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# *An Investigation of Leakage Current and Partial Discharge For Various Overhead Insulators*

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## Abstract

High voltage insulators used in various overhead forms are exposed to leakage current and partial discharge.

This work deals with different structure forms of insulator, such as (pin post, clamp top and tie top). These structures are applied in different tests, as covered and stripped states. The leakage current for these forms were measured by raising the insulator voltage to (5.25, 6.35, 7.57 kV) for covered and stripped state. Partial discharges were determined in covered and stripped state of these insulator forms using (straight and balanced detection method).

Pin post insulators have a leakage current and electric field larger than both clamp top and tie top. The clamp top and tie top insulator show almost the same value of leakage current measurements.

The stripped conductors always produce large partial discharge than covered conductor.

**Key words: Leakage current, Insulator Materials, Partial discharge, stripped Insulator, Covered Insulator.**

**التحقق من التيار المتسرب والتفريغ الجزئي للشحنة لاشكال مختلفة من عوازل رؤوس الأعمدة**

**الخلاصة**

عوازل الضغط العالي المستخدمة في أشكال مختلفة عند رؤوس الأعمدة تتعرض إلى تسرب تيار وتفريغ جزئي للشحنة . يتعامل هذا البحث مع أشكال مختلفة من العوازل ( Pin Post, Clamp Top, Tie Top ) استخدمت هذه البنيات في اختبارات مختلفة بحالتي تغطية ومكشوفة . التيار المتسرب لهذة الاشكال تم قياسها برفع فولتية العازل الى (5.25, 6.35, 7.57 كيلو فولت) لحالتي التغطية والمكشوفة . تم حساب التفريغ الجزئي للشحنة بحالتي التغطية والمكشوفة باشكال العوازل اعلاه باستخدام طريقة الكشوفات المباشرة والمتوازنة . تمتلك عوازل Pin Post تيار متسرب ومجال كهربائي اعلى من كلا النوعين الاخرين . توضح قياسات التيار المتسرب ل( Clamp Top, Tie Top ) نفس القيم تقريبا . الموصل المكشوف ينتج دائما تفريغ جزئي اكبر بالمقارنة مع الموصل المغطى.

## Introduction

Electrical Insulation Materials are materials in which electrostatic field can be persist for along time. The materials offer very high resistance to the passage of electric current under the action of the applied direct current – voltage [1].

Low voltage insulator materials operated at normal voltage up to 500V and subdivided into two group line insulations. The low voltage insulator is used for telegraph and telephone line and external low voltage network. High voltage insulator materials are very varied and operated at voltage above

500V depending on the break down voltage and it divided according to their purpose into line, machine, and power plant. High voltage insulator must be satisfy higher demands than the low voltage and must be able with stand sadden cooling with a differentials of 150C$^{o}$ [2]. High voltage insulator used for high voltage transmission line and equipments. The work presents the results of research into the performance of composite materials as good insulator for high voltage, The choice of composite dielectric for high voltage insulation is made base on the properties of the materials. These properties affect the performance of the composite materials in several key area: charging current, discharging current, field disruption, break down voltage, power consumption, thermal stability, interaction with other materials [3].One of the comparisons between the different arrangements is the amount of leakage current flowing across the outside of the insulators. The insulators are designed to maximize this distance by having folds along the outside, which increase the impedance thus reducing the magnitude of the current. The leakage current should be reduced to as little as possible, as it is a loss to the system. If this loss can be reduced, the power system becomes more efficient and therefore less costly to the distributor. The leakage current should be smaller as the polyethylene covering offers extra insulation. The bare conductor and the stripped conductor should have approximately the same leakage current, as both of these conductors are connected directly to the insulator [4] .

## Experimental Procedure

The test procedure to obtain acceptable values was designed and straight comparisons between conductor and insulator combinations are performed as shown in Fig (1).

## Leakage Current

The leakage current was measured by raising the insulator to 5.25kV, 6.35kV and 7.57kV. These values were chosen arbitrarily to give an indication of how leakage current varies with voltage. Then the current was measured through an ammeter that was connected from the base of the pin to the Pin Post insulator and from the base of the Trident structure to the Clamp and Tie Top to earth.

## Partial Discharges

The next test is to determine the onset of partial discharges in one phase of the system. This is important, because if partial discharges begin at a voltage above the rated voltage, they are less likely to occur when implemented and are therefore less likely to damage the covering and the conductor. There is still the possibility of partial discharges occurring though, as the inception voltage is higher than the retaining voltage. Therefore, if the inception voltage is only slightly higher than the rated voltage, and the retaining voltage is below the rated voltage, a small voltage swell could start the partial discharges and they would continue to occur as long as the retaining voltage is exceeded. Only one phase of the system could be tested at a time, as the transformer use only a single phase rated at 240V/80kV.

The maximum discharges on a conductor at 10kV (150% rated voltage) and at 13kV (200% rated voltage) should be 5pC and 50pC respectively. If these values are exceeded, the conductor is more likely to be susceptible to damage, and over a prolonged period of time, to snapping. It was also decided to measure the discharges at rated voltage of (6.35kV).Partial discharges can be detected with the Partial Discharge Display in a number of different methods that require different circuits. The most common methods are straight detection and balanced detection.

Balanced detection circuit Fig 2 uses impedances that can be varied until the circuit is balanced. The circuit is balanced once the variable impedances cancel out the background noise of the equipment, leaving only the discharges from the test sample. This is an ideal situation, though the circuit is much more difficult to set up and was thus not attempted due to constraints imposed by the equipment available [5].

This left the option of straight detection. Straight detection circuit Fig 3 detects all noise in the circuit including the test sample, transformer and connections. This makes it imperative to make all of the connections firm, and all corners and sharp edges covered by a hollow metal sphere. Any edges or corners unable to be protected by a sphere must be covered instead with Blue-Tack or plasticize. The edges and corners are where the electric field is strongest, by covering them, the chances of stray noise in the circuit are reduced and it is much easier to obtain a clean signal.

The negative peak Fig 4 was found by placing a sharp point on the ground near the conductor. This produces negative corona that appears on the display showing where the negative peak isOnce the negative peak is found, it is possible to determine where the discharges are originating [5].

Measurements were taken at these voltages as the voltage ascended and then as they descended. The 13kV reading for the descent was first raised to 14kV before being measured.

The reason for taking measurements as the voltage both increased and decreased was because partial discharges remain at lower voltages levels than at what they are originally induced. By taking measurements in both directions it was hoped to prove this phenomenon.

By putting a step voltage of 100V into the detector, the magnitude of the partial discharge could be measured by comparing the sizes of their respective lines on the partial discharge detector.

Then by adjusting the attenuation switches on the detector, it was possible to decrease the magnitude of the step input until it was the same size as that of the discharge. From the value of the attenuation switches it was then possible to calculate the size of the discharge from the following formula [6].

$$q_x = E_q C_q (1 + C_x/C_b) \qquad (1)$$

$C_x/C_b$ is small as the blocking capacitor $C_b >> C_x$

$q_x = E_q C_q$

$E_q$ = 100V x 10-dB/20 (where dB is the attenuation of the 100V input)

$C_q$ = 2pF

$$q_x = 200 \text{ x } 10\text{-dB/20pC} \qquad (2)$$

$q_x$: partial discharge

$E_q$: voltage descending

$C_q$: partial discharge capacitor

$C_b$: blocking capacitor

## Electric Field

The final test was to measure the Electro Magnetic Field. Again, there were no Australian Standards to follow for the measurement of the electric field. This test involved placing a Gauss-Maus in various positions and raising the line to rated voltage as shown in Fig 5. The detector was placed perpendicular to the way the current was flowing. Though there was no load, this method still enabled a comparison between each of the insulator and conductor configurations [7]. A measurement was taken with no voltage on the line and then at rated voltage. The difference between these two readings was the amount of electric field produced by the conductor. This is a necessary step as there is ambient electric field from such things as nearby equipment and even fluorescent lights [8].

## Results and Discussion

### *Leakage current*

All of the insulators display a tendency for the leakage current to increase proportionally with the voltage across the insulator as shown in Fig 5. The Pin Post insulators have a leakage current between 55% and 65% larger than both the Clamp and tie Top insulators. This is due to the actual physical design of the different insulators. The Pin Post is much smaller and has only two flanges, compared to the others four. These flanges increase the distance that the leakage current must travel and therefore increase the impedance. The Clamp Top and the Tie Top insulators have almost exactly the same leakage current measurements, usually within 5% of each other. This is because their flange design is almost identical. The clamp is made of metal and therefore conducts well, and this is attached to almost exactly where the conductor on the Tie Top is positioned, making the path for the current almost identical. Stripping the conductor on the Clamp Top insulator at 6.35kV results in a 9.1% increase in the leakage current, whereas stripping the conductor on the Tie Top makes only a 0.1% increase. Even though, it is only a slight increase over the entire 11kV network these, few micro-amps lead to greater losses, and will therefore be less efficient, providing yet another reason to avoid stripping when possible.

### *Electric Field Measurements*

The Pin Post insulator has slightly higher electric field values than the other insulators. This is due to the large pin inserted in the base of the insulator and matches exactly with the results obtained through Quick Field program.

Figure (7) to Figure (9) show that stripping the polymer covering near where the insulator attached almost always reduces the surrounding electric field. This is as expected as the voltage now is directly applied to the insulator. This insulator has a slightly larger dielectric constant and is a larger size than the polyethylene covering and therefore the voltage will decrease at a slower rate, resulting in a smaller electric field.

### *Partial Discharge*

Once a partial discharge is initiated, it will remain present as long as its voltage remains above the extinction level. This explains why larger discharges are observed when the voltage was descending. The original discharges are presented as well as those initiated at higher voltage levels that were yet to be extinguished. If the inception voltage is slightly greater than the rated voltage of a line and the extinction voltage for the discharges formed is below the rated voltage a problem may occur. The line may not have partial discharges occurring in it or none of significant size, but under swell conditions, the inception level may be surpassed, causing discharges to begin occurring. When the line returns to rated voltage, the discharges will remain and may cause damage over time if large enough and if they remain for long enough. This can be seen in Figure 10 to Figure 16, where the descending discharges are generally 25% larger, and in some cases even up to 33%.

Figure 17 to Figure 22 show that the stripped conductor always produces larger partial discharges than the covered conductor. Considering that the purpose of stripping covered conductor is to reduce the number and size of partial discharges, it would seem that this method does not work. When the stripping was performed, a few scratches were made by accident on the aluminum conductor. This could be the source of the discharges, and if so, these would not be of a detrimental nature to the system as they are not touching the covering and therefore not going to damage it. With no conductor connected, partial discharges were detected. This was due to background discharges in the equipment. This can be removed with the use of a balanced detection circuit, though due to the lack of equipment, this was not an option. The levels of discharge detected at 10kV were approximately 6.4pC. AS mentioned earlier, that the maximum allowable discharge at this voltage level is 5pC. As the background noise is already above this level it is impossible to verify the exact magnitude of the discharges in a conductor if they are below this background level. If the magnitude is significantly larger than this 6.4pC level, it is safe to say that these larger discharges are entirely within the conductor. This is due to the unlikelihood of an already existing discharge in the test equipment being superimposed by a new discharge in the conductor.

At 10kV, the entirety of the Clamp Top and Tie Top configurations has discharges in the range of 5pC to 7pC. This is in the same range as the background noise, and due to the inherent difficulties in measuring the discharge; it seems that the line is not contributing to the size of the discharges. The only way to validate this assumption is to use balanced detection, which was not available, to remove the background noise.

The discharges also had to be measured at 13kV. This test was much more conclusive, as none of the samples displayed discharges greater than 11.25pC and the maximum allowable discharge was 50pC. Therefore all of the configurations passed the Australian Standard level.

The Pin Post insulators provided some difficulties when being tested for partial discharges. The readings were fairly clear at 6.35kV, but as the voltage approached 10kV, a number of sizeable coronal discharges began occurring regularly. These discharges made it particularly difficult to make accurate measurements and once the voltage was increased to 13kV, it was impossible to obtain accurate readings due to the amount of corona, except for the covered conductor which seemed to have less noise. During the testing, a spark gap was placed across two of the terminals on the discharge detector. This was to reduce the chance of damage to the device as the flashover voltage of 75V corresponded to the maximum allowable current in the detector. On a few occasions this spark gap flashed over and produced a great deal of electrical noise. This noise generally occurred at around 12kV on the secondary side. This flashover voltage was not always the same as when the partial discharge measurements were taken, no flashover was heard or seen, even up to 14kV. It is possible that the spark gap is on the verge of flashing over and is producing these great amounts of noise. The spark gap could be removed, though this would leave the detector more susceptible to damage.

## Conclusions

The Tie Top and the Clamp Top are very similar in all respects, while the Pin Post has a higher leakage current. The spark gap on the discharge detector is believed to be the cause of the noise.

The leakage current increased as the conductor was in direct contact with the insulator.

The surrounding electric field decreased due to the removal of a low dielectric material that now allows the voltage to decrease at a reduced rate and thus a reduced electric field.
The amount and size of the partial discharges increases compared to covered insulator.
The leakage current for the stripped insulator is greater than that of the covered insulator, as is the amount of partial discharges.
This work shows that the practice of stripping covered insulator is not advised as it is not only harmful to the conductor itself, but also a costly practice.

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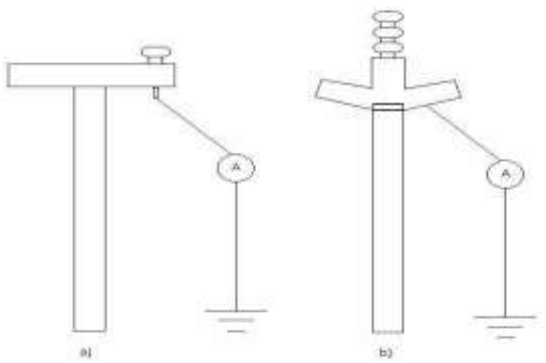


**Figure (1) Leakage Current Circuit for**
**a) Pin Post Insulator and**
**b) Clamp and Tie Top Insulator.**

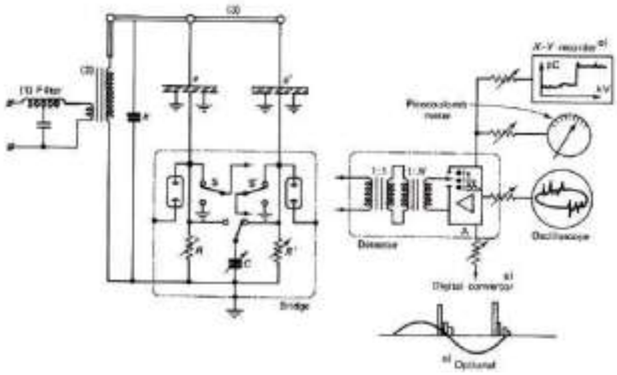


**Figure (2) Balanced detection circuits.**

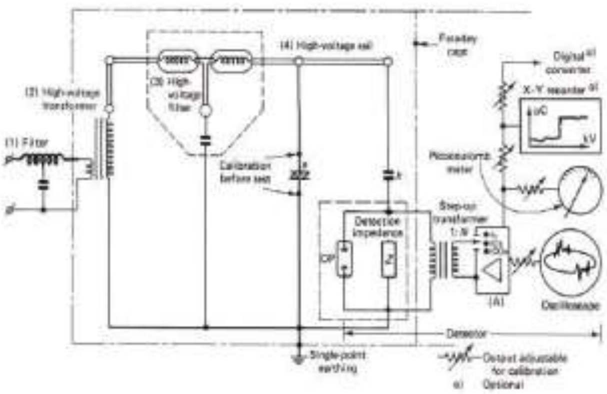



Figure (3) Straight detection circuits.

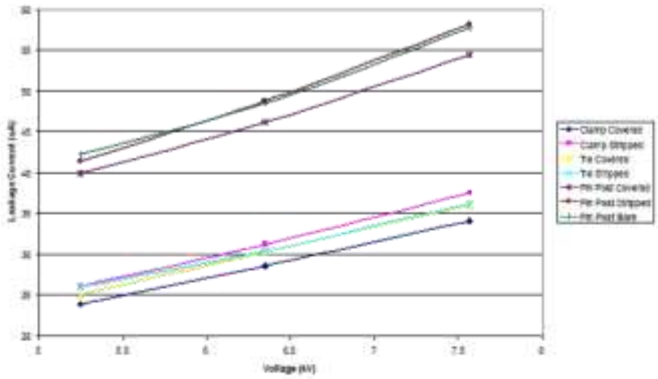


Figure (6) Leakage current vs Voltage.

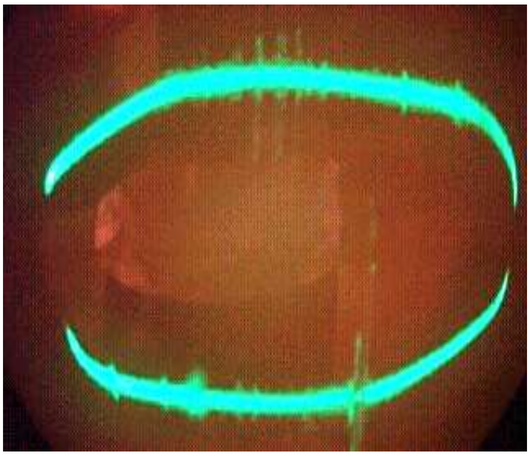


Figure (4) Oscilloscope output with negative peak corona at the top of the ellipse and the 100V input at the bottom right corner.

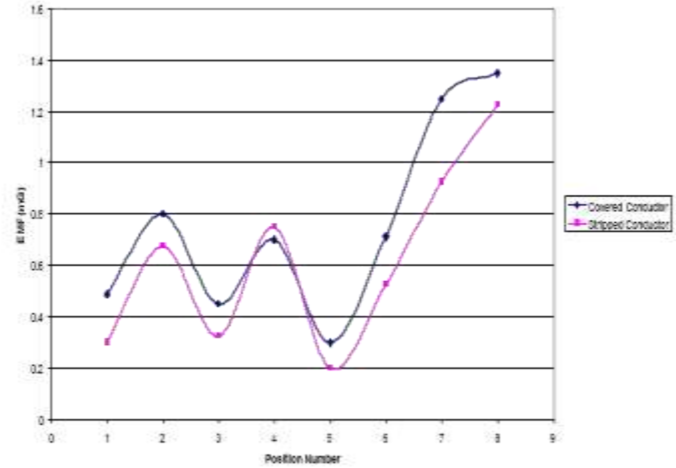



Figure (7) Average Electric Magnetic Field (EMF) Measurements for the Clamp Top insulator.

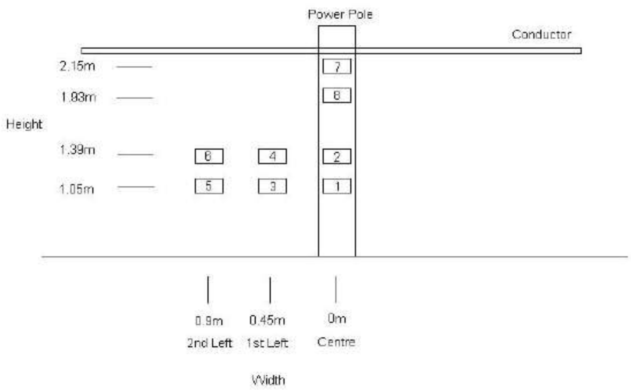



Figure (5) The Eight Positions used for Measuring the Electric Field.

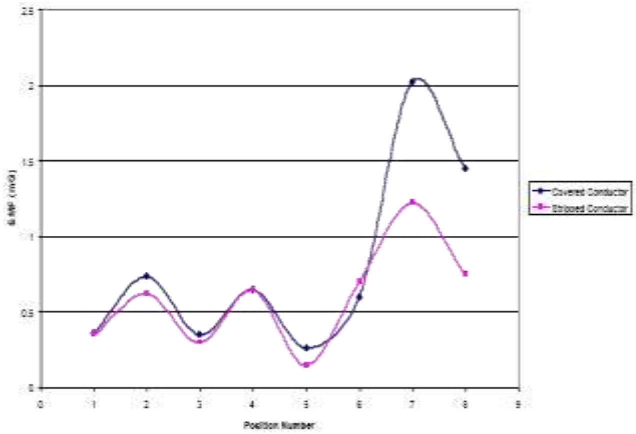



Figure (8) Average EMF Measurements for the Side Tie Insulator.

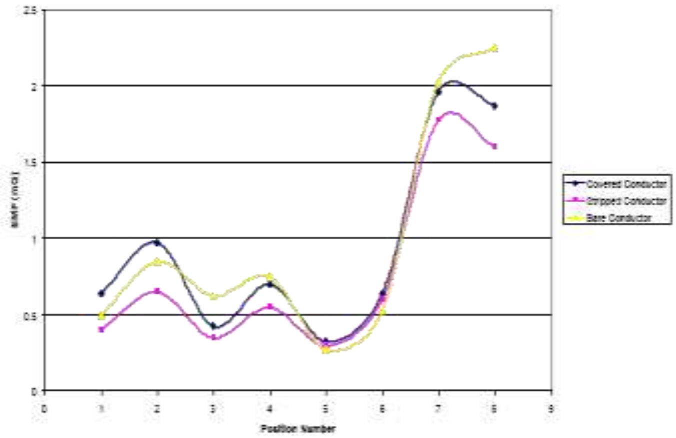



**Figure (9) Average EMF Measurements for the Pin Post Insulator.**

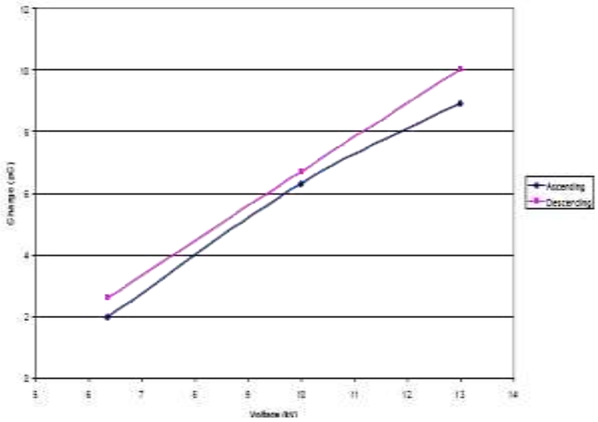



**Figure (12) Partial Discharge Side Tie - Covered insulator.**

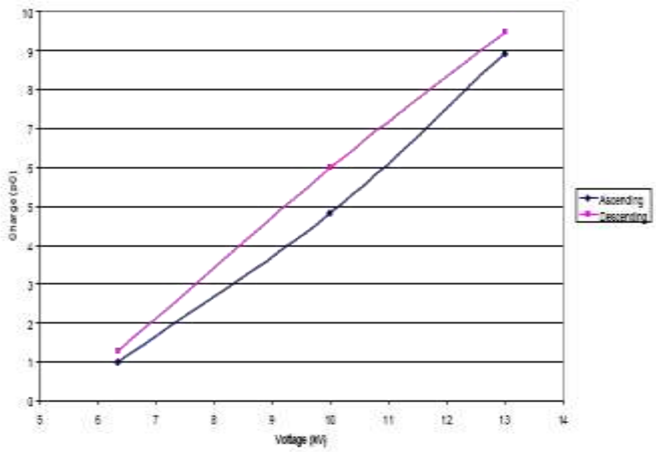



**Figure (10) Partial Discharge Clamp Top.**

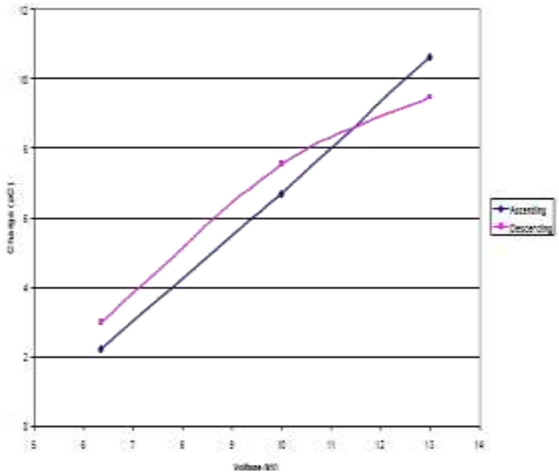



**Figure (13) Partial Discharge Side Tie - Stripped insulator.**

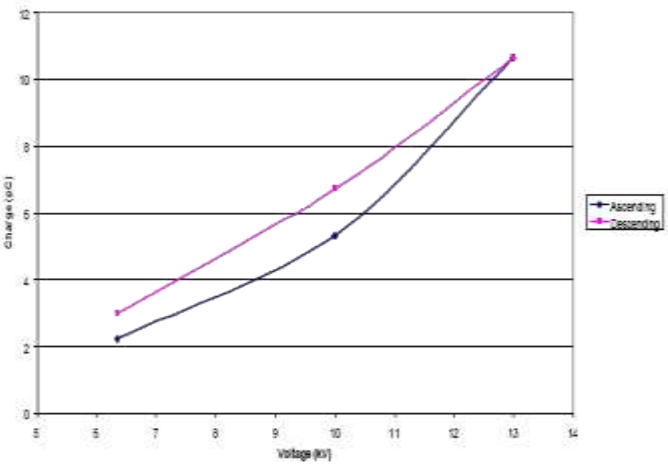



**Figure (11) Partial Discharge Clamp Top - Stripped Insulator.**

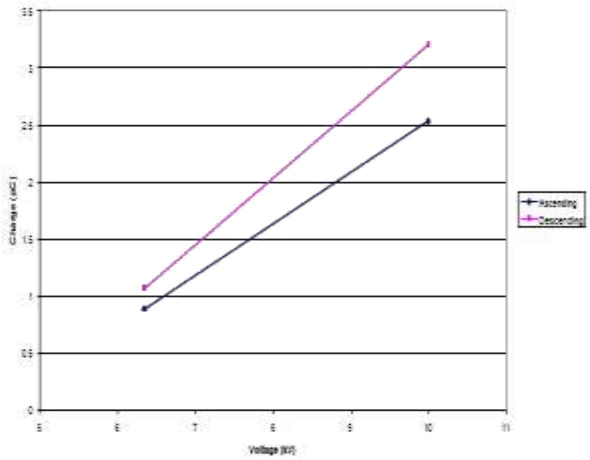



**Figure (14) Partial Discharge Pin Post - Stripped insulator.**

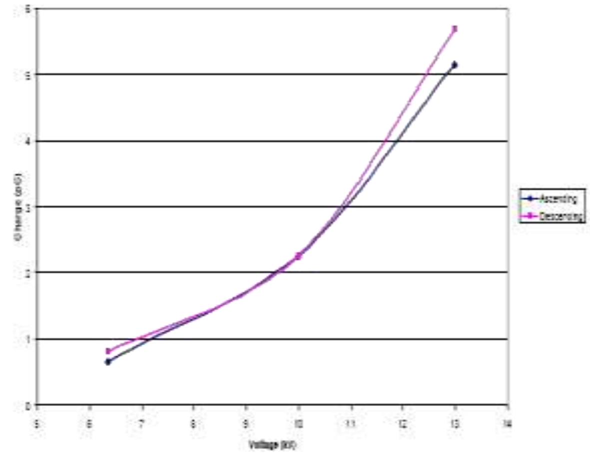



**Figure (15) Partial Discharge Pin Post - Covered insulator.**

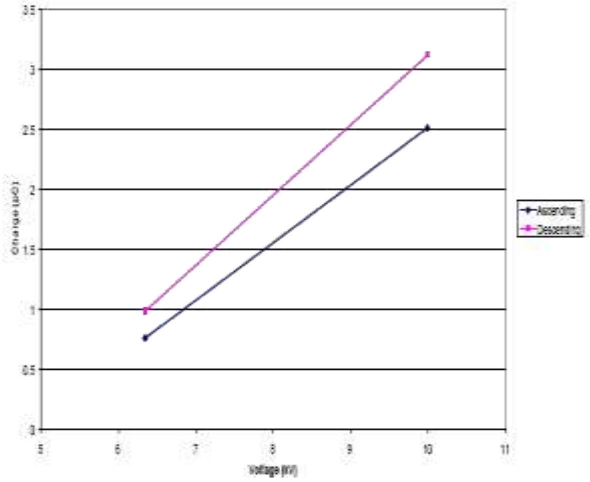



**Figure (16) Partial Discharge Pin Post .**

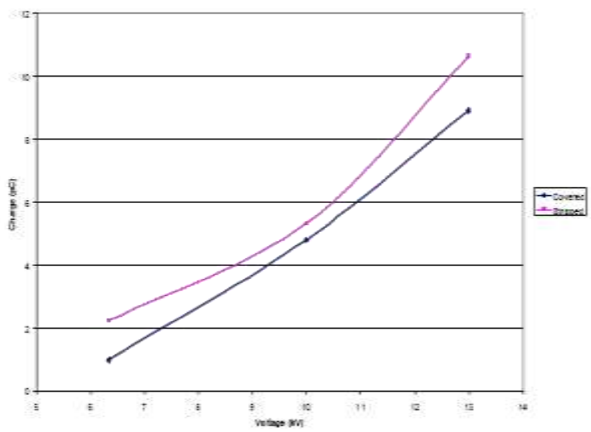



**Figure (17) Partial Discharge Clamp Top Ascending - Covered vs Stripped**

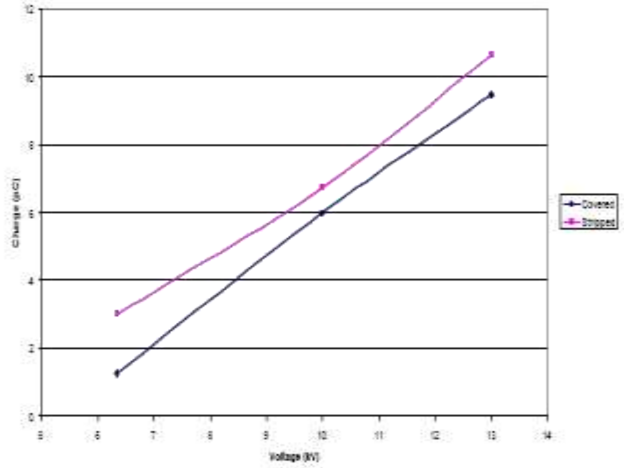
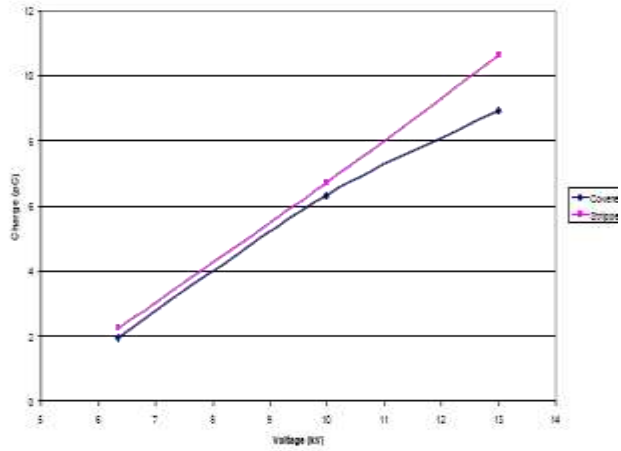
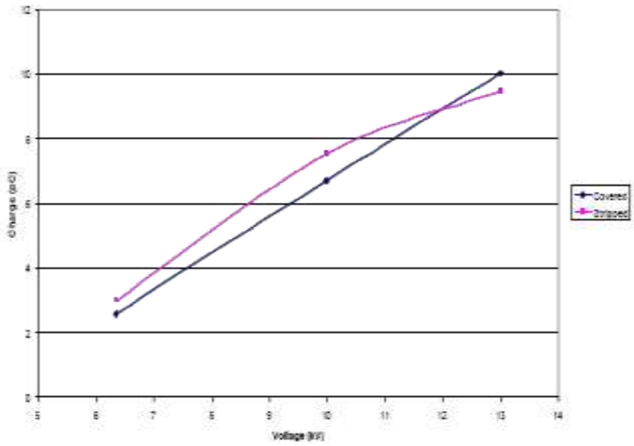



**Figure (18) Partial Discharge Clamp Top Descending - Covered vs Stripped**



**Figure(19) Partial Discharge Side Tie Ascending - Covered vs Stripped**




**Figure(20) Partial Discharge Side Tie Descending - Covered vs Stripped**

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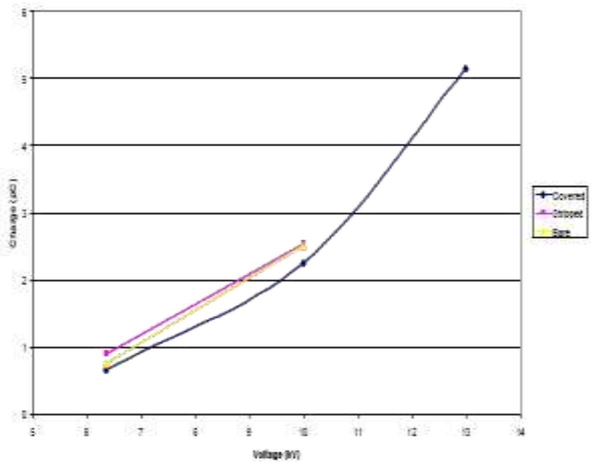
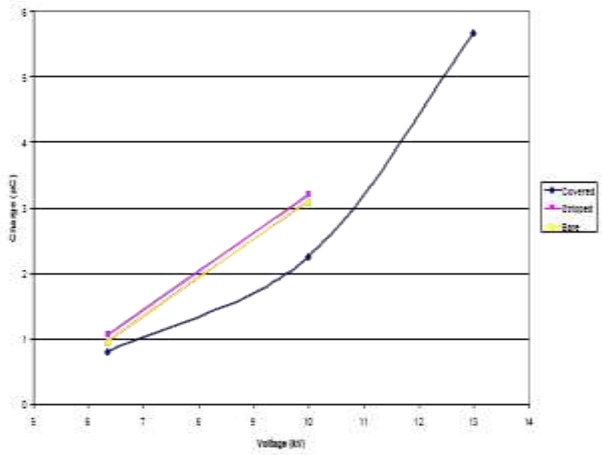



**Figure(21) Partial Discharge Pin Post Ascending - Covered vs Stripped**




**Figure(22) Partial Discharge Pin Post Descending - Covered vs Stripped**