on problems found by internal diagnostic routines and a status of self checking routines that run locally in node electronics unit **20**. The data transmitted to CCPU **24** via node electronics unit **20** is processed by CCPU **24**, which outputs a signal to node electronics unit **20** via digital network **22**. In the exemplary embodiment, node electronics unit **20** actuates circuit breaker **16** in response to the signal received from CCPU **24**. In one embodiment, circuit breaker **16** is actuated in response to commands sent only by CCPU **24**, i.e., circuit breaker **16** is not controlled locally by node **20**,but rather is operated remotely from CCPU **24** based on inputs received from current sensor **82**, voltage sensor **84**, and status inputs **86** received from node electronics unit **20** over network **22**.

[**0031**] **FIG. 5** is an exemplary schematic illustration of circuit breaker **16** that is electrically coupled to node electronics unit **20**. In the exemplary embodiment, circuit breaker **16** includes a switch assembly that includes movable and/or stationary contacts, an arc suppression means, and a tripping and operating mechanism. Circuit breaker **16** auxiliaries include only a trip coil **100**, a close coil **102**, an auxiliary switch **104**, a spring charge switch **106**, and a motor **108**. Circuit breaker **16** does not include a trip unit. Auxiliary switches and sensors are coupled to node electronics unit **20** through a standard wiring harness **110**, which may include both copper wiring and communications conduits. Current sensor **82**, and voltage sensor **84** are coupled to node electronics unit **20** through a cable **112** that may include copper wiring and/or communications conduits. Circuit breaker **16** is a unitary device mounted proximate to CCPU **20**, current sensor **82**, and voltage sensor **84**. The various components of breaker **16** (e.g., trip coil **100**, close coil **102**, auxiliary switch **104**, spring charge switch **106**, motor **108**) can be powered by node electronics unit **20**. Alternately, breaker **16** can be powered by secondary current available from current sensor **82** and/or voltage sensor **84**. Circuit breaker **16** is in electrical communication with node electronics unit **20** through a wiring harness **110** (not shown in **FIG. 5**), which may include copper wiring, communications conduits, and any combination thereof. Current sensor **82**, and voltage sensor **84** are in electrical communication with node electronics unit **20** through a cable **112** (not shown in **FIG. 5**) that may include copper wiring, communications conduits, and any combination thereof.

[**0032**] In use, actuation signals from node electronics unit **20** are transmitted to circuit breaker **16** to actuate a plurality of functions in circuit breaker **16**, such as, but not limited to, operating a trip coil **100**, operating a close coil **102**, and affecting a circuit breaker lockout feature. An auxiliary switch **104** and a spring charge switch **106** provide a status indication of circuit breaker parameters to node electronics unit **20**. Motor **108** is configured to recharge a close spring (not shown) after circuit breaker **16** closes. It should be appreciated that the motor **108** can include, for example, a spring charge switch, a solenoid or any other electromechanical device capable of recharging a trip spring. To close circuit breaker **16**, a close coil **102** is energized by a close signal from actuation power module **90**. Close coil **102** actuates a closing mechanism (not shown) that couples at least one movable electrical contact (not shown) to a corresponding fixed electrical contact (not shown). The closing mechanism of circuit breaker **16** latches in a closed position such that when close coil **102** is de-energized, circuit breaker **16** remains closed. When breaker **16** closes, an "a" contact of auxiliary switch **104** also closes and a "b" contact of auxiliary switch **104** opens. The position of the "a" and "b" contacts is sensed by node electronics unit **20**. To open circuit breaker **16**, node electronics unit **20** energizes trip coil (TC) **100**. TC **100** acts directly on circuit breaker **16** to release the latching mechanism that holds circuit breaker **16** closed. When the latching mechanism is released, circuit breaker **16** will open, opening the "a" contact and closing the "b" contact of auxiliary switch **104**. Trip coil **100** is then de-energized by node electronics unit **20**. After breaker **16** opens, with the close spring recharged by motor **108**, circuit breaker **16** is prepared for a next operating cycle. In the exemplary embodiment, each node electronics unit **20** is coupled to circuit breaker **16** in a one-to-one correspondence. For example, each node electronics unit **20** communicates directly with only one circuit breaker **16**. In an alternative embodiment, node electronics unit **20** may communicate with a plurality of circuit breakers **16**.

[**0033**] **FIG. 6** is a simplified block diagram of a power distribution system design computer system **600** including a server system **612** including a disk storage unit **613** for data storage, and a plurality of client sub-systems, also referred to as client systems **614**, connected to server system **612**. In one embodiment, client systems **614** are computers including a web browser, such that server system **612** is accessible to client systems **614** via the Internet. Client systems **614** are interconnected to the Internet through many interfaces including a network, such as a local area network (LAN) or a wide area network (WAN), dial-in-connections, cable modems and special high-speed ISDN lines. Client systems **614** could be any device capable of interconnecting to the Internet including a web-based phone, personal digital assistant (PDA), or other web-based connectable equipment. A database server **616** is connected to a database **618** containing information on a variety of matters, as described below in greater detail. In one embodiment, centralized database **618** is stored on server system **612** and can be accessed by potential users at one of client systems **614** by logging onto server system **612** through one of client systems **614**. In an alternative embodiment database **618** is stored remotely from server system **612** and may be non-centralized.

[**0034**] **FIG. 7** is an expanded version block diagram **700** of an example embodiment of a server architecture of power distribution system design computer system **100** shown in **FIG. 6**. Components in diagram **700**, identical to components of system **600** (shown in **FIG. 6**), are identified in **FIG. 7** using the same reference numerals as used in **FIG. 6**. System **700** includes server system **612** and client systems **614**. Server system **612** further includes database server **616**, an application server **722**, a web server **723**, a fax server **726**, a directory server **728**, and a mail server **730**. Disk storage unit **732** is coupled to database server **616** and directory server **728**. Servers **616**, **722**, **723**, **726**, **728**, and **730** are coupled in a local area network (LAN) **734**. In addition, a system administrator's workstation **738**, a user workstation **740**, and a supervisor's workstation **742** are coupled to LAN **734**. Alternatively, workstations **738**, **740**, and **742** are coupled to LAN **734** via an Internet link or are connected through an Intranet.

[**0035**] Each workstation, **738**, **740**, and **742** is a personal computer having a web browser. Although the functions performed at the workstations typically are illustrated as being performed at respective workstations **738**, **740**, and **742**, such functions can be performed at one of many personal computers coupled to LAN **734**. Workstations **738**, **740**, and **742** are illustrated as being associated with separate functions only to facilitate an understanding of the different types of functions that can be performed by individuals having access to LAN **734**. In an example embodiment, client system **614** includes a workstation **750** which can be used by an internal analyst or a designated outside field engineer to review power distribution system design information relating to a system.

[**0036**] Server system **612** is configured to be communicatively coupled to various individuals, including employee workstation **744** and to design engineer workstation **746** via an ISP Internet connection **748**. The communication in the example embodiment is illustrated as being performed via the Internet, however, any other wide area network (WAN) type communication can be utilized in other embodiments, i.e., the systems and processes are not limited to being practiced via the Internet. In addition, and rather than WAN **736**, local area network **734** could be used in place of WAN **736**.

[**0037**] In the exemplary embodiment, any authorized individual having a workstation **744** can access power distribution system design computer system **600**. At least one of the client systems includes a manager workstation **750** located at a remote location. Workstations **744** and **750** are personal computers having a web browser. Also, workstations **744** and **750** are configured to communicate with server system **612**. Furthermore, fax server **726** communicates with remotely located client systems, including a client system **750** via a telephone link. Fax server **726** is configured to communicate with other client systems **738**, **740**, and **742** as well.

[**0038**] **FIG. 8** is a flow chart illustrating an exemplary embodiment of a method **800** for operating power distribution system **10** shown in **FIG. 1**. Method **800** includes an algorithm that determines the redundancy level of each critical component in power distribution system **10**. This algorithm is controlled by minimizing the life cycle cost, subjected to a system availability constraint. This availability constraint is for circuit breaker control protection system **19** to have a greater availability than that of current local control protection systems.

[**0039**] Failure rate prediction methods provide a tool with which components may be selected. A set of conditions in which the components operate, such as, the temperature or environmental conditions is defined. The prediction methodology carries out a failure rate calculation as defined by predetermined parameters selected based on known and desired performance goals. For example, components that make up power distribution system **10** can be defined in a tree structure. The tree may be composed entirely of components or it could be subdivided into blocks each of which could hold other blocks or components. In this way power distribution system **10** can easily be represented as a combination of system and subsystems. A failure rate model for each component is made up of a base failure rate for that particular type of component and multiplying factors that depend on the operating conditions experienced by the component.

[**0040**] Method **800** utilizes an optimization procedure that receives **802** a set of parameters that describe power distribution system **10**. In one embodiment, the parameters include a number and/or reliability of available power sources, a number and/or configuration of branch circuits, a number and rating of a plurality of loads. The procedure then varies **804** the redundancy of each component in system **10** for a given set of parameters, while meeting predetermined requirements and expectations. The redundancy is limited to integer values only; thus resulting in realistic parameters that can be physically implemented. For each level of redundancy for each component, a power distribution system reliability is determined **806**. An associated life cycle cost, reliability and availability of each level of redundancy is considered **808**. A level of redundancy that yields an optimum level of redundancy for each component is determined **810** for the given set of parameters. In one embodiment used for circuit breaker control and protection system **19**, the resulting architecture is doubly redundant in the various components that constitute the centralized control architecture. For the particular example considered, these included the CCPU **24**, communication network **22**, and the power supply connections. Some features include redundancy determined in view of optimizing an application dependent cost function. In one embodiment, the calculation is fast by using a programmed Excel file, in which a "solver" function is employed. Features also include the ability to have any number of requirements or limitations, as well as any number of items that can be redundant. The only portion that needs to be updated for each particular system is its layout.

[**0041**] Accordingly, an ability to provide quick results that are able to be physically and realistically implemented is provided. Thus, resulting in "true" optimizations within a short period of time. One advantage is the optimally determined redundant architecture. In addition, the calculation is rigorous, fast, and simple, resulting in a structure that is able to be physically & realistically implemented. Additionally, a quick and easy procedure for determining the optimal redundancy of a complex system for a given set of constraints is provided. For example, one implementation considered the constraints to include overall life cycle costs and the systems availability. This procedure resulted in a doubly redundant circuit breaker control protection system architecture.

[**0042**] **FIG. 9** is a flow chart illustrating an exemplary embodiment of a method **900** for operating power distribution system **10** shown in **FIG. 1**. Method **900** facilitates optimizing a reliability of a plurality of control power sources in power distribution system **10**. The control power sources supply, for example, node electronics units **20** with power to energize node electronic unit **20** circuits and drive node electronic unit **20** outputs. Method **900** begins by determining **902** a user reliability goal. In one embodiment, the reliability goal may be mandated by a customer preference. In another embodiment, the reliability goal may be determined **902** by applying known standards or specifications to system **10** design inputs. An analysis of the control power supply for circuit breaker control protection system **19** is performed. In this analysis, the control power is optimized to yield a customer's expected reliability, or reliability goal. A reliability of the facility's available power supplies is determined **904** individually. A reliability of various combinations of these power supplies is determined **906** based on the reliability of the individual power supplies. The determined reliability of the combinations of power supplies is compared **908** to the reliability goal. If the determined reliability does not meet the reliability goal, the algorithm determines **906** a reliability of a different combination of power supply combinations. If the determined **606** reliability meets the reliability goal, the algorithm outputs the combination of power supply so that it may be implemented **910**. In the exemplary embodiment, the determined combination of available power supplies is implemented in the design phase of a new power distribution system **10**. In another embodiment, system **10** implements **910** the determined **906** combination of power supplies by generating commands and actions to appropriate circuit breakers **16** to achieve the optimum lineup determined **906**. In another embodiment, system **10** outputs recommended commands and actions for appropriate circuit breakers **16** for an operator to implement **910** to achieve the optimum lineup determined **906**.

[**0043**] Accordingly, a designer is enabled to quickly and accurately configure what power supplies should be utilized for the critical control system, thus allowing for quicker design time than at least some other methods. Additionally, any unneeded power supply redundancy is eliminated, thus reducing the quantity of equipment needed, the maintenance that the equipment might require, the cost of supplying such equipment. One aspect includes an ability to determine what combination of the facilities available power supplies are needed to obtain the desired system reliability. This procedure enables this result to be obtained in a short period of time.

[**0044**] **FIG. 10** is a flow chart illustrating an exemplary embodiment of a method **1000** for operating power distribution system **10** shown in **FIG. 1**. Method **1000** facilitates determining a probability that a circuit breaker error will not affect the power distribution system reliability. Because all power distribution system monitored parameters are available to CCPU **24** at all times, a circuit breaker error detected by CCPU **24** can be compensated for by reconfiguring the operation of circuit breakers **16** supplying power to the affected circuit breaker **16**. Method **1000** includes detecting **1002** a circuit breaker **16** error in any of the circuit breaker in power distribution system **10**. An error is defined as a power distribution system component malfunction that occurs when the protection features of power distribution system **10** are not needed. The protection features of power distribution system **10** are needed when a power line fault occurs. A power line fault is defined as a malfunction of the power delivery components of power distribution system **10** and loads **18**, such as, for example, but, not limited to, instantaneous over current, short and long time over current, ground fault, differential fault, and under and over frequency. A system failure is defined as a component error that coincides with a line fault. In such a situation, the protection features of power distribution system **10** would be needed to clear the line fault but, because of a component error, the protection features may be unavailable. When a component error is detected **1002**, power distribution system **10** responds by determining **1004** an alternative trip scheme for the affected circuit breaker **16** to enable clearing a fault, should one occur, necessitating operation of the affected circuit breaker **16**. For example, in a hierarchical power system, a plurality of supply circuit breakers each supply power from a power source to a power distribution system. The supply circuit breakers may supply a distribution bus that includes switchgear, such as, a plurality of feeder breakers that each supply power to an electrical load. Each bus may also be coupled to other buses through a bus-tie breaker. The system as described is hierarchical in that each circuit breaker is supplied from another circuit breaker usually with a larger current carrying capability and usually supplying other circuit breaker as well. The supply circuit breaker usually has the largest current carrying capability whereas individual load circuit breaker usually have the lowest current carrying capability. After the circuit breakers that supply the affected circuit breaker are determined, the operation of the determined supply circuit breakers may be adjusted **1006**. This may be done by adjusting **1008** trip curves for the supplying circuit breakers so that they will trip at a current level that will compensate for the loss of the affected breaker's functionality. Additionally, the global information set of power distribution system **10** electrical parameters may be used to calculate electrical parameters at the affected circuit breaker and a compensatory monitoring **1010** regime may be used to trip the determined supply circuit breakers to facilitate limiting current flow to the affected circuit breaker.

[**0045**] **FIG. 11** is a flow chart illustrating an exemplary embodiment of a method **1100** for operating power distribution system **10** shown in **FIG. 1**. Method **1100** facilitates determining an optimized power distribution system **10** configuration based on a predetermined power distribution system **10** configuration modified to incorporate software considerations into the determination. As discussed above, a configuration of power distribution system **10** is determined using optimization techniques that include optimizing system component reliability based on a redundancy of critical components, an inherent failure probability of components, i.e. mean time between failures (MTBF), mean time to failure (MTTF), and mean time to repair (MTTR), optimizing system component availability, and optimizing total system reliability and availability. In one embodiment, MTBF, is defined as being equal to the sum of MTTF and MTTR. The MTTF for a component may be obtained by analyzing historical data or using standard prediction methods. Once an optimum configuration based on reliability, availability and cost is determined, an additional, constructability evaluation is conducted. Constructability optimizes component availability, manufacturing, and power distribution system maintenance considerations. Additionally, an optimum power distribution system may include a level of redundancy that complicates constructability disadvantageously, necessitating a further review of the determined power distribution system **10** configuration. One area of review is the software which will be controlling power distribution system **10**. Software considerations for power distribution system **10** include the level of redundancy of the plurality of node electronics units **20**, redundancy of network **22** and the redundancy of CCPU **24**. For each level of redundancy software running on power distribution system **10** will manage communications and resolve conflicts. In one embodiment, conflict resolution solutions will use a safety priority resolution methodology. In another embodiment, software voting will resolve command conflicts in power distribution system **10**. Latency considerations influence the conflict resolution solution determined.

[**0046**] Once an optimized hardware configuration of power distribution system **10** is determined, a corresponding software configuration is determined **1102**. A cost to implement such a corresponding software configuration is determined **1104**. The determination includes labor, schedule, production resource variables. The determined hardware configuration and the corresponding software configuration are varied **1106** to establish an optimum hardware configuration/software configuration solution. For each configuration variation, cost is evaluated **1108** based on at least one of schedule, resources, reliability, availability and labor. Schedule, resource, and labor cost may be interrelated in that shortening a production or design schedule may increase labor costs due to increased numbers of people performing the work in a shorter time span and increased overtime costs. Resource cost also includes an opportunity cost for alternative uses of resources. Reliability and availability costs include costs associated with redundancy, component quality, and testing costs. After each evaluation, the process iterates to a subsequent configuration and evaluated again.

[**0047**] The above-described power distribution systems are cost-effective and highly reliable. Each system includes a central control unit and networked devices to facilitate protecting a set of switchgear. Devices local to each circuit breaker monitor voltage and current signals from sensors located proximate each circuit breaker. The central control receives all monitored signals from all devices over the high-speed network. The central control implements protection and optimization algorithms for each breaker node based on global voltage and current signals. This method offers performance advantages over existing local, non-networked protection. In many overcurrent faults, the fault level may appear at multiple levels in the electrical protection hierarchy. Branch, feeder and main circuit breakers may all "see" the fault. Protection engineers can partially avoid the problem by setting longer delays. This results in faults at high levels in the hierarchy causing more damage and still can result in multiple devices interrupting, removing electrical service from circuits that do not have a fault. Additionally the system components and configuration are facilitated to be optimized to provide high reliability and high availability. Accordingly, power distribution system **10** facilitates protection and optimization of power system operation in a cost-effective and reliable manner.

[**0048**] Exemplary embodiments of power distribution system components are described above in detail. The components are not limited to the specific embodiments described herein, but rather, components of each system may be utilized independently and separately from other components described herein. Each power distribution system component can also be used in combination with other power distribution system components.

[**0049**] While the invention has been described in terms of various specific embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the claims.

What is claimed is:

1. A method for determining a configuration of a redundant critical control system, said method comprising:

receiving power distribution system operating characteristic information;

using a computer, determining a plurality of alternative configurations of the power distribution system that are consistent with the operating characteristic information and determining life-cycle cost characteristics of each of the alternative configurations; and selecting a configuration from the plurality of alternative configurations.

2. A method in accordance with claim 1 wherein selecting a configuration comprises selecting a configuration that facilitates optimizing the power distribution system life-cycle cost of a plurality of components of the power distribution system.

3. A method in accordance with claim 2 wherein selecting a configuration comprises selecting a configuration wherein life-cycle costs include at least one of initial procurement cost, installation cost, maintenance cost, and replacement cost.

4. A method in accordance with claim 1 further comprises:

receiving optimization criteria; and

determining a system reliability and system availability of each of the alternative configurations based on the optimization criteria.

5. A method in accordance with claim 4 further comprising selecting a configuration that facilitates optimizing the power distribution system reliability wherein the reliability is measured as a probability of the system functionality at a first time that is greater than or equal to the system functionality at a second time wherein the first time is later than the second time.

6. A method in accordance with claim 4 further comprising selecting a configuration that facilitates optimizing the power distribution system availability wherein the availability is measured as a probability of the system functionality at any time is greater than or equal to a predetermined system functionality goal.

7. A method in accordance with claim 1 wherein determining a plurality of alternative configurations of the power distribution system comprises varying a number of components in a redundant scheme for each alternative configuration.

8. A method in accordance with claim 1 further comprising:

receiving a set of parameters describing a plurality components of the power distribution system;

varying a redundancy of the plurality components for the received set of parameters; and

determining a power distribution system reliability and system availability for each level of redundancy.

9. A method in accordance with claim 8 wherein varying a redundancy of the plurality of components comprises varying a redundancy of the plurality of components wherein the plurality of components includes at least one of a central control processing unit (CCPU), a CCPU communications interface, a digital communications network, an Ethernet switch, a node electronics unit (NEU), an uninterruptible power supply (UPS), a main power supply to the UPS, a communications connection, and a circuit breaker.

10. A method in accordance with claim 8 further comprising:

evaluating at least one of a life cycle cost, a system availability, and a system reliability for each level of redundancy; and

determining a level of redundancy to facilitate optimizing the power distribution system life-cycle cost, reliability, and availability.

11. A method in accordance with claim 8 wherein receiving a set of parameters comprises receiving a set of parameters that includes at least one of a number of available power sources, a reliability of available power sources, a number of branch circuits, a configuration of branch circuits, a number of a plurality of loads, and a rating of a plurality of loads.

12. A method in accordance with claim 8 further comprising:

determining a user's power distribution system reliability goal;

determining a reliability of each available control power supply;

determining a reliability of a plurality of combinations of each available control power supply; and

comparing the reliability of each combination of available power supplies to the determined reliability goal.

13. A method in accordance with claim 1 wherein the power distribution system includes at least one circuit breaker, each circuit breaker supplying a load with electrical power from at least one electrical source, the circuit breakers configured in a hierarchical format from load to source, said method further comprising:

detecting a circuit breaker error associated with a first circuit breaker that prevents the first circuit breaker from interrupting a flow of load current;

determining at least one alternate circuit breaker to interrupt the flow of load current;

adjusting an operation of the determined at least one alternative circuit breaker.

14. A method in accordance with claim 13 wherein adjusting an operation of the determined at least one alternative circuit breaker comprises modifying a trip curve of the determined at least one alternative circuit breaker.

15. A method in accordance with claim 13 wherein adjusting an operation of the determined at least one alternative circuit breaker comprises inferring electrical parameters at the first circuit breaker based on electrical parameters sensed in the power distribution system.

16. A method in accordance with claim 10 further comprising:

determining a power distribution system software configuration corresponding to the determined level of redundancy;

determining a cost of implementing the power distribution system software configuration;

varying the determined level of redundancy; and

determining the power distribution system software configuration that facilitates optimizing the power distribution system cost.

17. A method in accordance with claim 16 wherein determining a cost of implementing the power distribution system software configuration comprises determining a cost of implementing the power distribution system software configuration wherein cost includes at least one of a production schedule cost, a resource cost, and a labor cost.

18. A method in accordance with claim 16 wherein determining the power distribution system software configuration that facilitates optimizing the power distribution system cost comprises determining the power distribution system software configuration that facilitates optimizing the power distribution system cost wherein the power distribution system cost includes at least one of a production schedule cost, a resource cost, a labor cost, a reliability cost, and an availability cost.

19. A computer system for determining a configuration of a redundant critical control system, said computer configured to:

receive power distribution system operating characteristic information;

determine a plurality of alternative configurations of the power distribution system that are consistent with the operating characteristic information and determine life-cycle cost characteristics of each of the alternative configurations; and

select a configuration from the plurality of alternative configurations.

20. A computer system in accordance with claim 19 configured to select a configuration that facilitates optimizing the power distribution system lifecycle cost of a plurality of components of the power distribution system.

21. A computer system in accordance with claim 20 configured to select a configuration wherein life-cycle costs include at least one of initial procurement cost, installation cost, maintenance cost, and replacement cost.

22. A computer system in accordance with claim 19 further configured to:

receive optimization criteria; and

determine a system reliability and system availability of each of the alternative configurations based on the optimization criteria.

23. A computer system in accordance with claim 22 further configured to select a configuration that facilitates optimizing the power distribution system reliability wherein the reliability is measured as a probability of the system functionality at a first time that is greater than or equal to the system functionality at a second time wherein the first time is later than the second time.

24. A computer system in accordance with claim 22 further configured to select a configuration that facilitates optimizing the power distribution system availability wherein the availability is measured as a probability of the system functionality at any time is greater than or equal to a predetermined system functionality goal.

25. A computer system in accordance with claim 19 configured to determine a plurality of alternative configurations of the power distribution system based on varying a number of components in a redundant scheme for each alternative configuration.

26. A computer system in accordance with claim 19 further configured to:

receive a set of parameters describing a plurality components of the power distribution system;

vary a redundancy of the plurality components for the received set of parameters; and

determine a power distribution system reliability and system availability for each level of redundancy.

27. A computer system in accordance with claim 26 configured to vary a redundancy of said plurality of components wherein the plurality of components comprises at least one of a central control processing unit (CCPU), a CCPU communications interface, a digital communications network, an Ethernet switch, a node electronics unit (NEU), an uninterruptible power supply (UPS), a main power supply to the UPS, a communications connection, and a circuit breaker.

28. A computer system in accordance with claim 26 further configured to:

evaluate at least one of a life cycle cost, a system availability, and a system reliability for each level of redundancy; and

determine a level of redundancy to facilitate optimizing the power distribution system life-cycle cost, reliability, and availability.

29. A computer system in accordance with claim 26 configured to receive a set of parameters that includes at least one of a number of available power sources, a reliability of available power sources, a number of branch circuits, a configuration of branch circuits, a number of a plurality of loads, and a rating of a plurality of loads.

30. A computer system in accordance with claim 26 further configured to:

determine a user's power distribution system reliability goal;

determine a reliability of each available control power supply;

determine a reliability of a plurality of combinations of each available control power supply; and

compare the reliability of each combination of available power supplies to the determined reliability goal.

31. A computer system in accordance with claim 19 wherein the power distribution system includes at least one circuit breaker, each circuit breaker supplying a load with electrical power from at least one electrical source, the circuit breakers configured in a hierarchical format from load to source, said method further configured to:

detect a circuit breaker error associated with a first circuit breaker that prevents the first circuit breaker from interrupting a flow of load current;

determine at least one alternate circuit breaker to interrupt the flow of load current; and

adjust an operation of the determined at least one alternative circuit breaker.

32. A computer system in accordance with claim 31 configured to modify a trip curve of the determined at least one alternative circuit breaker.

33. A computer system in accordance with claim 31 configured to infer electrical parameters at the first circuit breaker based on electrical parameters sensed in the power distribution system.

34. A computer system in accordance with claim 28 further configured to:

determine a power distribution system software configuration corresponding to the determined level of redundancy;

determine a cost of implementing the power distribution system software configuration;

vary the determined level of redundancy; and

determine the power distribution system software configuration that facilitates optimizing the power distribution system cost.

35. A computer system in accordance with claim 34 configured to determine a cost of implementing the power distribution system software configuration wherein cost includes at least one of a production schedule cost, a resource cost, and a labor cost.

36. A computer system in accordance with claim 34 configured to determine the power distribution system software configuration that facilitates optimizing the power distribution system cost wherein said power distribution system cost includes at least one of a production schedule cost, a resource cost, a labor cost, a reliability cost, and an availability cost.

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