EVALUATION OF THE EFFECT OF FIRING PHASE ON THE POROSITY OF CERAMIC DISC INSULATORS DURING THE MANUFACTURING PROCESS THROUGH ADVANCED PARTIAL DISCHARGE ANALYSIS

PRADEEP. A [1], SANTA SAHA [1], MOUTUSI PAUL [1], RAVI SHANKAR K.V [2]

[1] Corporate R&D, Bharat Heavy Electricals Limited, Vikasnagar, Hyderabad - 500093, India.

[2] Electro porcelains division, Bharat Heavy Electricals Limited, Bangalore - 560012, India.

* Email: pradeep@bhelrnd.co.in

Abstract: The ceramic disc insulators support the live conductors and have to endure high electrical stresses through out their service life. In the process of manufacturing a disc insulator the firing stage plays a very important role, which determines the mechanical, thermal and electrical strength of insulators. There are different kilns and firing cycles that are used in an industry. The discs manufactured by each method assign unique characteristics to the respective category of disc insulators. The firing cycles affect the electrical characteristics of the insulators based on porosity, pore diameter and location. The categorization of the electrical properties of insulators manufactured in different kilns and firing cycles, based on advanced partial discharge analysis, which can extract the information on the pores formation is presented in this paper. This method can be used as a potential technique to assess the firing process in an industry with reference to electrical characteristics of disc insulators.

1. INTRODUCTION

In a power transmission system, line support insulators play an important role in maintaining the reliability of the system. Failure of the insulators is a major cause of concern in power transmission systems. The ceramic disc insulators in the form of string are used to support a conductor physically and to separate it electrically from other live lines and supporting tower. There are different kilns and firing cycles that are used in an industry. The discs manufactured by each firing process assign unique characteristics to the respective batch of manufactured discs. Heat treatment is a most important stage in the manufacture of ceramic disc insulators. It determines the formation of pores and thus the quality of insulation. Tunnel kilns are normally used for firing the insulators as fuel consumption is less and large volumes can be produced in shorter time, but the temperature variations from top to bottom of the cart and also across the channel makes the process unsuitable for uniform drying of discs on specialized lines. While microprocessor based shuttle kilns have an advantage of stable temperature fields, and can be used continuously for production of small volumes. Insulators fired in the shuttle kilns where strict control is maintained with regard to uniformity of temperature have different characteristics [1]. A printout of the firing curve, indicating the uniformity of temperature profile across the kiln cross section, is maintained. The fired insulators are inspected and subjected to mechanical and electrical tests.

Partial discharge (PD) detection can be used as a tool to judge the state of the insulation of equipment and the quality of its manufacture [2]. The puncture of porous porcelain insulators during routine electrical power frequency tests has proven to be one of the most significant factors influencing the rejection of disc insulators. The different breakdown voltages obtained during the routine high voltage tests on discs manufactured in different kilns has motivated to take up this work. The categorization of the discs was carried out based on the electrical characteristics obtained from the frequency resolved partial discharge analysis. The information on the pore formation in the disc insulators can also be evaluated from the PD analysis.

2. PARTIAL DISCHARGE MEASUREMENT

Porcelain insulators essentially consist of pin, cap, dielectric (porcelain) and cement. The metal parts are bound to the porcelain with the help of cement. The insulator dielectric (porcelain) is required to hold off the applied potential difference, typically for several decades without failure. The PD measurement setup is shown in Figure 1. The supply voltage is obtained from a 50kV discharge free transformer and passes through a filter and then connected to the coupling capacitor and test object. The disc is placed over an insulator to provide sufficient clearances and voltage is applied to the pin of the disc while the cap is grounded.

A partial discharge is the dissipation of energy caused by the build up of localized electric field intensity. PD analysis is one of the very important and useful diagnostic tools for quality assurance testing of any high voltage equipment during design and manufacturing. The partial discharge measurements on disc insulators can extract the concealed information about the integrity its insulation [3]. It can be a very helpful tool for identifying the defects at the microscopic level, which otherwise cannot be determined.

Figure 1: PD measurement setup

The performance of the disc insulators, as insulating material is greatly affected by the firing process. Different firing cycle results in subtle change in chemistry of the porcelain. Tunnel and shuttle kilns are two types of kilns generally used for firing the insulators. But with respect to temperature the firing process is totally different for both the kilns. As a result, it effects on the porosity of the disc insulator. Partial discharge measurements and analysis was carried out on two batches of 160 KN HVAC disc insulators manufactured under different firing conditions and the results are compared.

3. EVALUATION OF DISC INSULATORS

In the process of manufacturing a disc insulator the important factors that influence the strength of the disc are the choice of raw materials and type of firing used. The clay gets transformed into ceramic in the firing phase and thus kilns play a very important role in determining the electrical characteristics of disc insulators. The firing cycle of a disc insulator consists of four phases oxidising, reducing, neutral and cooling. Each phase follow a predefined temperature profile for a pre-determined duration. The variation in temperatures is from 35 to 1300 ℃ for about 60-120 hours. In tunnel kilns there are different zones for temperatures and the discs are passed through these zones as per their firing cycle, while in case of shuttle kilns the temperature of the kiln itself is varied as per its firing cycle, while the discs are held static.

The ceramic discs manufactured under different firing conditions exhibit different PD patterns. The electrical strength of insulators is mainly influenced by the porosity, pore-diameter and pore cluster locations [4], especially at the head portion of the disc insulators, which are basically determined during the firing phase. Partial Discharge (PD) measurement and characterization provide vital information on insulation condition, different aspects of insulation ageing useful for equipment integrity verification and diagnosis. At a particular applied voltage the amount of discharge in the insulation is measured in pico-coulombs. The PD pattern can provide information on type of discharges such as internal, surface or corona and also on the location of voids. The variations in PD inception voltage, discharge magnitude, repetition rate and also the dominant frequency of discharges with reference to the test voltage levels are closely related to the internal porous condition of the insulation between cap and pin, of the discs fired under different conditions.

Of importance in the PD measurements is the PD inception voltage and rate of rise of discharges at which the porosity in the head region of the disc insulators becomes observable. The measured data will provide information on the required raw materials and also on the efficiency of firing cycle. Right choice of raw materials and suitable firing cycles will reduce pore formation and also discharge magnitude during PD measurements. In the course of this experimental investigation to assess the insulation condition of the discs fired in different kilns is carried out and the required corrective actions are suggested.

The PD values with reference to applied voltage for different samples of 160 KN HVAC discs fired under kiln-1 are shown in Figure 2 and those under kiln-2 are plotted in Figure 3. The magnitude and repetition rate of discharges increase exponentially with applied voltage and % discharge are plotted with 1000PC as base value. The deviation in the PD characteristics for the discs fired in kiln-1 is less, while the PD inception (considering discharge magnitude of 10 PC) occurred at about 12-14 kV of applied voltage. The PD characteristics of discs fired in kiln-2 are different from those of kiln-1 and the PD inception occurs at 15-17 kV.

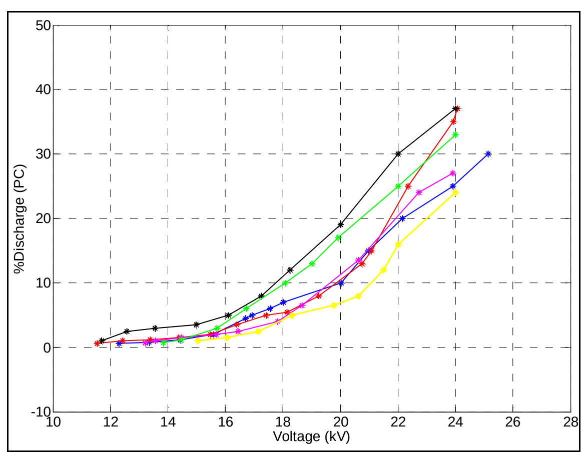

Figure 2: PD of discs fired in kiln-1

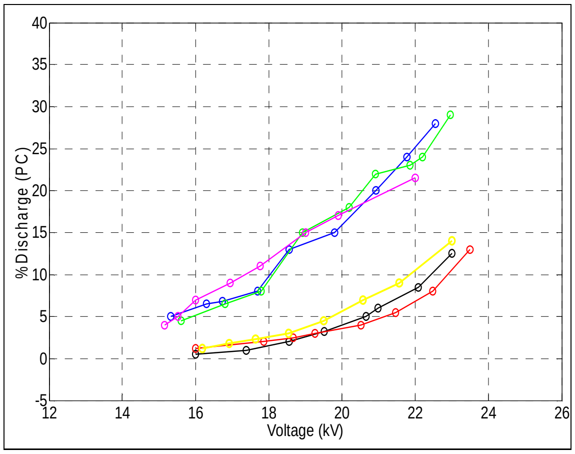

Figure 3: PD of discs fired in kiln-2

In kiln-2 the temperature profiles are not uniform across the cart and the discs samples are taken from two different layers of the cart. The reason for the two clusters of PD curves obtained from the discs taken from kiln-2 can be attributed to non-uniform temperature profiles across the cart during firing phase. Considering two sets of discs in the kiln-2 batch, the comparison of disc characteristics of kiln-1 and kiln-2 (set1 & set2) are plotted in Figure 4a and 4b respectively, with PD base value of 1000pC.

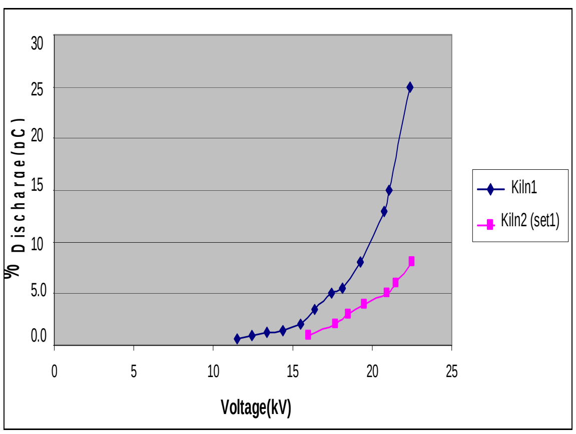

Figure 4a: PD of discs fired in kiln-1 & kiln-2(set1)

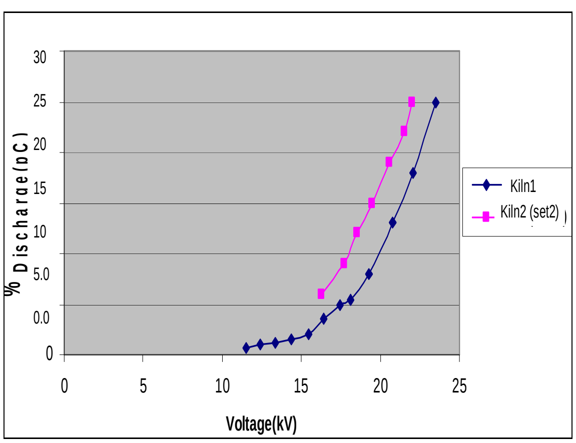

Figure 4b: PD of discs fired in kiln-1 & kiln-2(set2)

The PD characteristics of kiln-2 set1 discs are superior to kiln-1 with lower discharge magnitudes at different voltages, while kiln-2 set2 disc characteristics are inferior to those of kiln-1. The large variation in the PD characteristics due to non-uniform firing can lead to higher rejection rates during routine electrical tests. Hence, it is very important not only to accurately implement the firing cycle but also maintain uniformity of the temperatures along the cross section of the cart.

The typical PD plot of a disc insulator at a particular test voltage in sinusoidal form, elliptical representation and frequency distribution plot are shown in Figure 5. The PD amplitudes were measured at different voltages. It was observed that at 19kV applied voltage the disc from kiln-1 had maximum discharge magnitude of 200pC at centre frequency of 210 kHz, while the disc from kiln-2 exhibited 140pC at 240 kHz. The number of discharges or discharge count was higher for kiln-1 disc than kiln-2 disc. Similar patterns were obtained for other discs as well. The categorization of the discs can also be made on similar lines. In the present case the data on PD magnitude Vs voltage curves, present a better tool for comparison of different discs.

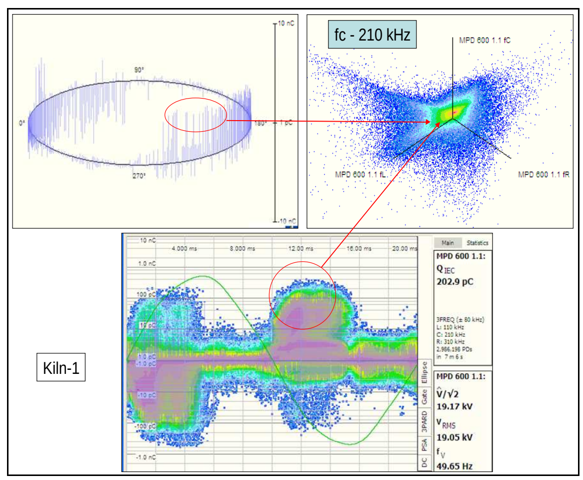

Figure 5: PD at 19 kV for disc fired in kiln-1

4. RESULTS AND DISCUSSIONS

The PD inception of the disc samples from kiln-1 occur at a lower voltage than the samples from kiln-2. For the same voltage, the discharge magnitude is high for kiln-1 sample than kiln-2, which indicates stronger dielectric characteristics of kiln-2 discs. The same raw materials used for the discs manufactured in both the kilns. The difference in insulation characteristics of the discs is due to different firing conditions in the respective kilns. Correlating the simulation results with that of experimental results the following points can be inferred:

- For kiln-1 samples the PD inception voltage is between 12 to 14 kV , whereas for kiln-2 samples the inception voltage is about 15 to17 kV
- The deviation of discharges within kiln-1 discs manufactured in is much less than those of kiln-2 discs. The kiln-2 discs exhibit two different clusters: kiln-2 set-1 and set-2 as mentioned above
- The discs occupying central rows of the cart and fired in kiln-2 display uniform insulation characteristics than those placed in top and bottom layers of cart
- The temperature profile has a bearing on the variation and spread of PD curves in the kiln-2 sets

The routine power frequency tests are carried out on all manufactured discs to ensure that the discs with defects are rejected, which otherwise can lead to catastrophic damage while in service. The electric stress concentration tends to be higher in the lower permittivity dielectric and the presence of voids, filled with air, in the porcelain can cause early breakdown [5]. It was observed that the required PD characteristics which can withstand the required test voltage without puncture are in between kiln-1 and kiln-2's set-1 curves. The disc rejection rate for kiln-1 is about 10% while that for kiln-2 is 3% corresponding to the discs falling in set-1 category. With the above analogy the effect of firing phase on integrity of insulation can be determined. The test results are in good agreement with the measured PD characteristics. Integration of routine electrical test results with the PD measurement values can be an asset for identifying such defects and in improving the manufacturing process.

The above procedure can be very helpful in studying and improving the efficiency of firing phase and thus the puncture rate of discs can be drastically reduced. The proposed method of evaluation helps in:

a) Elimination of scrap production and hence their disposal

b) Results in huge financial benefit by minimizing the rejection rate and increasing the overall productivity.

c) The measurement of partial discharges is a useful tool to ensure the product quality.

5. CONCLUSION

Unlike the general use of PD measurements for condition monitoring of various installed HV equipment, the advanced frequency resolved PD analysis was used to evaluate the effectiveness of firing process on the electrical strength of insulators during the manufacturing phase itself. This paper reports the findings of the experimental investigation carried out to categorize the electrical characteristics of insulators manufactured under different kilns and firing cycles. This method can be used as a potential technique to assess the firing process in a ceramic industry with reference to electrical characteristics of disc insulators. It can also help to improve the vitrification process and minimize the porosity in disc insulators.

6. ACKNOWLEDGMENTS

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