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SYSTEMS AND METHODS FOR PARALLEL ELECTRICAL ENDURANCE TESTING OF CONTACTS

Abstract

An apparatus for testing a plurality of electrical switches including contacts to connect multiple sample switches to an input and an output. A power source is connected to the inputs of the sample switches, and other switches are connected to the outputs of the sample switches so that the sample switches may be selectively connected to either a make load or a break load to perform testing on the sample switches. The sample switches may further be made of silicon carbide MOSFETs that shutoff using a zero-crossing current sensing logic. The voltage at the sample switches may further be monitored by a universal voltage board configured to sense various alternating and direct current (AC or DC) voltages so that various types of sample switches may be tested.

Publication Classification

Background/Summary

BACKGROUND

[0001] As a part of product safety testing and certification, electrical relays and switches may be evaluated to prove their performance safely in normal use through endurance testing. Such electrical endurance testing may be used to stress a given product to its maximum rated electrical, thermal, and/or mechanical limits through, for example, on-off cycling.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0002] FIG. **1** is a diagrammatic view of an example enclosure in which an electrical device may be tested, in embodiments.

[0003] FIG. **2** is a diagrammatic view of an electrical component that may be tested, in embodiments.

[0004] FIG. **3** is a diagrammatic view of another electrical component that may be tested, in embodiments.

[0005] FIGS. **4** and **6-8** are schematic wiring diagrams of example testing apparatuses in various states, in embodiments.

[0006] FIGS. **9-43** are diagrammatic views of example graphical user interfaces for using an example testing apparatus, in embodiments.

[0007] FIG. **44** is a schematic view of a SiC switch having two MOSFETs with a common source connection, in embodiments.

[0008] FIG. **45** is a diagrammatic view of a voltage and current waveform for an example SiC switch, in embodiments.

[0009] FIG. **46** is a schematic view of digital logic for implementing a zero-crossing current circuit, in embodiments.

[0010] FIG. **47** is a diagrammatic view of waveforms demonstrating implementation of a zero-crossing current circuit, in embodiments.

[0011] FIG. **48** is a schematic view of a universal voltage board for sensing both alternating current (AC) and direct current (DC) voltages, in embodiments.

[0012] FIG. **49** is a diagrammatic view of an example of a computing environment, in embodiments.

DETAILED DESCRIPTION

[0013] The following disclosure of example apparatuses, methods, and computer-readable media is not intended to limit the scope of the detailed description to the precise form or forms detailed herein. Instead, the disclosure herein is intended to be illustrative so that others may follow its teachings.

[0014] As a part of product safety testing and certification, relays and switches may be evaluated to prove their performance safely in normal use through endurance testing. Such electrical endurance testing may be designed to stress the product to its maximum rated electrical, thermal, and mechanical limits through on-off cycling of the relays and/or switches. For example, testing may be performed according to Underwriters Laboratories (UL) or International Electrotechnical Commission (IEC) standard 60730-1. However, the various embodiments described herein may be used in conjunction with or for other types of tests or test standards. The testing may be broken down into two electrical tests: an overload test and an endurance test. The overload test may run the product through a certain percentage over a maximum rating for a short period of time. The endurance test may run the product through its maximum rating for a long period of time. Previous tests of a single switch or relay may take, for example, over one month to complete.

[0015] As such, this type of testing may use a large amount of lab equipment and lab footprint to accomplish. As the testing required increases with more ratings, models, samples, etc. the testing

time can further increase significantly. Various embodiments described herein are configured to mitigate/eliminate these problems and provide a reduction in testing time per sample, laboratory footprint, equipment used, etc., all while providing more flexibility for testing more samples than previous test equipment, testing different types of samples at the same time, and/or the ability to perform different types of tests using the same test equipment as described herein in various embodiments.

[0016] Using the apparatuses, methods, and computer-readable media described herein, one example embodiment may be used to perform an overload test on a relay or switch with 50 cycles of overload at a rate of 1 second on and 9 seconds off and perform an endurance test on a relay or switch with 100,000 cycles of endurance load at a rate of 5 seconds on 5 seconds off. Given such an example cycle rate, testing using the embodiments herein may, for example, take approximately 12 days to complete testing on a relay/switch samples.

[0017] As such, described herein are various apparatuses, methods, and computer-readable media for reducing the amount of time it takes to test such relays or switches by, for example, testing multiple (e.g., 3, 6) relays/switches at the same time with a single device. The apparatuses, methods, and computer-readable media described herein may also reduce the overall electric loads used to test the relays/switches, thereby reducing the cost and amount of electricity needed to run the tests. The various embodiments herein may also advantageously be used to test multiple different samples (sample relays or switches may be referred to herein merely as a sample or samples) that are tested to different ratings at the same time. That is, different types of samples that may be different and therefore are subject to different tests, may also be simultaneously tested using the embodiments described herein.

[0018] Components used to conduct this testing may include a control system, controller, or processor to turn the sample(s) on and off (e.g., a small programmable logic controller or PLC); an oven or other heat source for providing a desired or predetermined amount of heat in which to test the samples; electrical loads capable of providing the required or desired predetermined power levels for long durations; a transformer or variable autotransformer (e.g., Variac™ transformers) to adjust electrical mains voltage; and a mains power configured to provide a desired or predetermined amount of power sufficient to run desired tests for the samples.

[0019] The various embodiments described herein therefore provide for test fixtures capable of various methods of parallel electrical endurance testing of relays and/or switch contacts. A section of sequencing relays in the various text fixtures described herein may advantageously allow electrical power to be multiplexed to the appropriate loads for a given sample. The multiplexing may be achieved using relays, which may also be referred to herein as backfeeds. These backfeed relays may prevent current from flowing in an unwanted direction (e.g., back to a power source of a test fixture through another test sample). For example, the backfeed relays may prevent current from flowing in an unwanted direction as the load current is connected through a normally open contact of a backfeed relay. In various embodiments the backfeed relays may be used for current carrying and not used for breaking any load. The multiplexing may also provide a way to reduce a total number of loads used to test multiple samples through load sharing, as further discussed herein.

[0020] FIG. **1** illustrates an example enclosure **160** in which an electrical device (e.g., sample, device under test (DUT)) may be tested. The example enclosure may include a user interface **170**, which may also be referred to herein as a human machine interface (HMI). A door **180** may open so that the inside may be accessed for servicing. The enclosure **160** may further include electrical equipment, such as that shown in any one of or any combination of FIGS. **4** and **5-8**. FIG. **2** illustrates an electrical component **200** (e.g., sample, device under test (DUT)) that may be tested in an external oven/environmental chamber. The electrical component **200** is a switch and demonstrates how the switch may be connected to a load when in a typical use. FIG. **3** illustrates another electrical component **300** similar to that of FIG. **2**, and shows a typical setup of how that

switch may be tested in various embodiments with Make and Break loads.

[0021] In an example embodiment, the sequencing of testing multiple DUTs in various embodiments described herein is divided up into six identical sections that may be configured in multiple ways to accommodate different sample configurations and test types to perform. This allows the flexibility of testing multiple samples to the same electrical rating, or multiple samples to different electrical ratings. Connections may be made with terminal block jumpers on the rear panel. This example test fixture may therefore advantageously perform testing on the following contact configurations at the same time, and may be either the same type or combinations of different types at once: [0022] 1. One, two, or three double throw switches [0023] 2. One, two, three, four, five, or six single throw switches of either normally open (NO) [0024] or normally closed (NC) [0025] 3. One double pole double throw switch [0026] 4. Two double pole single throw switches of either NO or NC [0027] 5. One three phase double throw switch [0028] 6. Two three phase single throw switches of either NO or NC

Input Sensing

[0029] The input sensing to a controller such as a PLC may be accomplished through specially designed universal voltage sensing circuit boards. These boards may sense a wide range of alternating current (AC) and direct current (DC) voltages and provide a constant 24 volts DC (VDC) output to digital inputs of a controller or PLC. The response time of these boards may be on the order of microseconds (μs). This may provide a controller with a very fast response to a closure of a contact/sample under test. The controller may therefore be used to set test sequence control, counting, on time duration, and/or off time duration. A separate universal voltage board may be used to measure the make inrush current time of each contact.

[0030] In various embodiments, there may be current sensing switches that are on each break line. These provide the ability to count when load sharing with a resistive or motor test as the load voltage may never drop low enough to indicate a change in state.

Timing

[0031] For accurate timing throughout the duration of the test a special watchdog timer may be used. This prevents timing drift in the controller or PLC scan rate. This timer may be driven from a PLC internal 10 Hertz (Hz) asynchronous clock. Every positive rising edge of the 10 Hz clock increases a counter block up by one count. The programmed value of the counter may be set to 100 counts. Given the period of a 10 Hz signal is 100 milliseconds (ms) multiplied by the 100 counts gives a total duration of ten seconds with 100 ms steps. Once the counter reaches 100 counts the output changes states and uses an internal memory bit to reset the counter back to zero. Due to the asynchronous nature of the 10 Hz clock this timing may not be affected by the PLC scan rate. The output count may then be used in the test sequence program blocks. Where count 1=100 ms, count 2=200 ms, etc., for example. The PLC outputs may then be set and reset in sequence with an equals comparator statement.

[0032] To adequately catch the short duration of the make load a PLC pulse train output (PTO) and high-speed counter input may be used. This provides accurate timing of the make load duration to conform with standard requirements. This may be handled through a PTO to DC circuit board. This board may include six DC to DC solid state relays (one for each contact and/or sample). The output of each make universal voltage input board may be connected to the DC input of a solid state relay (SSR). A SSR DC transistor output may be connected to a 10 kilohertz (kHz) 50% duty cycle pulse train output from the PLC. This may then be connected to a special high-speed counter input on the PLC. This may provide a tighter tolerance of time when the digital input is "on" or high. The high-speed counter PLC block may then convert the pulse counts to a time in milliseconds. This time may then be compared to check to make sure the value is within a predetermined or standard requirement.

Error Handling and Safety Shutdown

[0033] The PLC may also provide for supervisory control over process errors and safety shutdown

errors. The PLC may be configured to monitor the on-time of each contact and/or sample. If this on-time exceeds a predetermined time an alarm may be triggered and output via a user interface. This alarm may also trigger integrated shutdown relays (e.g., relays **2**, **10**, and **18** of FIGS. **4** and **7** while testing double throws samples; relays **2**, **7**, **12**, **17**, **22**, and **27** of FIGS. **6** and **8** while testing single throw samples). Each contact may be independently controlled so the shutdown of one sample does not affect the others while they continue to run.

Oven Control

[0034] For International Electrotechnical Commission (IEC) testing requirements, for example, the first 50% of test cycles are to be performed at room temperature, and the second 50% of test cycles are to be performed at a maximum or minimum rated temperature. An integrated contactor and thermocouple PLC module may provide control over an external oven or environmental chamber. If more than one sample is being tested to the same temperature the PLC may control the system such that all samples have achieved the required 50% of test cycles before powering the oven (or before powering down the oven if heated cycles are performed first). If a sample has fallen behind (e.g., due to error) the PLC may stop testing the other samples at the 50% point and wait until the other sample(s) have caught up. Testing may also be halted while the oven/chamber reaches its set point (or cools down to a room temperature), and the temperature stabilizes. Then the PLC will restart the test to complete the remaining 50% of test cycles on all samples.

Test Background

[0035] In overload and/or endurance testing there may be four basic types of tests: [0036] 1. Make & Break [0037] 2. Pilot Duty AC or DC [0038] 3. Motor (locking rotor amps (LRA)/full load amps (FLA)) [0039] 4. Resistive AC or DC

[0040] Each type of overload and/or endurance testing may have its own specific load ratings and requirements.

[0041] A Make & Break test is intended to simulate an AC motor load. The test starts with a "make" load current inrush for a time between 50 ms to 100 ms (standard requirement), then change-over to a "break" load. This is intended to simulate the contact under test to "make" the current inrush to start a motor, and "break" the steady state or running current of a motor. This make to break change-over is performed every contact cycle during a Make & Break test.

[0042] A Pilot Duty test is intended to simulate a moving armature load (e.g., a solenoid, a contactor). There is a 10× (ten times) current inrush and then change to a steady state current like a make & break test.

[0043] A Motor load test is intended to simulate a locked rotor amps (LRA) rating of a motor, and a full load amps (FLA) rating of a motor. The overload will be at the LRA current, and the endurance will be at the FLA current.

[0044] A Resistive test is intended to simulate a predominately resistive load like a heating element.

[0045] In various embodiments described herein, fixture sequencing for Make & Break and Pilot Duty testing may be grouped together in a same test block as they behave the same despite their rating differences. The same applies for Motor and Resistive tests, which may also be grouped together. As such, the embodiments described herein may be advantageously used and programmed to reduce the complexity of a system for performing these various tests on samples and may significantly simplify programming of a system for performing these various tests.

[0046] In addition, the Motor and Resistive test sequence may be or may utilize a same or similar logic as that used for testing a DC Resistive or Pilot Duty test.

Program Sequence Background

[0047] In various embodiments, non-transitory computer readable instructions stored on a memory and executed by a processor may be used to set up and control a testing apparatus. For example, where a PLC is used, its PLC program may be configured to have separate test sequence blocks, and these blocks may be selected by a user making user selections during test setup on a human-

machine interface (HMI) (e.g., a touchscreen or other display/interface in communication with a PLC or other controller/processor). In these blocks, control of the PLC outputs may be based on a mix of fixed timings and physical inputs. The fixed timings keep the sequencing synced between samples, and the physical inputs react to sample contact changes of state.

[0048] For double throw samples, for example, the normally closed (NC) contacts are already closed so the normally open (NO) contacts may be tested first on each sample. On the first cycle the sequence staggers the starting of each relay sample under test by three seconds. The staggering allows only one make current to happen at a time, thus allowing the use of only one make load instead of three separate loads. Because only one contact is carrying current at one time with a double throw sample this allows the break loads to be shared as one load. For example, Sample 1 is at time zero seconds, sample 2 is at time three seconds, and sample 3 is at time six seconds. FIG. **5** demonstrates oscilloscope waveforms that outlines this time sequence, the individual make events are shown as waveform **502** (channel **1**). Sample 1 break current is shown as waveform **504** (channel **2**), Sample 2 break current is shown as waveform **506** (channel **3**), and Sample 3 break current is shown as waveform **508** (channel **4**).

[0049] For Make & Break and Pilot Duty tests on a double throw sample when the DUT contact closes multiple things happen. First, the NO Break Backfeed turns on to provide a complete the path to the Break load. At the rising edge of the DUT voltage input of the NO contact a timer in the PLC program is started to allow a delay from sample contact closure to the NO Make/Break relay turning on. In this example, the timer is programmed for 32 ms. This delay combined with the propagation delay within the PLC system as well as the propagation delay in the Make/Break relay itself to provide a make load duration of approximately 70 ms to 80 ms. This allows deviation plus or minus and still stay within standard requirements. On the falling edge of the DUT voltage input of the NC contact from the previous cycle both the NC Break Backfeed relay and NC Make/Break relay are reset. This is to make sure that the DUT contact breaks the load circuit and not a relay inside the test fixture.

[0050] For overload tests on double throw samples the contacts are tested separately with the NO contacts first, then the NC contacts are tested. There is logic in the PLC program (or other instructions executed by a processor) to automatically make this switch from NO contact testing to NC contact testing.

[0051] For overload and endurance tests on single throw samples the contacts are tested all at once. During test setup the user tells the program which samples are normally open and which samples are normally closed on the HMI screen. This adjusts which sequence the PLC uses to activate the samples.

Program Sequences

[0052] FIGS. **4** and **6-8** show different configurations of a test apparatus that may be used to test various types of DUTs/samples/switches as described herein. Although FIGS. **4** and **6-8** vary somewhat from one another, each of the setups shown in FIGS. **4** and **6-8** may be advantageously implemented using the same test apparatus. For example, FIGS. **4** and **7** are similar, and those setups may be used to test three double throw relay samples (shown at elements **3**, **11**, and **19**). The difference between the setups in FIGS. **4** and **7** is that the load **29** and the relays **6**, **8**, **14**, **16**, **22**, and **24** may not be used in the setup of FIG. **7** while those components are used in the setup of FIG. **4**. As such, the tests run and described below with respect to FIGS. **4** and **7** may use the same equipment in a test apparatus, but not all of the components are necessarily used for each test. That is, the test apparatuses described herein may advantageously be used to perform each type of test described herein with respect to FIGS. **4** and **7**.

[0053] FIGS. **6** and **8** are also similar to one another, and these setups may be used to test six single throw relay samples (shown at elements **3**, **8**, **13**, **18**, **23**, and **28** of FIGS. **6** and **8**). The difference between the setups in FIGS. **6** and **8** is that the load **35** and the relays **5**, **10**, **15**, **20**, **25**, and **30** may not be used in the setup of FIG. **8** while those components are used in the setup of FIG. **6**. As such,

the tests run and described below with respect to FIGS. **6** and **8** may use the same equipment in a test apparatus, but not all of the components are necessarily used for each test. That is, the test apparatuses described herein may advantageously be used to perform each type of test described herein with respect to FIGS. **6** and **8**.

[0054] Furthermore, each of the tests described herein with respect to each of FIGS. **4** and **6-8** may be performed with the same equipment/components of a single test apparatus as described herein. For example, the embodiments in FIGS. **4/7** may have the same test equipment as FIGS. **6/8**, the setups just appear different in the figures due to how the samples/DUTs are hooked up to those components. For example, instead of a double throw switch at element **3** in FIG. **4** that connects safety switch **2** to relays **4** and **5**, in FIG. **6** that double throw switch at element **3** in FIG. **4** is replaced by single throw switches at elements **3** and **8**. Note that additional safety switches may further be provided so that each of the samples/DUTs is connected to its own safety switch regardless of which test is being run in any of the configurations. As such, a test apparatus with all of the components shown in FIG. **6**, for example, may be advantageously used to implement any of the tests shown in and described with respect to any of FIGS. **4** and **6-8**.

[0055] The following outlines an example sequence of operation for an AC Make & Break or Pilot Duty overload test on three double throw relay samples utilizing the normally open (NO) contacts, as shown in the examples of FIG. **4** and FIG. **5**. A power source **1** is shown in FIG. **4** to supply power to the three samples being tested, which are depicted in FIG. **4** at relays **3**, **11**, and **19**.

[0056] Referring to FIG. **4**, at time 0 ms Sample 1 NO Make Backfeed (relay **8**) is turned on. This is done before the device under test (DUT) is activated to allow a complete path to the Make load (load **29**). At time 100 ms Sample 1 DUT (relay **3**) is turned on. On the rising edge of the DUT voltage input Sample 1 NO Break Backfeed (relay **9**) turns on. After the 32 ms delay Sample 1 NO Make/Break (relay **5**) turns on to change-over from the Make load (load **29**) via relay **8** to the Break load (load **26**) via relay **9**. To allow sufficient time for the make current duration Sample 1 NO Make Backfeed (relay **8**) is turned back off at time 500 ms. At 1100 ms Sample 1 DUT turns back off (relay **3**) completing the one second contact on time. On the falling edge of the NO contact DUT voltage input both Sample 1 NO Break Backfeed (relay **9**) and Sample 1 NO Make/Break (relay **5**) are turned off.

[0057] At time 3000 ms Sample 2 NO Make Backfeed (relay **16**) is turned on to connect relay **16** to Make load **29**. At time 3100 ms Sample 2 DUT (relay **11**) is turned on. On the rising edge of the DUT voltage input Sample 2 NO Break Backfeed (relay **17**) turns on to connect relay **17** to the Break load **27**. After the 32 ms delay Sample 2 NO Make/Break (relay **13**) turns on to change-over from the Make load (load **29**) to the Break load (load **27**). To allow sufficient time for the make current duration Sample 2 NO Make Backfeed (relay **16**) is turned off at time 3500 ms. At 4100 ms Sample 2 DUT turns off (relay **11**) completing the one second contact on time. On the falling edge of the NO contact DUT voltage input both Sample 2 NO Break Backfeed (relay **17**) and Sample 2 NO Make/Break (relay **13**) are turned off.

[0058] At time 6000 ms Sample 3 NO Make Backfeed (relay **24**) is turned on to connect relay **24** to Make load **29**. At time 6100 ms Sample 3 DUT (relay **19**) is turned on. On the rising edge of the DUT voltage input Sample 3 NO Break Backfeed (relay **25**) turns on to connect relay **25** to the Break Load **28**. After the 32 ms delay Sample 3 NO Make/Break (relay **21**) turns on to change-over from the Make load (load **29**) to the Break load (load **28**). To allow sufficient time for the make current duration Sample 3 NO Make Backfeed (relay **24**) is turned off at time 6500 ms. At 7100 ms Sample 3 DUT turns off (relay **19**) completing the one second contact on time. On the falling edge of the NO contact DUT voltage input both Sample 3 NO Break Backfeed (relay **25**) and Sample 3 NO Make/Break (relay **21**) are turned off.

[0059] The chronological order of operations for an AC Make & Break or Pilot Duty overload test on three double throw relay samples utilizing the normally open (NO) contacts using the test apparatus shown in FIG. **4** is outlined in Table 1 below. This sequence may be repeated as many

times as desired or as called for to complete standard tests for the three double throw relays being tested (e.g., the sample DUTs at 3, 11, and 19 of FIG. **4**).

TABLE-US-00001 TABLE 1 Time (ms) Output Identifier State 0 Sample 1 NO Make Backfeed 8 Set 100 Sample 1 DUT 3 Set 1NO Input↑ Sample 1 NO Break Backfeed 9 Set 132 Sample 1 NO Make/Break 5 Set 500 Sample 1 NO Make Backfeed 8 Reset 1100 Sample 1 DUT 3 Reset 1NO Input↓ Sample 1 NO Break Backfeed 9 Reset 1NO Input↓ Sample 1 NO Make/Break 5 Reset 3000 Sample 2 NO Make Backfeed 16 Set 3100 Sample 2 DUT 11 Set 2NO Input↑ Sample 2 NO Break Backfeed 17 Set 3132 Sample 2 NO Make/Break 13 Set 3500 Sample 2 NO Make Backfeed 16 Reset 4100 Sample 2 DUT 11 Reset 2NO Input↓ Sample 2 NO Break Backfeed 17 Reset 2NO Input↓ Sample 2 NO Make/Break 13 Reset 6000 Sample 3 NO Make Backfeed 24 Set 6100 Sample 3 DUT 19 Set 3NO Input↑ Sample 3 NO Break Backfeed 25 Set 6132 Sample 3 NO Make/Break 21 Set 6500 Sample 3 NO Make Backfeed 24 Reset 7100 Sample 3 DUT 19 Reset 3NO Input↓ Sample 3 NO Break Backfeed 25 Reset 3NO Input↓ Sample 3 NO Make/Break 21 Reset

[0060] The following outlines the sequence of operation for an AC Make & Break or Pilot Duty overload test on three double throw relay samples (3, 11, and 19 in FIG. **4**) utilizing the normally closed (NC) contacts, as shown in the examples of FIG. **4** and FIG. **5**.

[0061] At time 0 ms Sample 1 DUT (relay **3**) is turned on to open the NC contact. This is done before the NC Make Backfeed is activated to allow a complete path to the Make load (load **29**). At time 100 ms Sample 1 NC Make Backfeed (relay **6**) is turned on. At time 200 ms Sample 1 DUT (relay **3**) is turned off turning the NC contact on. On the rising edge of the DUT voltage input Sample 1 NC Break Backfeed (relay **7**) turns on. After the 32 ms delay Sample 1 NC Make/Break (relay **4**) turns on to change-over from the Make load (load **29**) to the Break load (load **26**). To allow sufficient time for the make current duration Sample 1 NC Make Backfeed (relay **6**) is turned off at time 600 ms. At 1200 ms Sample 1 DUT (relay **3**) turns on opening the NC contact completing the one second contact on time. On the falling edge of the NC contact DUT voltage input both Sample 1 NC Break Backfeed (relay **7**) and Sample 1 NC Make/Break (relay **4**) are turned off.

[0062] At time 3000 ms Sample 2 DUT (relay **11**) is turned on to open the NC contact. At time 3100 ms Sample 2 NC Make Backfeed (relay **14**) is turned on to connect relay **14** to Make load **29**. At time 3200 ms Sample 2 DUT (relay **11**) is turned off turning the NC contact on. On the rising edge of the DUT voltage input Sample 2 NC Break Backfeed (relay **15**) turns on to connect relay **15** to the Break load **27**. After the 32 ms delay Sample 2 NC Make/Break (relay **12**) turns on to change-over from the Make load (load **29**) to the Break load (load **27**). To allow sufficient time for the make current duration Sample 2 NC Make Backfeed (relay **14**) is turned off at time 3600 ms. At 4200 ms Sample 2 DUT (relay **11**) turns on opening the NC contact completing the one second contact on time. On the falling edge of the NC contact DUT voltage input both Sample 2 NC Break Backfeed (relay **15**) and Sample 2 NC Make/Break (relay **12**) are turned off.

[0063] At time 6000 ms Sample 3 DUT (relay **19**) is turned on to open the NC contact. At time 6100 ms Sample 3 NC Make Backfeed (relay **22**) is turned on to connect relay **22** to Make load **29**. At time 6200 ms Sample 3 DUT (relay **19**) is turned off turning the NC contact on. On the rising edge of the DUT voltage input Sample 3 NC Break Backfeed (relay **23**) turns on to connect relay **23** to the Break load **28**. After the 32 ms delay Sample 3 NC Make/Break (relay **20**) turns on to change-over from the Make load (load **29**) to the Break load (load **28**). To allow sufficient time for the make current duration Sample 3 NC Make Backfeed (relay **22**) is turned off at time 6600 ms. At 7200 ms Sample 3 DUT (relay **19**) turns on opening the NC contact completing the one second contact on time. On the falling edge of the NC contact DUT voltage input both Sample 3 NC Break Backfeed (relay **23**) and Sample 3 NC Make/Break (relay **20**) are turned off.

[0064] The chronological order of operations for an AC Make & Break or Pilot Duty overload test on three double throw relay samples (3, 11, and 19 in FIG. **4**) utilizing normally closed (NC)

contacts is outlined below in Table 2. This sequence may be repeated as many times as desired or as called for to complete standard tests for given DUTs.

TABLE-US-00002 TABLE 2 Time (ms) Output Identifier State 0 Sample 1 DUT 3 Set 100 Sample 1 NC Make Backfeed 6 Set 200 Sample 1 DUT 3 Reset 1NC Input↑ Sample 1 NC Break Backfeed 7 Set 232 Sample 1 NC Make/Break 4 Set 600 Sample 1 NC Make Backfeed 6 Reset 1200 Sample 1 DUT 3 Set 1NC Input↓ Sample 1 NC Break Backfeed 7 Reset 1NC Input↓ Sample 1 NC Make/Break 4 Reset 3000 Sample 2 DUT 11 Set 3100 Sample 2 NC Make Backfeed 14 Set 3200 Sample 2 DUT 11 Reset 2NC Input↑ Sample 2 NC Break Backfeed 15 Set 3232 Sample 2 NC Make/Break 12 Set 3600 Sample 2 NC Make Backfeed 14 Reset 4200 Sample 2 DUT 11 Set 2NC Input↓ Sample 2 NC Break Backfeed 15 Reset 2NC Input↓ Sample 2 NC Make/Break 12 Reset 6000 Sample 3 DUT 19 Set 6100 Sample 3 NC Make Backfeed 22 Set 6200 Sample 3 DUT 19 Reset 3NC Input↑ Sample 3 NC Break Backfeed 23 Set 6232 Sample 3 NC Make/Break 20 Set 6600 Sample 3 NC Make Backfeed 22 Reset 7200 Sample 3 DUT 19 Set 3NC Input↓ Sample 3 NC Break Backfeed 23 Reset 3NC Input↓ Sample 3 NC Make/Break 20 Reset

[0065] The following outlines the sequence of operation for an AC Make & Break or Pilot Duty endurance test on three double throw relay samples, referencing FIGS. **4** and **5**.

[0066] At time 0 ms Sample 1 NO Make Backfeed (relay **8**) is turned on. This is done before the device under test (DUT) is activated to allow a complete path to the Make load (load **29**). At time 100 ms Sample 1 DUT (relay **3**) is turned on activating the NO contact and completing the previous five second on time of the NC contact. On the rising edge of the DUT NO contact voltage input Sample 1 NO Break Backfeed (relay **9**) turns on. On the falling edge of the DUT NC contact voltage input from the previous cycle both Sample 1 NC Break Backfeed (relay **7**) and Sample 1 NC Make/Break (relay **4**) are turned off. This is to make sure that the DUT contact breaks the circuit and nothing inside the test fixture. After the 32 ms delay from DUT NO contact voltage input Sample 1 NO Make/Break (relay **5**) turns on to change-over from the Make load (load **29**) to the Break load (load **26**). To allow sufficient time for the make current duration Sample 1 NO Make Backfeed (relay **8**) is turned off at time 500 ms. At 5000 ms Sample 1 NC Make Backfeed (relay **6**) is turned on to allow the NC contact Make current to pass. At 5100 ms Sample 1 DUT turns off (relay **3**) activating the NC contact and completing the five second on time of the NO contact. At this point Sample 1 NC Break Backfeed (relay **7**) turns on. On the falling edge of the DUT NO contact voltage input both Sample 1 NO Break Backfeed (relay **9**) and Sample 1 NO Make/Break (relay **5**) are turned off. After the 32 ms delay from DUT NC contact voltage input Sample 1 NC Make/Break (relay **4**) turns on to change-over from the Make load (load **29**) to the Break load (load **26**). At 5500 ms Sample 1 NC Make Backfeed (relay **6**) turns off.

[0067] At time 3000 ms Sample 2 NO Make Backfeed (relay **16**) is turned on. This is done before the device under test (DUT) is activated to allow a complete path to the Make load (load **29**). At time 3100 ms Sample 2 DUT (relay **11**) is turned on activating the NO contact and completing the previous five second on time of the NC contact. On the rising edge of the DUT NO contact voltage input Sample 2 NO Break Backfeed (relay **17**) turns on. On the falling edge of the DUT NC contact voltage input from the previous cycle both Sample 2 NC Break Backfeed (relay **15**) and Sample 2 NC Make/Break (relay **12**) are turned off. This is to make sure that the DUT contact breaks the circuit and nothing inside the test fixture. After the 32 ms delay from DUT NO contact voltage input Sample 2 NO Make/Break (relay **13**) turns on to change-over from the Make load (load **29**) to the Break load (load **27**). To allow sufficient time for the make current duration Sample 2 NO Make Backfeed (relay **16**) is turned off at time 3500 ms. At 8000 ms Sample 2 NC Make Backfeed (relay **14**) is turned on to allow the NC contact make current to pass. At 8100 ms Sample 2 DUT turns off (relay **11**) activating the NC contact and completing the five second on time of the NO contact. At this point Sample 2 NC Break Backfeed (relay **15**) turns on. On the falling edge of the DUT NO contact voltage input both Sample 2 NO Break Backfeed (relay **17**) and Sample 2 NO Make/Break (relay **13**) are turned off. After the 32 ms delay from DUT NC contact voltage input

Sample 2 NC Make/Break (relay **12**) turns on to change-over from the Make load (load **29**) to the Break load (load **27**). At 8500 ms Sample 2 NC Make Backfeed (relay **14**) turns off.

[0068] At time 6000 ms Sample 3 NO Make Backfeed (relay **24**) is turned on. This is done before the device under test (DUT) is activated to allow a complete path to the Make load (load **29**). At time 6100 ms Sample 3 DUT (relay **19**) is turned on activating the NO contact and completing the previous five second on time of the NC contact. On the rising edge of the DUT NO contact voltage input Sample 3 NO Break Backfeed (relay **25**) turns on. On the falling edge of the DUT NC contact voltage input from the previous cycle both Sample 3 NC Break Backfeed (relay **23**) and Sample 3 NC Make/Break (relay **20**) are turned off. This is to make sure that the DUT contact breaks the circuit and nothing inside the test fixture. After the 32 ms delay from DUT NO contact voltage input Sample 3 NO Make/Break (relay **21**) turns on to change-over from the Make load (load **29**) to the Break load (load **28**). To allow sufficient time for the make current duration Sample 3 NO Make Backfeed (relay **24**) is turned off at time 6500 ms. At 1000 ms Sample 3 NC Make Backfeed (relay **22**) is turned on to allow the NC contact make current to pass. At 1100 ms Sample 3 DUT turns off (relay **19**) activating the NC contact and completing the five second on time of the NO contact. At this point Sample 3 NC Break Backfeed (relay **23**) turns on. On the falling edge of the DUT NO contact voltage input both Sample 3 NO Break Backfeed (relay **25**) and Sample 3 NO Make/Break (relay **21**) are turned off. After the 32 ms delay from DUT NC contact voltage input Sample 3 NC Make/Break (relay **20**) turns on to change-over from the Make load (load **29**) to the Break load (load **28**). At 1500 ms Sample 3 NC Make Backfeed (relay **22**) turns off.

[0069] The chronological order of operations for an AC Make & Break or Pilot Duty endurance test on three double throw relay samples using the test apparatus of FIG. **4** is outlined below in Table 3. This sequence may be repeated as many times as desired or as called for to complete standard tests for given DUTs.

TABLE-US-00003 TABLE 3 Time (ms) Output Identifier State 0 Sample 1 NO Make Backfeed 8 Set 100 Sample 1 DUT 3 Set 1NO Input↑ Sample 1 NO Break Backfeed 9 Set 1NC Input↓ Sample 1 NC Break Backfeed 7 Reset 1NC Input↓ Sample 1 NC Make/Break 4 Reset 132 Sample 1 NO Make/Break 5 Set 500 Sample 1 NO Make Backfeed 8 Reset 1000 Sample 3 NC Make Backfeed 22 Set 1100 Sample 3 DUT 19 Reset 3NC Input↑ Sample 3 NC Break Backfeed 23 Set 3NO Input↓ Sample 3 NO Break Backfeed 25 Reset 3NO Input↓ Sample 3 NO Make/Break 21 Reset 1132 Sample 3 NC Make/Break 20 Set 1500 Sample 3 NC Make Backfeed 22 Reset 3000 Sample 2 NO Make Backfeed 16 Set 3100 Sample 2 DUT 11 Set 2NO Input↑ Sample 2 NO Break Backfeed 17 Set 2NC Input↓ Sample 2 NC Break Backfeed 15 Reset 2NC Input↓ Sample 2 NC Make/Break 12 Reset 3132 Sample 2 NO Make/Break 13 Set 3500 Sample 2 NO Make Backfeed 16 Reset 5000 Sample 1 NC Make Backfeed 6 Set 5100 Sample 1 DUT 3 Reset 1NC Input↑ Sample 1 NC Break Backfeed 7 Set 1NO Input↓ Sample 1 NO Break Backfeed 9 Reset 1NO Input↓ Sample 1 NO Make/Break 5 Reset 5132 Sample 1 NC Make/Break 4 Set 5500 Sample 1 NC Make Backfeed 6 Reset 6000 Sample 3 NO Make Backfeed 24 Set 6100 Sample 3 DUT 19 Set 3NO Input↑ Sample 3 NO Break Backfeed 25 Set 3NC Input↓ Sample 3 NC Break Backfeed 23 Reset 3NC Input↓ Sample 3 NC Make/Break 20 Reset 6132 Sample 3 NO Make/Break 21 Set 6500 Sample 3 NO Make Backfeed 24 Reset 8000 Sample 2 NC Make Backfeed 14 Set 8100 Sample 2 DUT 11 Reset 2NC Input↑ Sample 2 NC Break Backfeed 15 Set 2NO Input↓ Sample 2 NO Break Backfeed 17 Reset 2NO Input↓ Sample 2 NO Make/Break 13 Reset 8132 Sample 2 NC Make/Break 12 Set 8500 Sample 2 NC Make Backfeed 14 Reset

[0070] The following outlines the sequence of operation for an AC Make & Break or Pilot Duty overload test on six single throw relay samples, referencing the test apparatus shown in FIG. **6**.

[0071] For single throw samples they may be of NO type or NC type, selection is done during test setup on the HMI. Since any sample may be NO or NC the logic to handle both types are in place at the same time for each sample.

[0072] If Sample 1 is a NC contact at time 0 ms Sample 1 DUT (relay **3**) is turned on to open the

NC contact. This is done before the device under test activates the load allow a complete path to the Make load (load **35**). At time 100 ms Sample 1 Make Backfeed (relay **5**) is turned on. At time 200 ms one of two actions can happen depending on if the sample is NO or NC. If the sample is NO Sample 1 DUT (relay **3**) turns on to close the NO contact. If the sample is NC, then Sample 1 DUT (relay **3**) is turned off to close the NC contact. On the rising edge of the DUT contact voltage input Sample 1 Break Backfeed (relay **6**) turns on. After the 32 ms delay from DUT contact voltage input Sample 1 Make/Break (relay **4**) turns on to change-over from the Make load (load **35**) to the Break load (load **32**). To allow sufficient time for the make current duration Sample 1 Make Backfeed (relay **5**) is turned off at time 600 ms. At 1200 ms if the sample is NO then Sample 1 DUT (relay **3**) is turned off to open the NO contact. If the sample is NC, then Sample 1 DUT (relay **3**) is turned on to open the NC contact. This completes the contacts one second on time. On the falling edge of the contact DUT voltage input both Sample 1 Break Backfeed (relay **6**) and Sample 1 Make/Break (relay **4**) are turned off.

[0073] If Sample 2 is a NC contact at time 1500 ms Sample 2 DUT (relay **8**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Make load (load **35**). At time 1600 ms Sample 2 Make Backfeed (relay **10**) is turned on. At time 1700 ms one of two actions can happen depending on if the sample is NO or NC. If the sample is NO Sample 2 DUT (relay **8**) turns on to close the NO contact. If the sample is NC, then Sample 2 DUT (relay **8**) is turned off to close the NC contact. On the rising edge of the DUT contact voltage input Sample 2 Break Backfeed (relay **11**) turns on. After the 32 ms delay from DUT contact voltage input Sample 2 Make/Break (relay **9**) turns on to change-over from the Make load (load **35**) to the Break load (load **32**). To allow sufficient time for the make current duration Sample 2 Make Backfeed (relay **10**) is turned off at time 2100 ms. At 2700 ms if the sample is NO then Sample 2 DUT (relay **8**) is turned off to open the NO contact. If the sample is NC, then Sample 2 DUT (relay **8**) is turned on to open the NC contact. This completes the contacts one second on time. On the falling edge of the contact DUT voltage input both Sample 2 Break Backfeed (relay **11**) and Sample 2 Make/Break (relay **9**) are turned off.

[0074] If Sample 3 is a NC contact at time 3000 ms Sample 3 DUT (relay **13**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Make load (load **35**). At time 3100 ms Sample 3 Make Backfeed (relay **15**) is turned on. At time 3200 ms one of two actions can happen depending on if the sample is NO or NC. If the sample is NO Sample 3 DUT (relay **13**) turns on to close the NO contact. If the sample is NC, then Sample 3 DUT (relay **13**) is turned off to close the NC contact. On the rising edge of the DUT contact voltage input Sample 3 Break Backfeed (relay **16**) turns on. After the 32 ms delay from DUT contact voltage input Sample 3 Make/Break (relay **14**) turns on to change-over from the Make load (load **35**) to the Break load (load **33**). To allow sufficient time for the make current duration Sample 3 Make Backfeed (relay **15**) is turned off at time 3600 ms. At 4200 ms if the sample is NO then Sample 3 DUT (relay **13**) is turned off to open the NO contact. If the sample is NC, then Sample 3 DUT (relay **13**) is turned on to open the NC contact. This completes the contacts one second on time. On the falling edge of the contact DUT voltage input both Sample 3 Break Backfeed (relay **16**) and Sample 3 Make/Break (relay **14**) are turned off.

[0075] If Sample 4 is a NC contact at time 4500 ms Sample 4 DUT (relay **18**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Make load (load **35**). At time 4600 ms Sample 4 Make Backfeed (relay **20**) is turned on. At time 4700 ms one of two actions can happen depending on if the sample is NO or NC. If the sample is NO Sample 4 DUT (relay **18**) turns on to close the NO contact. If the sample is NC, then Sample 4 DUT (relay **18**) is turned off to close the NC contact. On the rising edge of the DUT contact voltage input Sample 4 Break Backfeed (relay **21**) turns on. After the 32 ms delay from DUT contact voltage input Sample 4 Make/Break (relay **19**) turns on to change-over from the Make load (load **35**) to the Break load (load **33**). To allow sufficient time for the make current

duration Sample 4 Make Backfeed (relay **20**) is turned off at time 5100 ms. At 5700 ms if the sample is NO then Sample 4 DUT (relay **18**) is turned off to open the NO contact. If the sample is NC, then Sample 4 DUT (relay **18**) is turned on to open the NC contact. This completes the contacts one second on time. On the falling edge of the contact DUT voltage input both Sample 4 Break Backfeed (relay **21**) and Sample 4 Make/Break (relay **19**) are turned off.

[0076] If Sample 5 is a NC contact at time 6000 ms Sample 5 DUT (relay **23**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Make load (load **35**). At time 6100 ms Sample 5 Make Backfeed (relay **25**) is turned on. At time 6200 ms one of two actions can happen depending on if the sample is NO or NC. If the sample is NO Sample 5 DUT (relay **23**) turns on to close the NO contact. If the sample is NC, then Sample 5 DUT (relay **23**) is turned off to close the NC contact. On the rising edge of the DUT contact voltage input Sample 5 Break Backfeed (relay **26**) turns on. After the 32 ms delay from DUT contact voltage input Sample 5 Make/Break (relay **24**) turns on to change-over from the Make load (load **35**) to the Break load (load **34**). To allow sufficient time for the make current duration Sample 5 Make Backfeed (relay **25**) is turned off at time 6600 ms. At 7200 ms if the sample is NO then Sample 5 DUT (relay **23**) is turned off to open the NO contact. If the sample is NC, then Sample 5 DUT (relay **23**) is turned on to open the NC contact. This completes the contacts one second on time. On the falling edge of the contact DUT voltage input both Sample 5 Break Backfeed (relay **26**) and Sample 5 Make/Break (relay **24**) are turned off.

[0077] If Sample 6 is a NC contact at time 7500 ms Sample 6 DUT (relay **28**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Make load (load **35**). At time 7600 ms Sample 6 Make Backfeed (relay **30**) is turned on. At time 7700 ms one of two actions can happen depending on if the sample is NO or NC. If the sample is NO Sample 6 DUT (relay **28**) turns on to close the NO contact. If the sample is NC, then Sample 6 DUT (relay **28**) is turned off to close the NC contact. On the rising edge of the DUT contact voltage input Sample 6 Break Backfeed (relay **31**) turns on. After the 32 ms delay from DUT contact voltage input Sample 6 Make/Break (relay **29**) turns on to change-over from the Make load (load **35**) to the Break load (load **34**). To allow sufficient time for the make current duration Sample 6 Make Backfeed (relay **30**) is turned off at time 8100 ms. At 8700 ms if the sample is NO then Sample 6 DUT (relay **28**) is turned off to open the NO contact. If the sample is NC, then Sample 6 DUT (relay **28**) is turned on to open the NC contact. This completes the contacts one second on time. On the falling edge of the contact DUT voltage input both Sample 6 Break Backfeed (relay **31**) and Sample 6 Make/Break (relay **29**) are turned off.

[0078] The chronological order of operations for an AC Make & Break or Pilot Duty overload test on six single throw relay samples using the test apparatus of FIG. **6** is outlined below in Table 4. This sequence may be repeated as many times as desired or as called for to complete standard tests for given DUTs.

TABLE-US-00004 TABLE 4 Time (ms) Output Identifier State 0 (NC) Sample 1 DUT (open NC) 3 Set 100 Sample 1 Make Backfeed 5 Set 200 (NO) Sample 1 DUT (close NO) 3 Set 1 Input↑ (NO) Sample 1 Break Backfeed 6 Set 232 (NO) Sample 1 Make/Break 4 Set 200 (NC) Sample 1 DUT (close NC) 3 Reset 1 Input↑ (NC) Sample 1 Break Backfeed 6 Set 232 (NC) Sample 1 Make/Break 4 Set 600 Sample 1 Make Backfeed 5 Reset 1200 (NO) Sample 1 DUT (open NO) 3 Reset 1 Input↓ (NO) Sample 1 Break Backfeed 6 Reset 1 Input↓ (NO) Sample 1 Make/Break 4 Reset 1200 (NC) Sample 1 DUT (open NC) 3 Set 1 Input↓ (NC) Sample 1 Break Backfeed 6 Reset 1 Input↓ (NC) Sample 1 Make/Break 4 Reset 1500 (NC) Sample 2 DUT (open NC) 8 Set 1600 Sample 2 Make Backfeed 10 Set 1700 (NO) Sample 2 DUT (close NO) 8 Set 2 Input↑ (NO) Sample 2 Break Backfeed 11 Set 1732 (NO) Sample 2 Make/Break 9 Set 1700 (NC) Sample 2 DUT (close NC) 8 Reset 2 Input↑ (NC) Sample 2 Break Backfeed 11 Set 1732 (NC) Sample 2 Make/Break 9 Set 2100 Sample 2 Make Backfeed 10 Reset 2700 (NO) Sample 2 DUT (open NO) 8 Reset 2 Input↓ (NO) Sample 2 Break Backfeed 11 Reset 2 Input↓ (NO) Sample 2 Make/Break 9 Reset 2700 (NC)

Sample 2 DUT (open NC) 8 Set 2 Input↓ (NC) Sample 2 Break Backfeed 11 Reset 2 Input↓ (NC) Sample 2 Make/Break 9 Reset 3000 (NC) Sample 3 DUT (open NC) 13 Set 3100 Sample 3 Make Backfeed 15 Set 3200 (NO) Sample 3 DUT (close NO) 13 Set 3 Input↑ (NO) Sample 3 Break Backfeed 16 Set 3232 (NO) Sample 3 Make/Break 14 Set 3200 (NC) Sample 3 DUT (close NC) 13 Reset 3 Input↑ (NC) Sample 3 Break Backfeed 16 Set 3232 (NC) Sample 3 Make/Break 14 Set 3600 Sample 3 Make Backfeed 15 Reset 4200 (NO) Sample 3 DUT (open NO) 13 Reset 3 Input↓ (NO) Sample 3 Break Backfeed 16 Reset 3 Input↓ (NO) Sample 3 Make/Break 14 Reset 4200 (NC) Sample 3 DUT (open NC) 13 Set 3 Input↓ (NC) Sample 3 Break Backfeed 16 Reset 3 Input↓ (NC) Sample 3 Make/Break 14 Reset 4500 (NC) Sample 4 DUT (open NC) 18 Set 4600 Sample 4 Make Backfeed 20 Set 4700 (NO) Sample 4 DUT (close NO) 18 Set 4 Input↑ (NO) Sample 4 Break Backfeed 21 Set 4732 (NO) Sample 4 Make/Break 19 Set 4700 (NC) Sample 4 DUT (close NC) 18 Reset 4 Input↑ (NC) Sample 4 Break Backfeed 21 Set 4732 (NC) Sample 4 Make/Break 19 Set 5100 Sample 4 Make Backfeed 20 Reset 5700 (NO) Sample 4 DUT (open NO) 18 Reset 4 Input↓ (NO) Sample 4 Break Backfeed 21 Reset 4 Input↓ (NO) Sample 4 Make/Break 19 Reset 5700 (NC) Sample 4 DUT (open NC) 18 Set 4 Input↓ (NC) Sample 4 Break Backfeed 21 Reset 4 Input↓ (NC) Sample 4 Make/Break 19 Reset 6000 (NC) Sample 5 DUT (open NC) 23 Set 6100 Sample 5 Make Backfeed 25 Set 6200 (NO) Sample 5 DUT (close NO) 23 Set 5 Input↑ (NO) Sample 5 Break Backfeed 26 Set 6232 (NO) Sample 5 Make/Break 24 Set 6200 (NC) Sample 5 DUT (close NC) 23 Reset 5 Input↑ (NC) Sample 5 Break Backfeed 26 Set 6232 (NC) Sample 5 Make/Break 24 Set 6600 Sample 5 Make Backfeed 25 Reset 7200 (NO) Sample 5 DUT (open NO) 23 Reset 5 Input↓ (NO) Sample 5 Break Backfeed 26 Reset 5 Input↓ (NO) Sample 5 Make/Break 24 Reset 7200 (NC) Sample 5 DUT (open NC) 23 Set 5 Input↓ (NC) Sample 5 Break Backfeed 26 Reset 5 Input↓ (NC) Sample 5 Make/Break 24 Reset 7500 (NC) Sample 6 DUT (open NC) 28 Set 7600 Sample 6 Make Backfeed 30 Set 7700 (NO) Sample 6 DUT (close NO) 28 Set 6 Input↑ (NO) Sample 6 Break Backfeed 31 Set 7732 (NO) Sample 6 Make/Break 29 Set 7700 (NC) Sample 6 DUT (close NC) 28 Reset 6 Input↑ (NC) Sample 6 Break Backfeed 31 Set 7732 (NC) Sample 6 Make/Break 29 Set 8100 Sample 6 Make Backfeed 30 Reset 8700 (NO) Sample 6 DUT (open NO) 28 Reset 6 Input↓ (NO) Sample 6 Break Backfeed 31 Reset 6 Input↓ (NO) Sample 6 Make/Break 29 Reset 8700 (NC) Sample 6 DUT (open NC) 28 Set 6 Input↓ (NC) Sample 6 Break Backfeed 31 Reset 6 Input↓ (NC) Sample 6 Make/Break 29 Reset

[0079] The following outlines the sequence of operation for an AC Make & Break or Pilot Duty endurance test on six single throw relay samples, referencing the test apparatus shown in FIG. **6**.

[0080] For single throw samples they may be of NO type or NC type, selection is done during test setup on the HMI. Since any sample may be NO or NC the logic to handle both types are in place at the same time for each sample.

[0081] This endurance behaves in a similar way to the double throw endurance, except there is control over when each contact turns on or off.

[0082] If Sample 1 is a NC contact at time 0 ms Sample 1 DUT (relay **3**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Make load (load **35**). At time 100 ms Sample 1 Make Backfeed (relay **5**) is turned on. At time 200 ms two actions happen at the same time, Sample 1 is turned on, and Sample 2 is turned off. If Sample 1 is NO then Sample 1 DUT (relay **3**) turns on to close the NO contact. If Sample 1 is NC, then Sample 1 DUT (relay **3**) is turned off to close the NC contact. If Sample 2 is NO then Sample 2 DUT (relay **8**) turns off to open the NO contact. If Sample 2 is NC, then Sample 2 DUT (relay **8**) turns on to open the NC contact. On the rising edge of Sample 1 DUT contact voltage input Sample 1 Break Backfeed (relay **6**) turns on. On the falling edge of the Sample 2 DUT contact voltage input both Sample 2 Break Backfeed (relay **11**) and Sample 2 Make/Break (relay **9**) are turned off. After the 32 ms delay from the Sample 1 DUT contact voltage input Sample 1 Make/Break (relay **4**) turns on to change-over from the Make load (load **35**) to the Break load (load **32**). To allow sufficient time for the make current duration Sample 1 Make Backfeed (relay **5**) is turned off at

time 600 ms.

[0083] If Sample 2 is a NC contact at time 5000 ms Sample 2 DUT (relay **8**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Make load (load **35**). At time 5100 ms Sample 2 Make Backfeed (relay **10**) is turned on. At time 5200 ms two actions happen at the same time, Sample 2 is turned on, and Sample 1 is turned off. If Sample 1 is NO then Sample 1 DUT (relay **3**) turns off to open the NO contact. If Sample 1 is NC, then Sample 1 DUT (relay **3**) is turned on to open the NC contact. If Sample 2 is NO then Sample 2 DUT (relay **8**) turns on to close the NO contact. If Sample 2 is NC, then Sample 2 DUT (relay **8**) turns off to close the NC contact. On the rising edge of Sample 2 DUT contact voltage input Sample 2 Break Backfeed (relay **11**) turns on. On the falling edge of the Sample 1 DUT contact voltage input both Sample 1 Break Backfeed (relay **6**) and Sample 1 Make/Break (relay **4**) are turned off. After the 32 ms delay from the Sample 2 DUT contact voltage input Sample 2 Make/Break (relay **9**) turns on to change-over from the Make load (load **35**) to the Break load (load **32**). To allow sufficient time for the make current duration Sample 2 Make Backfeed (relay **10**) is turned off at time 5600 ms.

[0084] If Sample 3 is a NC contact at time 3000 ms Sample 3 DUT (relay **13**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Make load (load **35**). At time 3100 ms Sample 3 Make Backfeed (relay **15**) is turned on. At time 3200 ms two actions happen at the same time, Sample 3 is turned on, and Sample 4 is turned off. If Sample 3 is NO then Sample 3 DUT (relay **13**) turns on to close the NO contact. If Sample 3 is NC, then Sample 3 DUT (relay **13**) is turned off to close the NC contact. If Sample 4 is NO then Sample 4 DUT (relay **18**) turns off to open the NO contact. If Sample 4 is NC, then Sample 4 DUT (relay **18**) turns on to open the NC contact. On the rising edge of Sample 3 DUT contact voltage input Sample 3 Break Backfeed (relay **16**) turns on. On the falling edge of the Sample 4 DUT contact voltage input both Sample 4 Break Backfeed (relay **21**) and Sample 4 Make/Break (relay **19**) are turned off. After the 32 ms delay from the Sample 3 DUT contact voltage input Sample 3 Make/Break (relay **14**) turns on to change-over from the Make load (load **35**) to the Break load (load **33**). To allow sufficient time for the make current duration Sample 3 Make Backfeed (relay **15**) is turned off at time 3600 ms.

[0085] If Sample 4 is a NC contact at time 8000 ms Sample 4 DUT (relay **18**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Make load (load **35**). At time 8100 ms Sample 4 Make Backfeed (relay **20**) is turned on. At time 8200 ms two actions happen at the same time, Sample 4 is turned on, and Sample 3 is turned off. If Sample 3 is NO then Sample 3 DUT (relay **13**) turns off to open the NO contact. If Sample 3 is NC, then Sample 3 DUT (relay **13**) is turned on to open the NC contact. If Sample 4 is NO then Sample 4 DUT (relay **18**) turns on to close the NO contact. If Sample 4 is NC, then Sample 4 DUT (relay **18**) turns off to close the NC contact. On the rising edge of Sample 4 DUT contact voltage input Sample 4 Break Backfeed (relay **21**) turns on. On the falling edge of the Sample 3 DUT contact voltage input both Sample 3 Break Backfeed (relay **16**) and Sample 3 Make/Break (relay **14**) are turned off. After the 32 ms delay from the Sample 4 DUT contact voltage input Sample 4 Make/Break (relay **19**) turns on to change-over from the Make load (load **35**) to the Break load (load **33**). To allow sufficient time for the make current duration Sample 4 Make Backfeed (relay **20**) is turned off at time 8600 ms.

[0086] If Sample 5 is a NC contact at time 6000 ms Sample 5 DUT (relay **23**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Make load (load **35**). At time 6100 ms Sample 5 Make Backfeed (relay **25**) is turned on. At time 6200 ms two actions happen at the same time, Sample 5 is turned on, and Sample 6 is turned off. If Sample 5 is NO then Sample 5 DUT (relay **23**) turns on to close the NO contact. If Sample 5 is NC, then Sample 5 DUT (relay **23**) is turned off to close the NC contact. If Sample 6 is NO then Sample 6 DUT (relay **28**) turns off to open the NO contact. If Sample 6 is NC, then

Sample 6 DUT (relay **28**) turns on to open the NC contact. On the rising edge of Sample 5 DUT contact voltage input Sample 5 Break Backfeed (relay **26**) turns on. On the falling edge of the Sample 6 DUT contact voltage input both Sample 6 Break Backfeed (relay **31**) and Sample 6 Make/Break (relay **29**) are turned off. After the 32 ms delay from the Sample 5 DUT contact voltage input Sample 5 Make/Break (relay **24**) turns on to change-over from the Make load (load **35**) to the Break load (load **34**). To allow sufficient time for the make current duration Sample 5 Make Backfeed (relay **25**) is turned off at time 6600 ms.

[0087] If Sample 6 is a NC contact at time 1000 ms Sample 6 DUT (relay **28**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Make load (load **35**). At time 1100 ms Sample 6 Make Backfeed (relay **30**) is turned on. At time 1200 ms two actions happen at the same time, Sample 6 is turned on, and Sample 5 is turned off. If Sample 5 is NO then Sample 5 DUT (relay **23**) turns off to open the NO contact. If Sample 5 is NC, then Sample 5 DUT (relay **23**) is turned on to open the NC contact. If Sample 6 is NO then Sample 6 DUT (relay **28**) turns on to close the NO contact. If Sample 6 is NC, then Sample 6 DUT (relay **28**) turns off to close the NC contact. On the rising edge of Sample 6 DUT contact voltage input Sample 6 Break Backfeed (relay **31**) turns on. On the falling edge of the Sample 5 DUT contact voltage input both Sample 5 Break Backfeed (relay **26**) and Sample 5 Make/Break (relay **24**) are turned off. After the 32 ms delay from the Sample 6 DUT contact voltage input Sample 6 Make/Break (relay **29**) turns on to change-over from the Make load (load **35**) to the Break load (load **34**). To allow sufficient time for the make current duration Sample 6 Make Backfeed (relay **30**) is turned off at time 1600 ms.

[0088] The chronological order of operations for an AC Make & Break or Pilot Duty endurance test on six single throw relay samples using the test apparatus of FIG. **6** is outlined below in Table 5. This sequence may be repeated as many times as desired or as called for to complete standard tests for given DUTs.

TABLE-US-00005 TABLE 5 Time (ms) Output Identifier State 0 (NC) Sample 1 DUT (open NC) 3 Set 100 Sample 1 Make Backfeed 5 Set 200 (NO) Sample 1 DUT (close NO) 3 Set 1 Input↑ (NO) Sample 1 Break Backfeed 6 Set 232 (NO) Sample 1 Make/Break 4 Set 200 (NO) Sample 2 DUT (open NO) 8 Reset 2 Input↓ (NO) Sample 2 Break Backfeed 11 Reset 2 Input↓ (NO) Sample 2 Make/Break 9 Reset 200 (NC) Sample 1 DUT (close NC) 3 Reset 1 Input↑ (NC) Sample 1 Break Backfeed 6 Set 232 (NC) Sample 1 Make/Break 4 Set 200 (NC) Sample 2 DUT (open NC) 8 Set 2 Input↓ (NC) Sample 2 Break Backfeed 11 Reset 2 Input↓ (NC) Sample 2 Make/Break 9 Reset 600 Sample 1 Make Backfeed 5 Reset 1000 (NC) Sample 6 DUT (open NC) 28 Set 1100 Sample 6 Make Backfeed 30 Set 1200 (NO) Sample 5 DUT (open NO) 23 Reset 5 Input↓ (NO) Sample 5 Break Backfeed 26 Reset 5 Input↓ (NO) Sample 5 Make/Break 24 Reset 1200 (NO) Sample 6 DUT (close NO) 28 Set 6 Input↑ (NO) Sample 6 Break Backfeed 31 Set 1232 (NO) Sample 6 Make/Break 29 Set 1200 (NC) Sample 5 DUT (open NC) 23 Set 5 Input↓ (NC) Sample 5 Break Backfeed 26 Reset 5 Input↓ (NC) Sample 5 Make/Break 24 Reset 1200 (NC) Sample 6 DUT (close NC) 28 Reset 6 Input↑ (NC) Sample 6 Break Backfeed 31 Set 1232 (NC) Sample 6 Make/Break 29 Set 1600 Sample 6 Make Backfeed 30 Reset 3000 (NC) Sample 3 DUT (open NC) 13 Set 3100 Sample 3 Make Backfeed 15 Set 3200 (NO) Sample 3 DUT (close NO) 13 Set 3 Input↑ (NO) Sample 3 Break Backfeed 16 Set 3232 (NO) Sample 3 Make/Break 14 Set 3200 (NO) Sample 4 DUT (open NO) 18 Reset 4 Input↓ (NO) Sample 4 Break Backfeed 21 Reset 4 Input↓ (NO) Sample 4 Make/Break 19 Reset 3200 (NC) Sample 3 DUT (close NC) 13 Reset 3 Input↑ (NC) Sample 3 Break Backfeed 16 Set 3232 (NC) Sample 3 Make/Break 14 Set 3200 (NC) Sample 4 DUT (open NC) 18 Set 4 Input↓ (NC) Sample 4 Break Backfeed 21 Reset 4 Input↓ (NC) Sample 4 Make/Break 19 Reset 3600 Sample 3 Make Backfeed 15 Reset 5000 (NC) Sample 2 DUT (open NC) 8 Set 5100 Sample 2 Make Backfeed 10 Set 5200 (NO) Sample 1 DUT (open NO) 3 Reset 1 Input↓ (NO) Sample 1 Break Backfeed 6 Reset 1 Input↓ (NO) Sample 1 Make/Break 4 Reset 5200 (NO) Sample 2 DUT (close NO) 8 Set 2 Input↑ (NO) Sample 2 Break Backfeed 11 Set 5232 (NO) Sample 2

Make/Break 9 Set 5200 (NC) Sample 1 DUT (open NC) 3 Set 1 Input↓ (NC) Sample 1 Break Backfeed 6 Reset 1 Input↓ (NC) Sample 1 Make/Break 4 Reset 5200 (NC) Sample 2 DUT (close NC) 8 Reset 2 Input↑ (NC) Sample 2 Break Backfeed 11 Set 5232 (NC) Sample 2 Make/Break 9 Set 5600 Sample 2 Make Backfeed 10 Reset 6000 (NC) Sample 5 DUT (open NC) 23 Set 6100 Sample 5 Make Backfeed 25 Set 6200 (NO) Sample 5 DUT (close NO) 23 Set 5 Input↑ (NO) Sample 5 Break Backfeed 26 Set 6232 (NO) Sample 5 Make/Break 24 Set 6200 (NO) Sample 6 DUT (open NO) 28 Reset 6 Input↓ (NO) Sample 6 Break Backfeed 31 Reset 6 Input↓ (NO) Sample 6 Make/Break 29 Reset 6200 (NC) Sample 5 DUT (close NC) 23 Reset 5 Input↑ (NC) Sample 5 Break Backfeed 26 Set 6232 (NC) Sample 5 Make/Break 24 Set 6200 (NC) Sample 6 DUT (open NC) 28 Set 6 Input↓ (NC) Sample 6 Break Backfeed 31 Reset 6 Input↓ (NC) Sample 6 Make/Break 29 Reset 6600 Sample 5 Make Backfeed 25 Reset 8000 (NC) Sample 4 DUT (open NC) 18 Set 8100 Sample 4 Make Backfeed 20 Set 8200 (NO) Sample 3 DUT (open NO) 13 Reset 3 Input↓ (NO) Sample 3 Break Backfeed 16 Reset 3 Input↓ (NO) Sample 3 Make/Break 14 Reset 8200 (NO) Sample 4 DUT (close NO) 18 Set 4 Input↑ (NO) Sample 4 Break Backfeed 21 Set 8232 (NO) Sample 4 Make/Break 19 Set 8200 (NC) Sample 3 DUT (open NC) 13 Set 3 Input↓ (NC) Sample 3 Break Backfeed 16 Reset 3 Input↓ (NC) Sample 3 Make/Break 14 Reset 8200 (NC) Sample 4 DUT (close NC) 18 Reset 4 Input↑ (NC) Sample 4 Break Backfeed 21 Set 8232 (NC) Sample 4 Make/Break 19 Set 8600 Sample 4 Make Backfeed 20 Reset

[0089] The following outlines the sequence of operation for an AC Resistive/Motor or DC Resistive/Pilot Duty overload test on three double throw relay samples utilizing the NO contacts, referencing the test apparatus shown in FIG. **7** and the oscillograph shown in FIG. **5**.

[0090] At time 0 ms Sample 1 NO Break Backfeed (relay **9**) and Sample 1 NO Make/Break (relay **5**) are turned on. This is done before the device under test (DUT) is activated to allow a complete path to the Break load (load **26**). At time 100 ms Sample 1 DUT (relay **3**) is turned on. At 1100 ms Sample 1 DUT turns off (relay **3**) completing the one second contact on time. On the falling edge of the Sample 1 NO contact DUT current input both Sample 1 NO Break Backfeed (relay **9**) and Sample 1 NO Make/Break (relay **5**) are turned off.

[0091] At time 3000 ms Sample 2 NO Break Backfeed (relay **17**) and Sample 2 NO Make/Break (relay **13**) are turned on. This is done before the DUT is activated to allow a complete path to the Break load (load **27**). At time 3100 ms Sample 2 DUT (relay **11**) is turned on. At 4100 ms Sample 2 DUT turns off (relay **11**) completing the one second contact on time. On the falling edge of the Sample 2 NO contact DUT current input both Sample 2 NO Break Backfeed (relay **17**) and Sample 2 NO Make/Break (relay **13**) are turned off.

[0092] At time 6000 ms Sample 3 NO Break Backfeed (relay **25**) and Sample 3 NO Make/Break (relay **21**) are turned on. This is done before the DUT is activated to allow a complete path to the Break load (load **28**). At time 6100 ms Sample 3 DUT (relay **19**) is turned on. At 7100 ms Sample 3 DUT turns off (relay **19**) completing the one second contact on time. On the falling edge of the Sample 3 NO contact DUT current input both Sample 3 NO Break Backfeed (relay **25**) and Sample 3 NO Make/Break (relay **21**) are turned off.

[0093] The chronological order of operations for an AC Resistive/Motor or DC Resistive/Pilot Duty overload test on three double throw relay samples utilizing the NO contacts and the test apparatus of FIG. **7** is outlined below in Table 6. This sequence may be repeated as many times as desired or as called for to complete standard tests for given DUTs.

TABLE-US-00006 TABLE 6 Time (ms) Output Identifier State 0 Sample 1 NO Break Backfeed 9 Set 0 Sample 1 NO Make/Break 5 Set 100 Sample 1 DUT 3 Set 1100 Sample 1 DUT 3 Reset 1NO Input↓ Sample 1 NO Break Backfeed 9 Reset 1NO Input↓ Sample 1 NO Make/Break 5 Reset 3000 Sample 2 NO Break Backfeed 17 Set 3000 Sample 2 NO Make/Break 13 Set 3100 Sample 2 DUT 11 Set 4100 Sample 2 DUT 11 Reset 2NO Input↓ Sample 2 NO Break Backfeed 17 Reset 2NO Input↓ Sample 2 NO Make/Break 13 Reset 6000 Sample 3 NO Break Backfeed 25 Set 6000 Sample 3 NO Make/Break 21 Set 6100 Sample 3 DUT 19 Set 7100 Sample 3 DUT 19 Reset 3NO

Input↓ Sample 3 NO Break Backfeed 25 Reset 3NO Input↓ Sample 3 NO Make/Break 21 Reset

[0094] The following outlines the sequence of operation for an AC Resistive/Motor or DC Resistive/Pilot Duty overload test on three double throw relay samples utilizing the NC contacts, referencing the test apparatus shown in FIG. **7** and the oscillograph shown in FIG. **5**.

[0095] At time 0 ms Sample 1 DUT (relay **3**) is turned on to open the NC contact. At 100 ms Sample 1 NC Break Backfeed (relay **7**) and Sample 1 NC Make/Break (relay **4**) are turned on. This is done before the device under test (DUT) is activated to allow a complete path to the Break load (load **26**). At time 200 ms Sample 1 DUT (relay **3**) is turned off turning the NC contact on. At 1200 ms Sample 1 DUT (relay **3**) turns on opening the NC contact completing the one second contact on time. On the falling edge of the Sample 1 NC contact DUT current input both Sample 1 NC Break Backfeed (relay **7**) and Sample 1 NC Make/Break (relay **4**) are turned off.

[0096] At time 3000 ms Sample 2 DUT (relay **11**) is turned on to open the NC contact. At 3100 ms Sample 2 NC Break Backfeed (relay **15**) and Sample 2 NC Make/Break (relay **12**) are turned on. This is done before the DUT is activated to allow a complete path to the Break load (load **27**). At time 3200 ms Sample 2 DUT (relay **11**) is turned off turning the NC contact on. At 4200 ms Sample 2 DUT (relay **11**) turns on opening the NC contact completing the one second contact on time. On the falling edge of the Sample 2 NC contact DUT current input both Sample 2 NC Break Backfeed (relay **15**) and Sample 2 NC Make/Break (relay **12**) are turned off.

[0097] At time 6000 ms Sample 3 DUT (relay **19**) is turned on to open the NC contact. At 6100 ms Sample 3 NC Break Backfeed (relay **23**) and Sample 3 NC Make/Break (relay **20**) are turned on. This is done before the DUT is activated to allow a complete path to the Break load (load **28**). At time 6200 ms Sample 3 DUT (relay **19**) is turned off turning the NC contact on. At 7200 ms Sample 3 DUT (relay **19**) turns on opening the NC contact completing the one second contact on time. On the falling edge of the Sample 3 NC contact DUT current input both Sample 3 NC Break Backfeed (relay **23**) and Sample 3 NC Make/Break (relay **20**) are turned off.

[0098] The chronological order of operations for an AC Resistive/Motor or DC Resistive/Pilot Duty overload test on three double throw relay samples utilizing the NC contacts using the test apparatus of FIG. **7** is outlined below in Table 7. This sequence may be repeated as many times as desired or as called for to complete standard tests for given DUTs.

TABLE-US-00007 TABLE 7 Time (ms) Output Identifier State 0 Sample 1 DUT (open NC) 3 Set 100 Sample 1 NC Break Backfeed 7 Set 100 Sample 1 NC Make/Break 4 Set 200 Sample 1 DUT (close NC) 3 Reset 1200 Sample 1 DUT (open NC) 3 Set 1NC Input↓ Sample 1 NC Break Backfeed 7 Reset 1NC Input↓ Sample 1 NC Make/Break 4 Reset 3000 Sample 2 DUT (open NC) 11 Set 3100 Sample 2 NC Break Backfeed 15 Set 3100 Sample 2 NC Make/Break 12 Set 3200 Sample 2 DUT (close NC) 11 Reset 4200 Sample 2 DUT (open NC) 11 Set 2NC Input↓ Sample 2 NC Break Backfeed 15 Reset 2NC Input↓ Sample 2 NC Make/Break 12 Reset 6000 Sample 3 DUT (open NC) 19 Set 6100 Sample 3 NC Break Backfeed 23 Set 6100 Sample 3 NC Make/Break 20 Set 6200 Sample 3 DUT (close NC) 19 Reset 7200 Sample 3 DUT (open NC) 19 Set 3NC Input↓ Sample 3 NC Break Backfeed 23 Reset 3NC Input↓ Sample 3 NC Make/Break 20 Reset

[0099] The following outlines the sequence of operation for an AC Resistive/Motor or DC Resistive/Pilot Duty endurance test on three double throw relay samples. Reference FIG. **7** drawing and FIG. **5** oscillograph.

[0100] At time 0 ms Sample 1 NO Break Backfeed (relay **9**) and Sample 1 NO Make/Break (relay **5**) are turned on. This is done before the device under test (DUT) is activated to allow a complete path to the Break load (load **26**). At time 100 ms Sample 1 DUT (relay **3**) is turned on activating the NO contact and completing the previous five second on time of the NC contact. On the falling edge of the DUT NC contact current input from the previous cycle both Sample 1 NC Break Backfeed (relay **7**) and Sample 1 NC Make/Break (relay **4**) are turned off. This is to make sure that the DUT contact breaks the circuit and nothing inside the test fixture. At 5000 ms Sample 1 NC Break Backfeed (relay **7**) and Sample 1 NC Make/Break (relay **4**) are turned on to allow the NC

current to pass. At 5100 ms Sample 1 DUT turns off (relay **3**) activating the NC contact and completing the five second on time of the NO contact. On the falling edge of the DUT NO contact current input both Sample 1 NO Break Backfeed (relay **9**) and Sample 1 NO Make/Break (relay **5**) are turned off.

[0101] At time 3000 ms Sample 2 NO Break Backfeed (relay **17**) and Sample 2 NO Make/Break (relay **13**) are turned on. This is done before the DUT is activated to allow a complete path to the Break load (load **27**). At time 3100 ms Sample 2 DUT (relay **11**) is turned on activating the NO contact and completing the previous five second on time of the NC contact. On the falling edge of the DUT NC contact current input from the previous cycle both Sample 2 NC Break Backfeed (relay **15**) and Sample 2 NC Make/Break (relay **12**) are turned off. This is to make sure that the DUT contact breaks the circuit and nothing inside the test fixture. At 8000 ms Sample 2 NC Break Backfeed (relay **15**) and Sample 2 NC Make/Break (relay **12**) are turned on to allow the NC current to pass. At 8100 ms Sample 2 DUT turns off (relay **11**) activating the NC contact and completing the five second on time of the NO contact. On the falling edge of the DUT NO contact current input both Sample 2 NO Break Backfeed (relay **17**) and Sample 2 NO Make/Break (relay **13**) are turned off.

[0102] At time 6000 ms Sample 3 NO Break Backfeed (relay **25**) and Sample 3 NO Make/Break (relay **21**) are turned on. This is done before the DUT is activated to allow a complete path to the Break load (load **28**). At time 6100 ms Sample 3 DUT (relay **19**) is turned on activating the NO contact and completing the previous five second on time of the NC contact. On the falling edge of the DUT NC contact current input from the previous cycle both Sample 3 NC Break Backfeed (relay **23**) and Sample 3 NC Make/Break (relay **20**) are turned off. This is to make sure that the DUT contact breaks the circuit and nothing inside the test fixture. At 1000 ms Sample 3 NC Break Backfeed (relay **23**) and Sample 3 NC Make/Break (relay **20**) are turned on to allow the NC current to pass. At 1100 ms Sample 3 DUT turns off (relay **19**) activating the NC contact and completing the five second on time of the NO contact. On the falling edge of the DUT NO contact current input both Sample 3 NO Break Backfeed (relay **25**) and Sample 3 NO Make/Break (relay **21**) are turned off.

[0103] The chronological order of operations for an AC Resistive/Motor or DC Resistive/Pilot Duty endurance test on three double throw relay samples using the test apparatus of FIG. **7** is outlined below in Table 8. This sequence may be repeated as many times as desired or as called for to complete standard tests for given DUTs.

TABLE-US-00008 TABLE 8 Time (ms) Output Identifier State 0 Sample 1 NO Break Backfeed 9 Set 0 Sample 1 NO Make/Break 5 Set 100 Sample 1 DUT 3 Set 1NC Input↓ Sample 1 NC Break Backfeed 7 Reset 1NC Input↓ Sample 1 NC Make/Break 4 Reset 1000 Sample 3 NC Break Backfeed 23 Set 1000 Sample 3 NC Make/Break 20 Set 1100 Sample 3 DUT 19 Reset 3NO Input↓ Sample 3 NO Break Backfeed 25 Reset 3NO Input↓ Sample 3 NO Make/Break 21 Reset 3000 Sample 2 NO Break Backfeed 17 Set 3000 Sample 2 NO Make/Break 13 Set 3100 Sample 2 DUT 11 Set 2NC Input↓ Sample 2 NC Break Backfeed 15 Reset 2NC Input↓ Sample 2 NC Make/Break 12 Reset 5000 Sample 1 NC Break Backfeed 7 Set 5000 Sample 1 NC Make/Break 4 Set 5100 Sample 1 DUT 3 Reset 1NO Input↓ Sample 1 NO Break Backfeed 9 Reset 1NO Input↓ Sample 1 NO Make/Break 5 Reset 6000 Sample 3 NO Break Backfeed 25 Set 6000 Sample 3 NO Make/Break 21 Set 6100 Sample 3 DUT 19 Set 3NC Input↓ Sample 3 NC Break Backfeed 23 Reset 3NC Input↓ Sample 3 NC Make/Break 20 Reset 8000 Sample 2 NC Break Backfeed 15 Set 8000 Sample 2 NC Make/Break 12 Set 8100 Sample 2 DUT 11 Reset 2NO Input↓ Sample 2 NO Break Backfeed 17 Reset 2NO Input↓ Sample 2 NO Make/Break 13 Reset

[0104] The following outlines the sequence of operation for an AC Resistive/Motor or DC Resistive/Pilot Duty overload test on six single throw relay samples referencing the test apparatus of FIG. **8**.

[0105] For single throw samples they may be of NO type or NC type, selection is done during test

setup on the HMI. Since any sample may be NO or NC the logic to handle both types are in place at the same time for each sample.

[0106] If Sample 1 is a NC contact at time 0 ms Sample 1 DUT (relay **3**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Break load (load **32**). At time 100 ms Sample 1 Break Backfeed (relay **6**) and Sample 1 Make/Break (relay **4**) are turned on. At time 200 ms one of two actions can happen depending on if the sample is NO or NC. If the sample is NO Sample 1 DUT (relay **3**) turns on to close the NO contact. If the sample is NC, then Sample 1 DUT (relay **3**) is turned off to close the NC contact. At 1200 ms if the sample is NO then Sample 1 DUT (relay **3**) is turned off to open the NO contact. If the sample is NC, then Sample 1 DUT (relay **3**) is turned on to open the NC contact. This completes the contacts one second on time. On the falling edge of the contact DUT current input both Sample 1 Break Backfeed (relay **6**) and Sample 1 Make/Break (relay **4**) are turned off.

[0107] If Sample 2 is a NC contact at time 1500 ms Sample 2 DUT (relay **8**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Break load (load **32**). At time 1600 ms Sample 2 Break Backfeed (relay **11**) and Sample 2 Make/Break (relay **9**) are turned on. At time 1700 ms one of two actions can happen depending on if the sample is NO or NC. If the sample is NO Sample 2 DUT (relay **8**) turns on to close the NO contact. If the sample is NC, then Sample 2 DUT (relay **8**) is turned off to close the NC contact. At 2700 ms if the sample is NO then Sample 2 DUT (relay **8**) is turned off to open the NO contact. If the sample is NC, then Sample 2 DUT (relay **8**) is turned on to open the NC contact. This completes the contacts one second on time. On the falling edge of the contact DUT current input both Sample 2 Break Backfeed (relay **11**) and Sample 2 Make/Break (relay **9**) are turned off.

[0108] If Sample 3 is a NC contact at time 3000 ms Sample 3 DUT (relay **13**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Break load (load **33**). At time 3100 ms Sample 3 Break Backfeed (relay **16**) and Sample 3 Make/Break (relay **14**) are turned on. At time 3200 ms one of two actions can happen depending on if the sample is NO or NC. If the sample is NO Sample 3 DUT (relay **13**) turns on to close the NO contact. If the sample is NC, then Sample 3 DUT (relay **13**) is turned off to close the NC contact. At 4200 ms if the sample is NO then Sample 3 DUT (relay **13**) is turned off to open the NO contact. If the sample is NC, then Sample 3 DUT (relay **13**) is turned on to open the NC contact. This completes the contacts one second on time. On the falling edge of the contact DUT current input both Sample 3 Break Backfeed (relay **16**) and Sample 3 Make/Break (relay **14**) are turned off.

[0109] If Sample 4 is a NC contact at time 4500 ms Sample 4 DUT (relay **18**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Break load (load **33**). At time 4600 ms Sample 4 Break Backfeed (relay **21**) and Sample 4 Make/Break (relay **19**) are turned on. At time 4700 ms one of two actions can happen depending on if the sample is NO or NC. If the sample is NO Sample 4 DUT (relay **18**) turns on to close the NO contact. If the sample is NC, then Sample 4 DUT (relay **18**) is turned off to close the NC contact. At 5700 ms if the sample is NO then Sample 4 DUT (relay **18**) is turned off to open the NO contact. If the sample is NC, then Sample 4 DUT (relay **18**) is turned on to open the NC contact. This completes the contacts one second on time. On the falling edge of the contact DUT current input both Sample 4 Break Backfeed (relay **21**) and Sample 4 Make/Break (relay **19**) are turned off.

[0110] If Sample 5 is a NC contact at time 6000 ms Sample 5 DUT (relay **23**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Break load (load **34**). At time 6100 ms Sample 5 Break Backfeed (relay **26**) and Sample 5 Make/Break (relay **24**) are turned on. At time 6200 ms one of two actions can happen depending on if the sample is NO or NC. If the sample is NO Sample 5 DUT (relay **23**) turns on to close the NO contact. If the sample is NC, then Sample 5 DUT (relay **23**) is turned off to close the NC

contact. At 7200 ms if the sample is NO then Sample 5 DUT (relay **23**) is turned off to open the NO contact. If the sample is NC, then Sample 5 DUT (relay **23**) is turned on to open the NC contact. This completes the contacts one second on time. On the falling edge of the contact DUT current input both Sample 5 Break Backfeed (relay **26**) and Sample 5 Make/Break (relay **24**) are turned off.

[0111] If Sample 6 is a NC contact at time 7500 ms Sample 6 DUT (relay **28**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Break load (load **34**). At time 7600 ms Sample 6 Break Backfeed (relay **31**) and Sample 6 Make/Break (relay **29**) are turned on. At time 7700 ms one of two actions can happen depending on if the sample is NO or NC. If the sample is NO Sample 6 DUT (relay **28**) turns on to close the NO contact. If the sample is NC, then Sample 6 DUT (relay **28**) is turned off to close the NC contact. At 8700 ms if the sample is NO then Sample 6 DUT (relay **28**) is turned off to open the NO contact. If the sample is NC, then Sample 6 DUT (relay **28**) is turned on to open the NC contact. This completes the contacts one second on time. On the falling edge of the contact DUT current input both Sample 6 Break Backfeed (relay **31**) and Sample 6 Make/Break (relay **29**) are turned off.

[0112] The chronological order of operations for an AC Resistive/Motor or DC Resistive/Pilot Duty overload test on six single throw relay samples using the test apparatus of FIG. **8** is outlined below in Table 9. This sequence may be repeated as many times as desired or as called for to complete standard tests for given DUTs.

TABLE-US-00009 TABLE 9 Time (ms) Output Identifier State 0 (NC) Sample 1 DUT (open NC) 3 Set 100 Sample 1 Break Backfeed 6 Set 100 Sample 1 Make/Break 4 Set 200 (NO) Sample 1 DUT (close NO) 3 Set 200 (NC) Sample 1 DUT (close NC) 3 Reset 1200 (NO) Sample 1 DUT (open NO) 3 Reset 1 Input↓ (NO) Sample 1 Break Backfeed 6 Reset 1 Input↓ (NO) Sample 1 Make/Break 4 Reset 1200 (NC) Sample 1 DUT (open NC) 3 Set 1 Input↓ (NC) Sample 1 Break Backfeed 6 Reset 1 Input↓ (NC) Sample 1 Make/Break 4 Reset 1500 (NC) Sample 2 DUT (open NC) 8 Set 1600 Sample 2 Break Backfeed 11 Set 1600 Sample 2 Make/Break 9 Set 1700 (NO) Sample 2 DUT (close NO) 8 Set 1700 (NC) Sample 2 DUT (close NC) 8 Reset 2700 (NO) Sample 2 DUT (open NO) 8 Reset 2 Input↓ (NO) Sample 2 Break Backfeed 11 Reset 2 Input↓ (NO) Sample 2 Make/Break 9 Reset 2700 (NC) Sample 2 DUT (open NC) 8 Set 2 Input↓ (NC) Sample 2 Break Backfeed 11 Reset 2 Input↓ (NC) Sample 2 Make/Break 9 Reset 3000 (NC) Sample 3 DUT (open NC) 13 Set 3100 Sample 3 Break Backfeed 16 Set 3100 Sample 3 Make/Break 14 Set 3200 (NO) Sample 3 DUT (close NO) 13 Set 3200 (NC) Sample 3 DUT (close NC) 13 Reset 4200 (NO) Sample 3 DUT (open NO) 13 Reset 3 Input↓ (NO) Sample 3 Break Backfeed 16 Reset 3 Input↓ (NO) Sample 3 Make/Break 14 Reset 4200 (NC) Sample 3 DUT (open NC) 13 Set 3 Input↓ (NC) Sample 3 Break Backfeed 16 Reset 3 Input↓ (NC) Sample 3 Make/Break 14 Reset 4500 (NC) Sample 4 DUT (open NC) 18 Set 4600 Sample 4 Break Backfeed 21 Set 4600 Sample 4 Make/Break 19 Set 4700 (NO) Sample 4 DUT (close NO) 18 Set 4700 (NC) Sample 4 DUT (close NC) 18 Reset 5700 (NO) Sample 4 DUT (open NO) 18 Reset 4 Input↓ (NO) Sample 4 Break Backfeed 21 Reset 4 Input↓ (NO) Sample 4 Make/Break 19 Reset 5700 (NC) Sample 4 DUT (open NC) 18 Set 4 Input↓ (NC) Sample 4 Break Backfeed 21 Reset 4 Input↓ (NC) Sample 4 Make/Break 19 Reset 6000 (NC) Sample 5 DUT (open NC) 23 Set 6100 Sample 5 Break Backfeed 26 Set 6100 Sample 5 Make/Break 24 Set 6200 (NO) Sample 5 DUT (close NO) 23 Set 6200 (NC) Sample 5 DUT (close NC) 23 Reset 7200 (NO) Sample 5 DUT (open NO) 23 Reset 5 Input↓ (NO) Sample 5 Break Backfeed 26 Reset 5 Input↓ (NO) Sample 5 Make/Break 24 Reset 7200 (NC) Sample 5 DUT (open NC) 23 Set 5 Input↓ (NC) Sample 5 Break Backfeed 26 Reset 5 Input↓ (NC) Sample 5 Make/Break 24 Reset 7500 (NC) Sample 6 DUT (open NC) 28 Set 7600 Sample 6 Break Backfeed 31 Set 7600 Sample 6 Make/Break 29 Set 7700 (NO) Sample 6 DUT (close NO) 28 Set 7700 (NC) Sample 6 DUT (close NC) 28 Reset 8700 (NO) Sample 6 DUT (open NO) 28 Reset 6 Input↓ (NO) Sample 6 Break Backfeed 31 Reset 6 Input↓ (NO) Sample 6 Make/Break 29 Reset 8700 (NC)

Sample 6 DUT (open NC) 28 Set 6 Input↓ (NC) Sample 6 Break Backfeed 31 Reset 6 Input↓ (NC) Sample 6 Make/Break 29 Reset

[0113] The following outlines the sequence of operation for an AC Resistive/Motor or DC Resistive/Pilot Duty endurance test on six single throw relay samples, referencing the test apparatus shown in FIG. **8**.

[0114] For single throw samples they may be of NO type or NC type, selection is done during test setup on the HMI. Since any sample may be NO or NC the logic to handle both types are in place at the same time for each sample.

[0115] This endurance behaves in a similar way to the double throw endurance, except there is control over when each contact turns on or off.

[0116] If Sample 1 is a NC contact at time 0 ms Sample 1 DUT (relay **3**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Break load (load **32**). At time 100 ms Sample 1 Break Backfeed (relay **6**) and Sample 1 Make/Break (relay **4**) are turned on. At time 200 ms two actions happen at the same time, Sample 1 is turned on, and Sample 2 is turned off. If Sample 1 is NO then Sample 1 DUT (relay **3**) turns on to close the NO contact. If Sample 1 is NC, then Sample 1 DUT (relay **3**) is turned off to close the NC contact. If Sample 2 is NO then Sample 2 DUT (relay **8**) turns off to open the NO contact. If Sample 2 is NC, then Sample 2 DUT (relay **8**) turns on to open the NC contact. On the falling edge of the Sample 2 DUT contact current input both Sample 2 Break Backfeed (relay **11**) and Sample 2 Make/Break (relay **9**) are turned off.

[0117] If Sample 2 is a NC contact at time 5000 ms Sample 2 DUT (relay **8**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Break load (load **32**). At time 5100 ms Sample 2 Break Backfeed (relay **11**) and Sample 2 Make/Break (relay **9**) are turned on. At time 5200 ms two actions happen at the same time, Sample 2 is turned on, and Sample 1 is turned off. If Sample 1 is NO then Sample 1 DUT (relay **3**) turns off to open the NO contact. If Sample 1 is NC, then Sample 1 DUT (relay **3**) is turned on to open the NC contact. If Sample 2 is NO then Sample 2 DUT (relay **8**) turns on to close the NO contact. If Sample 2 is NC, then Sample 2 DUT (relay **8**) turns off to close the NC contact. On the falling edge of the Sample 1 DUT contact current input both Sample 1 Break Backfeed (relay **6**) and Sample 1 Make/Break (relay **4**) are turned off.

[0118] If Sample 3 is a NC contact at time 3000 ms Sample 3 DUT (relay **13**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Break load (load **33**). At time 3100 ms Sample 3 Break Backfeed (relay **16**) and Sample 3 Make/Break (relay **14**) are turned on. At time 3200 ms two actions happen at the same time, Sample 3 is turned on, and Sample 4 is turned off. If Sample 3 is NO then Sample 3 DUT (relay **13**) turns on to close the NO contact. If Sample 3 is NC, then Sample 3 DUT (relay **13**) is turned off to close the NC contact. If Sample 4 is NO then Sample 4 DUT (relay **18**) turns off to open the NO contact. If Sample 4 is NC, then Sample 4 DUT (relay **18**) turns on to open the NC contact. On the falling edge of the Sample 4 DUT contact current input both Sample 4 Break Backfeed (relay **21**) and Sample 4 Make/Break (relay **19**) are turned off.

[0119] If Sample 4 is a NC contact at time 8000 ms Sample 4 DUT (relay **18**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Break load (load **33**). At time 8100 ms Sample 4 Break Backfeed (relay **21**) and Sample 4 Make/Break (relay **19**) are turned on. At time 8200 ms two actions happen at the same time, Sample 4 is turned on, and Sample 3 is turned off. If Sample 3 is NO then Sample 3 DUT (relay **13**) turns off to open the NO contact. If Sample 3 is NC, then Sample 3 DUT (relay **13**) is turned on to open the NC contact. If Sample 4 is NO then Sample 4 DUT (relay **18**) turns on to close the NO contact. If Sample 4 is NC, then Sample 4 DUT (relay **18**) turns off to close the NC contact. On the falling edge of the Sample 3 DUT contact current input both Sample 3 Break Backfeed (relay **16**) and Sample 3 Make/Break (relay **14**) are turned off.

[0120] If Sample 5 is a NC contact at time 6000 ms Sample 5 DUT (relay **23**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Break load (load **34**). At time 6100 ms Sample 5 Break Backfeed (relay **26**) and Sample 5 Make/Break (relay **24**) are turned on. At time 6200 ms two actions happen at the same time, Sample 5 is turned on, and Sample 6 is turned off. If Sample 5 is NO then Sample 5 DUT (relay **23**) turns on to close the NO contact. If Sample 5 is NC, then Sample 5 DUT (relay **23**) is turned off to close the NC contact. If Sample 6 is NO then Sample 6 DUT (relay **28**) turns off to open the NO contact. If Sample 6 is NC, then Sample 6 DUT (relay **28**) turns on to open the NC contact. On the falling edge of the Sample 6 DUT contact current input both Sample 6 Break Backfeed (relay **31**) and Sample 6 Make/Break (relay **29**) are turned off.

[0121] If Sample 6 is a NC contact at time 1000 ms Sample 6 DUT (relay **28**) is turned on to open the NC contact. This is done before the device under test activates the load to allow a complete path to the Break load (load **34**). At time 1100 ms Sample 6 Break Backfeed (relay **31**) and Sample 6 Make/Break (relay **29**) are turned on. At time 1200 ms two actions happen at the same time, Sample 6 is turned on, and Sample 5 is turned off. If Sample 5 is NO then Sample 5 DUT (relay **23**) turns off to open the NO contact. If Sample 5 is NC, then Sample 5 DUT (relay **23**) is turned on to open the NC contact. If Sample 6 is NO then Sample 6 DUT (relay **28**) turns on to close the NO contact. If Sample 6 is NC, then Sample 6 DUT (relay **28**) turns off to close the NC contact. On the falling edge of the Sample 5 DUT contact current input both Sample 5 Break Backfeed (relay **26**) and Sample 5 Make/Break (relay **24**) are turned off.

[0122] The chronological order of operations for an AC Resistive/Motor or DC Resistive/Pilot Duty endurance test on six single throw relay samples using the test apparatus shown in FIG. **8** is outlined below in Table 10. This sequence may be repeated as many times as desired or as called for to complete standard tests for given DUTs.

TABLE-US-00010

TABLE 10

Time (ms)	Output	Identifier	State
0	(NC) Sample 1 DUT (open NC)	3	Set
100	Sample 1 Break Backfeed	6	Set
100	Sample 1 Make/Break	4	Set
200	(NO) Sample 1 DUT (close NO)	3	Set
200	(NO) Sample 2 DUT (open NO)	8	Reset
2 Input↓	(NO) Sample 2 Break Backfeed	11	Reset
2 Input↓	(NO) Sample 2 Make/Break	9	Reset
200	(NC) Sample 1 DUT (close NC)	3	Reset
200	(NC) Sample 2 DUT (open NC)	8	Set
2 Input↓	(NC) Sample 2 Break Backfeed	11	Reset
2 Input↓	(NC) Sample 2 Make/Break	9	Reset
1000	(NC) Sample 6 DUT (open NC)	28	Set
1100	Sample 6 Break Backfeed	31	Set
1100	Sample 6 Make/Break	29	Set
1200	(NO) Sample 5 DUT (open NO)	23	Reset
1200	(NO) Sample 6 DUT (close NO)	28	Set
5 Input↓	(NO) Sample 5 Break Backfeed	26	Reset
5 Input↓	(NO) Sample 5 Make/Break	24	Reset
1200	(NC) Sample 5 DUT (open NC)	23	Set
1200	(NC) Sample 6 DUT (close NC)	28	Reset
5 Input↓	(NC) Sample 5 Break Backfeed	26	Reset
5 Input↓	(NC) Sample 5 Make/Break	24	Reset
3000	(NC) Sample 3 DUT (open NC)	13	Set
3100	Sample 3 Break Backfeed	16	Set
3100	Sample 3 Make/Break	14	Set
3200	(NO) Sample 3 DUT (close NO)	13	Set
3200	(NO) Sample 4 DUT (open NO)	18	Reset
4 Input↓	(NO) Sample 4 Break Backfeed	21	Reset
4 Input↓	(NO) Sample 4 Make/Break	19	Reset
3200	(NC) Sample 3 DUT (close NC)	13	Reset
3200	(NC) Sample 4 DUT (open NC)	18	Set
4 Input↓	(NC) Sample 4 Break Backfeed	21	Reset
4 Input↓	(NC) Sample 4 Make/Break	19	Reset
5000	(NC) Sample 2 DUT (open NC)	8	Set
5100	Sample 2 Break Backfeed	11	Set
5100	Sample 2 Make/Break	9	Set
5200	(NO) Sample 1 DUT (open NO)	3	Reset
5200	(NO) Sample 2 DUT (close NO)	8	Set
1 Input↓	(NO) Sample 1 Break Backfeed	6	Reset
1 Input↓	(NO) Sample 1 Make/Break	4	Reset
5200	(NC) Sample 1 DUT (open NC)	3	Set
5200	(NC) Sample 2 DUT (close NC)	8	Reset
1 Input↓	(NC) Sample 1 Break Backfeed	6	Reset
1 Input↓	(NC) Sample 1 Make/Break	4	Reset
6000	(NC) Sample 5 DUT (open NC)	23	Set
6100	Sample 5 Break Backfeed	26	Set
6100	Sample 5 Make/Break	24	Set
6200	(NO) Sample 5 DUT (close NO)	23	Set
6200	(NO) Sample 6 DUT (open NO)	28	Reset
6 Input↓	(NO) Sample 6 Break Backfeed	31	Reset
6 Input↓	(NO) Sample 6 Make/Break	29	Reset
6200	(NC) Sample 5 DUT (close NC)	23	Reset
6200	(NC) Sample 6 DUT (open NC)	28	Set
6 Input↓	(NC) Sample 6 Break Backfeed	31	Reset
6 Input↓	(NC) Sample 6 Make/Break	29	Reset

8000 (NC) Sample 4 DUT (open NC) 18 Set 8100 Sample 4 Break Backfeed 21 Set 8100 Sample 4 Make/Break 19 Set 8200 (NO) Sample 3 DUT (open NO) 13 Reset 8200 (NO) Sample 4 DUT (close NO) 18 Set 3 Input↓ (NO) Sample 3 Break Backfeed 16 Reset 3 Input↓ (NO) Sample 3 Make/Break 14 Reset 8200 (NC) Sample 3 DUT (open NC) 13 Set 8200 (NC) Sample 4 DUT (close NC) 18 Reset 3 Input↓ (NC) Sample 3 Break Backfeed 16 Reset 3 Input↓ (NC) Sample 3 Make/Break 14 Reset

Example Human Machine Interfaces (HMIs)

[0123] FIGS. **9-43** are diagrammatic views of example graphical user interfaces or human machine interfaces (HMIs) for using an example testing apparatus. These HMIs allow a user to select different interface elements described herein to configure a test as desired to perform different types of tests on different types of samples as desired. An HMI **900** in FIG. **9** shows a main screen where a user may select "Test Setup" to setup a test for double throw switches or to setup a test for single throw switches. The HMI **900** includes "Test Dashboard DT" and "Test Dashboard ST" to see running test information. The HMI **900** also includes an interface element to manually control an oven of the test apparatus apart from a particular test by selecting "Manual Oven Control." An element "Oven Temperatures" may also be selected so that the current temperature of one or more ovens of the test apparatus is displayed. A "Test Completed DT" element may be selected to display information related to an already completed double throw relay test. A "Test Completed ST" element may be selected to display information related to an already completed single throw relay test. The "Run" and "Stop" buttons may be selected to run or stop a test, respectively. And a "Count Reset" button may be selected by a user to reset a test back to an original count, for example if something about a test was incorrect and needs to be restarted.

[0124] An HMI **1000** in FIG. **10** shows elements so that the user can select whether each sample for a current test will run the "Same Test" or whether different samples installed in the test apparatus will have "Different Tests" run. An HMI **1100** in FIG. **11** prompts the user to indicate and/or confirm whether single throw or double throw samples are being tested.

[0125] An HMI **1200** in FIG. **12** is shown, for example, if the user selects "Double Throw" in the HMI **1100**. At the HMI **1200**, the user can select whether 1, 2, or 3 samples are being tested. Similarly, an HMI **1300** in FIG. **13** is shown, for example, if the user selects "Single Throw" in the HMI **1100**. At the HMI **1300**, the user can select whether 1, 2, 3, 4, 5, or 6 samples are being tested.

[0126] An HMI **1400** in FIG. **14** allows the user to input, where single throw relays/switches are being tested, whether each sample is a normally open (NO) or normally closed (NC) switch. Different types of switches may be tested at the same time (e.g., the user may select NO or NC for different switches at the HMI **1400**).

[0127] An HMI **1500** in FIG. **15** allows the user to select whether all the samples being tested will be tested for the same number of cycles or not. An HMI **1600** of FIG. **16** allows the user to enter how many counts or cycles the test may complete for all samples if "Yes" is selected in the HMI **1500**. HMIs **1700** in FIGS. **17** and **1800** in FIG. **18** allow the user to enter different numbers of counts/cycles to test switches for if "No" is selected in the HMI **1500**, where the HMI **1700** is displayed if the user has selected to test double throw switches and the HMI **1800** is displayed if the user has selected to test single throw switches.

[0128] An HMI **1900** in FIG. **19** allows the user to select whether all the samples for a given test will be tested in one oven. That is, the user can indicate whether each of the samples should be tested at the same (by selecting "Yes") or different (by selecting "No") temperatures. An HMI **2000** in FIG. **20** is displayed if the user selects "Yes" in the HMI **1900**, and allows the user to set the single oven temperature. An HMI **2100** in FIG. **21** allows the user to select different oven temperatures and indicate which sample is in which oven (e.g., what temperature each given switch should be tested at). An HMI **2200** in FIG. **22** allows the user to select what type of standard (e.g., "UL" or "IEC") is being used to test the switches. This selection may control, for example, how many cycles of a given test are performed at a particular oven temperature and how many cycles of

a given test are performed at room temperature. For example, an IEC test may perform 50% of cycles at an ambient or room temperature while 50% of cycles are performed at a set oven temperature. In contrast, a UL test may be performed with 100% of cycles at either of an ambient/room temperature or a set oven temperature.

[0129] An HMI **2300** in FIG. **23** may further allow a user to select what type of switches are being tested (e.g., "Relay," "Mechanical," "Air Pressure," "Thermal," "Tungsten"). An HMI **2400** in FIG. **24** allows the user to select what type of test is to be run (e.g., "Make & Break," "AC Pilot Duty," "Motor," "Resistive," "DC Pilot Duty"). An HMI **2500** in FIG. **25** allows the user to select different types of overload or endurance tests. The example in the HMI **2500** particularly allows a user to select double throw overload normally closed, double throw overload normally open, five second on five second off endurance, or one second on nine second off endurance tests.

[0130] An HMI **2600** in FIG. **26** allows the user to select between alternating current or direct current for a test. An HMI **2700** in FIG. **27** allows the user to officially start a test for which information has been entered on the other HMIs.

[0131] An HMI **2800** in FIG. **28** shows an example HMI that may be displayed during a test of double throw relays. In particular, the HMI **2800** shows information for a first sample during a test, including what count the test is at for both of the normally closed and normally open components of Sample 1 is at, what percentage of a given test is complete for both of the normally closed and normally open components of Sample 1 (e.g., how many counts of a total number of desired counts have been completed), whether an oven is on for Sample 1 and at what temperature the oven is currently at for Sample 1. The HMI **2800** also includes buttons that a user may select to show similar information for Samples 2 and 3 that are under test, if applicable. If the user selects one of those buttons, one of HMI **2900** of FIG. **29** or HMI **3000** of FIG. **30** may be displayed, and HMIs **2900** and **3000** may similarly include buttons to select that information related to other samples be displayed. Each of the HMIs **2800**, **2900**, and **3000** may also include a "Main Screen" button to go back to a home or default HMI.

[0132] An HMI **3100** of FIG. **31**, an HMI **3200** of FIG. **32**, and/or an HMI **3300** of FIG. **33** may be sequentially displayed if the "Different Tests" option is selected at the HMI **1000**, so that the user can enter information for how each sample for up to three double throw samples will be tested. An HMI **3400** of FIG. **34** may display information selected on HMIs **3100**, **3200**, and **3300** so that the user can confirm the details of each test for the different samples.

[0133] HMIs **3500** of FIG. **35**, **3600** of FIG. **36**, **3700** of FIG. **37**, **3800** of FIG. **38**, **3900** of FIG. **39**, and **4000** of FIG. **40** may be similar to HMIs **3100**, **3200**, and **3300** except the HMIs of FIGS. **35-40** are for when up to 6 single throw switches are being tested and some of the switches may have different tests. HMI **4100** of FIG. **41** further shows an HMI similar to HMI **3400** for the user to confirm the details for each sample when single throw samples are being tested. HMIs **4200** of FIG. **42** and HMI **4300** of FIG. **43** further show status screens that may be displayed while single throw tests are being completed so that a status for each switch may be displayed and monitored.

SiC Switch for Use in Example Test Apparatuses

[0134] When using traditional electromechanical relays for switching electrical power there may be a reduction in contact life due to degradation from arcing. For example, a normally closed (NC) contact of a switch such as in the relay **4** of FIG. **4** may degrade over time from breaking the current during testing. For example, the contacts may eventually weld together. Even before the contacts weld together and become unusable, the duration of time to break the contact may go up as the contacts begin to degrade.

[0135] As an alternative to electromechanical relays for use with electrical power switching, a solid-state solution is often used for longevity. In the case of product safety compliance electrical endurance testing a standard SCR (or similar) solid-state relay may not suffice because of the forward voltage drop. As such, a metal-oxide-semiconductor field-effect transistor (MOSFET) as described herein may be advantageously used as it does not require a forward voltage to conduct.

This may allow maximum power transfer to a device under test upon switching. As such, as described further herein, the relay **4** of FIG. **4**, for example, and other similar relays of FIGS. **4** and **6-8** may be a make SiC switch and a break SiC switch as described herein. The make SiC switch may further advantageously use current sensing and a zero-cross cutoff logic and/or circuit to turn off the load connected to the switch (e.g., load **29** of FIG. **4**). In various embodiments, the break SiC switch may not utilize zero-cross cutoff logic/circuitry.

[0136] In particular a SiC switch as used herein may encompass two N-Channel Enhancement Mode MOSFETs connected in a common source configuration. FIG. **44** is a schematic diagram of the MOSFETs common source connection. This configuration allows the switch to not only allow current flow in two directions in the on state, but to block current both in the positive and negative directions in the off state. The MOSFET internal diode is only used as a blocking diode when the MOSFETs are in an off state. When the MOSFETs are in an on state the voltage drop across each MOSFET is below the forward voltage drop of the diode and it does not conduct. The switch can switch AC or DC loads in the same physical configuration.

[0137] In this application the MOSFETs are not pulsed on and off at a given frequency like in power conversion topologies. In this configuration the MOSFETs are pulsed on and held on 100% until the desired switch off time.

[0138] In this application both MOSFETs use a common gate driver IC. This IC is capable of driving the current necessary to charge both gates simultaneously while maintaining isolation between the gate input drive and source connections.

[0139] For material selection, silicon carbide (SiC) may be advantageously used. In this application, the SiC material allows higher power at a lower drain-source on-resistance (RDS (on)) than traditional Si materials. This allows the transition away from electromechanical relays in a wider range of load applications. This also allows this switch to be scalable. Utilizing a MOSFET with an increased drain current may increase the available or possible use cases.

[0140] To prevent the MOSFET from going into an avalanche breakdown while switching an inductive AC load, a zero-crossing current detector circuit may also be used. This circuit will delay the switching off of the MOSFETs gates until a zero-crossing event of the current waveform. The current may be used as the zero-crossing cutoff threshold so as to not limit the ability of the switch to handle a wide range of load power factors. This zero-crossing cutoff eliminates the voltage transient of an inductive circuit. This switch may see, for example, an inductive power factor anywhere between 1.0 and 0.35 or less in application, and because of this the zero-crossing of the voltage may not be useful or advantageous to use. See FIG. **45**, which is a diagrammatic view of a voltage and current waveform for an example SiC switch. In various embodiments, zero-crossing logic and circuitry may also be used with other types of switches or relays than the SiC switches described herein.

[0141] For the current zero-crossing to control the shutdown behavior of the switch the following digital logic is employed. The input to the digital logic stage comes from an amplifier and comparator stage. This amplifies a current sensor signal and then creates a square wave output with a comparator. Each edge of the square wave denotes a zero-crossing event. This digital logic stage is placed in between the input trigger stage and the gate driver stage. See FIG. **46**, which is a schematic view of digital logic for implementing a zero-crossing current circuit.

[0142] Logic gates **1**-**5** of FIG. **46** are inverter gates connected in series. This connection not only inverts the logic level but takes advantage of the inherent propagation delay of the integrated circuit (IC) to delay the input briefly to logic gates **6** and **7** of FIG. **46**. Logic gate **6** is a NOR gate that is used for triggering an output clock pulse when the AC current zero-cross is negative (falling edge of comparator output). For a brief moment both inputs to gate **6** are low triggering a high clock pulse output. Logic gate **7** is an AND gate that is used for triggering an output clock pulse when the AC current zero-cross is positive (rising edge of comparator output). For a brief moment both inputs to gate **7** are high triggering a high clock pulse output. Logic gate **8** is an OR gate that allows

either the positive or the negative edge clock pulse to trigger the NAND gate stage. Logic gates **9-12** of FIG. **46** are NAND gates and form an edge triggered D Latch. When the switch input stage signal is high, that logical 1 is not passed to the output of the D latch until the next clock signal (zero-crossing). While the switch input stage is high the zero-crossing clock pulse has no affect on the gate drive due to the OR logic gate **13** of FIG. **46**. When the switch input stage signal goes low the gate drive circuit is still high and holding the switch on. Only when the next zero-crossing event clock signal triggers the D latch it will move the logic low to gate **13** and the gate driver input will go low turning off the switch. This logic allows a random turn on, and zero-crossing turn off. This zero-crossing cutoff also allows control over non-sinusoidal AC signals.

[0143] SiC MOSFETs may be configured in discrete units or in modules, for example. The various embodiments herein may use a switch configuration that has either discrete units or separate modules. However, MOSFET modules may have a half-bridge topology with two MOSFETs but connected in a drain to source configuration. Two separate modules may therefore be utilized in the embodiments described herein to provide the bi-directional blocking. Thus, using two MOSFET modules in this manner may unnecessarily increase size, heating mitigations, and cost of the various embodiments herein. As such, discrete SiC MOSFETs modules may have their MOSFETs connected in the configuration described herein where the switch configuration has the MOSFETs' common source is used as AC/DC switches in one package. Such a switch may also be used in other commercial and industrial uses than the relay testing embodiments described herein, particularly because such switches may provide for reduced RDS (on) and larger current handling capabilities than other MOSFET modules available commercially.

[0144] FIG. **47** is a diagrammatic view **4700** of waveforms demonstrating implementation of a zero-crossing current circuit, in embodiments. Waveform **4702** is an amplifier output, waveform **4704** represents the voltage, and waveform **4706** represents the current. As shown, as soon as the waveform **4706** (current) gets to zero it goes to off to keep the waveform **4706** (current) from crossing zero. Then when the switch is turned off there is not a large or significant amount of buildup of current present in the switch, and the switch can be turned off without damaging or without causing significant damage to the switch.

[0145] As such, described herein are advantageous configurations of common source configurations of SiC MOSFETs that may be used in various product safety compliance testing apparatuses. A zero-crossing current sensing logic and circuitry may also be used with such switches or in other applications as a standalone solution to provide for switching where there is no buildup or presence of current. Furthermore, the common source configuration with SiC MOSFETS may be advantageously used outside of product safety compliance testing.

Universal Voltage Board

[0146] Various embodiments described herein may further benefit from a circuit capable of sensing a wide range of AC and DC voltages. Such a circuit as described herein may advantageously allow the sensing of when a sample DUT switch closes and sensing of anywhere from, for example, 5 volts (V) to 700 V or even 5 V up to 1600 V, and the sensing may sense either AC or DC voltages quickly and accurately so that voltage levels at the switches/samples being tested may be read quickly and accurately no matter what type of switch it is. This may be advantageous to have a circuit for sensing different AC and DC voltages, as a PLC for example may operate at a 24 VDC, for example, limiting the types, amounts, and/or quickness with which a PLC system may be able to, on its own, be configured to measure different AC or DC voltages.

[0147] The universal voltage board described herein solves the problem of trying to step down higher voltages either with transformers or voltage dividers for sensing in a control system. This circuit advantageously has provisions for AC or DC voltage sensing. FIG. **48** is a schematic view of a universal voltage board **4800** for sensing both alternating current (AC) and direct current (DC) voltages.

[0148] AC voltages are connected to the L**1** & L**2** inputs of FIG. **48**, and can be line to line or line

to neutral referenced voltages. The voltage level is reduced with capacitive reactance from a series capacitor C**1** or C**2** in FIG. **48**. Capacitors C**1** and C**2** provide voltage reduction, and resistors R**1** and R**2** in FIG. **48** are bleeder resistors. DC voltages are connected to the DC+ and DC− connections. Voltage is reduced by series resistors R**3** or R**4** of FIG. **48** and are connected directly to the diode bridge D**1** of FIG. **48**.

[0149] The signal is then full wave rectified by D**1**, filtered by capacitor C**3** of FIG. **48** and held to a low voltage level by Zener diode D**2** of FIG. **48** (e.g., 5.6V). This allows a constant voltage to trigger the output solid-state relay U**1** of FIG. **48**. One side of the solid-state relay is connected to a control signal (e.g., 24 VDC of a PLC system). When voltage is present on the boards input terminals the control signal is switched on to pass to the rest of the control system. In this way, regardless of the voltage level of the AC or DC input the same control signal level is used on the output to indicate to the control system when a switch has switched on or off. This output signal to the control system can then be used to sense voltage presence for counting and accurate timing of load cycling, including in the various embodiments for switch/relay testing described herein, including for sensing voltage presence and cycle timing.

CONCLUSION

[0150] As such, described herein are various embodiments for a test fixture designed to conduct relay/switch electrical endurance tests, such as those covered in UL/IEC 60730-1 for example. The controller and apparatuses described herein allow for parallel testing of three double throw samples at one time, for example (or six single throw samples at one time), while reducing the required electrical loads used to test such samples if they were tested individually. Because the apparatuses and controller described herein may run multiple samples at once, time savings of approximately 66% from prior testing methods may be achieved, creating increased throughput for a testing lab.

[0151] As such, the time savings for testing samples may dramatically increase such as going from over 1 month in test completion time to approximately 12 days because multiple samples may be tested at once.

[0152] The methods and apparatuses described herein may also be used to test multiple samples to different ratings at one time, further increasing throughput of a given testing lab. The system may also test samples to different temperatures (e.g., where half of cycles are heated and half of cycles are at room/ambient temperature). Furthermore, this testing of different samples at different temperatures may advantageously be achieved in a single chamber/apparatus while a test runs and may be automated so that a user does not have to move switches around to different test equipment or manually restart or alter test conditions to achieve different testing temperatures.

[0153] The systems and method further provide for a system that can quickly and efficiently manage the timing of switching samples/DUTs on and off to achieve power usage savings while still completing tests efficiently. For example, in some devices such as PLCs there is a scan rate going from first rung of ladder down to the bottom and then repeat. If a different rung is used to control the timing for switching each switch/DUT, there can be some error or drift that comes into the system if there are minor errors every time the logic ladder for a given switch refreshes or scans. As such, the embodiments herein solve this potential issue by controlling all of the given DUTs in a test on a single timer or rung instead of operating switching logic for each switch/DUT on its own timer/rung.

[0154] Furthermore, drift from using ladder scanning rungs of a PLC may be further avoided, for example, by using an asynchronous timer that is not part of the ladder scanning of a PLC. Such an asynchronous timer may operate as a master clock signal that is used to control timing of the various switches described herein instead of timers built into the rungs of a PLC controller. For example, embodiments herein may use a timer that has a 10 Hz on/off cycle and any logic present in the rungs built using a PLC controller just refers back to that 10 Hz timer and count cycles to measure time instead of using logic that may use or operate separate timers.

[0155] In various embodiments, the systems and methods herein may also be implemented to test

single and double throw switches at the same time. For example, the apparatus described above with respect to FIGS. **4** and **6-8** may be used to test one double throw and up to four single throw switches at the same time, up to two double throw switches and up to two single throw switches at the same time, etc. Various embodiments may also be capable of testing different numbers of switches, such as an embodiment that can test up to 6 double throw switches or up to 12 single throw switches, or an embodiment that can test up to 9 double throw switches or up to 18 single throw switches.

Example Computing Environment

[0156] FIG. **49** is a diagrammatic view of an example of a computing environment that includes a general-purpose computing system environment **100**, such as a desktop computer, laptop, smartphone, tablet, or any other such device having the ability to execute instructions, such as those stored within a non-transient, computer-readable medium. Various computing devices as disclosed herein (e.g., a processor, controller, PLC, or any other computing device used to control or communicate with components of a test apparatus) may be similar to the computing system **100** or may include some components of the computing system **100**. Furthermore, while described and illustrated in the context of a single computing system **100**, those skilled in the art will also appreciate that the various tasks described hereinafter may be practiced in a distributed environment having multiple computing systems **100** linked via a local or wide-area network in which the executable instructions may be associated with and/or executed by one or more of multiple computing systems **100**.

[0157] In its most basic configuration, computing system environment **100** typically includes at least one processing unit **102** and at least one memory **104**, which may be linked via a bus **106**. Depending on the exact configuration and type of computing system environment, memory **104** may be volatile (such as RAM **110**), non-volatile (such as ROM **108**, flash memory, etc.) or some combination of the two. Computing system environment **100** may have additional features and/or functionality. For example, computing system environment **100** may also include additional storage (removable and/or non-removable) including, but not limited to, magnetic or optical disks, tape drives and/or flash drives. Such additional memory devices may be made accessible to the computing system environment **100** by means of, for example, a hard disk drive interface **112**, a magnetic disk drive interface **114**, and/or an optical disk drive interface **116**. As will be understood, these devices, which would be linked to the system bus **306**, respectively, allow for reading from and writing to a hard disk **118**, reading from or writing to a removable magnetic disk **120**, and/or for reading from or writing to a removable optical disk **122**, such as a CD/DVD ROM or other optical media. The drive interfaces and their associated computer-readable media allow for the nonvolatile storage of computer readable instructions, data structures, program modules and other data for the computing system environment **100**. Those skilled in the art will further appreciate that other types of computer readable media that can store data may be used for this same purpose. Examples of such media devices include, but are not limited to, magnetic cassettes, flash memory cards, digital videodisks, Bernoulli cartridges, random access memories, nano-drives, memory sticks, other read/write and/or read-only memories and/or any other method or technology for storage of information such as computer readable instructions, data structures, program modules or other data. Any such computer storage media may be part of computing system environment **100**.

[0158] A number of program modules may be stored in one or more of the memory/media devices. For example, a basic input/output system (BIOS) **124**, containing the basic routines that help to transfer information between elements within the computing system environment **100**, such as during start-up, may be stored in ROM **108**. Similarly, RAM **110**, hard drive **118**, and/or peripheral memory devices may be used to store computer executable instructions comprising an operating system **126**, one or more applications programs **128** (which may include the functionality disclosed herein, for example), other program modules **130**, and/or program data **122**. Still further, computer-executable instructions may be downloaded to the computing environment **100** as needed, for

example, via a network connection.

[0159] An end-user may enter commands and information into the computing system environment **100** through input devices such as a keyboard **134** and/or a pointing device **136**. While not illustrated, other input devices may include a microphone, a joystick, a game pad, a scanner, etc. These and other input devices would typically be connected to the processing unit **102** by means of a peripheral interface **138** which, in turn, would be coupled to bus **106**. Input devices may be directly or indirectly connected to processor **102** via interfaces such as, for example, a parallel port, game port, firewire, or a universal serial bus (USB). To view information from the computing system environment **100**, a monitor **140** or other type of display device may also be connected to bus **106** via an interface, such as via video adapter **132**. In addition to the monitor **140**, the computing system environment **100** may also include other peripheral output devices, not shown, such as speakers and printers.

[0160] The computing system environment **100** may also utilize logical connections to one or more computing system environments. Communications between the computing system environment **100** and the remote computing system environment may be exchanged via a further processing device, such a network router **152**, that is responsible for network routing. Communications with the network router **152** may be performed via a network interface component **154**. Thus, within such a networked environment, e.g., the Internet, World Wide Web, LAN, or other like type of wired or wireless network, it will be appreciated that program modules depicted relative to the computing system environment **100**, or portions thereof, may be stored in the memory storage device(s) of the computing system environment **100**.

[0161] The computing system environment **100** may also include localization hardware **186** for determining a location of the computing system environment **100**. In some instances, the localization hardware **156** may include, for example only, a GPS antenna, an RFID chip or reader, a WiFi antenna, or other computing hardware that may be used to capture or transmit signals that may be used to determine the location of the computing system environment **100**.

[0162] While this disclosure has described certain embodiments, it will be understood that the claims are not intended to be limited to these embodiments except as explicitly recited in the claims. On the contrary, the instant disclosure is intended to cover alternatives, modifications and equivalents, which may be included within the spirit and scope of the disclosure. Furthermore, in the detailed description of the present disclosure, numerous specific details are set forth in order to provide a thorough understanding of the disclosed embodiments. However, it will be obvious to one of ordinary skill in the art that systems and methods consistent with this disclosure may be practiced without these specific details. In other instances, well known methods, procedures, components, and circuits have not been described in detail as not to unnecessarily obscure various aspects of the present disclosure.

[0163] Some portions of the detailed descriptions of this disclosure have been presented in terms of procedures, logic blocks, processing, and other symbolic representations of operations on data bits within a computer or digital system memory. These descriptions and representations are the means used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art. A procedure, logic block, process, etc., is herein, and generally, conceived to be a self-consistent sequence of steps or instructions leading to a desired result. The steps are those requiring physical manipulations of physical quantities. Usually, though not necessarily, these physical manipulations take the form of electrical or magnetic data capable of being stored, transferred, combined, compared, and otherwise manipulated in a computer system or similar electronic computing device. For reasons of convenience, and with reference to common usage, such data is referred to as bits, values, elements, symbols, characters, terms, numbers, or the like, with reference to various presently disclosed embodiments.

[0164] It should be borne in mind, however, that these terms are to be interpreted as referencing physical manipulations and quantities and are merely convenient labels that should be interpreted

further in view of terms commonly used in the art. Unless specifically stated otherwise, as apparent from the discussion herein, it is understood that throughout discussions of the present embodiment, discussions utilizing terms such as "determining" or "outputting" or "transmitting" or "recording" or "locating" or "storing" or "displaying" or "receiving" or "recognizing" or "utilizing" or "generating" or "providing" or "accessing" or "checking" or "notifying" or "delivering" or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data. The data is represented as physical (electronic) quantities within the computer system's registers and memories and is transformed into other data similarly represented as physical quantities within the computer system memories or registers, or other such information storage, transmission, or display devices as described herein or otherwise understood to one of ordinary skill in the art.

[0165] Although certain example methods and apparatus have been described herein, the scope of coverage of this patent is not limited thereto. On the contrary, this patent covers all methods, apparatus, and articles of manufacture fairly falling within the scope of the appended claims either literally or under the doctrine of equivalents.

Claims

1. An apparatus for testing a plurality of electrical switches comprising: first contacts configured to connect to a first sample switch of the plurality of electrical switches, wherein the first contacts comprise at least a first input contact and a first output contact; second contacts configured to connect to a second sample switch of the plurality of electrical switches, wherein the second contacts comprise at least a second input contact and a second output contact; a power source connected to the first input contact and the second input contact; at least one first switch connected to the first output contact, the at least one first switch configured to selectively connect the first sample switch to a first make load; at least one second switch connected to the first output contact, the at least one second switch configured to selectively connect the first sample switch to a first break load; at least one third switch connected to the second output contact, the at least one third switch configured to selectively connect the second sample switch to a second make load; and at least one fourth switch connected to the second output contact, the at least one fourth switch configured to selectively connect the second sample switch to a second break load.

2. The apparatus of claim 1, wherein the first make load and the second make load are a same make load.

3. The apparatus of claim 1, wherein the first break load and the second break load are a same break load.

4. The apparatus of claim 1, wherein the first sample switch and the second sample switch are each a double throw switch.

5. The apparatus of claim 1, wherein the first sample switch and the second sample switch are each a single throw switch.

6. The apparatus of claim 5, wherein: the first sample switch and the second sample switch are each a single throw normally open switch; the first sample switch and the second sample switch are each a single throw normally closed switch; the first sample switch is a single throw normally open switch and the second sample switch is a single throw normally closed switch; or the first sample switch is a single throw normally closed switch and the second sample switch is a single throw normally open switch.

7. The apparatus of claim 1, further comprising third contacts configured to connect to a third sample switch of the plurality of electrical switches.

8. The apparatus of claim 1, further comprising a safety switch connected between the power source and the first input contact.

9. The apparatus of claim 1, wherein the at least one first switch comprises two MOSFETs

configured to have a common source, wherein the at least one first switch allows current to flow in two directions in an on state and blocks current in both positive and negative directions in an off state.

10. The apparatus of claim 9, wherein the two MOSFETs are comprised of silicon carbide.

11. The apparatus of claim 9, wherein the at least one first switch further comprises a zero-crossing current sensor, wherein the at least one first switch is turned off only when the current output by the at least one first switch is at or near zero current.

12. The apparatus of claim 1, further comprising a universal voltage sensing circuit configured to sense alternating current (AC) voltage or direct current (DC) voltage, wherein the universal voltage sensing circuit is connected to the first output contact of the first sample switch.

13. The apparatus of claim 12, wherein an output of the universal voltage sensing circuit is connected to a controller of the apparatus, wherein the controller is configured to determine a cycle of a test of the first sample switch based on the output of the universal voltage sensing circuit.

14. A method for testing a plurality of electrical switches comprising: connecting, by a controller of an electrical switch testing apparatus, a first sample switch of the plurality of electrical switches to a make load; disconnecting, by the controller at a first predetermined time after the first sample switch is connected to the make load, the first sample switch from the make load; connecting, by the controller at a second predetermined time after the first sample switch is connected to the make load, the first sample switch to a break load; and connecting, by the controller at a third predetermined time after the first sample switch is connected to the make load, a second switch of the plurality of electrical switches to the make load.

15. The method of claim 14, further comprising disconnecting, by the controller at a fourth predetermined time after the first sample switch is connected to the make load, the second sample switch from the make load.

16. The method of claim 15, further comprising connecting, by the controller at a fifth predetermined time after the first sample switch is connected to the make load, the second sample switch to the break load.

17. The method of claim 16, further comprising connecting, by the controller at a sixth predetermined time after the first sample switch is connected to the make load, a third sample switch of the plurality of electrical switches to the make load.

18. The method of claim 17, further comprising: disconnecting, by the controller at a seventh predetermined time after the first sample switch is connected to the make load, the third sample switch from the make load; and connecting, by the controller at an eighth predetermined time after the first sample switch is connected to the make load, the third sample switch to the break load.

19. The method of claim 14, further comprising determining, by the controller, that the first predetermined time after the first sample switch is connected to the make load has elapsed based a timer count based on an internal asynchronous clock signal of the controller.

20. An apparatus for testing a plurality of electrical switches comprising: first contacts configured to connect to a first sample switch of the plurality of electrical switches, wherein the first contacts comprise at least a first input contact and a first output contact, and wherein the first sample switch is one of a double throw switch, a single throw normally open switch, or a single throw normally closed switch; second contacts configured to connect to a second sample switch of the plurality of electrical switches, wherein the second contacts comprise at least a second input contact and a second output contact, and wherein the second sample switch is one of a double throw switch, a single throw normally open switch, or a single throw normally closed switch; at least one first switch connected to the first output contact, the at least one first switch configured to selectively connect the first sample switch to a first make load; at least one second switch connected to the first output contact, the at least one second switch configured to selectively connect the first sample switch to a first break load; at least one third switch connected to the second output contact, the at least one third switch configured to selectively connect the second sample switch to a second make

load; and at least one fourth switch connected to the second output contact, the at least one fourth switch configured to selectively connect the second sample switch to a second break load.