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Motor leakage current detector, devices using same and related methods

Abstract

A motor leakage current detector and/or a heat compensating circuit, devices using same and related methods are disclosed herein. Included are a uniquely wired current transformer to allow for polarity agnostic leakage current detection, a leakage current detector using same and having a notifier to alert a user. In other forms, an accessory power cord and power strip are disclosed capable of detecting early motor failure conditions. In still other forms, other machinery failure early warning systems are disclosed as are numerous motor operated devices using same including without limitation pumps.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a continuation of prior application Ser. No. 17/219,101, filed Mar. 31, 2021, which claims the benefit of U.S. Provisional Application No. 63/004,356, filed Apr. 2, 2020, and U.S. Provisional Application No. 63/166,131, filed Mar. 25, 2021, both of which are all incorporated herein by reference in their entirety.

FIELD
(1) The present disclosure generally relates to an apparatus and methods for detecting a failure condition in an electric motor driven device and/or for addressing heat issues related to circuits, and, more particularly, to apparatus and methods for detecting leakage current in a motor driven device when the motor driven device is not operating and addressing heat dissipation issues in a circuit, and devices using the above, and related methods to same.
BACKGROUND
(2) Electric motor driven devices have been used for many years and have a wide range of applications. Many applications require the motor to turn on automatically and operate when certain conditions are present. Often in these applications, the failure of the motor to operate when the conditions are present has undesirable effects. It thus is desirable to know when a motor is predisposed to or starting to fail, so the undesired effects of a motor failure can be avoided. While there are many different types of motor driven devices and applications where the failure of a motor has undesirable effects, one example is a submersible sump pump. Many homeowners place submersible sump pumps in the sump pits in the basement of their home. When the water level in the sump pit rises to a certain level (e.g., when it rains), the pump will turn on and transport the water to a different location. If the sump pump fails and does not turn on, the homeowner's basement may flood and cause damage to the things in the homeowner's basement such as carpet or drywall. Electric sump pumps are generally powered via an AC power source that plugs into a home's AC power supply (or mains electricity, domestic power, grid power, etc.).
(3) Many common issues of sump pump failure are known, and many improvements have been made to sump pump technology. A common problem among sump pumps is that the mechanical float switch that detects the height of the water corrodes or otherwise breaks down over time and fails. This results in the pump failing to run even when the water level rises beyond the maximum allowable level. Some solutions to this problem have been to use a solid-state fluid level sensor or a pneumatic fluid level sensor rather than a mechanical float. This reduces the number of mechanical parts that are exposed to water that cause the mechanical floats to fail. Indeed, float switch failure is the most common problem associated with sump pumps and reason for their failure, however, there are other problems that can occur that are harder to detect.
(4) The next leading problem for pumps is motor failure caused by difficult to detect problems such as compromised insulation systems and/or water intrusion into the pump. These may be due to problems with the potting material used to encase the motor and waterproof it, or due to cracks in

the motor housing, etc. For example, water intrusion can be caused by the failure of a seal which allows water to leak into the motor cavity. Once water gets to the motor cavity, the insulation around the motor windings begin to gradually deteriorate causing a variety of electrical problems for the motor, such as a short circuit or ground fault. While the pump may continue to run for some period of time, once water gets into the motor, the motor of the pump will likely fail in the near future. These types of problems are not currently detected until the pump fails which is too late, particularly if the failure occurs when the pump is needed most in a storm or flood condition.

(5) Before discussing how the leakage current detector operates, the cause of the existence of leakage current will first be explained. Motors have windings that are encased in insulation. The insulation may be made of any material that is non-conducting, including non-conducting varnishes. This provides an insulative barrier between the motor windings and the motor housing or the cavity walls in which the motor is placed in. The insulative barrier prevents the motor windings from short circuiting across the windings or from leaking current to ground through the motor housing or other components that the motor may be near. Once in contact with water, the motor insulation degrades and deteriorates. This allows current to flow through or leak out of the motor through the degraded portion of the motor insulation. This can not only result in dangerous conditions, but also indicates that the motor will no longer operate properly once the degradation of the motor winding insulation has progressed further. The motor insulation may degrade due to age or other environmental conditions, not just due to contact with water. Thus, it has become important to know when this failure or degradation occurs so that action may be taken to prevent motor failure at an inopportune time.

(6) Similarly, motors are often encased in epoxy resin to waterproof the housing and/or protect electronics therein. This resin can breakdown over time as well and cause some of the same problems as those discussed immediately above. Thus, having the ability to detect motor leakage current and to monitor other features of the motor as will be discussed herein are very important and useful to detect issues in advance of them becoming major problems so that they can be reported to a user prior to any damage being done.

(7) Systems to detect leakage current exist, however, many systems require the motor to be running for leakage current to be detected. This is problematic in applications where a motor is only running when certain conditions are present, e.g., when water reaches a certain level. Using many of the existing leakage current detection systems, it could only be discovered that a motor exhibits failure conditions once the conditions requiring the motor to operate are present, which is often too late.

(8) Another limitation of existing leakage current detection system is that the system must know with certainty which conductor is the Neutral and which is the Line or Hot conductor. Standard electrical outlets in the U.S. are designed to provide this information, with code defining that the big prong receptacle on an electrical outlet is Neutral and the small prong receptacle is Line. Normally code also requires the wiring to be color coded (e.g., line/hot is black wire, neutral is white wire, ground wire is plain copper wire, etc.). Unfortunately, in many homes and buildings in the United States, care has not been taken to ensure that the electrical outlets are wired properly (e.g., sometimes wires are hooked to wrong prongs, sometimes a white wire is marked with electrical tape to indicate it is being used as a line/hot wire instead of neutral, etc.). Thus, when using many of the existing leakage current detection systems with electrical outlets that are wired backward, leakage current is not able to be detected. This results in motors not being identified as exhibiting motor failure conditions, ultimately resulting in an unexpected motor failure.

(9) Another problem with conventional circuits is their inability to address or dissipate heat in circuits, particularly those having an alternating current (“AC”) switch. In some devices, thermal cutoff switches are used to prevent a circuit from overheating and/or doing damage to the circuitry (or one or more components of the circuitry). This interrupts use of the circuit or device associated

with same which is not desirable. In alternate forms, large heatsinks are used to address the heat, but these can be expensive and/or require valuable space to be taken-up with the heatsink.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) Described herein are embodiments of systems, methods and apparatus for addressing shortcomings of known sump pumps.

(2) This description includes drawings, wherein:

(3) FIG. **1** is an exemplary block diagram for a leakage current detector in according with aspects of the invention;

(4) FIG. **2** is an exemplary circuit diagram for a leakage current detector used in connection with a pump;

(5) FIG. **3** is an alternate exemplary circuit diagram for a leakage current detector in accordance with aspects of the invention;

(6) FIGS. **4**A-C are top perspective, bottom perspective, and partial cutaway views, respectively, of a smart power cord assembly in accordance with aspects of the invention illustrating the power cord with one half of the housing removed in FIG. **1**C to show internal components;

(7) FIGS. **5**A-B are top plan views of an alternate smart power cord in accordance with the invention illustrating the housing in FIG. **5**A and illustrating the housing with a detailed overlay applied thereto in FIG. **5**B;

(8) FIG. **6** is a flow chart illustrating an exemplary leakage current detection routine in accordance with aspects of the invention;

(9) FIG. **7** is a flow chart illustrating an exemplary conductor test routine in accordance with aspects of the invention;

(10) FIG. **8** illustrates exemplary uses for the smart power cord disclosed herein and illustrates how it may be used with any motor driven device;

(11) FIGS. **9**A-C are front elevation, left-side elevation, and right-side elevation views, respectively, of an exemplary smart AC powered sump pump in accordance with aspects of the invention that utilize a leakage current detector and notifier;

(12) FIG. **10** is a right-side elevation view of an alternate smart AC powered sump pump similar to that shown in FIGS. **9**A-C, but illustrating an alternate way in which the fluid level sensor housing may be mounted to the pump;

(13) FIG. **11** is a front perspective view of an alternate battery back-up pump system utilizing the smart AC pump and smart power cord (or smart controller) disclosed herein along with a battery back-up DC pump, and illustrating a wireless communication interface between the smart controller and a smart battery;

(14) FIG. **12** is an exemplary circuit diagram for a leakage detector of an alternate configuration used in connection with a pump.

(15) Corresponding reference characters in the attached drawings indicate corresponding components throughout the several views of the drawings. In addition, elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of various embodiments. Also, common but well-understood elements that are useful or necessary in a commercially feasible embodiment are often not depicted or described in order to facilitate a less obstructed view of the illustrated elements and a more concise disclosure.

DETAILED DESCRIPTION

(16) This disclosure is directed to various apparatuses, systems, and methods for leakage current

detection and applications of same including without limitation an apparatus or device that detects whether leakage current in an electric motor, which may indicate to a motor operator that the motor exhibits conditions indicating the motor is predisposed to or starting to show signs it is going to fail. The devices, systems and methods disclosed herein are for identifying when a failure condition is present in a device, such as an electric motor driven/operated device, and notifying a user of the failure condition. The identified failure conditions may even be further analyzed and categorized as indicating that failure is imminent or that failure conditions are present, but immediate failure is not likely. In preferred forms, the apparatuses, systems and methods disclosed herein can conduct the leakage current detection test while the device is not in operation and provide early warning as to motor failure issues well in advance of a motor failure actually happening.

(17) The devices, systems and methods of this disclosure may come in many forms. For example, in FIG. **1** a block diagram of an exemplary embodiment is illustrated and referenced generally as smart controller **100** and includes a leakage current detector **110** and notifier **120** for indicating to the user a resultant of the test conducted by the smart controller **100**. The smart controller **100** is connected between a power supply **140** (e.g., domestic power supply, grid power, mains electricity, etc.) and a motor **150**.

(18) In a preferred form, the notifier will be one of a visual and/or audible device for alerting the user as to an outcome of a test conducted by the smart controller. The alerting may occur only if the leakage current detector **110** indicates early motor failure is detected, but in other preferred instances it may be configured to always provide a response (e.g., providing an alert of a first type if the motor has passed the test conducted by the smart controller **100** and an alert of a second type different than the first if the motor has not passed the test). For example, in a preferred form, the smart controller **100** will include a light or series of lights that provide a green light when the motor has passed the test, a yellow light when early signs of motor failure are detected and a red light when signs of urgent or imminent motor failure are detected. This can be accomplished in one multi-colored LED or it can entail using separate LEDs if desired. In other forms a more comprehensive display, such as a digital display, may be provided that provides additional information (e.g., text, images or symbols, etc.) regarding test results of the smart controller **100**.

(19) As mentioned above, the smart controller **100** may include an audible notifier **120** either in addition to the visual display or instead of the visual display. In a preferred form, the smart controller **100** will include both audible and visual devices for communicating test results of smart controller **100** to the user. In the form show, the audible sound is generated by a buzzer or speaker and may be configured to provide one sound, such as a chirp, to acknowledge the depressing of inputs and another sound, such as a longer and repeated beep or constant sound when either an early motor failure condition is detected, or an imminent motor failure condition is detected by smart controller **100**. In one form, the smart controller will chirp when an early motor failure condition is detected but change to a constant audible alert when a more urgent motor failure condition is detected.

(20) In the form shown in FIG. **1**, the notifier **120** of smart controller **100** may also include a communication circuit **130** for sending alerts or test results from smart controller **100** to a user that is located remote from the smart controller **100**. In some forms, this may be a wireless communication module that alerts the user via a local area network (LAN) or wide area network (WAN). In a preferred form, the communication module **130** will be a Wi-Fi enabled circuit that communicates the test results to the remote user via a Wi-Fi network the smart controller **100** is connected to so that the user may get the alerts on a mobile device, such as a smart phone. In alternate embodiments other forms of wireless communication may be utilized such as radio frequency (RF), infrared (IR), Bluetooth (BT), Bluetooth Low Energy (BLE), Near Field Communication (NFC), cellular, etc. While the preferred message will be in the form of text or graphics and text, in other forms an audio recorded message may be utilized as well (or instead of the text) advising of the test results.

(21) In a preferred form, the smart controller **100** is utilized with a software application (App) and is capable of monitoring voltage (V), current (A), current leakage to ground (leakage current) and phase angle. The device **100** via a processor (e.g., either onboard or remote via the cloud, etc.) can process the data to operate like an oscilloscope capturing both waveforms as well as phase angle between them. By knowing and recording the V, A, leakage current and phase angle, the smart controller **100** will be capable of detecting any of the motor driven device's parameters has fallen outside of normal levels. For example, a change in phase angle could indicate an issue with the motor's capacitor meaning the motor capacitor may need to be replaced. Unusual current may indicate the motor bearing is worn or rubbing and needs attention, or that an obstruction is present and needs to be cleared. Leakage current will indicate motor issues like those discussed herein (e.g., insulation breakdown, infiltration of fluid, etc.). Unusual voltage input can also be detected to alert of unstable conditions (e.g., poor power source or power cord, surge, etc.).

(22) In FIG. **2**, an exemplary circuit is shown for smart control **100**. For convenience, items in this embodiment that are similar to those discussed in FIG. **1** will utilize the same latter two-digit reference numeral but the prefix **2** instead of 1. Thus, the smart control of FIG. **2** is referred to generally by reference numeral **200** (instead of 100 as was used in FIG. **1**), power supply **240** (instead of 140) and motor **250** (instead of 150). In the circuit of FIG. **2**, the smart control **200** is connected between the power supply **240** and motor **250** of a sump pump **260** located in a sump **261**. The smart control **200** is connected to power supply **208** via power cord **201** which in turn is connected to a power resister, such as shunt resistor **211**, a current transformer **212** and triacs **213**, **214** which collectively serve as part of the leakage current detector **210**. The smart control **200** further includes a controller **202** connected to an audible alarm **221**, visual display, such as water level LEDs **222** and pump status LED **223** and Wi-Fi status LED **224**, and communication circuit, such as Wi-Fi module **230**. Collectively the audible alarm **221**, LEDs **222**, **223** and **224**, and communication circuit **230** serve as part of the notifier **220**. Water level LEDs **222** illuminate to represent how high the fluid level is in sump **261** (e.g., illuminating more LEDs as the water level rises). Preferably, multiple colors will be used to draw the user's attention to the fluid level LEDs **222** when the fluid level is getting critically high or too high representing a potential flooding condition. For example, in a preferred form, of the five LEDs show, at least the fifth LED will illuminate in red while the others illuminate in another color (e.g., blue, green, yellow, etc.) in order to indicate that the water level is critically high. In some forms, multiple colored LEDs will be used such as green or blue for low fluid level, yellow for intermediate fluid levels and red for high fluid level.

(23) Pump status LED **223** illustrates if the pump is operating correctly and in a preferred form will include a multi-color LED capable of glowing green to indicate the pump is ok, glowing yellow to indicate the pump has some problem with it (e.g., early motor failure conditions have been detected, or any other anomaly with the pump such as an unusual current or voltage draw possibly indicating an obstructed impeller, etc.) and glowing red to indicate the pump is not working correctly (e.g., an urgent motor failure condition has been detected by the testing of smart control **200**, or any other anomaly with the pump such as a thermal cut-off (TCO) switch has been triggered, extremely high or low voltages or currents detected, etc.). Wi-Fi status LED **224** illustrates if the smart control **200** is connected to Wi-Fi and/or the strength of that signal. In a preferred form Wi-Fi status LED **224** will be a multi-color LED capable of glowing green when the smart control **200** is connected to Wi-Fi and the signal strength is good, will glow yellow if the smart control **200** is connected to Wi-Fi but the signal is weak, and will glow red if the smart control **200** is not connected to Wi-Fi. It should be understood, that multi-color LEDs may be replaced by multiple single-color LEDs if desired and/or that the smart control **200** could alternatively be setup only to illuminate an LED when an error condition is detected (e.g., only illuminate a fluid level LED to indicate the fluid level is too high, only illuminate a pump status LED when the pump is not working or an imminent motor failure condition has been detected, only

illuminate a Wi-Fi status LED to indicate the smart control **200** is not connected to Wi-Fi, etc.).
(24) As shown in FIG. **2**, the smart control **200** includes an enclosure, such as housing **203** and utilizes a user input **204** to allow the user to interact with the smart control **200**. In a preferred form, the user input **204** is a multi-purpose or multi-function button that allows the user to manually initiate the smart control **200** to test the pump motor **250** of sump pump **260**. The input **204** may also be used by a user to mute the audible alarm **221** if it is activated. The input **204** may further be used to sync the smart control **200** to a local Wi-Fi network. In a preferred form, the smart control **200** will be setup via the user downloading an app from a software application store (e.g., Apple's App Store, Google Play, etc.) and the user will use the app and the multi-function input **204** to connect the smart control **200** to the local Wi-Fi and check the status of the smart control **200** remotely. In the form shown, the smart control **200** further includes a pressure transducer **205** for operating as the pneumatic or air switch for detecting fluid level in sump **261**. As will be discussed in later embodiments, the pressure transducer will be connected to an air chamber or housing via tubing to determine pressure changes that reflect changes in the fluid level of sump **261**.
(25) In operation, smart controller **200** is capable of performing a leakage current detection test while the motor **250** is not being operated because of the uniquely configured circuitry. As mentioned, this has the added benefit of reducing or minimizing background noise or interference that the operation of the motor would cause. The controller **202** uses triacs **213**, **214** to open one triac and thus power line (e.g., hot or neutral) and see if there is leakage to ground and then close that triac and open the other triac and power line (e.g., neutral or hot depending on which was opened via the initial triac) to see if there is any leakage to ground. If leakage to ground is detected, the smart control **200** will determine how critical the condition is and determine how to notify the user of same. In a preferred form, if the leakage detected is 0.05 mA to 0.1 mA, the smart control **200** will send an alert to the user via communication circuit **230** and change the pump status LED **223** to yellow. However, if the leakage detected is greater than 0.1 mA, the smart control **200** will not only send the user an alert via communication circuit **230**, but it will also trigger the audible alarm **221** and change the pump status LED **223** to red indicating a more urgent motor failure condition is present. These leakage current thresholds/ranges are exemplary and may be adjusted as desired for a particular motor operated device or application as desired.
(26) As mentioned above, the inventions disclosed herein may be implemented in numerous different embodiments. As an example, an alternate more simplistic circuit is illustrated in FIG. **3** for the smart control. In keeping with prior practice, items that are similar to those discussed above will use the same latter two-digit reference numeral but begin with the prefix **3** to distinguish this embodiment form other embodiments. Thus, in FIG. **3**, the smart control is referenced generally by reference numeral **300** which is connected between power supply **340** and motor **350**. In this form, first and second triacs, **313**, **314** respectively, are again in front of transformer **312**, but the circuit also includes additional resister or switch pairs **315**, **317** and **316**, **318** located behind transformer **312**. This circuit operates similarly to that of FIG. **2**, but lacks some of the functionality and additional features associated with the notifier/communication circuit, etc. In particular, isolation transformer **312** is a dual primary current transformer with triac **313** connecting the first primary coil (or Primary L (PR-L)) **312***a* to line or hot **340***a* and triac **314** connecting the second primary coil (or Primary N (PR-N)) **312***b* to neutral **340***b*. Again, that is assuming the wiring of the outlet the circuit is connected to is wired correctly. In operation the secondary coil (or SEC.) **312***c* is used with each coil **312***a*, **312***b* to conduct the leakage current detection test. First triac **313** is opened to test leakage current on neutral wire/line **340***b* and second triac **314** is opened to test leakage current on the line/hot wire/line **340***a*. This allows the leakage current detection test to be conducted without the need to have motor **350** operating. A benefit of this is that there is reduced or minimal background noise or interference when doing the test because the motor is not running. Not shown in the circuit is an audible alarm device (e.g., buzzer, speaker, horn, etc.), input for user interface and pressure transducer.

(27) In looking at the leakage current detector of the circuit of FIG. **3** more closely, the connection between the leakage current detector **310** and the electrical power supply lines of the motor **350** may be in the form of a transformer **312** placed in proximity to the Line wire and Neutral wire that collectively power the motor **220**. The transformer **312** may include a first primary coil **312***a*, a second primary coil **312***b*, and one secondary coil **312***c*. The first primary coil **312***a* is what should be the Line conductor wound into a coil and the second primary coil **312***b*, which is the Neutral conductor, wound into a coil. While it should only be necessary for the Line conductor to be the only primary coil, both the Line and Neutral conductors, are used as primary coils, because it cannot be known with certainty whether the electrical outlet the motor has been plugged into was wired correctly, i.e., that the Line is wired to the small prong receptacle and the Neutral is wired to the large prong receptacle. Using two primary coils allows the leakage current detector **310** to be indifferent to which power supply conductor is Line or Neutral (e.g., polarity agnostic). The secondary coil **312***c* is in close proximity to the first and second primary coils **312***a*, **312***b* so that current flowing in either the first or second primary coil **312***a*, **312***b* induces current flow in the secondary coil **312***c*. The secondary coil **312***c* has leads on either end of the coil that connect to the rest of the leakage current detection circuit **310**.
(28) The leakage current detector **310** is capable of detecting small currents, specifically, currents below those which a ground fault circuit interrupter (GFCI) or ground fault interrupter (GFI) will detect and interrupt the circuit. Many GFCI/GFI devices will not allow current to flow to a device when the leakage to ground is greater than 6 mA. The leakage current detector **310** may be designed and configured to detect current flow below that which a GFCI/GFI will interrupt the circuit, to detect the early signs of motor failure, before the leakage current gets above 6 mA. It should be understood that in other regions of the world GFCI/GFI are referred to as residual-current devices (RCD) or residual-current circuit breakers (RCCB).
(29) The Line and Neutral conductors (or wires) may be connected to the Line and Neutral terminals of an electric outlet, through a power cord. The leakage current detection circuitry **310** further includes a first switch **313** on the first conductor and a second switch **314** on the second conductor. These switches **313**, **314** are controlled by the leakage current detection circuitry **310** and allow the leakage current detection circuitry **310** to control whether each conductor is open or closed. These switches **313**, **314** may be switched to open or closed independently of each other.
(30) The leakage current detector **310** may test the condition of the motor **350** at set intervals. The condition of the motor **350** may also be detected by the leakage current detector **310** at any period of time or when prompted to do so (such as by the user requesting such through an App or via actuation of a physical button (like input **204**). In one example, the leakage current detector **310** performs its test periodically, for example, once a week, every 24 hours, every hour, every minute, every 30 seconds, every second, etc., although other periods of time are contemplated. In another example, the leakage current detector **310** is configured to test the motor **350** when another system of the motor driven device performs a diagnostic test. The leakage current detector **310** may be configured to automatically perform a test on the motor **350** when the motor (or in the preferred case pump) is connected to a power supply **340**, e.g., when plugged into an outlet or power is restored.
(31) In one embodiment, the leakage current detector **310** is configured to test the motor **350** immediately before the motor **350** is commanded to run. This could be in pump applications, for example, when water rises above a predetermined level. This may be done to ensure the GFCI/GFI will not trip and interrupt the circuit.
(32) In another embodiment, the motor or pump system includes a push-button like input **204** in the circuit of FIG. **2**, which can be pressed, for example, by a user to run the leakage current detection test. The push-button may also be used for any other test the system may be configured to run, for example, the push-button or another push-button may be pressed to determine whether the battery is sufficiently charged. The push-button can also be used for one or more other functions,

including, for example, to silence an alarm, deactivate a notification, re-set warning signals, start a test cycle, or the like.

(33) As mentioned, one benefit of the leakage current detector disclosed herein (e.g., **110**, **210**, **310**, etc.) is that the motor does not have to be running to do the test. Another benefit is that it is configured to be polarity agnostic so that it can make-up for situations where the wiring of the electrical socket the motor is connected to was not done correctly. To use such a tool, the motor need only be connected to the power source and then, without needing to operate the motor, the leakage current detector can test the circuit to see if there are signs of motor failure (e.g., motor insulation breakdown, fluid breach into the motor, etc.). For example, in FIG. **3**, the electric motor driven device and motor **350** are connected to the power supply **340**. The leakage current detector **310** receives a signal to test for leakage. This may be a signal prompted by the passing of a certain amount of time or initiated by the user as discussed above. The leakage current detector **310** then closes switch **313** and opens switch **314**. This allows electricity to freely flow over the closed first switch **313** and to the Line conductor. If the insulation of the motor **350** is still in good condition, there is no leakage current and no current will flow because the second switch **314** is open and the circuit is not complete. If the insulation of the motor has degraded or deteriorated to the point it has a low resistance through which current may flow, current will leak to the ground through the motor's insulation. This means that current will be flowing in the conductor coupled to the first switch. If the first switch **313** is connected to the Neutral conductor instead of Line conductor (not what is shown in the circuit of FIG. **3** but possible due to improper wiring in the outlet), then no current will flow regardless of the condition of the insulation of the motor. The leakage current detection circuitry **310** measures the amount of current that is flowing and may even record this amount.

(34) After measuring and recording the current flow, the leakage current detection circuitry **310** then opens the first switch **313** and closes the second switch **314**. The leakage current detection circuit **310** then measures and, if desired, records the flow of current. If the second switch **314** connects to the Line conductor (instead of Neutral conductor because of improper wiring), then current will flow if the insulation of the motor had degraded such that it has low enough resistance for current to flow to ground. The leakage current detection circuit **310** then determines whether the current flowing in the first or second test was an acceptable amount. Some current may flow when the motor **350** is connected to the Line conductor even if the motor insulation is in good condition. This can be because the motor insulation resistance is not infinite, so some current will flow through the insulation to ground. Small amounts of this leakage current may be acceptable, and not indicate any immediate concern of the condition of the motor **350**. If the current flowing was greater than an acceptable amount, the leakage current detection circuitry **310** may communicate this to a notifier circuit (not shown but see **120** and **220**). In another example, the leakage current detection circuit **310** communicates the amount of current flow detected to another circuit, such as the notifier circuit, which will then determine if the amount of current flow is not acceptable.

(35) In a preferred form, the circuit of FIG. **3** would also include a notifier such as that discussed with respect to FIG. **2**. In a preferred form, the notifier would provide a user with an alert when a failure condition has been detected in the one or more devices plugged into the accessory or, in instances where the smart controller is integrated into an OEM product, the single device itself. The notifier is a notification system to alert a user or another portion of the system that a leakage current has been detected or that some other fault has been detected with respect to the pump (e.g., anomaly relating to current draw, voltage draw, phase shift, etc.). The notifier circuit may be a separate circuit or a portion of the leakage current detector **310**. The notifier may be configured to alert a user in response to a determination by the motor leakage current detector **310** that a leakage amount greater than a predetermined amount has been detected, for example, greater than 0.05 mA. For example, the notifier may alert a user when an impermissible leakage current is detected by sending an alert to notify the user or operator. To alert the user when leakage current has been

detected, there may be a light or multiple lights disposed on the top surface of the smart controller that light up when a failure condition has been detected. In another example, there are two lights, each being a different color. The lights may be LEDs and may even be a single multi-colored LED. The first color light may be configured to illuminate when a failure condition is present, for example, the leakage current detection circuit **310** detected a current flow of 0.01-0.05 mA. The second color light may be configured to illuminate when an imminent motor failure condition has been detected, for example, when a leakage current in the range of 0.05-0.6 mA has been detected. The smart controller may also include an audible device, such as a speaker or a buzzer, to alert the user to either of the two conditions, for example, by a sound such as a beeping or alarm noise. The speaker or buzzer may be used in combination with a light illuminating to alert users to a failure condition or may be used by itself.
(36) In another example, the notifier includes communication circuitry like **130** discussed above in FIG. **1** configured to transmit a notification to a user. This may be performed using, as examples, one or more of wireless fidelity (Wi-Fi), Cellular, radio frequency (RF), infrared (IR), Bluetooth (BT), Bluetooth Low Energy (BLE), Zigbee and near field communication (NFC). Other wireless protocols may also be used. In one example the alert produced by the notifier is transmitted to a display screen viewable by an operator. This may be, as example, a computer or smartphone screen.
(37) The notifier may be configured to use more than one method of communication to a user. In one embodiment, the wireless communication circuitry is configured to communicate via an internet connection as the primary way of notifying a user of a failure condition, but, if the internet connection is not available, the communication circuitry may be configured to communicate via a direct wireless connection, such as NFC as an example. In another embodiment, the notifier both sounds an alarm through a speaker and sends a notification to a user's smartphone through the internet over Wi-Fi when a failure condition has been detected.
(38) The notifier may be configured to categorize the degree of the motor failure condition. For example, the notifier may send an alert when it detects the leakage current is within a certain range, for example, less than 0.05 milliamps and configured to send an alarm when the current is detected to be between 0.05 milliamps and 6 milliamps. The alert would notify a user when a motor failure condition exists that does not require immediate attention, and the alarm would notify a user that an imminent motor failure condition exists upon hearing or seeing the notifier alarm. As examples, the alert may be a flashing LED, while the alarm may be an alarm sound playing through a speaker.
(39) The categorization of the degree of seriousness of the motor failure condition may be determined at least based in part on the amount of leakage current flow. The amount of leakage current can be used to categorize the leakage current to mean either a failure condition is present, or a failure is imminent. In a preferred form, the audible device will be a piezo alarm that goes off when a certain or first leakage current threshold is met or exceeded. For example, if the leakage current detected is below 0.1 mA the piezo buzzer or alarm may chirp at a consistent interval to alert the user to the condition. If the leakage current detected exceeds a second threshold (e.g., over 0.1 mA) the chirp may get louder and/or more frequent or may even become a constant sound to alert the user more urgently. In other forms, the audible device may be configured to actuate only after a period of time has passed since the fault or error condition was first detected and reported. For example, the system may be configured to alert the user via the App initially and then use the audible device to escalate the matter by sounding an alarm after a period of time has expired since the first notice without any corrective action or measures being taken.
(40) In FIGS. **4**A-C, a smart power cord is shown with the smart control circuit illustrated in FIG. **3** above (meaning it is a more simplistic version). In keeping with prior practice, features of this embodiment that are similar to those discussed above will include the same latter two-digit reference numerals, but use the prefix **4** to distinguish this embodiment from others. Thus, the power cord is referenced general as power cord **401** and smart control **400**. The smart control **400**

of power cord **401** has an enclosure or body **403**, and the power cord **401** has an electrical plug **406** to connect the power cord **401** to a power supply (obviously the plug types will differ depending on the region of the world this power cord **401** will be used). The enclosure or body **403** includes a speaker opening **403***a* and has a user input **404** for allowing the user to interact with the smart control **400**. The power cord continues on from the smart control **400** to the motor (not shown) on the opposite side of smart control housing **403** as the plug **406** is on, along with an air tube **405***a* which is connected to the pressure transducer (not visible).

(41) As can best be seen in FIG. **4**C, the body or enclosure **403** encloses a circuit board **407** containing the audible device **421**, power circuitry **408** which drops the AC power down to DC for use by smart control **400**, current transformer **412**, pressure transducer **405**, first triac **413** and second triac **414** and heatsink **409** which is connected to the power circuitry **408** and triacs **413**, **414** and, in a preferred form, also serves as the earth ground for a portion of the circuit. Thus, the line/hot wire **401***a* and neutral wire **401***b* of electrical power cord **401** come in from the plug end **406** of the power cord **401** and connect to the printed circuit board (PCB) **407**, then are connected to the power circuitry **408**, transformer **412** and exit the PCB **407** at an opposite end thereof. The ground wire **401***c* comes in and connects to one end of heatsink **409** and exits the opposite end of the heatsink **409** before exiting the housing/enclosure **403** and back into the power cord **401**. The pressure transducer tubing or air tube **405***a* may connect to pressure transducer **405** and exit the house adjacent or proximate the power cord **401** and, preferably, substantially or generally parallel thereto. In the form shown, the smart controller housing or enclosure **403** includes a receiver sleeve **405***b* to align the air tube **405***a* passing through the enclosure **403**. In a preferred form, the receiver sleeve **405***b* will actually serve a strain relief role hindering the air tubing **405***a* from being pulled out of the smart controller **400** or disconnecting from transducer **405**. In alternate forms, however, it should be understood that the air tube receiver **405***b* could alternatively be a tube coupling that allows a segment of air tubing to be connected between the transducer **405** to the coupling and another segment of air tubing to be connected externally to the smart control from the external portion of the coupling to the air tube housing located on the pump.

(42) While FIGS. **4**A-C illustrate the smart power cord **401**, it should be understood that this power cord could be sold as an accessory to connect to existing electrical motor driven products to detect early motor failure via leakage current detection. Alternatively, the smart power cord **401** may be a permanent or integrated feature included on the power cord of the motor driven devices, for example, manufactured as part of the power cord from the factory (instead of as a standalone component or accessory, that may be attached by a user to their motor driven device).

(43) In FIGS. **5**A-B, an alternate form of the smart power cord is illustrated that is configured for the circuit discussed above in FIG. **2**. In keeping with prior practice, features of this embodiment that are common to earlier ones will use the same latter two-digit reference numeral but use the prefix **5** to distinguish this embodiment from others. Thus, the smart power cord is referred to general by reference numeral **501** and includes smart control **500**. The power cord **501** enters the power control housing or enclosure **503** on one end and exits on another and preferably opposite end with the air tube **505***a* positioned proximate to the exiting portion of the power cord **501**. The housing or enclosure **503** includes an audible device opening, such as buzzer, speaker or horning opening **503***a*. Unlike the prior embodiment of FIGS. **4**A-C, however, the embodiment of FIGS. **5**A-B has the user input **504** positioned proximate the audible device opening **503**. Below that (as illustrated in FIGS. **5**A-B), is located the fluid level LEDs **522**. In the form shown, those LEDs **522** are positioned off to a side of housing **503** so that a graphical overlay **522***a* can be placed showing what the water level LEDs **522** are indicating as illustrated in FIG. **5**B. As shown, the graphical overlay **522***a* displays an inverted pyramid indicating the detected water level. As the water level rises, the LEDs associated with a level indicated by the graphical overlay **522***a* may light up. For example, when the water level is low, only the lowest LED is lit. As the water level increases, the LEDs may sequentially light up until the water level is high, at which point the uppermost LED

illuminates. The LEDs **522** may be multi-color LEDs that illuminate a color indicating a severity associated with the detected water level. As one example, if the water level is low, the LEDs that are lit may be green. When the water level is high, the LEDs may be red and may be flashing to indicate to the user that the water level is high. When the water level is in between low and high levels the LEDs may be yellow or orange as examples. In one form, the LEDs are configured to illuminate only a single color. For example, the uppermost LED associated with a high water level may illuminate red when lit. The lower LEDs may illuminate a color indicating a lower level of severity such as blue or green.

(44) Next, the pump status LED **523** is positioned preferably centered on the housing and with room for graphical information **523***a* below or above the LED **523** as illustrated in FIG. **5**B. As one example, the graphical information may display "Pump Status," "Green—OK", Yellow—Failing," and "Red—Replace." The pump status LED **523** may accordingly be a multi-color LED configured to illuminate a certain color to indicate to the user the status of the pump. The pump status may be determined by evaluating and weighing a plurality of inputs. For example, the pump status may be based on one or more of a water level, elapsed time, pump run time, current draw, supply voltage, inrush current, power factor, and detected amount of leakage current. The smart power cord processes the data and presents a status of the pump based on one or more measured conditions to provide the end user with a simple indication of the status of their pump. In some forms, the smart power cord may communicate the data to a remote processing device such as a server computer for processing and a determination of the pump status. The smart power cord may receive the pump status from the remote processing device and display the pump status via the pump status LED **523** to the end user.

(45) The Wi-Fi status LED **524** is located next and preferably centered with room to provide graphical information **524***a* below or above as well (like illustrated in FIG. **5**B). As one example, the graphical information **524***a* may display "Wi-Fi Status," "Green—OK," "Yellow—Connecting," and "Red—No Connection." The Wi-Fi status LED **524** may accordingly be a multi-color LED configured to illuminate a certain color to indicate to the user the Wi-Fi connectivity status. The power cord **501** then exits the smart control housing **503** along with air tube **505***a*. In this way, the power cord **501** and air tube **505***a* can easily be coupled to one another via a connector, such as a cable tie/zip tie if desired, so as to maintain a clean looking configuration.

(46) FIGS. **6** and **7** illustrate flow charts for a preferred form of operation of the smart controls illustrated herein. In FIG. **6**, a leakage current test routine starts at step **680** and a leakage current test is performed on the first and second conductors (e.g., Line and Neutral wires) in step **681**. In step **682**, the routine asks if a leakage current issue exists. If not, the routine returns to start **680**. If so, the routine alerts the user in step **683** and then ends in step **684** until the next leakage current test is to be conducted at which time the routine starts back over at step **680**. In FIG. **7**, an exemplary test sub-routine is shown that may be used by the routine of FIG. **6** to detect if a leakage current issue exists. In the subroutine of FIG. **7**, the routine starts at step **690** and asks if the leakage current on either conductor tested is equal to or greater than 0.05 mA. If not, the routine ends at step **695**. If so, however, the routine then checks to see if the leakage current detected on either conductor is greater than 0.1 mA. If not, the routine alerts the user in step **693** and ends via step **695**. If it is greater than 0.1 mA, the routine not only alerts the user, but also actuates an alarm in step **694** as a more critical motor failure has been detected and ends in step **695**. As mentioned above, these threshold figures of 0.05 mA and 0.1 mA are preferred for a pump application, but may be adjusted depending on the application the test is to be used for (e.g., thresholds may differ depending on type of motor being tested, type of product being tested, if higher or lower thresholds are desired for initiating alerts and/or alarms, etc.).

(47) While the above embodiments show the smart control having power cords extending from opposite ends, it should be understood that in other embodiments, the smart control could alternatively have a power cord on one end and an electrical socket located elsewhere on the smart

control housing that the power cord of an electric motor operated device would simply be plugged into in order to get the benefit of the smart control. In this way, the smart power cord would be more of an accessory for attaching to existing electric motor operated devices.
(48) In some forms, the smart power cord would have numerous such electrical sockets that electrical devices can be plugged into so that it operates like a smart power strip capable of detecting early motor failure or critical motor failure issues for all devices plugged into the strip. The power strip would be able to detect when one of the electric motor operated devices plugged into it is exhibiting early or imminent motor failure conditions and notify the user of same so that the user can test the devices individually to determine which was exhibiting the motor failure condition detected. Alternatively, LEDs may be provided by each outlet to indicate which device/power cord has exhibited the early or imminent/urgent motor failure concerns.
(49) As mentioned above, however, in alternate forms the smart control would simply be integrated into OEM products instead of being an accessory for same. As also mentioned above, the smart controller may be used with any type of electric motor operated device. For example, in FIG. **8** applications for such a smart control **800** with power cord **801** include numerous different appliances such as washers or dryers **870** or blenders **871**, vehicles **872** (e.g., electric vehicles), and other pumps **873**. Thus, it should be understood that any motor operated device that could benefit from such a leakage current detection to detect early or imminent motor failure is intended to be covered by the disclosure herein.
(50) As an example of an original OEM product having a smart control integrated therein (rather than as an accessory capable of being connected and disconnected therefrom), FIGS. **9**A-C illustrate a submersible pump having such a smart control. In keeping with prior practice, the same latter two-digit reference numerals will be used for items similar to those discussed above with the prefix **9**. Thus, in these figures, the pump is referenced generally by reference numeral **960** and includes a motor housing **962**, cap **963**, water handler, such as volute **964**, with a discharge outlet **964***a* having an air switch mount or bracket **965** for supporting an air switch housing **905***c* and an outlet coupling **966** to which a discharge pipe may be coupled. The pump **960** can be any type of pump as mentioned above and may be a top suction type pump, a bottom suction type pump or a combination of both as shown in Applicant's U.S. Patent Application Publication 2018/0128272, published, May 10, 2018, entitled Dual Inlet Volute, Impeller and Pump Housing for Same, and Related Methods, which is incorporated by reference herein in its entirety. The pump illustrated is a top suction pump with a filter **967** located above the volute **964**. The motor is sealed in the housing **962** by epoxy resin and cap **963**, however, it is these sealing features that can breakdown and lead to motor leakage current that ultimately leads to motor failure. Hence, by pairing pump **960** with a smart controller **900** affords the pump **960** the ability to provide early motor failure detection and even imminent motor failure warnings.
(51) In the form shown, the power controller **900** is configured on the circuit of FIG. **2** and layout of FIGS. **5**A-B and the air switch housing **905***c* is mounted to the pump **960** via a bracket that fits into the discharge **964***a* of water handler or volute **964**. In a preferred form, the air switch housing **905***c* fastens to the mount or bracket **965** via depressible clips or hooks that can easily be squeezed together to release the housing **905***c* from mount or bracket **965** if desired such as for assembly, repair or replacement. The clips engage mating surfaces formed by recesses in the air housing mount or bracket **965** to secure the air switch housing **905***c* to the bracket **965**. Coupling **966** has male threading that allows it to be inserted through an opening in the air housing mount or bracket **965** and threaded into mating female threading in outlet **964***a* of water handler/volute **964** to secure (e.g., sandwich or clamp) the air housing mount bracket **965** between the coupling **966** and outlet **964***a* of volute **964**.
(52) As best seen in FIG. **9**C, the air switch housing further includes a spacer **905***d* that is used to ensure the air switch housing **905***c* will maintain adequate spacing from pump housing **962** regardless of what size pump and pump housing is used. In alternate embodiments, however, the air

switch housing **905***c* may be connected to the pump in different manners. For example, in FIG. **10**, an alternate pump is illustrated and referenced as **1060**. In this embodiment, the pump includes a capacitive fluid level sensor where the sensor housing **1005***c* is connected to the pump **1060** via a fastener, such as one of the assembly bolts **1068** that is used to connect and secure the pump cap **1063**, housing **1062**, filter **1067** and volute **1064** together. In the form shown, the sensor housing **1005***c* has three protrusions or arms extending from the housing that define coaxial openings through with the motor assembly bolt **1068** to capture the air switch housing **1005***c* on the bolt **1068** and preferably between the motor cap **1063** and filter **1067**. While the embodiment of FIG. **10** shows a capacitive fluid level sensor, it should be understood that in alternate embodiments a pneumatic pressure sensor could be mounted to the pump **1060** in a similar way, e.g., the air switch housing of the pneumatic pressure sensor could be similarly mounted to an exposed bolt **1068** of the pump housing **1062**.

(53) In the form shown in FIGS. **9**A-C and as best seen in FIG. **9**B, the smart controller **900** will preferably have additional heatsinks **903***a*, **903***b* that are visible on the exterior of housing **903** of the smart controller **900**. These additional heatsinks allow the electronics located within housing **903** to further dissipate heat generated from the power circuitry and mainly the transformer and triacs on the PCB. In alternate forms, external heatsinks such as **903***a*, **903***b* may not be used, however, in the instant circuit they are in order to reduce heat associated with the product.

(54) While the pump embodiments discussed up to now have been single pump systems, it should be understood that the smart controller disclosed herein may be used in multiple pump systems as well. For example, in FIG. **11** there is illustrated a battery back-up sump pump system. In keeping with practice, similar items in this figure will be marked with similar latter two-digit reference numerals and the prefix **11** will be added to distinguish this embodiment from others. As shown, the system includes a first smart AC pump **1160** having a smart controller **1100** and a battery backup DC pump **1169** that is powered by a battery **1174** when power is lost to the main AC pump **1160**, such as due to a power outage, tripped breaker/fuse or ground fault circuit interrupter (GFCI) or ground fault interrupter (GFI) (also known as a residual-current device (RCD) or residual-current circuit breaker (RCCB)).

(55) In the form shown, battery **1174** is a smart battery such as a Lithium Ion battery (Li-ion battery) with a wireless communication circuit capable of communicating with smart control **1100** of AC pump **1160**. In a preferred form, the wireless communication technique used is Bluetooth (BT) communication, but in alternate forms it may be any other communication technique like those discussed above (e.g., radio frequency (RF), Bluetooth low energy (BLE), near field communication (NFC), Wi-Fi, cellular, or other communication technique used by Internet of Things (IoT) devices, etc.). In this way, the smart battery **1174** is capable of communicating to smart controller **1100** pertinent information relating to the smart battery to alert the user to any anomaly detected with same and vice versa (smart control **1100** is capable of communicating its data back to smart battery **1174**). For example, the smart battery **1160** is capable of communicating to smart control **1100** information regarding the battery's voltage, amperage, state of battery health or state of health (SOH), state of battery charge or state of charge (SOC), etc., so that this information may be conveyed to the user via the app used in connection with the smart control **1100**. Thus, during normal operation (e.g., not a power outage or the like) the smart control **1100** can not only relay information to the user regarding smart AC pump **1160**, but also relating to the battery back-up system.

(56) In some forms, the smart control **1100** may have its own internal battery to power itself even during a power outage so that it can continue to provide information relating to the pump system or sump **1161**. In such instances, the smart control **1100** could convey the information back to the smart battery **1174** and allow the smart battery **1174** to relay that information to the user via the app due to the ability of the back-up system to run off the battery power of smart battery **1174**.

(57) One benefit to the setup illustrated in FIG. **11** is that a simple battery charger **1175** may be

used with the system instead of needing something more complex (more expensive, more energy consuming, etc.). Another benefit is that Li-ion batteries are very easy to monitor in this way and, thus, would be preferred for such applications. However, it should be understood that in alternate embodiments, the battery charger could be battery backed-up smart charger as well and capable of communicating with any one or more of the AC pump **1160**, DC pump **1169** and/or battery **1174**. In some embodiments, all the system components (e.g., AC pump/smart controller, DC pump, battery and battery charger) may be smart, however, that would be for a very high-end system. Normally, it would be preferred to have smart controller **1100** and only one of the battery **1174** or battery charger **1175** be "smart" as well (or equipped with reporting/communication capabilities) in order to keep the cost down and of those, it would make most sense to have the smart battery as the battery charger is not an essential component and would simply use-up more battery that could otherwise be focused on the operation of the DC pump **1169**.
(58) In the above pump examples, the pumps include a fluid level detector to control the pumping of fluid by the system. The fluid level detector monitors the level of the fluid. When the fluid rises to or beyond a predetermined level, the fluid level detector is configured to detect the rise in fluid and cause the power cord accessory **100** to turn on and/or deliver power to the pump motor. The fluid level detector may be a pneumatic pressure tube or switch. More details of such a switch may be found in Applicant's U.S. Patent Application Publication Nos. 2017/0175746, published Jun. 22, 2017, entitled Integrated Sump Pump Controller With Status Notifications; and 2018/0163730, published Jun. 14, 2018, entitled Pump Communication Module, Pump System Using Same and Methods Relating Thereto, which are hereby incorporated by reference in their entirety. In the forms shown, a tube may be connected to the transducer and pass through the air tube receiver and down into a sump pit. Use of a pneumatic pressure switch reduces (if not eliminates) the number of moving mechanical parts, which can result in an increase in system reliability. The pressure tube has a pressure tube inlet, and is connected to a switch device (e.g., the transducer), which may be contained within the smart controller as shown previously.
(59) Such systems may evoke additional steps to ensure that the air tube is back to atmospheric pressure. For example, the pneumatic pressure switch system can be configured to flush air after a predetermined period to recalibrate and eliminate problems with condensation build-up or tube leakage. The pneumatic pressure fluid level detection system may alternatively employ sensors that are adapted to operate so that the water level is held below an opening. In this manner the fluid level in the sump pit maintains a certain level with respect to the fluid level in the tube (e.g., the pit and tube fluid levels do not have to be equal or level with one another, but rather simply correlate with one another so that the level in the tube can be used to calculate a corresponding level of fluid within the pit). Further, in some examples, the systems will be configured to turn on after a predetermined time so that the air in the tube returns to atmospheric pressure. In a preferred form, the system will be configured to detect when the pressure reading from the air switch indicates a high fluid level has been reached, will operate the pump to draw fluid down and then will stop the pump once a substantially constant pressure reading has been reached as that will mean the air switch has returned to atmospheric pressure. The reason a particular pressure value is not looked for in determining when to stop the pump but rather a constant pressure is that looking for a particular pressure value would require the pump to be calibrated (possibly often) and would require knowledge of where the pump will be used or in what type of application as the particular pressure value might be different based on elevation or application (e.g., is it used on a regular sump pump application, is it being used in a sealed radon sump system, etc.). By not requiring a specific or particular pressure value to be looked for and rather just a generally or substantially constant pressure value to be seen, the system does not have to worry about these other details/factors and simply knows this means to shut the pump off when this condition is detected.
(60) In still other forms, a solid state fluid level switch may be used such as those disclosed in Applicant's U.S. Pat. No. 8,380,355, U.S. Patent Application Publication No. 2013/0156605,

published Jun. 20, 2013, entitled Capacitive Sensor and Method and Apparatus for Controlling a Pump Using Same, and U.S. application Ser. No. 13/768,899 (Mayleben et. al.), which are hereby incorporated by reference in their entirety.
(61) While various example pump embodiments have been disclosed, it should be understood that the disclosed subject matter may be broadly applied to other forms of pumps, for example, single flow or discharge utility pumps, well pumps, lawn pumps, sewage pumps, pool pumps, etc. For example, pumps such as Applicant's utility pumps illustrated in U.S. Patent Application Publication Nos. 2017/0030371, published Feb. 2, 2017, entitled Multi-Outlet Utility Pump, and 2019/0048875, published Feb. 14, 2019, entitled Thermally Controlled Utility Pump and Methods Relating to Same, which are incorporated herein by reference in their entirety.
(62) Again, while a pump has been primarily used as an example application for the disclosed invention, it should not be assumed that the disclosure is limited to submersible pump applications, but rather can be broadly applied to any motor driven device. The above principles may be used to detect when motor driven machinery will fail or that it exhibits signs indicating a failure will occur in the near future or that failure is imminent. The machinery may be plugged into a power cord accessory which is plugged into the wall outlet or a power strip with such technology. Alternatively, the machinery may be built to include a leakage current detector and notifier discussed in this disclosure within the machinery. In either example, the leakage current detector tests the machinery's motor before the motor is run. The leakage current detector determines if any leakage current exists and to what extent. If the leakage current falls within the range that indicates any type of failure condition is present, then the notifier of the machinery or the power cord accessory will alert the machinery operator of this failure condition, so they may be aware that the machinery may fail, allowing the operator to take appropriate action. The machinery may include a warning system that the notifier circuit communicates with to alert or notify the operator or machinery supervisor that a machinery failure condition has been detected.
(63) In an alternative embodiment, a smart control including circuitry as illustrated in FIG. **12** may be used. The smart control **1200** of this embodiment is similar to the smart control **200** discussed above in regard to FIG. **2**, the differences of which are highlighted in the following description. In keeping with prior practice, items that are similar to those discussed above will use the same latter two-digit reference numeral but begin with the prefix **12** to distinguish this embodiment from other embodiments. Thus, in FIG. **12**, the smart control is referenced generally by reference numeral **1200** which is connected between power supply **1240** and motor **1250**. In this embodiment, the smart control **1200** includes an AC switch, such as triac **1252**, in parallel with a normally open relay on the Line wire after the transformer **1212**. The triac **1252** may be controlled by the controller **1202** to provide power the pump **1260** when the controller **1202** determines that the pump **1260** must be run, for example, when the water level within the sump pit **1261** is above a threshold. Since the pump **1260** often will only operate for a few seconds at a time, the heat generated by the triac **1252** that delivers power to the pump **1260** is able to be dissipated without the need for a heat sink attached to the triac **1252**. In a preferred form, triac **1252** will be an optotriac or solid-state relay (SSR) which allows a low-power DC control circuit to switch on AC power to an AC device like pump **1260** while preventing the low-power DC components from being exposed to the AC power and without the need for a more expensive transformer.
(64) In situations where the pump **1260** needs to run for a longer period of time, the triac **1252** may generate too much heat to be adequately dissipated between run cycles. Instead of using a large and/or expensive heat sink to aid in heat dissipation for these situations, the smart control **1200** of this embodiment includes a relay **1254** in parallel with the triac **1252**. The controller **1202** may be in communication with a temperature sensor **1256** that monitors the temperature of the triac **1252**. When the temperature of the triac **1252** is above a threshold temperature (e.g., 60 degrees Celsius) and/or the triac **1252** is powered on by the controller **1202** for a certain period of time, the controller **1202** may turn off the triac **1252** and close the normally open relay **1254**. Power is then

supplied to the pump **1260** via the relay **1254** while the triac **1252** is off, thus allowing the triac **1252** to cool.

(65) In some forms, rather than turning off the triac **1252**, the controller **1202** simply closes the relay **1254** with the triac **1252** still on. This reduces the heat generated by the triac **1252** while allowing the triac **1252** to serve as the main conduit for powering the pump **1260**. This reduces the burden on the relay **1254** as power (e.g., 120 VAC) is provided to the pump **1260** via the both the relay **1254** and the triac **1252**. This aids in increasing the life of the relay **1254**. In still other forms, however, the relay provides a path of least resistance and, thus, the current passes through the relay rather than the triac **1252** because of the resistance associated with the triac **1252**. This still offers significant benefits, however, in that the relay **1254** is not exposed to direct line voltage at start-up, but rather a reduced start-up voltage associated with the internal resistance of the triac **1252**. Thus, the relay **1254** is turned-on or activated much more gradually than if it was exposed to direct alternating current ("AC") line voltage at start-up. This protects the relay and prolongs the life by not exposing it to the higher start-up line voltage it would otherwise be exposed to but for the triac. For example, the more gradual or manageable start-up prevents damage to the relay such as pitting that can cause relays to die earlier than their desired life expectancy.

(66) In another form, the controller **1202** turns on the triac **1252** to power the pump **1260** and then shortly after, closes the relay **1254** to provide power to the pump **1260**. For instance, where the triac **1252** is above a certain temperature (e.g., 60 degrees Celsius) and the controller **1202** determines that the pump **1260** must be powered, the controller **1202** may first turn on the triac **1252** to provide power to the motor of the pump **1260** and after a certain period of time (e.g., 20 ms) close the relay **1254**. Under this approach, the triac **1252** bears the brunt of the 120 VAC power that is used to turn on the motor **1250** of the pump **1260**. Then the relay **1254** may be closed, which, being connected in parallel to the triac **1252**, aids in providing the power to the pump **1260** and reduces the amount of heat generated by the triac **1252**. Turning the relay **1254** on after the triac **1252** initially powers the pump **1260** aids in reducing the wear placed on the relay **1254** (e.g., pitting of the relay contact, extreme relay parameter operation, etc.) that would occur under the high current draw associated with initially powering the pump **1260** and specifically motor **1250**.

(67) Providing a relay **1254** in parallel with the triac **1252** also adds redundancy into the smart control **1200**. For instance, if the triac **1252** should fail, the controller **1202** may use the relay **1254** to deliver power to the pump **1260**. Thus, even if the triac **1252** fails, the pump **1260** may be operated via the relay **1254**. The smart control **1200** may be configured to provide an error signal or notification indicating that the triac **1252** of the smart control **1200** has failed and that the smart control **1200** is in need of maintenance or replacement while still allowing the unit to operate in the meantime (e.g., if not a full redundant operation, at least a limp-home feature that provides for some operability). The opposite is true as well in that the triac **1252** provides redundancy for the relay **1254**. Thus, if the relay fails, the triac will continue to allow the system to operate, however, it may have to shutdown from time to time if heat build-up becomes a problem since the relay is no longer available to help address that issue. In practice, the relay **1254** will not be needed until the pump has been running for an excessive period of time. In some forms this may be greater than ten seconds (10s), however, in other forms it may be a lower threshold such as six seconds (6s).

(68) In view of the above, it should be understood that numerous apparatus, systems and methods are disclosed herein. For example, in some forms, apparatus, systems and methods are disclosed for detecting motor leakage current indicative of a failing motor so that early warning of this situation may be provided without a pump owner or user experiencing failure that might otherwise lead to further damage (e.g., flooding of an area, the cessation of a motor driven device during a critical time of operations, etc.). In a preferred form, the apparatus, systems and methods disclosed herein will alert the user to the problem with sufficient time to address same before it becomes a bigger problem. In this regard, one form of the apparatus, systems and methods disclosed herein involves monitoring leakage current to ground without needing the motor to be operated (or turned on) so

that the line and neutral wires can be checked for leaking to ground and alerting the user to that situation when it is detected well in advance of motor failure. In some forms, the apparatus, system and methods can alert the user when the polarity of the outlet the motor is connected to is wired incorrectly (or the polarity the motor is exposed to is incorrect). In some forms the apparatus, system and method will alert the user to the improper polarity, such as by way of an audible alert and/or a visual alert (e.g., a buzzer, an illuminated light, etc.). In a preferred form, the alert will be provided via a message sent to the user's mobile device alerting him/her to the early failure detection prior to it becoming a more serious issue.
(69) In other forms, the apparatus, systems and methods disclosed herein address heat issues circuitry may be exposed to due to operation of the motor driven device. For example, in one form, an AC switch is used to allow the motor driven device to operate off conventional AC line voltage or power. Such switches can be exposed to excessive heat generation that can cause protective components or circuitry like thermal cutoffs (TCOs) to kick in to prevent the circuitry or motor driven device from overheating. For example, in the sump pump embodiment disclosed above, a triac is used to serve as the AC switch. The triac is capable of operating the pump for a reasonable period of time without generating excessive heat (e.g., six seconds, ten seconds, etc.). When excessive heat is generated, the apparatus, system and method disclosed herein could simply use a thermal cutoff or TSO switch to shutdown the motor driven device, however, in a preferred form, the circuit will include a relay in parallel to the AC switch to allow the relay to close such that it diverts (or largely diverts) the current and power from the triac to the relay to allow the triac to cool. This configuration allows the heat generation issue associated with the triac to be addressed while also allowing the relay to be powered-up or started more gently by not exposing it to the brunt of the AC line voltage at start-up and instead subjecting it only to the much lower start-up voltage associated with the resistive drop over the triac. This protects and prolongs the life of the relay by preventing it from the damage or wear and tear that a relay normally sees when exposed directly to AC line voltage (e.g., pitting, relay contact and/or terminal damage, etc.). Thus the circuit has a first switch in combination with a second switch wired generally in parallel with the first switch so that the second switch may be used to address heat issues associate with the first switch when necessary, and doing so in a way that protects or prolongs the life of the second switch during its operation. The terms first and second switch may be used generically to refer to either the triac or relay. In some forms discussed herein, the triac is simply called-out as the triac with the relay being referred to as the first switch wired in parallel with the triac to takeover operation of the powering of the motor driven device when the triac needs a break due to heat build-up.

Claims

1. A pump comprising: a fluid inlet; a fluid outlet; an electric motor operable to pump fluid from the fluid inlet toward the fluid outlet; one or more power conductors to provide electrical power to the electric motor from a power source; and a leakage current detector having a current transformer operably connected to the one or more power conductors and a leakage current detection circuit connected to the current transformer, the leakage current detection circuit configured to: detect leakage current flowing in the one or more power conductors using the current transformer without operating the electric motor; and output a signal to provide notice of a problem with the pump based at least in part on the detected leakage current.
2. The pump of claim 1 wherein the current transformer includes at least one primary winding connected to a Line conductor and/or a Neutral conductor of the one or more power conductors and a secondary winding coupled to the at least one primary winding to detect leakage current through the Line conductor and/or Neutral conductor.
3. The pump of claim 2 wherein the secondary winding of the current transformer is electrically connected to the leakage current detection circuit.

4. The pump of claim 2 wherein the at least one primary winding includes a first primary winding connected to the Line conductor and a second primary winding connected to the Neutral conductor.
5. The pump of claim 1 wherein the leakage current detection circuit is configured to output the signal when detected leakage current exceeds a predetermined threshold.
6. The pump of claim 5 wherein the predetermined threshold is 0.05 mA.
7. The pump of claim 1 wherein to output the signal includes outputting an alert signal when leakage current indicates an advance motor failure condition exists and outputting an alarm signal when an imminent motor failure condition exists.
8. The pump of claim 7 wherein the alert signal is output when the detected leakage current is between about 0.05 mA and 6 mA and wherein the alarm signal is output when the detected leakage current is above 6 mA.
9. The pump of claim 1 wherein the leakage current detector further includes: a first switch operable to permit current to flow through a Line conductor of the one or more power conductors relative to the electric motor; and a second switch operable to permit current to flow through a Neutral conductor of the one or more power conductors relative to the electric motor, wherein to operate the electric motor both the first switch and the second switch are closed and to detect leakage current without operating the electric motor includes the leakage current detection circuit causing one of the first switch and the second switch to be open and the other of the first switch and the second switch to be closed.
10. The pump of claim 9 wherein the first switch comprises a relay switch in parallel with a triac, wherein the at least one of the relay switch and the triac are operable to permit current to flow through the Line conductor relative to the electric motor.
11. The pump of claim 1 further comprising a fluid level sensor to detect a fluid level, wherein the electric motor is operated when the detected fluid level exceeds a predetermined threshold.
12. The pump of claim 1 wherein to output the signal includes wirelessly transmitting a message to a user advising when the detected leakage current exceeds a predetermined threshold.
13. The pump of claim 1 wherein the leakage current detection circuit is further configured to inhibit operation of the motor when the detected leakage current exceeds a predetermined threshold.
14. The pump of claim 13 wherein the predetermined threshold is 6 mA.
15. A pump system comprising: a DC pump including a battery and communication circuitry; an AC pump including: an electric motor; a leakage current detector configured to detect leakage current in the electric motor; and communication circuitry configured to wirelessly communicate with the DC pump.
16. The pump system of claim 15 wherein at least one of the DC pump and the AC pump are configured to wirelessly transmit information relating to the pump system to a remote device of a user.
17. The pump system of claim 16 wherein the at least one of the DC pump and the AC pump are configured to communicate via at least one of wireless fidelity (Wi-Fi), Cellular, radio frequency (RF), infrared (IR), Bluetooth (BT), Bluetooth Low Energy (BLE), Zigbee and near field communication (NFC).
18. The pump system of claim 15 wherein the DC pump includes a battery charger configured to be connected to an AC power source and operable to charge the battery.
19. The pump system of claim 15 wherein the DC pump operates using electric power of the battery when AC power is unavailable to the AC pump.