AC vs. DC Dielectric Withstand Testing

Abstract: Dielectric withstand testing is used to evaluate wiring insulation after it has been installed in a mobile home. As described below, if voltages are correctly set, dielectric withstand testing using a DC voltage will perform the tests with the same outcome as an AC dielectric test with significant safety and performance improvements.

In the discussion below, the following are explained: the purpose and method of dielectric testing, the differences between AC and DC voltages as they pertain to dielectric withstand tests, and levels of operator safety inherent in both the AC and DC dielectric withstand tests.

1. The purpose of dielectric testing: Dielectric testing is a simple, non-destructive method of verifying the adequacy of electrical insulation to withstand the sort of transients that can occur during transient (surge) events. In addition, the dielectric test can verify that the insulation in question has an adequate amount of performance "headroom". This is necessary to ensure that the insulation does not fail because of degradation of the insulation due to aging, moisture, wear due to vibration, etc.

2. The method of dielectric testing: A high voltage (typically 1000 Volts or higher) is applied between two conductors that are "supposed" to be electrically insulated from each other. If the two conductors (an insulated "live" wire, and a metal enclosure, for example) are completely isolated from each other, then the application of a large voltage difference between the two conductors will not allow current to flow between the conductors. The insulation will "withstand" the application of a large voltage potential between the two conductors - hence the term "dielectric withstand test".

In general, there are two results of the test that are considered a failure of the insulation: (1) excessive current flow during the test due to low insulation resistance of the insulating material which separates the two conductors, and (2) an abrupt dielectric breakdown due to electrical arcing or discharge, either through the insulation material, over the surface of the insulation material, or a discharge through air.

3. The determination of a suitable test voltage: If the test voltage is too low, the insulation material in question will not be adequately stressed during the test. This could cause inadequate insulation to pass the test, and be considered acceptable. On the other hand, if the test voltage is too high, then the test could cause permanent damage to an insulation material that is otherwise adequate for the application. A general "rule of thumb" that is used for the testing of mains wiring which operates at voltages of 120-240 Vac is 1000 V plus two times the operating voltage. Using this rule, 120 V wiring would be tested using a voltage of 1240 Vac.

4. Duration of the test: Generally, the test voltage is applied for one minute, in order to adequately stress the insulation. Many standards allow the test duration to be reduced to 1 second for production-line testing in order to accommodate large-volume production testing. In this case, standards quite often require that the test voltage be increased by 20% in order to ensure that the shorter test duration of one second will adequately test the insulation in question.

5. AC vs. DC - background: The nominal line voltage in the United States is 120 Vac, 60 Hz. 60 Hz (also known as Hertz, or cycles per second) refers to the frequency of the voltage. The waveshape of the voltage is sinusoidal.

120 Volts refers to the RMS value of the voltage. RMS stands for "root mean square", and is a mathematical way to determine the effective heating value of a voltage. In other words, an AC voltage of 120 V RMS, applied to a resistor (or a NiChrome-wire heater) will generate the same heat output as if a DC voltage of 120 V (from a battery, for example) were used instead.

The instantaneous voltage of 120 Vac, 60 Hz varies with time. In one cycle (which repeats 60 times a second), the voltage will start at zero volts, increase to a peak of about 170 V, drop down to zero volts again, continue to drop to a negative peak of -170 V, and then increase again to zero volts. Taking the simple "average" of the voltage over one cycle results in a value of zero volts. Calculating the RMS value results in a measurement of 120 Volts. By definition, the peak of a sinusoidal waveform will be the RMS value times the square root of 2 (Vpeak = VRMS x 1.414).

6. AC vs. DC - dielectric test voltages: The intent of the dielectric test is to stress the insulation for a short period of time, and check that it does not fail. Testing using a 60 Hz AC

voltage is done only as a matter of convenience - a transformer with a high-voltage secondary winding (such as a neon-sign transformer) can be used to generate the high voltage needed to perform the dielectric test. A 60 Hz AC test voltage is no more of a "simulation" of real-world events than is a DC test voltage. Even high voltage transients (surges) that appear on the 120 Vac mains are not AC: they are momentary voltage "spikes" with a typical duration that is measured in microseconds (millionths of a second) or milliseconds (thousandths of a second).

The voltage used for testing AC vs. DC must take into consideration the intent of the test, which is to stress the insulation being tested. The higher the voltage, the more stress that is applied to the insulation. When an AC test voltage is used, the highest amount of stress is applied to the insulation at the moments when the test voltage is at a positive or negative peak. At other points of the sinusoidal AC waveform, the electrical stress is lower.

An AC test voltage of 1000 Vrms will have voltage peaks of 1414 Volts. Therefore, if a DC test voltage is used, the test voltage must be increased to 1414 Vdc in order to produce the same level of stress to the insulation as would 1000 Vac RMS. This difference in test voltage for DC vs. AC is supported by National Testing and Standards writing organizations such as Underwriters Laboratories, Factory Mutual Corporation, the Institute of Electrical and Electronic Engineers (IEEE) the American National Standards Institute (ANSI), as well as international organizations such as the International Electrotechnical Committee (IEC), and others.

7. AC vs. DC - advantages and disadvantages: Historically, DC test voltages are more difficult to generate. This can result in more costly, complicated test equipment. This disadvantage is offset by performance and safety enhancements. To explain these advantages, some additional background information is needed:

An electric charge will develop when ever a voltage difference is applied between two conductors that are separated by an insulator. The amount of charge that is created is proportional to the voltage applied, and is also proportional to the <u>capacitance</u> between the two conductors. If charge is represented by the letter "Q", Voltage represented by "V", and the letter "C" used for capacitance, then the mathematical relationship between these three can be represented as Q = C times V, or Q = CV.

In practical applications, capacitance can exist due to discrete capacitors, but can also exist inadvertently when ever two conductors that have a voltage difference between them are placed physically close together. Examples of this type of capacitance are electric motors, transformers, multi-conductor electrical wiring, and single-conductor wiring that is routed near metal. If the voltage is varied, the charge varies. If the voltage swings both positive and negative, the charge will do the same.

A second fundamental concept is that electric current will flow through a capacitor when ever the voltage changes. This is due to the fact that as the voltage is increased across a capacitor, the amount of charge increases. Electric current is simply the measurement of how much the charge changes over a period of time. The letter "I" is often used to indicate current (which is measured in Amperes, or Amps). The amount of charge (Q) is measured in Coulombs. One Amp of current is defined as the amount of charge flow of one Coulomb per second. Mathematically, this is represented as follows: 1 Amp = 1 Coulomb per Second.

Combining these two concepts yields the following: A changing voltage generates a changing charge. This changing charge is (by definition) the flow of electric current. Therefore, a changing voltage will cause current to flow between two conductors that are physically insulated from each other, because of the capacitance between the two conductors. The more capacitance between the conductors, the more current that will flow.

When performing dielectric tests using an AC test voltage, an electric current will flow between the two points that are being tested, due to the capacitance between the two conductors. This current does not represent a failing test result (due to a low insulation resistance). Therefore, an AC dielectric tester must compensate for this allowable flow of current. The most common method to accomplish this is to allow the tester to supply a significant amount of current (typically 20 milliamps or more) without indicating an excess current failure. If multiple products are tested with the same dielectric tester, this current limit set-point may need to be adjusted even higher, in order to accommodate the equipment that has the highest amount of capacitance between the conductors being tested. In other words, the dielectric tester must be de-sensitized so that it will ignore current levels below 20 milliamps (for example). This situation creates two very dangerous problems:

1. The "desensitized" AC dielectric tester can not tell the difference between 5 milliamps and 15 milliamps. Consider what happens if the circuit under test has capacitance between the

conductors that causes 5 milliamps to flow in normal conditions during the test. A product being tested that has faulty insulation which allows 300% of the normal amount of current to flow (15 milliamps) would still be considered an acceptable test result by the AC dielectric tester.

2. The "desensitized" AC dielectric tester can supply a LETHAL amount of current to the human body, and still not shut down due to excess current. If the equipment being tested allows 5 milliamps to flow, and the test operator accidentally comes in contact with the test voltage such that 10 milliamps of current flows through the operator, the dielectric tester will not shut down, and the operator will likely be seriously injured or killed.

When performing dielectric tests using a DC test voltage, electric current only flows while the voltage is being ramped up from zero Volts to the final test voltage. In this case, the amount of current flowing is very small, because the voltage is typically ramped up over a period of 1-2 seconds, compared to an AC test voltage that goes from a positive peak to a negative peak and back again 60 times every second (remember that the current flow is proportional to the change in voltage over time). In fact, a DC test voltage that is ramped up over two seconds will cause only 1/120 (less than 1%) of the current to flow as would an AC test voltage. As soon as the DC voltage reaches the final test level, the current essentially stops altogether. In most cases, the amount of current that flows during a DC dielectric test is negligible, regardless of the amount of capacitance that exists in the equipment being tested.

Comparing this situation to an AC dielectric test, DC testing offers the following advantages:

1. The maximum allowable test current can be set to a much lower level (one milliamp is typical). The DC tester will shut down when more than one milliamp of current flows during the test. This highly-sensitive test allows the operator to identify marginal constructions that would have been overlooked by an AC tester.

2. The lower test current levels are significantly safer for the operator. At one milliamp, the current is enough to shock the operator, but the test current can be automatically shut off (due to a current flow of more than one milliamp). The likelihood of injury or death has been reduced significantly.

In conclusion:

- AC and DC dielectric testing can accomplish the same goal of verifying the suitability of insulation between conductors.

- Voltage levels must be adjusted according to whether the test voltage is AC or DC.

- DC testing represents the state-of-the-art. It offers significant advantages over AC testing. DC and AC testing provide an equivalent level of breakdown detection due to total insulation failure. The heightened accuracy of DC leakage current detection may allow marginal insulation systems to be detected only with a DC test. DC dielectric testing is superior in operator safety. Neglecting to consider DC testing as an alternative to AC testing potentially jeopardizes the test operator (from shock hazards during testing), as well as the end-consumer (from AC testing which overlooks marginal insulation).

Respectfully submitted,

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Attention: Mr. David Nemmir
Acting Director

Reference: 24 CFR Ch. XX, Para. 3280-810: Electrical Testing

Subject: Dielectric Withstand Tests conducted with DC voltages

Gentlemen:

We've been made aware by NTA Inc. and Cavalier Homes that there is some question about conducting dielectric testing referenced above with DC voltage. As the referenced paragraph is written, AC or DC voltage of 900-1079 volts is acceptable to test the manufactured home. While this is not entirely correct because of differences in calculation of peak voltages between AC and DC, the lack of distinction between the two types of voltages is valid, because either AC or DC will successfully test the insulation of the electrical wiring of the manufactured home. Furthermore, the DC tests afford benefits in detecting marginal insulation systems and in operator safety.

Our Chief Design Engineer, Jeff Gray, is a Registered Professional Engineer in the State of California, and his analysis and comment regarding the subject is attached for your consideration.

After reading his comments, we hope you will agree with us that the DC test should be considered as an acceptable substitute for an AC test, provided the correct voltage is specified. We believe the Referenced Paragraph does need clarification but we feel the change should be to correctly specify the DC voltage required as noted below:

§ 3280.810 Electrical Testing.

(a) *Dielectric Withstand Test.* The wiring of each manufactured home shall be subjected to a 1-minute, 900 to 1079 volt <u>AC or 1272 to 1526 volt DC</u> dielectric strength test (with all switches closed) between live parts and the manufactured home ground, and neutral and the manufactured home ground. Alternatively, the test may be performed at 1080 to 1250 volts <u>AC or 1527 to 1768 volts DC</u> for one second. This test shall be performed after branch circuits are complete.....

We feel this modification to the CFR will clearly convey to manufacturers and others how to set equipment to conduct a DC test. Please note that any manufacturers wishing to conduct an AC test would still be allowed to do so.

We realize the National Electrical Code also neglects to make a distinction between AC and DC voltages, and we are planning to submit the same request and reasoning to the NFPA.

However, for the present, we respectfully request that HUD evaluate this and any other material and if agreeable, allow manufacturers to fulfill the requirements of Para. 3280.810 using DC voltages.

Very truly yours,

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