Investigation of partial Discharge Suppression in Electronic Converters using Electrets based on Corona Charging

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Abstract

Partial Discharge (PD) is a limiting factor in electrical insulation and electrical wires especially in power electronics related setup/applications. Basically, it behaves as the conduction bridge between a conductor and an insulator where voltage travels from conductor to insulator crossing the insulation components and makes the components less efficient in high voltage operations. To overcome the limitations of partial discharge, certain methods are being designed such as geometry-based methods and material-based methods etc., just to mention a few. In the former solution, the geometry of the components is changed in such a way that partial discharge is reduced to much lower level, but these methods are very expensive and sophisticated at the same time, while the latter ones used specific kind of materials that are added to the power electronics components or systems so that the partial discharge can be suppressed. These methods include adding some substances that increase the viscosity, breaking point and potential of the components and comparatively less expensive in providing the efficient outcomes. Owing the on-board partial discharge limitations, in this research, a new method is contributed, in which the electronic components such as inverters, DC-DC converters and rectifiers are coated with ELECTRET with the help of Corona Charging, which helps reducing the partial discharge of the converters to an average of 5% in comparison with the conventional conformal coating and almost 20% as compared to the non-coated converters

Keywords: Partial Discharge (PD), Conformal Coating, Electret Coating, Corona Charging.

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I. INTRODUCTION

Converters are most commonly used power electronics devices which are based on switching power electronic components. MOSFETS IGBTs and Thyristors, all come in different voltage ratings depending upon the thickness of substrate which has to bear all the reverse voltage. Reverse voltage induces partial discharges in the substrate of switching devices which does not immediately results in failure of substrate but gradually produces cavities which ultimately lead to failure of switching device. Investigation of the partial discharge occurring inside the substrate of the switching device could give an insight into failure modes and mechanisms.

A. Overview

Wide Band Gap (WBG) semi-conductors are recently being used widely for the power electronics applications. These are also known as next generation semi-conductors as they hold high power density, high temperature operation and high breakdown voltage. Commonly used WBG semi-conductors are SiC and GaN. Due to increased dv/dt, power density increases which results in the use of thinner layer of insulators when it comes to using these materials in making transistors which are in turn being used in converters and various switches and are performing in an outclass way [1][2] With the advent of SiC power transistors and its use in commercial products and high power applications, packaging methods seem to be using the conventional methods as Sic and other power semi-conductors increase the power density. This reduces the thickness which inevitably increases the electric stress i.e. electric field which causes the increase in partial discharge of these devices hence inducing the electric treeing in those devices. As a result, the devices age faster compared to the devices made by the help conventional power

electronic systems [3] When it comes to the rotating devices such as motors, partial discharge is a very well discussed issue in these, as due to the enhanced speed of motors using conventional methods, electric field enhances and it causes increase in temperature and PD. This can reduce the life of motors to a great extent and also effects the performance of devices and ultimately increases the chance of device failure. Using the SiC and GaN in solid insulators used in these motors causes the enhanced partial discharge as well [4][5] Partial discharge typically occurs on triple points, cracks, sharp edges and bubbles or air gaps. Triple point is the point is the point where three types of materials coexist. As different materials vary in their properties i.e. resistivity, permittivity etc., it results in generation of high electric field which increases the partial discharge. Air gaps or bubbles are causes when the material is not properly manufactured and some of the air gets trapped inside it while its formation. Therefore the materials are properly dehydrated and made in air- tight containers to avoid this situation. Cracks are formed in device when device comes under stress as it goes through various electrical and mechanical stresses. It causes the voltage penetration inside the insulator and causes partial discharge.[6]

B. Different Techniques to Reduce PD

Different techniques to reduce the partial discharge are being discussed and worked on since the last decade. These techniques are either geometry based or material based.

In material based techniques, epoxy incorporation in materials is tested, epoxy is a compound consisting of different carbon chains that are attached with various elements like oxygen, nitrogen and hydrogen. Incorporation of epoxy resin in semi-conductor materials used for making transistors and switches enhances the insulation properties and reduces the partial discharge. Epoxy resins are being developed for certain outdoor and indoor applications and its formation completely depends on the level of voltage that particular material has to bear. Epoxy resins are incorporated with nano fillers such as SiO_2, TiO_2 or TiO_2@SiO_2 and the partial discharge studies are done which shows a lot of improvement in PD suppression with the help of these nano-fillers. Among these nano-fillers, TiO_2@SiO_2 gives the better results when incorporated in Zepoxy (a military scale epoxy) as leakage current reduces with the use of these nano fillers. Zepoxy encapsulation on materials reduces PD in the devices [7]. Secondly, by covering the surface of the ceramic substrates and metallization layers which emit very high electric fields with the nonlinear resistive field grading material that has resistivity varying nonlinearly as a function of electric field, high electric fields on sharp edges and triple points are reduced. This approach is a type of resistive field grading method widely used in conventional high-voltage applications including cable terminations and rotating machines [8]

In geometry based approaches, triple point in the devices is moved to a place where the electric field is lowest which enhances the performance and suppresses the partial discharge. Also, the metallization has round edges which helps in PD suppression as main cause of PD is sharp edges and triple points. It is done with the help of protrusion in the ceramic and a metallization layer is encapsulated on this protrusion. With the help of this structure, the triple point is moved away from a point where the electric field is low because maximum electric field occurs in encapsulants now.[9]

A new approach using Electret in devices and materials for partial discharge suppression is introduced in the last decade. Electrets can either be made of inorganic materials that are based on silicon dioxide (SiO_2) or organic materials that are based on polytetrafluoroethylene (PTFE) or high density polyethylene (HD-PE) etc. and these electrets can bring revolution in high to medium voltage electronics as these might become able to fully suppress the partial discharge [10] Theoretical studies to prove the effectiveness of Electret are discussed in [11]. Two surfaces with arbitrary electric potential and an electret layer in between them are taken. It is assumed that surface on top has charge Q_1 and surface on bottom has a charge Q_2 and the electret layer that is incorporated between them has an electric charge density of σ_e. The distance between the top and bottom surface is $D = d_1 + d_2$. Electric field is defined as E_1 across v_1 pointing towards the top surface and the electric field E_2 across v_2 pointing towards the bottom surface. Area of all three surfaces is assumed to be A, the total amount of charge of the electret is $Q_e = A\sigma_e$. With the presence of the electret layer. Taking the electric potential difference between top and bottom surfaces, solving the equation of charge for v and also taking the value of electric field, the results show that either the surface charge density of distance between the top and bottom layers of the setup can be used to reduce the partial discharge as these can be used to change the electric field across the surfaces as follows:

$$\sigma_e=(v\varepsilon_o\,\varepsilon_r)/d \qquad (1)$$

$$d=D-(v\varepsilon_o\,\varepsilon_r)/\sigma_e \qquad (2)$$

Further research about the electret is done in [12] by taking a polyvinylidene fluoride (PVDF) film and charging it with electret with the help of corona charging technique and then measuring the PD characteristics of both charged and uncharged films of PVDF. Numerical studies are also done for electret based partial discharge suppression phenomenon. Two high voltage supplies were taken i.e. of 20kv and 650V, 20KV voltage supply is used to generate the corona discharge when applied at the needle electrode, 650V supply placed below the needle electrode to create uniform electric field. The charged particles are bombarded due to uniform electric field and transformed to electrets. An induction heater is also used to maintain the temperature at 70 degrees. After the whole process surface charge densities of both the charged and uncharged film are measured that are different as no visible difference can be seen in these.

In response to this growing issue, Electret incorporation has become a new hot topic of research after realization of its benefits in partial discharge suppression. In this research, partial discharge suppression ability of Electrets based on corona charging in converters will be investigated. Electrets help to distribute the electric field in the vicinity of switching devices thereby increasing the partial discharge inception voltages. Three different types of converters will be taken and using corona charging technique we incorporate electrets in them and measure partial discharge suppression. Proposed research has been validated by evaluating and comparing the uncharged (without electret insertion) converters with charged converters for partial discharge suppression studies

II. MATERIALS AND METHODS

A. PD Measurement Setup

Some market scale converters were taken that included DC-DC Converters, Inverters and Rectifiers. Without opening the circuitry and dismantling the system on PCB (Proto circuit boards) the experimentation is performed. Partial discharge of all types of converters is done as shown below

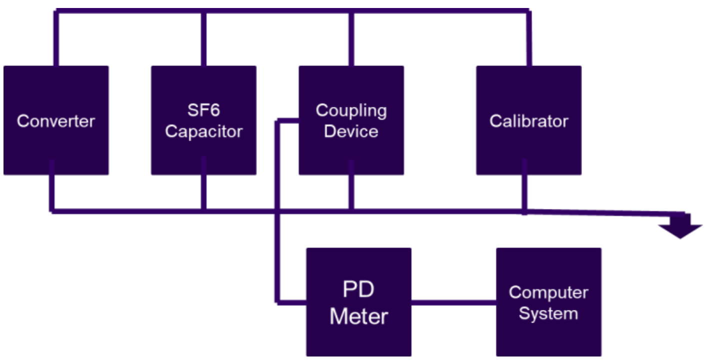


Fig 1: PD Measurement Setup

SF6 gas filled capacitor that is used for high accuracy and reliable insulation. Calibrator is used in high voltage systems when the setup's partial discharge is not desirable in the results. It is used to calibrate the data that is being read on partial discharge meter. PD meter is used to measure the partial discharge of windings before they cause actual damage. It measure Partial discharge Inception Voltage (PDIV) and Partial discharge Extinction Voltage (PDEV). PDIV is basically the voltage level of the converter or winding just before the partial discharge is occurring and PDEV is the highest voltage at which partial discharge is occuring. This experimentation is done in three steps.

PD Measurement Without Coating
PD Measurement with Conformal Coating
PD Measurement with Electret Coating

III. PD MEASUREMENT WITH CONFORMAL COATING

Conformal coating is basically a polymeric coating. As polymers are the biggest molecules, they protect the converters from various environmental constraints. It is applied with the thickness of 25-250um. Environmental constraints include chemicals, dust, temperature and most importantly Partial Discharge. It can be applied with various methods such as brushing, spraying, dip coating or dispensing. If conformal coating is done in a right way, it can protect the components from corroding as well. These coating are generally breathable, which means the trapped moisture inside the electronic devices can leave the coating but no new moisture can enter. A number of materials are being used for conformal coating such as urethanes, silicons, acrylics and parylene. Each has a distinguished characteristic. If silicon coating is being used. It is either done with the spray or with the soldering process, silicon rods are attached. In this research silicon coating is done on the converters to study the partial discharge ability of this coating with the help of spray gun.

After the coating of silicon on the converters, they are kept in sun for a few days for drying. In case of inverter, calculations are performed with in supply mode i.e. when the voltage is being taken from the national grid and other in inverter mode, i.e., when the voltage or power is being taken from the batteries attached with it. Experimentation is performed on different loads (2A, 2.5A, 3A, 3.5A,4A).Both in supply and inverter mode.

IV. PD MEASUREMENT WITH ELECTRET COATING

Electrets are basically a permanently polarized material and it is analogues to permanent magnet. It has quasi permanent electric field. It is basically generated by the help of contact rectification. As it has a permanent electric dipole moment, it is used in the materials for coating to protect the materials from the environmental constraints such as harsh weather, high temperature and partial discharge. Previously electret chips are used that inserted in the materials while formation with the help of corona charging. After removal of conformal coating from market scale converters, we incorporated electret on them with the help of corona charging. After the coating of electret on the converters, they are kept in sun for a few days for drying. During drying or healing process, converters are subjected to corona charging to make the electrets more adhesive and in turn more efficient.

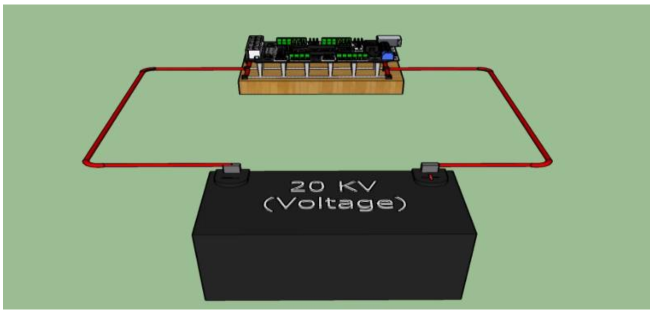


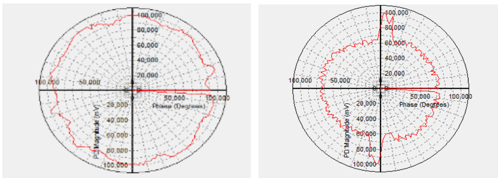
Fig 2: Corona Charging Setup

In case of inverter, calculations are performed with in supply mode i.e. when the voltage is being taken from the national grid and other in inverter mode, i.e., when the voltage or power is being taken from the batteries attached with it. Experimentation is performed on different loads (2A, 2.5A, 3A, 3.5A,4A).Both in supply and inverter mode.

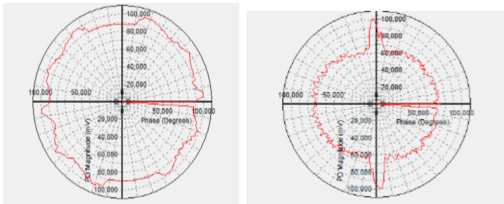
V. RESULTS AND DISCUSSIONS

A. Non Coated Converters:

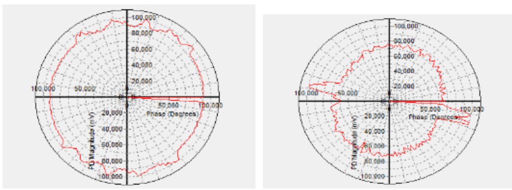
Results of Non-coated converters in supply and inverter mode at different loads are given below



1.5 A (Supply mode **R**, Inverter Mode **L)**



2.5 A (Supply mode **R**, Inverter Mode **L)**

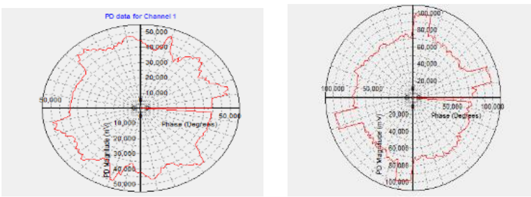


3.5 A (Supply mode **R**, Inverter Mode **L)**

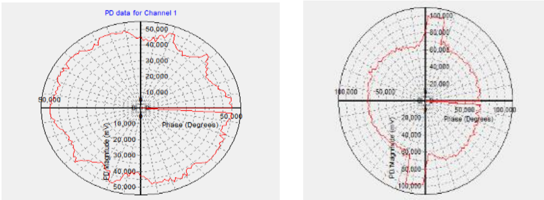
Fig 3: PD measurement of Non Coated Converters

B. Conformal Coated Converters:

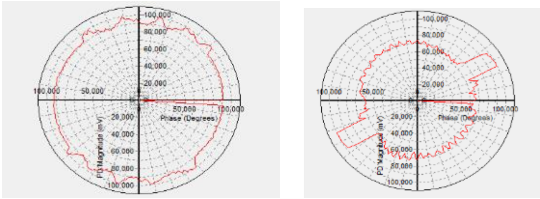
Results of Conformal-coated converters in supply and inverter mode at different loads are given below



1.5 A (Supply mode **R**, Inverter Mode **L)**



2.5 A (Supply mode **R**, Inverter Mode **L)**

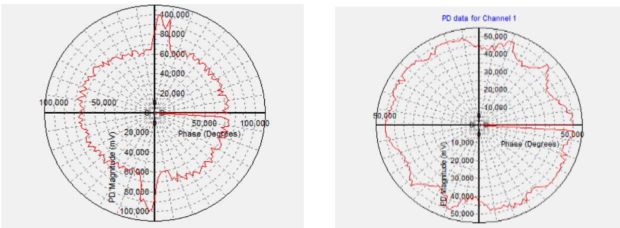


3.5 A (Supply mode **R**, Inverter Mode **L)**

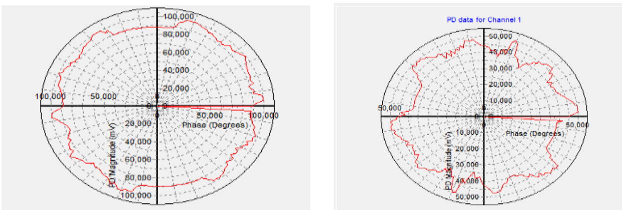
Fig 4: PD measurement of Conformal Coated Converters

C. PD Measurement of Electret Coated Converters:

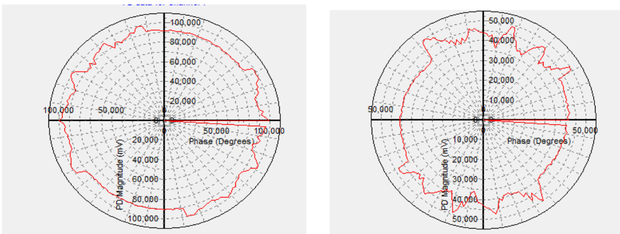
Results of Electret-Coated converters in supply and inverter mode at different loads are given below



1.5 A (Supply mode **R**, Inverter Mode **L)**



2.5 A (Supply mode **R**, Inverter Mode **L)**



3.5 A (Supply mode **R**, Inverter Mode **L)**

Fig 5: PD measurement of Electret Coated Converters

D. Comparison of PD Suppressions of Inverters with of Without Coating:

Ser No	PD Without Coating		PD With Coating	
	Load Current (A)	Non-Coated Converters	Conformal Coating	Electret Coating
1	1.5	86pC	67pC	62pC
2	2	89pC	69pC	65pC
3	2.5	90pC	70pC	68pC
4	3	95pC	72pC	70pC
5	3.5	97pC	80pC	75pC

Table 1: PD Measurement in Supply Mode

Ser No	PD Without Coating		PD With Coating	
	Load Current (A)	Non-Coated Converters	Conformal Coating	Electret Coating
1	1.5	61pC	45pC	40pC
2	2	62pC	47pC	42pC
3	2.5	65pC	49pC	42pC
4	3	68pC	50pC	44pC
5	3.5	70pC	52pC	45pC

Table 2: PD Measurement in Inverter Mode

E. Discussions:

Average value of partial discharge during supply mode of the inverter without conformal coating is around 90pC and the peaks reach up to 100pC. While, in inverter mode the value decreases to around 65 pC average value. Similarly, the average value of partial discharge of the inverter with conformal coating is around 45pC in inverter mode 70pC in supply mode. Average value of Partial Discharge in case of Electret Coating is 42pC in inverter mode and almost 68pC in supply mode. Partial discharge of the inverter with conformal coating on it is more in supply mode than in the inverter mode. This is due to the reason that utility voltage is higher than the voltage in case of the inverter mode i.e. around 260V which causes an increase in the partial discharge. Electret Coating helps in improving PD suppression characteristics to an average of 5% as compared to conventional conformal coating and almost 20% in comparison with non-coated converters

CONCLUSION

Performance of market scale converters is made better by investigating the partial discharge properties through already known and workable processes and then by introducing a process i.e. electret incorporation through corona charging. Results of different methods were compared and it is concluded that performance parameters of the converters with electret coating were enhanced by 20% overall.

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