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(54) **HVAC SYSTEM FAULT ROOT CAUSE SELF-DETERMINATION**

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(57) **ABSTRACT**

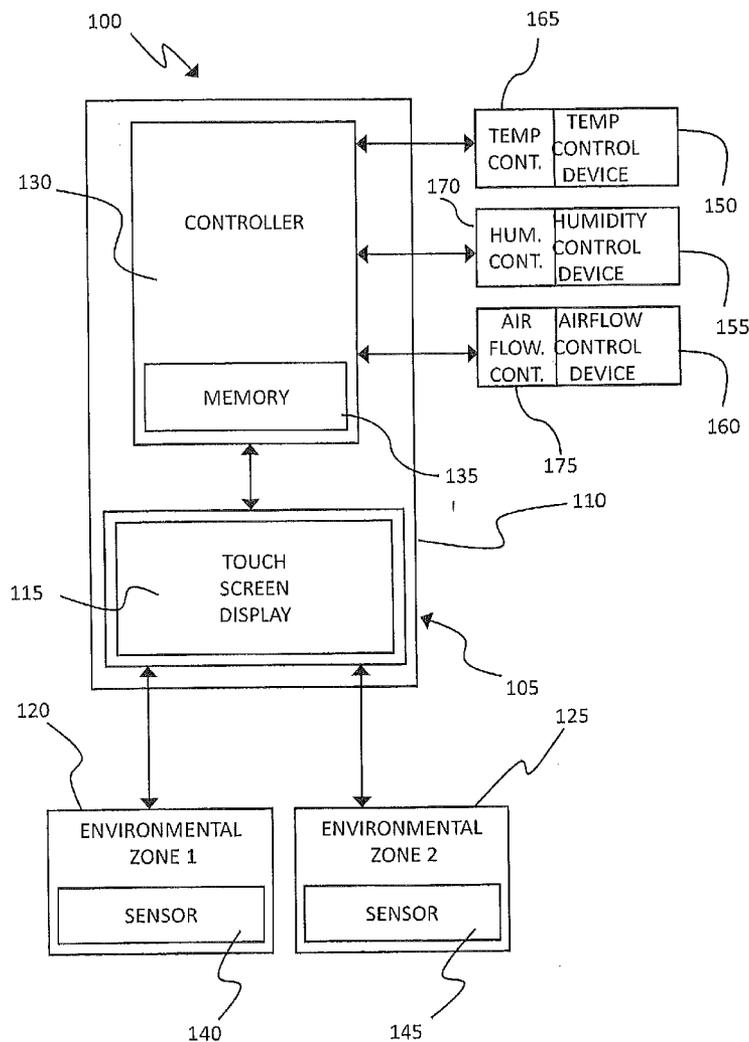
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A method for self-determining a root cause of a system fault in a heating, ventilation, and cooling (HVAC) system includes receiving a fault message indicative of a fault condition in an operating characteristic of the HVAC system; determining a causal relationship between the fault condition and a predetermined list of root causes associated with the fault condition; receiving information indicative of operating conditions of the HVAC system; and eliminating at least one root cause that is unrelated to the fault condition in response to the receiving of the information.

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Related U.S. Application Data

(60) Provisional application No. 61/590,934, filed on Jan. 26, 2012.



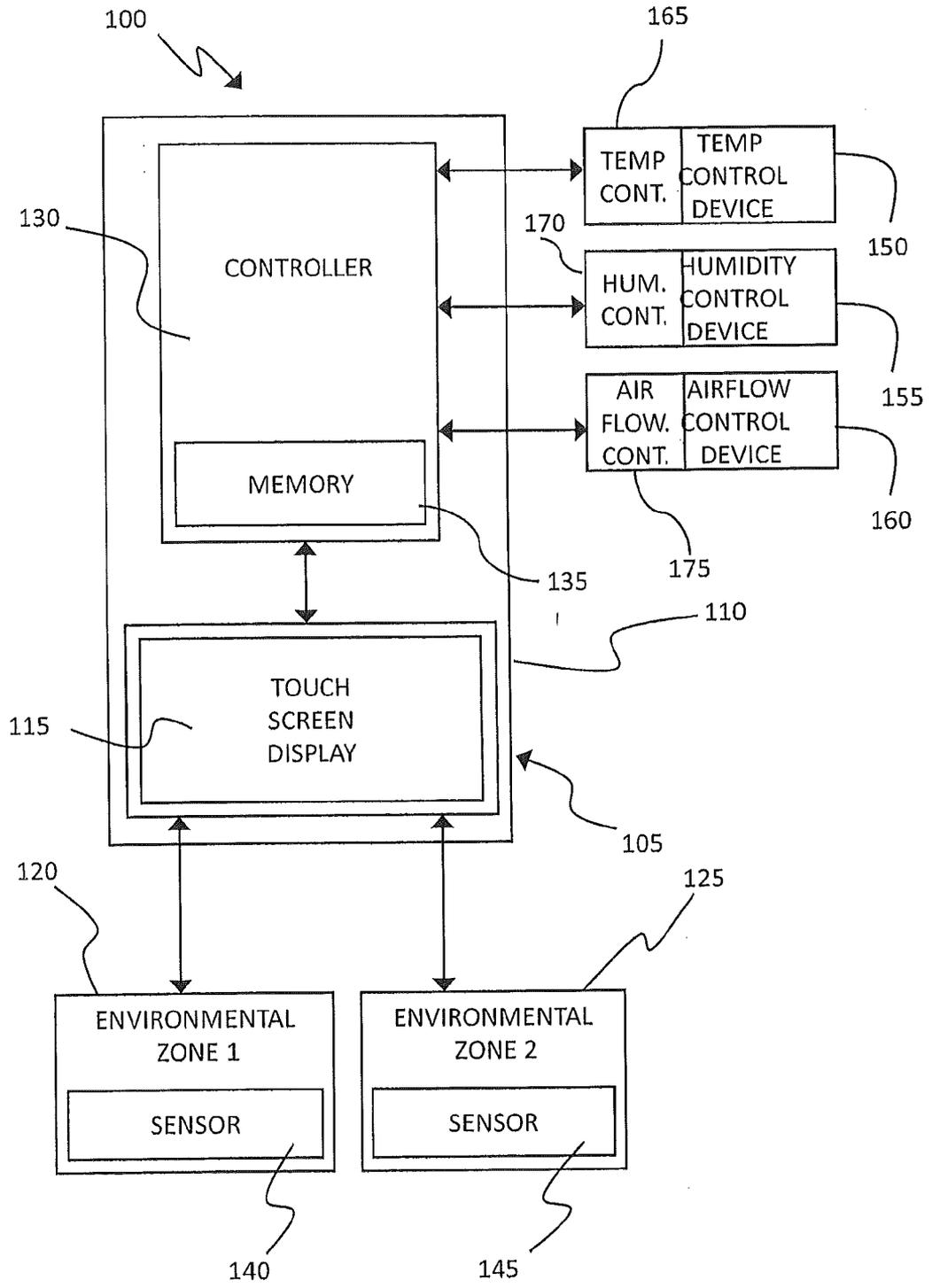


FIG. 1

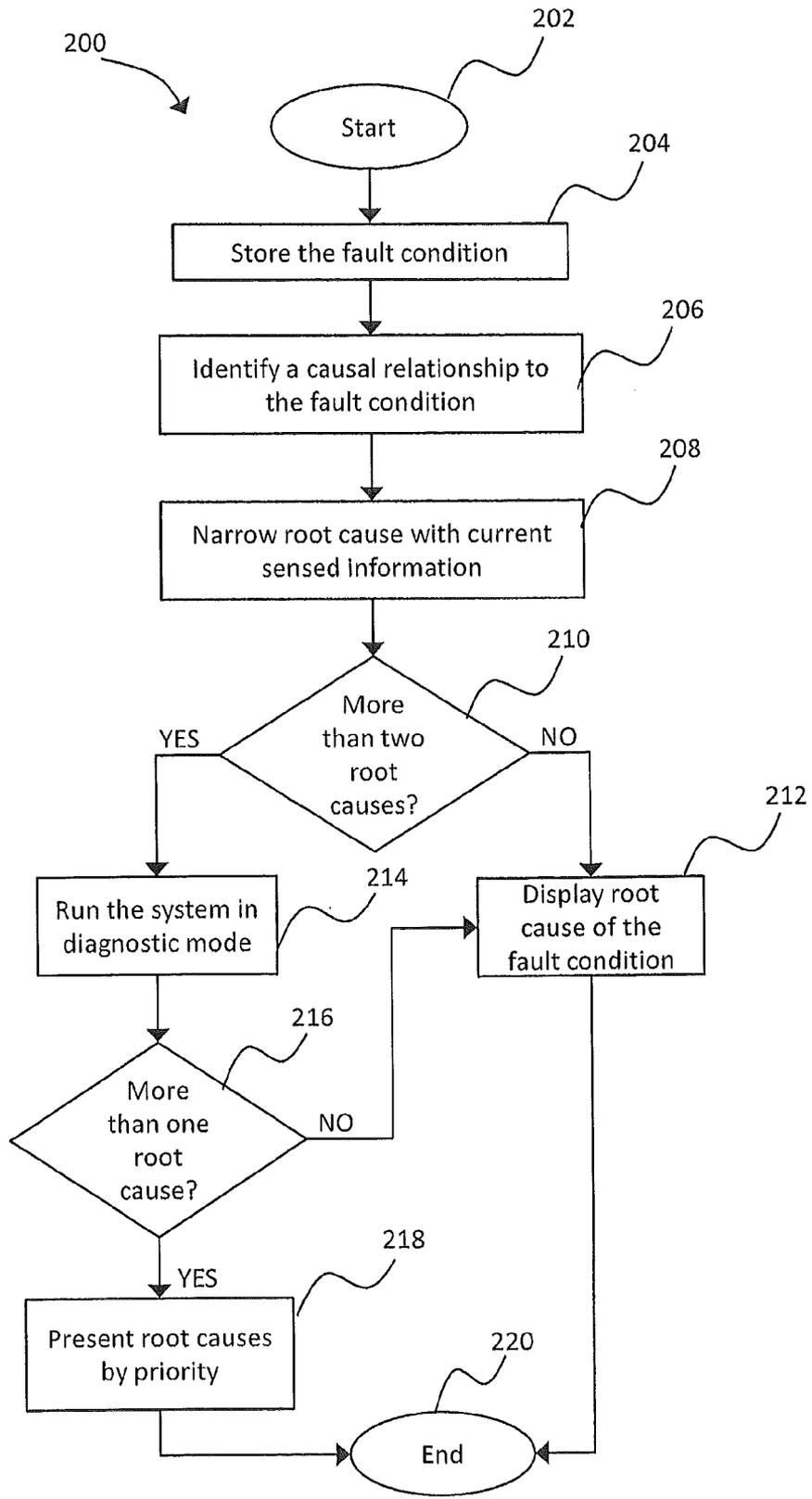


FIG. 2

**HVAC SYSTEM FAULT ROOT CAUSE
SELF-DETERMINATION**

**CROSS-REFERENCE TO RELATED
APPLICATIONS**

[0001] This application claims the benefit of U.S. provisional patent application Ser. No. 61/590,934 filed Jan. 26, 2012, the contents of which are incorporated by referenced herein in their entirety.

FIELD OF INVENTION

[0002] This invention relates generally to heating, ventilation, and cooling (HVAC) systems for residential or light commercial air conditioning applications and, more particularly, to a method and system for a root cause self-determination of fault conditions in an HVAC system.

DESCRIPTION OF RELATED ART

[0003] HVAC systems often do not function as well as expected due to faults developed during routine operation. While these faults are indicative of a failure mode, many faults do not result in immediate system shut down or costly damages. However, most faults, if unnoticed for a long period of time, could adversely affect system performance, life, and lifecycle cost.

[0004] Fault diagnostics refer to detection of faults and identification of solutions to the fault. A fault mode in one system component may cause issues in another component. Approaches to diagnostics may deal with direct measurement of monitored quantities as well as dedicated sensors for measurement of crucial system parameters in order to isolate the problem and provide a solution. Misdiagnosis of a root cause for the fault may result in good operating components to be replaced, resulting in repeated callbacks for a service technician and increased warranty costs. Additionally, dedicated sensors for diagnosis are typically costly to implement. Therefore, it is desirable to provide a method and system for self-determining a root cause in an HVAC system utilizing algorithms and sensors that provide a prompt and economical resolution of faults in an HVAC system.

BRIEF SUMMARY

[0005] According to one aspect of the invention, a method for self-determining a root cause of a system fault in a heating, ventilation, and cooling (HVAC) system includes receiving a fault message indicative of a fault condition in an operating characteristic of the HVAC system; determining a causal relationship between the fault condition and a predetermined list of root causes associated with the fault condition; receiving information indicative of operating conditions of the HVAC system; and eliminating at least one root cause that is unrelated to the fault condition in response to the receiving of the information.

[0006] According to another aspect of the invention, a method for self-determining a root cause of a system fault in a heating, ventilation, and cooling (HVAC) system includes receiving a first list associated with a plurality of fault conditions in the HVAC system; identifying a second list of root causes associated with a particular fault condition of the plurality of fault conditions; receiving information indicative of operating conditions of the HVAC system; and eliminating

at least one root cause from the second list of root causes that is unrelated to the particular fault condition in response to the receiving of the information.

[0007] According to yet another aspect of the invention, a programmable control unit for self-determining a root cause in an HVAC system includes a controller configured for receiving a fault message indicative of a fault condition in an operating characteristic of the HVAC system and for determining a causal relationship between the fault condition and a predetermined list of root causes associated with the fault condition; where the controller receives information indicative of operating conditions of the HVAC system and eliminates at least one root cause in response to the receiving of the sensed information.

[0008] According to yet another aspect of the invention, an environmental control system for an HVAC system includes a programmable control unit configured for establishing user desired environmental control parameters for one or more control zones; and at least one unit controller configured for storing information indicative of at least one system parameter for a control system, the at least one unit controller operatively coupled to the programmable control unit; where the programmable control unit or the unit controller is configured for receiving a fault message indicative of a fault condition in an operating characteristic of the HVAC system, for determining a causal relationship between the fault condition and a predetermined list of root causes associated with the fault condition, for receiving information indicative of operating conditions of the HVAC system, and for eliminating at least one root cause in response to the receiving of the sensed information.

[0009] Other aspects, features, and techniques of the invention will become more apparent from the following description taken in conjunction with the drawings.

**BRIEF DESCRIPTION OF THE SEVERAL
VIEWS OF THE DRAWINGS**

[0010] Referring now to the drawings wherein like elements are numbered alike in the FIGURES:

[0011] FIG. 1 is a schematic view of an environmental control system including a programmable controller for root cause determination in accordance with an embodiment of the invention; and

[0012] FIG. 2 is a flow diagram illustrating a method for determining a root cause of a fault condition in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

[0013] Embodiments of a system for root cause self-determination of a fault condition in an HVAC system include a control unit assembly including software for utilizing fault tree analysis techniques, predetermined system knowledge, and current sensed information that is received from one or more sensors during the time of the fault condition. In an embodiment, the control unit assembly includes an integrated controller for operating the system in a diagnostic mode in order to gather additional data needed to narrow the fault condition down to a single root cause. In other embodiments, where the root causes may not be narrowed to a single root cause, the control unit assembly utilizes historical probabilities of the system as well as cost information regarding the components in the system to present the root causes in an optimal order to a user, for example, a technician to fix.

[0014] Referring to FIG. 1, there is shown an example of an environmental control system 100 including a control unit assembly 105 for self-determining a root-cause of a fault condition or error associated with one or more environmental control zones in an HVAC system according to an embodiment of the invention. Particularly, environmental control system 100 includes a programmable control unit assembly 105 including a housing 110 and a user input/output device shown in the form of a touch screen display 115 that allows a user of the HVAC system to establish and view various environmental control parameters or conditions for one or more environmental control zones 120, 125 such as, for example, environmental parameters related to temperature, humidity and/or airflow in a first and second environmental control zone 120, 125. Also, as well as to provide fault conditions detected in any of the first and second control zones 120, 125 and root-causes of the fault conditions for a service technician to fix, which is shown and described below in FIG. 2. In other embodiments, programmable control unit assembly 105 may be used to control a single environmental zone, for example environmental control zone 120 or more than two environmental control zones. Further, programmable control unit assembly 105 includes an integrated controller 130 that is operatively connected to, in embodiments, a temperature control system 150 such as, for example, a gas furnace, air conditioner, and/or heat pump, a humidity control system 155 such as, for example, an air conditioner or a humidifier, and an airflow control system 160. The integrated controller 130 establishes user desired environmental control parameters such as, for example, temperature, indoor air quality, humidity and/or airflow for first and second environmental control zones 120 and 125 as well as self-determination of root causes in systems 150, 155, and 160 associated with a deviation in the desired environmental control parameters in zones 140, 145, as is shown and described below in FIG. 2.

[0015] In an embodiment, systems 150, 155, 160 include respective unit controllers 165, 170, 175, each having a processor and a memory (not shown) that stores local sensed information as well as information regarding predetermined system parameters for the respective temperature control system 150, humidity control system 155, and airflow control system 160 in order to eliminate root causes for fault detected within systems 150, 155, 160. It is to be appreciated that integrated controller 130 may be utilized to establish other user desired environmental control parameters in addition to indoor air quality control, and the like for first and second environmental control zones 120 and 125 as well as self-determination of root causes in these control zones 120, 125.

[0016] The touch screen display 115 causes fault conditions from, in one embodiment, desired environmental parameters, for example, temperature, humidity and/or airflow for the environmental control zones 120, 125 or fault conditions in temperature control system 150, humidity control system 155 and/or airflow control system 160, to be displayed to a technician including a reporting of one or more root causes the displayed fault condition. Additionally, the touch screen display 115 may provide information on one or more possible components to be replaced for components associated with the fault conditions in the environmental control zones 120, 125 and systems 150, 155, and 160. Also, controller 130 includes a processor and a memory 135 that stores various programs for execution including algorithms utilizing, in one embodiment, a fault tree analysis technique that is executed by the processor for self-identifying a list of

root causes of the fault conditions (i.e., predetermining a list of root causes) detected in the environmental control system 100. The processor of controller 130 can be any type of processor (CPU), including a general purpose processor, a digital signal processor, a microcontroller, an application specific integrated circuit, a field programmable gate array, or the like. Additionally, controller 130 receives information regarding parameters of system 100 as well as predetermined historical information regarding system 100 that are stored in memory 135, and utilizes these for narrowing down the list of root causes. In one embodiment, memory 135 stores information about the current sensed conditions at the time of the fault condition, which is received from the one or more devices 150, 155, 160 and one or more sensors 140, 145. In other embodiments, the memory 135 may store sensed information preceding the fault condition or sensed information generated during a root causes determination one or more programs stored in memory 135. It is to be appreciated that while controller 130 is shown integrated within programmable control unit assembly 105, controller 130 may, in an embodiment, be remotely located from housing 110.

[0017] In an embodiment, a process of narrowing the list of root causes of a particular fault condition can occur in several places in a coordinated manner. For example, one or more of the unit controllers 165, 170, 175, can begin the process of diagnosing a fault in its respective unit by starting from a predetermined list of possible root causes for the fault and, based on information available to, for example, unit controller 165, eliminate one or more of the root causes. In one non-limiting example, the unit controller 165 passes the narrower list of root causes to the integrated controller, 130, which then further narrows the list based on information available to it as well as information received from other units in the system. Furthermore, the integrated controller, 130, may transmit its narrowed list of root causes over a communication channel, such as a WiFi network or the internet, to a remote device such as, for example, a personal computer or a server. These remote devices may have additional databases with historical and other information related to the fault, which may be used to narrow the root cause list even further. The final narrowed list may be displayed to the technician or user on the touch screen display 115, as well as on any remote display such as on the personal computer or a smart phone. It is to be appreciated that any of the other unit controllers 170, 175 may also perform the process of narrowing the possible list of root causes as described above with respect to unit controller 165.

[0018] Referring now to FIG. 2, there is shown a flow diagram illustrating a root cause self-determination process 200 according to an embodiment of the invention. The process 200 includes self-determining a root cause of one or more system fault conditions in the environmental control system 100 or root cause in any of the systems 150, 155, or 160 (shown in FIG. 1) including self-determining the root cause to a system fault event in one system component that may cause issues in another component. In an exemplary embodiment, the root cause process 200 may identify a fault condition such as, for example, a low pressure on an outdoor unit (not shown) of a temperature control system 150 (FIG. 1), for example, an air conditioner or a heat pump unit, and accurately narrows the root cause to low indoor airflow from several other root causes such as, in some non-limiting examples, low refrigerant charge, faulty outdoor pressure switches, faulty outdoor expansion valve, faulty outdoor

reversing valve, or faulty outdoor compressor. While a single fault condition is described below, it is to be appreciated that a root cause of additional fault conditions may be determined by the environmental control system 100 utilizing a similar process 200 described herein. It is to be appreciated that a root cause elimination may occur within the controller 130 or any of the unit controllers 165, 170, 175 through a similar process as shown and described below.

[0019] The process 200 is initiated at 202, and, in 204, a fault condition such as, for example, low-pressure lockout in the cooling mode may be stored in the memory 135 (FIG. 1) for determining a root cause. The controller 130 may receive local sensed data or any other information from, in one embodiment, systems 150, 155, 160 and one or more sensors 140, 145, in order to determine fault conditions that cause the system 100 to deviate from user or system defined environmental parameters, e.g., temperature, humidity and/or airflow for the environmental control zones 120, 125 (FIG. 1). Further, controller 130 determines whether the received information indicates a deviation from the desired environmental parameters and presents these as a fault condition on display 115 (FIG. 1). This fault condition is stored in memory 135 (FIG. 1), in embodiments, as either error codes, for example fault code 83 and/or as a text message, for example “Fault 83: Low Pressure Lockout for 4 Hours”.

[0020] In 206, controller 130 (FIG. 1) determines a causal relationship between the fault condition and one or more root causes of the fault condition. In one embodiment, the controller 130 (FIG. 1) utilizes algorithms stored in memory 135 (FIG. 1) to implement a fault tree model such as, for example, a cause-and-effect diagram in order to identify a predetermined list of root causes associated with the particular fault condition. In an embodiment, the predetermined list of root causes associated with the fault condition are causally linked by the fault tree model within the controller 130 and may be accessed for each fault condition that is particularly detected by controller 130. In 208, the controller 130 analyzes the information on the current sensed conditions received from controllers 165, 170, 175 in the respective systems 150, 155, 160 using locally sensed information from systems 150, 155, 160 as well as predetermined information that are received about systems 150, 155, 160 substantially contemporaneous at the time of the fault condition or preceding the fault condition in order to eliminate unrelated root causes from the predetermined list of root causes and limit it to a single root cause for the fault condition. Particularly, the controller 130 (FIG. 1) analyzes the current sensed conditions obtained from, in embodiments, sensors 140, 145, temperature control system 150, humidity control system 155 and/or airflow control system 160 (FIG. 1) at the time of the fault condition or preceding the fault condition in order to eliminate one or more root causes not related to the fault condition.

[0021] In 210, if the sensed information indicates that there is a single root cause, then in 212, the single root cause is provided to the technician on touch screen display 115 including the solutions for fixing the particular fault condition. However, if the controller 130 determines that there may be several root causes associated with the fault condition, then, in 214, the controller 130 will run the system 100 in a particular diagnostic mode in order to generate additional specific data and further limit the possible root causes and eliminate unrelated root causes. In the diagnostic mode, the controller 130 is programmed for presetting the system 100 to predefined parameters associated with an operating charac-

teristic of the HVAC system that generated the fault condition such as, for example controlling the speed of the compressor or the speed of the indoor fan, in order to obtain additional data needed for eliminating one or more root causes of a particular fault condition. This additional information obtained is stored in memory 135 for additional fault diagnosis by the controller 130. In 216, if a single root cause remains after the diagnostic mode is implemented, then the root cause is provided to the technician on touch screen display 115 in 212. However, in 216, if more than one root cause remains then, in 218, the controller 103 utilizes the predetermined historical information regarding the probability or likelihood of a defect in one of the various components in system 100 that is associated with the fault condition to display a list of possible root causes in the order of priority for the technician to fix or address. In one embodiment, the root causes may be prioritized base on historical probabilities of the system 100 as well as the cost associated with replacing one or more components associated with the root cause. The process end at 220.

[0022] The technical effects and benefits of embodiments relate to an HVAC a system programmed for determining a root cause of a fault condition including software utilizing a fault tree analysis methodology, historical information of the HVAC system, and current sensed information for eliminating one or more erroneous root causes of the fault condition.

[0023] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. While the description of the present invention has been presented for purposes of illustration and description, it is not intended to be exhaustive or limited to the invention in the form disclosed. Many modifications, variations, alterations, substitutions, or equivalent arrangement not hereto described will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the invention. Additionally, while various embodiment of the invention have been described, it is to be understood that aspects of the invention may include only some of the described embodiments. Accordingly, the invention is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

1. A method for self-determining a root cause of a system fault in a heating, ventilation, and cooling (HVAC) system, comprising:

- receiving a fault message indicative of a fault condition in an operating characteristic of the HVAC system;
- determining a causal relationship between the fault condition and a predetermined list of root causes associated with the fault condition;
- receiving information indicative of operating conditions of the HVAC system; and
- eliminating at least one root cause that is unrelated to the fault condition in response to the receiving of the information.

2. The method of claim 1, wherein the receiving of the information further comprises receiving sensor information substantially contemporaneous with a time of the fault condition.

3. The method of claim 1, wherein the receiving of the information further comprises receiving sensor information regarding historical information of the HVAC system preceding the fault condition.

4. The method of claim 1, wherein the receiving of the information further comprises receiving predetermined sys-

tem parametric information for one of a temperature control, humidity control, and airflow control system.

5. The method of claim 1, further comprising operating the HVAC system in a diagnostic mode to generate additional operating information for the HVAC system, the operating information being related to the fault condition.

6. The method of claim 1, further comprising presetting the HVAC system to predefined parameters to eliminate additional root causes from the predetermined list.

7. The method of claim 6, wherein the predefined parameters are associated with the operating characteristic that generated the fault condition,

8. The method of claim 1, further comprising receiving historical information about the HVAC system and eliminating additional root causes from the predetermined list responsive to the receiving of the historical information.

9. The method of claim 1, wherein the controller comprises one of a system controller associated with at least one environmental control zone or one or more unit controllers associated with respective temperature control, humidity control, and airflow control systems.

10. The method of claim 1, further comprising providing to a user a related root cause in response to the eliminating of the at least one root cause that is unrelated .

11. The method of claim 10, wherein the providing of the at least one root cause further comprises displaying the at least one root cause on a touch screen display.

12. The method of claim 1, further comprising displaying a prioritized list of the root causes based on at least one of a predetermined historical information regarding the HVAC system, cost information regarding at least one component of the HVAC system, or a likelihood of the one or more of root causes based on a combination of the historical information and the cost information.

13. The method of claim 1, further comprising traversing a fault tree model to identify the predetermined list of root causes.

14. The method of claim 1, further comprising transmitting to a remote server information regarding a plurality of root causes associated with the fault condition via a communication network,

15. The method of claim 14, further comprising eliminating additional root causes from the plurality of root causes responsive to the transmitting of the information regarding the plurality of root causes.

16. A method for self-determining a root cause of a system fault in a heating, ventilation, and cooling (HVAC) system, comprising:

receiving a first list associated with a plurality of fault conditions in the HVAC system;

identifying a second list of root causes associated with a particular fault condition of the plurality of fault conditions;

receiving information indicative of operating conditions of the HVAC system; and

eliminating at least one root cause from the second list of root causes that is unrelated to the particular fault condition in response to the receiving of the information.

17. The method of claim 16, wherein the identifying of the second list further comprises determining a causal relationship between the second list of root causes associated with the particular fault condition.

18-30. (canceled)

31. A programmable control unit for self-determining a root cause in an HVAC system, comprising:

a controller configured for receiving a fault message indicative of a fault condition in an operating characteristic of the HVAC system and for determining a causal relationship between the fault condition and a predetermined list of root causes associated with the fault condition;

wherein the controller receives information indicative of operating conditions of the HVAC system; and wherein the controller eliminates at least one root cause in response to the receiving of the sensed information.

32-42. (canceled)

43. An environmental control system for an HVAC system, comprising:

a programmable control unit configured for establishing user desired environmental control parameters for one or more control zones; and

at least one unit controller configured for storing information indicative of at least one system parameter for a control system, the at least one unit controller operatively coupled to the programmable control unit;

wherein the programmable control unit or the unit controller is configured for receiving a fault message indicative of a fault condition in an operating characteristic of the HVAC system, for determining a causal relationship between the fault condition and a predetermined list of root causes associated with the fault condition, for receiving information indicative of operating conditions of the HVAC system, and for eliminating at least one root cause in response to the receiving of the sensed information.

44-55. (canceled)

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