

# The Investigation of Replacing Ceramic Bushings with Silicon Bushings in the Distribution Transformers

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Received 28 July 2014; revised 25 August 2014; accepted 13 September 2014

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## Abstract

In recent years, the deficiencies of ceramic insulators along with their high maintenance costs have resulted in the replacement of ceramic insulators with silicon type in the pollution area. This idea has been employed for more than two decades in the polluted areas. Humidity of the weather in the south of Iran and the presence of pollutants in the air have made special conditions for construction and maintenance of some equipment including transformer bushings. Usual ceramic bushings, due to their ability in absorbing pollution and the rapid reduction of creepage distance (in a limited time period), have reduced transformer disconnection severely as a result of earth fault. Additionally, they are costly to be washed regularly. Therefore, using intelligent materials in designing bushing can increase the reliability of network and consequently reduction of costs. In this regard, this paper investigates the use of silicon bushings in the distribution systems and proposes operational ideas for the optimal operation of these devices in the polluted areas. The sample bushing was evaluated based on the IEC60137 standard test.

## Keywords

Ceramic Bushing, Silicon Bushing, Distribution Transformer, Insulator Pollution

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## 1. Introduction

Bushings are a critical component in electricity transportation. They are used in substation buildings, transfor-

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mers, locomotives, and switchgear. The main purpose of a bushing is to transfer load currents in and out of metal enclosures at system voltages. The insulation system breaks down, and causes bushing failure results in catastrophic event such as tank rupture, violent explosion of the bushing and fire. Clearly, the risk and likelihood of collateral and personnel damage and reduction of reliability system are an imported major concern in such an eventuality. The different potential surfaces on the two sides of this equipment make specific features electrical-ly for this equipment. Some of these features are: insulation level, creepage distance, withstanding the impulse wave, etc. One of the electrical signification features of this equipment is their insulation level. More than the electrical conditions, determination of the insulation level suitable for an isolator depends on environmental conditions. For example, in a wet, humid weather, it is necessary to increase the insulation level or creep away. If sultry addition, other pollutants in the air should be needed to further increase the level of insulation creepage distance. According to DIN5009 standard, the beach of the Persian Gulf is classified in the areas with high and severe pollution. High humidity, salty soil, long-term droughts and high degree of UV radiation have put the isolation of the power system components and materials in the condition of severe pollution [1]. Accordingly, in the last two decades, the silicon insulators have replaced the ceramic insulators suitably. These silicon insulators are made of fiberglass core with silicon cover. The most significant characteristics of the silicon insulator are high reliability in polluted areas, low weight and high resistance in front of deterioration [2] [3]. In the studies done on the insulators located in the tropical areas using the monitoring of breakdown current and measurement of ESDD-NSDD, useful criteria were found for choosing the appropriate distribution insulators in the beach areas. The profile of the insulator has a vital role to determine its breakdown current value and the amount of pollution on the surface of the insulator. The especial hydrophobicity quality of silicon insulators is the main reason of their successful performance at beach areas. This event results in small variation of the breakdown current (because of high humidity) during the day at these areas [4]-[8]. The amount of breakdown current of insulators in the polluted areas is as the result of surface pollution of the insulators, and it is also related with the creepage distance of these devices [9]-[11]. Some of the main deficiencies of ceramic insulators are internal punch and low mechanical resistance. Any carelessness of the operator can damage the ceramic disc of the insulators and thus reduces the reliability of the power system [12]-[16]. Traditionally, the high-power insulators were constructed of ceramic materials. But, after several years and visiting the deficiencies of the ceramic insulators they were replaced with silicon insulators.

## 2. Comparison of Silicon Insulators with Ceramic Insulators

The weight of ceramic insulator is about 1.5 times of silicon insulator that will result in more weight of the whole power system. As the result of electric resistance, high stability and proper cost, the ceramic insulations are popular at low frequency applications. However, they show poor performance in front of electric shock and vibration and therefore will create much limitation in designing (insulator cannot be made in any required shape). On the opposite side, the silicon insulators as the result of high flexibility can be made in any shape. In the ceramic coverage, any external strike can break the insulator but this event does not happen in silicon type. Also, as the result of higher weight and fragility, the condition of installing the ceramic insulator is much harder than the silicon insulator. The ceramic insulator requires more effort to avoid damaging and therefore higher operational costs should be paid. But, the silicon insulator as the result of high flexibility can be bend easily and its bending tension does not make any problem. Therefore, the installation of the silicon insulator is easier and no further cost for the maintenance is required. In the ceramic insulator, when the electric force to the insulator is increased, the insulation breakdown can happen. Also, mechanic tensions can break the ceramic insulator. The high weight of the ceramic insulator is a problem that is more sensible at higher voltage levels. The low resistance of the ceramic insulation causes the punctuation problem when this problem does not exist in the silicon insulators. According to the studies on the silicon insulator for 9 years, this equipment could pass all the electric and mechanic tests successfully. It should be regarded that the surface devastation rate of the silicon insulator depends on the material of the silicon completely. Regarding the thermal deficiencies of ceramic insulations, there are small cracks in the surface of the insulator that would increase the pollution level and increasing the surface current. In the long term, these issues will increase the depth of the cracks and thus the possibility of electric breakdown increases. About the corrosion deficiencies, any mechanical problem caused by mechanical strike or thermal problem caused by partial discharge can increase the depth of the cracks in the ceramic insulator and thus current leakage happens. For chemical corrosion in the polluted areas, the surface of the insulator should be washed periodically to avoid surface stoke and making problem for the whole network. The silicon

insulator as the result of especial characteristics can avoid pollution from its surface when the ceramic surface cannot. The ceramic insulator does not have hydrophobicity aspect and wet surface causes flashover and increasing the leakage current in it. But, the silicon rubber has the intrinsic hydrophobicity quality and thus will recover itself.

### 3. Transformer Bushing

In order to make sufficient distance between the feeder connection point and the surface of the transformer tank as well as to create connection between the power source and the consumers, low voltage and high voltage bushings are employed in the transformers. In fact, the transformer bushings are fixed insulators that the input and output currents are fed to them. There is a conductor inside of these insulators that leads current toward the transformer coils. These currents should be kept far from the surface of the transformer tank that this duty is done with the bushing.

According to the voltage and current magnitude, bushings are made at different sizes with different number of sheds that their length is determined according to their voltage level. It should be considered that there no break, crack or unsmooth surface exist in the ceramic sheds. Since the voltage magnitude is high at the top of the bushing, any crack in the ceramic of the busing can let humidity inside or let gas and oil go out of the bushing tank. Of course, electric breakdown can break and destroy the transformer bushing.

According to IEC60815, the creepage distance of insulators for areas with different pollution degree is different. The design of the sheds is done based on the IEC60815 and the especial characteristics and parameters required. Based on the IEC1109, the structure of the cross-linked silicon insulators does not contain any filler or additional material. The insulator rod is made of fiberglass (epoxy impregnated with fiber glass) and special ECR (electric usage and resistive in front of acid) and is bought from the depending manufacturers based on IEC1109. In the method of measuring leakage current and air pollution, silicon-rubber insulators are assessed under the operational condition with leakage current technique.

The peak magnitude of the leakage current is a criterion that determines the possibility of surface breakdown. In the Verma equation, the peak magnitude of the leakage current is evaluated in the last cycle before the surface breakdown as follows:

$$I_{\max} = \left( \frac{S_{CD}}{15.32} \right)^2 \quad (1)$$

where  $S_{CD}$  is the specials creepage distance and is calculated as below:

$$S_{CD} = \frac{L}{U_{\max}} \quad (2)$$

where  $L$  is the creepage distance of the insulator per mm and  $U_{\max}$  is the maximum effective phase-to-phase voltage of the system per kV.

In fact, by the use of the peak values of the leakage current can assess the relative performance of the insulator and thus determine the possibility of surface breakdown. The strikes of the leakage currents occur before the last electric breakdown. By the use of the test of calculating the number of strokes can determine the condition of insulator pollution and thus a cautious about the breakdown status.

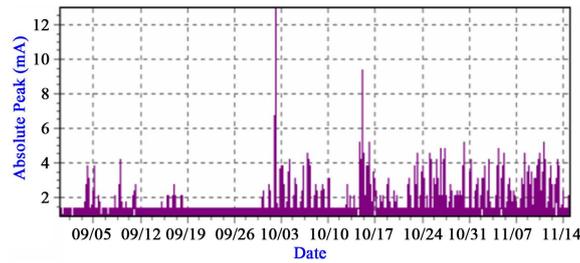
In [5], the sample insulators are silicon type with standard sheds. Here the results of pollution measurement based on ESDD and NSDD methods shows that the amount of pollution on the ceramic insulator is high. But the silicon insulator has attracted less pollution that is as the result of aerodynamic and wide structure of the sheds and thus providing better air circulation among them.

### 4. Practical Results of Installation of Bushings in the South of Iran

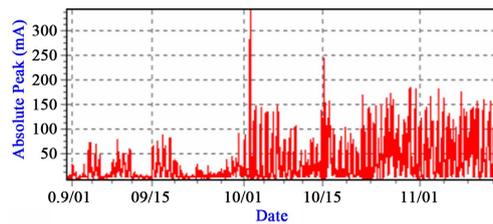
From the view of leakage current, silicon insulator has more appropriate performance, high level of peak current less than 12 mA, proper creepage distance and better surface resistance. The direct results of these characteristics of silicon insulation are less pollution, less conductive surface and equivalent distribution of pollution. For the ceramic insulators, the current level is about 350 mA. In ceramic insulators, it is assumed that the surface resistance consists of two components: one part is associated with the insulator surface with less creepage distance and less surface resistance; the other part is associated with the insulator surface with higher creepage distance

and higher surface resistance. In the situation that operational test is done in a polluted area, the pollutions are gathered under the insulator and thus the resistance is decreased in humid condition. **Figure 1** and **Figure 2** show the diagrams of the maximum peak of the leakage current for both silicon and ceramic insulators.

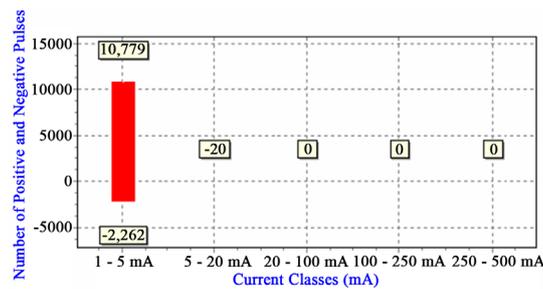
By the analysis of impulse test, the degree of pollution can be determined that is a criterion for the electric breakdown. In the below diagrams, the number of strokes of leakage current in the range of current is plotted. In **Figure 3** and **Figure 4**, the number of strokes of leakage current for both silicon and ceramic samples are shown.



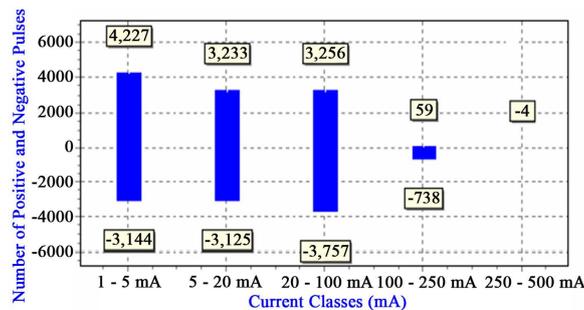
**Figure 1.** Diagram of the maximum peak of the leakage current for silicon insulator.



**Figure 2.** Diagram of the maximum peak of the leakage current for ceramic insulator.



**Figure 3.** Diagram of number of strokes of leakage current in silicon insulator.



**Figure 4.** Diagram of number of strokes of leakage current in ceramic insulator.

Once the insulator is put in the polluted area, the error of pollution affects the distribution systems locally. This event will result in decreasing the creepage distance and increasing the leakage current of the insulator that will reduce the reliability of the power systems. In order to deal with this issue, the insulators should be washed periodically.

From the aggregated electric charge of the above diagram, it is clear that the maximum electric charge is on the disc insulator. **Figure 5** shows the aggregated electric charge in the test insulators.

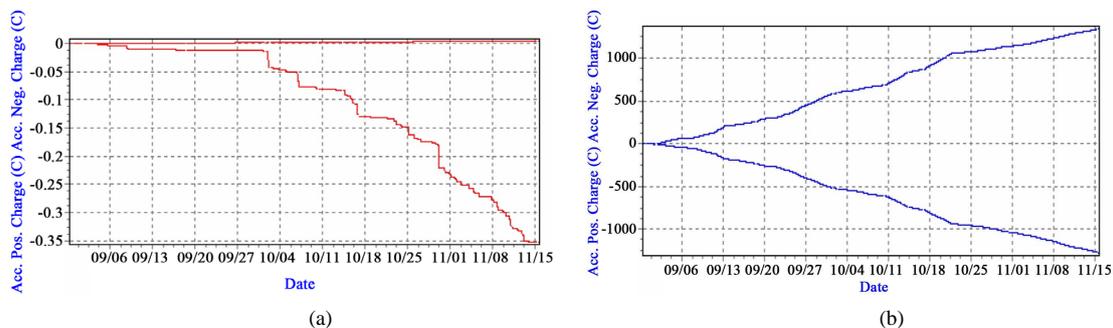
Based on the above points, by replacing the ceramic insulators with silicon insulators in distribution transformers, lower weight, higher mechanical stability and superior insulating would be achieved. Also, the flashover effect on the silicon bushing is 10 times more than the ceramic bushing which of course the pollution severity can create the flashover occurrence at lower voltages. Consequently, at areas with sever pollution, longer insulators with higher creepage distance are considered. The idea for construction of silicon bushings was created after using silicon insulators in the beach and meeting their undeniable valuable benefits. While replacing the ceramic insulators with silicon insulators has reduced the maintenance cost of the system effectively (as the result of exchanging the punched insulators and washing the ceramic insulators) and the system is more stable than before, but yet the existence of ceramic bushings on the available transformers is a source of instability in the electric air lines. Therefore, the necessity of replacement of these bushings made this decision for us to analyze both types of ceramic and silicon insulators to reach a model which has the maximum efficiency and the least deficiency.

The issues that were considered for design and construction of these devices are:

- Mechanical stability—stable in front of breaking, flashover, electric and mechanic tensions;
- Appropriate creepage distance for areas with severe pollution;
- Appropriate flash over distance;
- Preserving the hydrophobicity aspect;
- Easy replacement of the old ceramic bushings with new bushings (possibly in the place and on the top of the electric pole);
- Less weight;
- No need to punctuation of the bushing when overvoltage occurs in network.

According to the above items, our decision was to make the hybrid silicon bushing by the cooperation with the Niroo Tajhiz Barghe Parse Company as a powerful and professional company product of silicon insulators and bushing. Therefore, the first design was constructed using fiberglass core with the silicon covering. The constructed samples after passing the routine tests of IEC in the laboratory of Niroo Tajhiz Barghe Parse Company were send to the Hormozgan Electrical Distribution Co. for installation in the network. The bushing samples installed on a 315 kVA transformer in the Bandar-Abbas Beach Bolv. After about one year, there was no stroke from the creepage current, flashover or surface deterioration. **Figure 6** show the bushing samples installed in the network of Hormozgan Electrical Distribution Co.

While there was no mechanical or electrical problem in the constructed sample bushings, but it was required to transfer the transformer to the network for installing the new bushings and the necessary connections. This problem was a discouraged the operator for replacing the traditional bushings with new silicon bushings. In order to overcome this issue, the entire design of the bushing was amended. Now, the purpose was to make use of silicon bushings by preserving the installation condition of the ceramic bushings. After consulting with the Iran Insulator Company, the idea of hybrid bushings by the use of ceramic core was born. This idea is yet in its first



**Figure 5.** Diagram of aggregated electric charge in the test insulators.



**Figure 6.** Sample bushing installed in the network.

steps of design and construction. We hope that by construction of these hybrid bushings can overcome the deficiencies of the ceramic bushings from different aspects including electrical and mechanical views as well as to provide fast exchange of the bushings in place.

## 5. Conclusion

The available ceramic bushings in the distribution systems with the creepage distance of 450 mm have the highest leakage current. This issue can result in instability of the network during night hours at polluted areas. In order to solve this problem, this paper suggested a new hybrid design for bushings. The proposed hybrid bushing has a ceramic core with silicon discs to make use of the best characteristics of both ceramic and silicon simultaneously.

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