HOW DOES IT WORK?
PARTIAL DISCHARGE TESTING EXPLAINED

Introduction

One of the main functions of power magnetic components is to provide isolation between two sections of an electronic circuit. This isolation may be necessary to comply to a relevant safety specification or to protect sensitive circuits from high voltages or transients. In general, the isolation required is set by the voltage present in the circuit and the level of safety insulation that is required. The design of the magnetic can ensure that the isolation requirements are met in principle, but the design cannot ensure that certain defects, due to variations in materials or manufacturing processes, will not lead to failures through time due to the transient or repetitive voltages appearing across the insulation barrier. It is therefore necessary to apply some sort of test to the components to evaluate the integrity of the insulation.

Several semi-destructive and non-destructive tests have been established to accurately determine the isolation capability of the component.:

Hi-pot test, in which a voltage is applied across the insulation barrier and the leakage current is measured, is the most common test performed and is effective to test the dielectric breakdown. However, it is not effective at identifying certain long-term failure mechanisms.

Impulse test which verifies if the clearances in the device would withstand specified transient over-voltages, is also not effective enough to provide data regarding the real time operating condition of the device.

As a result, partial discharge testing is increasingly utilized to evaluate the ability of the insulation barrier to withstand a repetitive peak voltage (U_{rp}) applied over the lifetime of the component and to define a component voltage rating.

What is Partial discharge

Partial discharge is a localized electrical discharge that only partially bridges the insulation between conductors, and which may or may not occur adjacent to a conductor.

When an insulation barrier has a defect, such as an internal void, the defect will display localized ionization when exposed to a sufficiently high voltage. Localized ionization is the process by which the atom or molecule acquires negative or positive charge by gaining or losing electrons. The voltage, at which ionization starts, is called the inception voltage. As the voltage is lowered the ionization continues until the extinction voltage is reached at which point the ionization stops.

When a high voltage is applied to the barrier the voltage will also build up across any voids or defects. When the inception voltage is reached, the void ionizes, shorting itself out. When the voltage across the void drops below the extinction voltage, ionization ceases. This action redistributes charge within the barrier and is known as partial discharge.

If the voltage rises again another partial discharge cycle will begin. If the voltage is repetitive and is large enough, partial discharge cycles will repeat many times. If the ionization begins and continues, it can damage the barrier, leading to a degradation of the isolation capability over time and eventual dielectric breakdown. If the discharge level is minimal, the barrier receives no damage. The inception voltage of the individual voids tends to be constant.

The total charge redistributed within the barrier is a very good indicator of the number of voids and their likelihood of becoming a failure. Setting a low limit on the allowable partial discharge in testing gives a very high degree of confidence that a high voltage failure will not occur with time. Since the current required for the partial discharge to occur is extremely low compared to that of the current in the hi-pot test, it would not be possible to measure this long-term failure with the hi-pot test method and hence partial discharge testing is implemented.

Therefore, in addition to the knowledge of the maximum dielectric breakdown isolation capability of the component, knowing the long-term voltage rating would be relevant to a more real-world scenario of the component's usage. This parameter could be determined with the highest confidence through the partial discharge test.

Partial Discharge Testing

The IEC safety standards and guidelines play a crucial role in determining the applicability of partial discharge testing and its usage in defining the long-term voltage rating. To provide greater clarity on the applicable standards and commonly used terms, a comprehensive overview is included in Appendix A. This section serves as an introduction to partial discharge testing and its outcomes.

The IEC 61558-1 defines a partial discharge test as mandatory for applications which conform to basic or reinforced insulation, if the working voltage, the maximum steady state voltage differential, or the recurring peak voltage, applied to the component is greater than 750V, i.e.,

For components providing only functional insulation, IEC 61558-1 defines a hi-pot test requirement with the test voltage being 500V greater than the working voltage. Therefore, the components offering functional insulation have a low requirement to confirm the ability to withstand a repetitive peak voltage and the partial discharge test is not applicable.

Input voltage waveform – AC voltage test

The IEC-60664-1 defines a voltage waveform, based on the applied U_{rp}, with inception voltage, U_1 to initiate the partial discharge and a maximum discharge at extension voltage U_2 for a positive result. The applied waveform is AC, but U_1 and U_2 are peak values of that AC waveform and are multiples of U_{rp}

Multiplication factors

In accordance with IEC-60664-1, the following multiplication factors are applied to U_{rp}, depending upon whether basic or reinforce insulation is required.

F_1 Environment correction multiplier

It takes into consideration factors influenced by the test environment such as temperature, humidity, etc. These influences are taken into consideration by a factor of 1.2. Therefore, for basic insulation, U_2 should be at least 1.2 times U_{rp}

$$U_2=F_1 * U_{rp}=1.2*U_{rp}$$

F_2 Hysteresis factor

It occurs between the U_1 and U_2. The factor F_2 shall not be greater than 1.25. For basic insulation, the value of the test voltage is therefore calculated as

$$U_1=F_1 * F_2=(1.25*1.2)*U_{pd}$$
$$U_1=1.5* U_{rp}$$

F_3 Additional safety factor for partial discharge testing and dimensioning reinforced insulation

For the reinforced insulation, a more stringent risk assessment is considered. Therefore, an additional safety factor of 1.25 is considered. U_1 is therefore adjusted as

$$U_1 = F_1 * F_2 * F_3 = (1.25 * 1.2 * 1.25) * U_{rp}$$
$$U_1 = 1.875 * U_{rp}$$

Due to the presence of the additional safety factor, U_2 in the case of reinforced insulation therefore would be:

$$U_2 = F_1 * F_3 * U_{rp} = (1.2 * 1.25) * U_{rp}$$
$$U_2 = 1.5 * U_{rp}$$

Test procedure

The test equipment for the partial discharge test is as shown in Figure 2, which consists of a high voltage test chamber, partial discharge tester and computer with the measurement software for viewing the measurements.

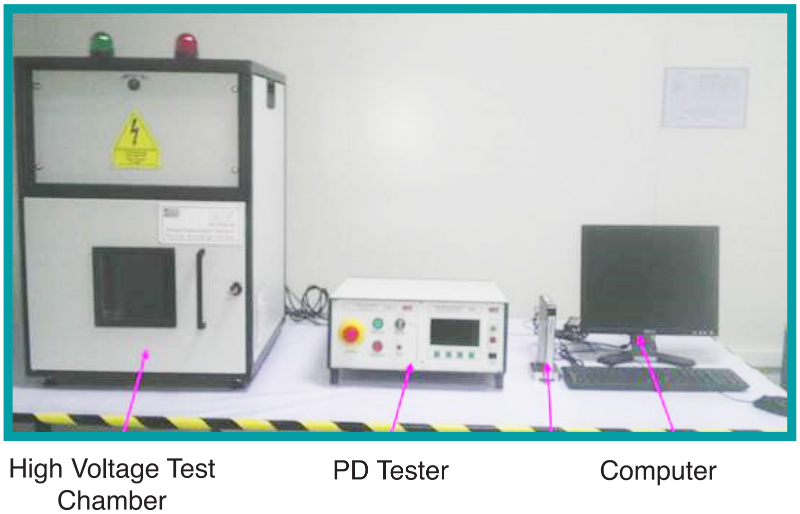

Figure 2: Test equipment for partial discharge testing

The test is started from a voltage below U_{rp} the voltage is linearly increased to the value of U_1 (1.5*U_{rp} for basic insulation or 1.875*U_{rp} for reinforced insulation) held for a maximum time of 5 seconds. The voltage is then linearly decreased to, U_1 (1.2*U_{rp} for basic insulation or 1.5*U_{rp} for reinforced insulation) and held for a maximum of 15 seconds, during which the partial discharge is measured. Figure 3 elucidates the said procedure.

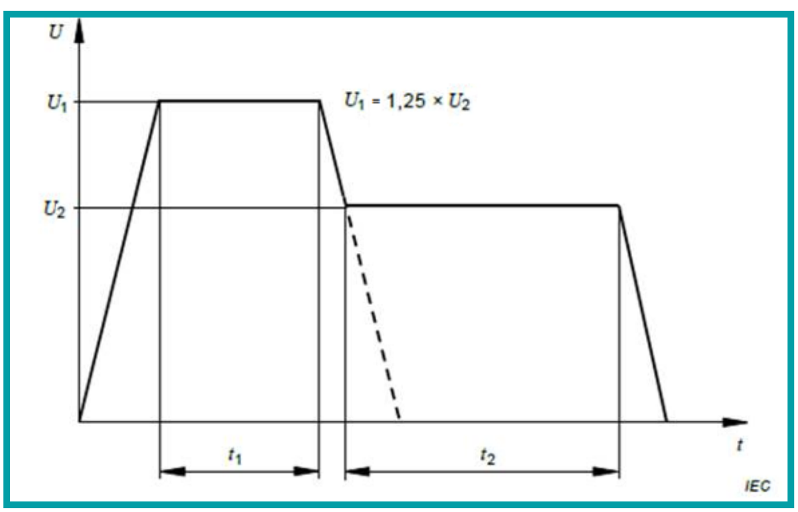

Figure 2: Partial discharge test procedure

Figure 4: Transformer with stray capacitances

As per the standard IEC 60664-1, the device is considered to have passed the partial discharge test if the charge on the stray capacitances as depicted in Figure 4, is less than 10pC during the measurement period.

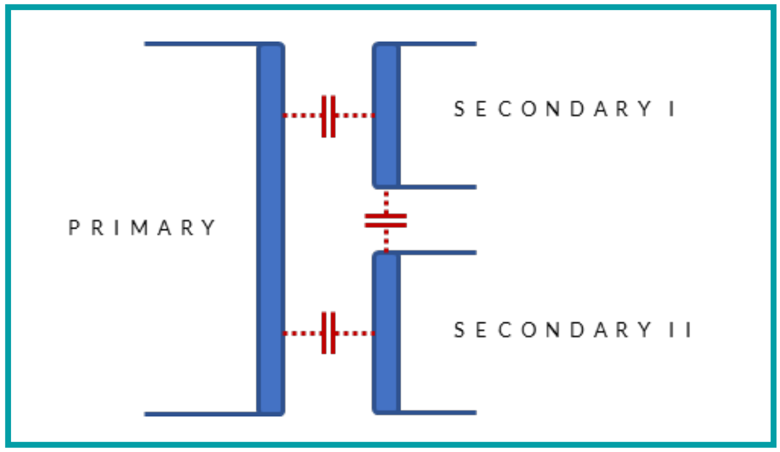

Figure 4 and Figure 5 show the measurement of charge on the stray capacitances during the partial discharge test, from Figure 4, the device under test passes the partial discharge test, U_{PD} as the charge on the stray capacitance during the testing period is less than 10pC, this measurement can be seen in PD1 and PD2. Likewise, the device shown in Figure 5 fails the partial discharge test as the charge on stray capacitance measures far greater than 10pC during the measurement period.

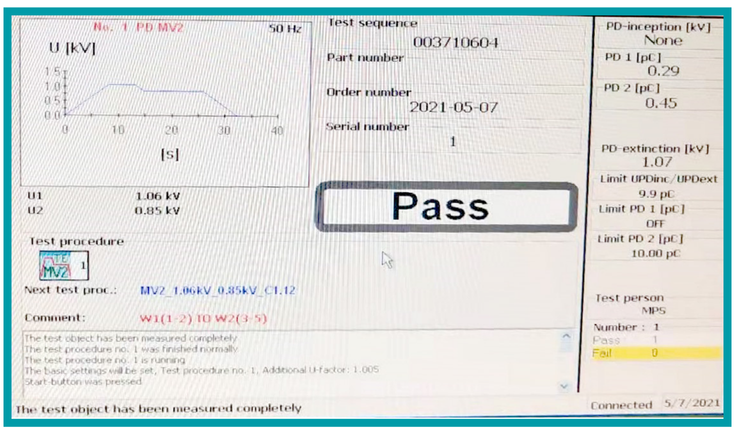

Figure 5: Sample partial discharge pass result

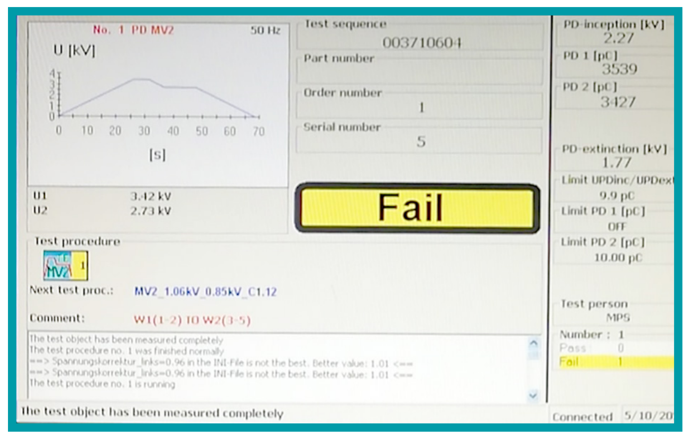

Figure 6: Sample partial discharge fail result

Benefits of partial discharge testing

Along with identifying the defects that may have occurred during system installation or the manufacturing process, the partial discharge testing is also a predictive qualitative analysis tool that warns of a potential upcoming system failure. As a result, insulation deterioration due to normal operating conditions can be identified beforehand.

In addition to defect identification, partial discharge testing offers several advantages over other testing methods with the primary advantage being that the test is a non-destructive test as it does not result in the device under test being stressed to failure, thereby it does not affect the existing insulation capability of the component.

An equally important parameter that can be identified using partial discharge testing is the voltage rating of the component. The U_{rp} is in effect the component voltage rating.

Pulse Magnetics with High Constant Isolation Capability

In conclusion, partial discharge testing is an excellent mechanism for identifying issues with the insulation of a magnetic component, can identify potential long-term issues and allows a long-term voltage rating to be established.

Below is an example of a pulse product which was tested for peak repetitive voltage U_rp using partial discharge testing depending upon the insulation class. Therefore, the rated voltage is mentioned in addition to the Hi-Pot isolation voltage of the component.

High Isolation Power Transformers

EP7 Platform SMD - PH9185.XXXNL and PM2190.XXXNL

Pulse
A YAGEO Company

ROHS COMPLIANT · AEC-Q200 · IATF 16949 · MSL

- *Push Pull Transformer*
- *Reinforced insulation for isolated power supply driver*
- *8mm creepage*
- *5KVrms isolation (1000Vrms continuous)[1]*
- *UL and TUV certified*

Electrical Specifications @ 25°C - Operating Temperature -40°C to +125°C

Part Number		Inductance (1-3)	Leakage Inductance	DCR (1-3)	DCR (4-6)	ET MAX (1-3)[1]	CAP	Turns Ratio	Isolated Voltage[4]
Commercial	Automotive[8]	(µH ±45%)	(µH MAX)	(Ω MAX)	(Ω MAX)	(V-µsec MAX)	(pF MAX)	(1:3) (6:4)	(Vrms)
PH9185.011NL	PM2190.011NL	750	1.2	0.50	0.55	66	10.0	1CT : 1CT	5000
PH9185.012NL	PM2190.012NL	450	0.9	0.40	0.80	52	10.0	1CT : 2CT	
PH9185.013NL	PM2190.013NL	200	0.6	0.35	0.95	36	8.0	1CT : 3CT	
PH9185.021NL	PM2190.021NL	1800	3.0	0.75	0.45	100	10.0	2CT : 1CT	
PH9185.034NL	PM2190.034NL	750	1.2	0.50	0.75	66	10.0	3CT : 4CT	
PH9185.038NL	PM2190.038NL	310	0.9	0.44	1.00	44	8.0	3CT : 8CT	
PH9185.043NL	PM2190.043NL	1260	1.5	0.70	0.56	89	12.0	4CT : 3CT	
PH9185.083NL	PM2190.083NL	2350	6.0	0.90	0.40	110	8.0	8CT : 3CT	

Notes:

1. The ET Max is calculated to limit the core loss and temperature rise at 100KHz based on a bipolar flux swing of 180mT Peak.
2. For Push-Pull topology, where the voltage is applied across half the primary winding turns, the ET needs to be derated by 50% for the same flux swing.
3. The applied ET may need to be further derated for higher frequencies based on the ... which results f... the core and co... losses

C. To calculate temperature rise, use the following formula: Temperature Rise (°C) = 90 * (Core Loss(W) + Copper Loss (W))

4. The AEC-Q200 temperature and humidity operational life testing was completed ... a dielectric strength test of 5000Vdc.
5. Optional Tape & Reel packing ... red by ... (i.e. P...

Appendix A: Brief Look into Insulation Safety Standards

Transformers are fundamental components of various electronic systems and find extensive use across multiple applications. When designing a transformer for an application requiring electrical isolation, it is essential to consider several key factors to ensure the transformer's safety, reliability, and efficiency.

One of the primary reasons to use an isolated power converter is for safety purposes, particularly when working with high and potentially dangerous voltages. Isolation separates the output from hazardous voltages on the input side, providing an additional layer of protection for end users. When designing the transformer for safety compliance, three main aspects should be considered:

1. Insulation type: Choosing the appropriate insulation type is critical to ensure the transformer can withstand the voltage levels involved and that the output is fully isolated from the input.

2. Hi-Pot isolation voltage: The hi-pot isolation voltage is the maximum voltage that the insulation can withstand without breaking down. The transformer must be designed to meet the required level of hi-pot isolation voltage to comply with safety standards.

3. Working voltage: The transformer's design must consider the maximum voltage that it will be exposed to during normal operation to ensure safe and efficient performance. Overlooking this aspect can compromise the transformer's reliability and safety, and ultimately the performance of the power converter.

Insulation type

Ensuring safety is a key concern when designing transformers for isolated power converters, and the insulation grade is an important factor to consider. Compliance with insulation requirements is determined by safety standards, which consider the level of hazardous voltage exposure to the user. The level of insulation required for a given application depends on the potential risk of exposure to hazardous voltage levels. The insulation grade can be classified into different levels based on the required level of protection:

Functional
Functional insulation is sometimes referred to as operational insulation. This type of insulation serves the purpose of ensuring that a product operates correctly, not to protect the user from hazardous voltages. An example of this is the enamel insulation surrounding the wire used to create a coil. It only needs to be strong enough to prevent the coil's windings from shorting together. The safety regulations do not pertain to the effectiveness of functional insulation.

Basic
Basic insulation is a solitary layer of insulation that guards against dangerous voltages. A classic illustration of basic insulation is the plastic insulation that surrounds each wire in a typical AC power cord. This layer of insulation is enough to safeguard the user from electrical shock, but in the event of a malfunction, the user may be exposed to hazardous voltages.

Supplementary
Supplementary insulation is a secondary layer of insulation that operates separately from the primary layer. This additional layer serves to offer protection from hazardous voltages in the event of a failure of the basic insulation. When a safety ground is not present in a power source, supplementary insulation is added to the basic insulation for added protection. A common example of supplementary insulation is the plastic exterior of an external power supply.

Double

Double insulation refers to the combination of both basic and supplementary insulation in a design and is considered as a safety measure rather than a specific type of insulation (though it is often classified as a type of insulation in technical documents). Both the primary and secondary layers of insulation are included due to concerns that the basic insulation layer may fail, potentially exposing the user to dangerous voltages.

Reinforced

Reinforced insulation provides the same level of protection as double insulation, but with only one layer of insulation. To be considered reinforced, the insulation must meet more stringent requirements than those for basic or supplementary insulation.
Pulse electronics' magnetics are provided in functional, basic, and reinforced safety insulation classes.

Hi-pot Isolation voltage

Hi-Pot Isolation voltage represents a test that assesses an insulator's capability to reduce the flow of electrical current when a high voltage is applied. Most insulators display extremely low current flow and high impedance until the applied voltage (and therefore the resulting voltage field strength) becomes strong enough to cause the insulation to "breakdown". Once the insulation has broken down, it ceases to function as a good insulator and becomes a poor conductor, allowing hazardous levels of current to pass through the isolation barrier.

The breaking down of insulation is dependent upon both the magnitude and the duration of the applied voltage stress. For this reason, the specifications of isolation voltage include a voltage magnitude of the test voltage, a time duration of the test voltage and a maximum allowed current flow during the test voltage stress.

Working voltage

The idea behind Hi-Pot isolation voltage is to temporarily apply a high voltage for a brief period and observe the performance of the insulation. On the other hand, the working voltage pertains to the behaviour of the insulation when exposed to a voltage level that may persist for a prolonged time.

IEC61558-1 clause 3.3.8, defines U as the working voltage across any insulation and defines requirements in order to comply with the standard based on the level of insulation required. Therefore, U is the continuous isolation voltage across any insulation, which is as illustrated in Figure 1. It may be different to the repetitive peak voltage U_{rp} that is applied to the component.

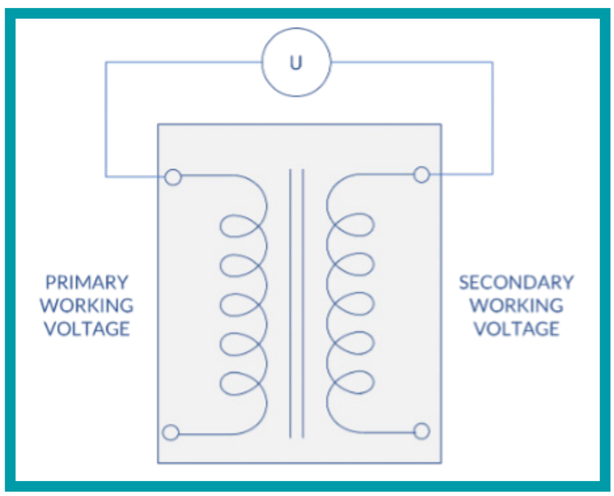

Figure 1: Working voltage of the transformer

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