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Effect of the Combined Pollution of Brick Industry and Sandstorms on the Performance of High Voltage Insulators and Flashover Phenomenon

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ABSTRACT

Recent repeated flashovers and power outage incidents in an (400/132) kV substation, located in the Ad Diwaniyah Province, have called for extensive investigations to evaluate the effect of subsequent deposition of sandstorm and free carbon particles (soot) on the performance of HV insulators and probable flashover occurrences. In the Ad Diwaniyah Province, the insulators of the transmission lines and substations are normally subjected to sandstorms (once or twice per year). Moreover, rapid brick industry expansion (10 brick factories constructed and operated over the last ten years) within the area of the Shafeyea, where, the (400/132) kV substation is located, has also led to a noticeable industrial pollution. Porcelain and polymeric insulators were exposed to sand and soot polluted environments and the effect of pollution severity on the flashover characteristics was investigated. Flashover voltages were measured under various simulated polluted environments for both porcelain and polymeric insulators. Obtained results show that the deposition rate of soot particles is highly increased when both porcelain and polymeric insulators are already polluted with sand particles regardless of whether the sand particles are charged or not. However, moistening was found very critical to pollutant layer build-up and consequently increases the severity of pollution.

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تأثير التلوث المشترك لدخان معامل الطابوق والعواصف الترابية على اداء عوازل الضغط العالي وظاهرة الومضة العابرة

الخلاصة

استدعت حوادث انقطاع الكهرباء المتكررة في محطة التحويل الثانوية (132/400 كي في) الواقعة في محافظة الديوانية، الى اجراء الدراسة المستفيضة لتقييم تأثير الترسب المتعاقب لذرات غبار العواصف الترابية ودقائق الكاربون المنبعثة من معامل الطابوق على اداء عوازل الضغط العالي واحتمالية حدوث الومضة العابرة. تتعرض عوازل الضغط العالي في المحطات الثانوية وخطوط النقل في محافظة الديوانية الى العواصف الترابية مرة او مرتين في السنة. وكذلك حدث توسع في صناعة الطابوق في منطقة الشافعية المجاورة للمحطة الثانوية (132/400 كي في) نتيجة زيادة عدد معامل الطابوق الى 10 معامل خلال السنوات العشرة الماضية مما ادى الى التلوث الصناعي في منطقة الدراسة. تم تعرض عوازل البورسلاين والعوازل البوليمرية الى بيئة متعاقبة للغبار ودقائق الكاربون وتم دراسة تاثير شدة التلوث المتعاقب على خصائص العوازل والومضة العابرة. بينت النتائج المستحصلة ان معدل ترسب دقائق الكاربون تزداد باضطراد على عوازل البورسلاين والعوازل البوليمرية عندما تتعرض تلك العوازل الى العواصف الرملية بغض النظر عما اذا كانت جسيمات الغبار تحمل شحنة ام لا. وعلى اية حال وجد ان تعرض تلك العوازل الملوثة بالغبار ودقائق الكاربون الى الرطوبة يزيد بشكل كبير بناء طبقة الملوث وشدة التلوث وبالتالي تدهور خصائص العوازل.

1. INTRODUCTION

Outdoor insulators are widely used in high voltage power transmission systems. They are usually exposed to different pollutants such as; airborne salt near coastal areas, desert sands, and industrial plumes and particles. The pollutants deposit and accumulate on the surfaces of insulators at different rates. The rate of deposition primarily depends on the meteorological conditions and the

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roughness and geometry of insulators. Insulator polluted surface is usually bridged under wet conditions when the thickness of the pollutant layer exceeds a threshold value, and a pollution flashover takes place. However, hydrophobic insulator's surfaces retain wetting agents (normally water) as droplets and suppress the formation of pollutant conductive layer, and consequently bridging is considerably reduced. Obenaus [1], considered the pioneer of the pollution flashover. Most of the present research adopts Obenaus model to simulate and investigate the effect of pollution on flashover phenomena. Hamza [2], studied the effect of the desert sandstorms on the reliability of the HV transmission lines, and concluded that only charged sand particles reduce flashover voltages. However, long-time exposure of sand particles to electric fields results in charging the sand particles deposited on the surfaces of insulators. Warid [3], concluded that sandstorms reduce the reliability of the HV transmission system in the southern network of Iraq, due to a significant reduction of flashover voltage of insulators when subjected to sandstorm conditions. Sand particles are classified as Non Soluble pollution source, and usually measured using the Non Soluble Deposit Density (NSDD) technique with unit of measurement (mg/cm^2). BadachiI [4] concluded that 89% of power outages were due to insulator's pollution flashovers. Therefore, extensive natural and artificial pollution flashover testing were conducted to predict pollution-induced flashover voltages. Wind borne pollution is considered as a major source of pollution in desert environment. Strong winds and rain periods usually work as cleaning mechanism to detach sand particles from insulator's surface, while dew conditions can increase the stickiness of sand particles on the surface of insulator. Challagondla [5] referred to possible contamination of 1.4 mg/cm^2 in desert areas, so using ceramic insulators with standard creepage distance of 31 mm/kV phase to phase (53.7 mm/kV phase to ground) has proven to be insufficient to withstand desert pollution.

Another important source of pollution is industrial pollution. Industrial pollution usually constitutes of gases and solid particles which are normal products of combustion processes. When combustion products are conveyed by wind, suspended carbon particles (soot) may be adsorbed onto the insulator surface due to gravity and electrostatic forces [6,7]. Zhong [8] demonstrated that the deposition of the soot particles depends on insulator's surface roughness, insulator geometry, and wetting properties.

Deng [9], Wang [10], and Liu [11] showed that the deposited layer of the soot particles become conductive due to the ionized atmosphere around the insulator and can cause a distortion of the electric field distribution. This distortion enhances the electric field strength to a higher level beyond the air breakdown and a probable partial discharge takes place. Haberecht [12] demonstrated that highest deposition rate occurs on clean surfaces of insulators, then the deposition rate decreases with time due to the decline of the capture efficiency. The decrease of the deposition rate will lead to a small accumulation (retention) rate of pollutant onto the surface of the insulator. The present research shows that the deposition rate of other pollutant (not the same pollutant) experienced different trend to that concluded by Haberecht. It was found that the deposition rate of soot particles onto a surface of an insulator pre-contaminated with sand particles increases with time and worsen the electrical characteristics of the insulator. An (400/132) kV substation located in the Ad Diwaniyah province near Al-Shafeyea city suffered a repeated power outages during the last three years. During the last ten years, a rapid brick industry expansion has been witnessed and air pollution within the area of study becomes detectable. In case of an incomplete combustion takes place at one or more of the brick factories, black smoke disperses and cover the area of study. It was observed that the frequency of occurrences of the substation power outages increases when sandstorms prevails the area of study and considerably declines when they are minimum. Therefore, extensive investigations were carried out to simulate and evaluate the effect of the subsequent deposition of sand and soot onto the surface of insulators under dew and mist conditions on the flashover voltage and the performance of Porcelain and Polymeric insulators, which are widely used in the substation.

2. EXPERIMENTAL SETUP

A schematic diagram of the experimental setup is shown in Fig. 1. Clean strings of porcelain and Polymeric insulators were selected for this work. The porcelain insulator is of eight units and the polymeric insulator is of seven discs. Both strings were hanged 2 m apart and 3.5 m height (top). The test room was (6 m length, 4 m width, 4.5 m height) made of polystyrene cloth and steel frame. It was provided with air inflow opening where industrial exhaust fan was fixed to introduce sand-polluted air or soot-polluted air into the test room at (2-3) m/s velocity, and an outlet opening where similar exhaust fan was also fixed to draw polluted air out of the room. The inlet opening was located near the top of the cover of the test room, while the outlet opening was located near the bottom of the test room, so polluted air was enforced to flow from the top of

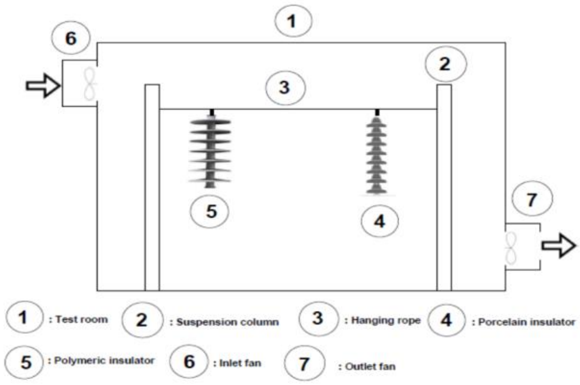

Fig. 1. Schematic representation of experimental setup.

the strings down to their bottom simulating the environment of the falling particles. The rate of air changes per hour was chosen 6 (workshop criterion) and the fan capacity was 750m^3/hr. The sand grain size falls within fine sand category, while the soot grain size falls within the PM10 (Particulate Matter). However, soot was found to quickly agglomerate to form large particles under wetting conditions.

Experiments were conducted under dry and wet conditions. Wet conditions experiments were carried out under various humidity levels. Sandstorm simulation was carried out under dry conditions only, and humid atmospheres were applied after sand deposition, before the introduction of the soot-polluted air into the test room.

2.1. Experimental Procedure

The procedure which was followed to simulate the conditions of the subsequent deposition of sand particles and soot consists of the following steps:

- Preparation step of sand particles; the pollution environment of sandstorm was simulated through sieving a mixture of desert sand to control the grain size of sand particles within the desert dust aerosol (below 250 µ).
- Preparation step of carbon particles (soot); soot was collected from local sources where incomplete combustion takes place and carbon black is formed. The samples were kept isolated in plastic bags to ensure dryness.
- Clean (non-contaminated) porcelain and polymeric insulators were tested using the Rising Voltage Test. The test was designed to be divided into two zones; zone I was of a duration step of 3 minutes and an amplitude step of 15 kV, while zone II was of a duration step of 8 minutes and an amplitude step of 7 kV. The step-wise fashion was adopted to define both duration and amplitude steps. The primary part of the test uses shorter duration steps and higher amplitude steps as the system is far from flashover voltage, while the main part of the test uses longer duration steps and lower amplitude steps as the system is close to flashover voltage.
- Sandstorm environment simulation step; both porcelain and polymeric insulators were hanged inside the test room as shown in Fig. 1, then sandstorm environment was simulated for 10 minutes. The insulators were carefully handled and moved to the test facility to measure the breakdown voltages. Then, the insulators were cleaned and the sandstorm environment test was repeated for 10 minutes, the polluted insulators were left at the test room for 1 hr under dry air flow conditions to simulate the erosion effect of wind on polluted insulators. Then, the insulators were carefully handled and moved to the test rig for measurement purposes. The test was repeated using humid air (spraying water droplets within the incoming air) instead of dry air to simulate the effect of wet conditions on the stickiness of sand particles on the surface of the insulator, then the polluted insulators were tested as in the previous case.
- Subsequent sandstorm and soot environments simulation step; both porcelain and polymeric insulators were hanged inside the test room as shown in Fig. 1, then sandstorm environment was simulated for 10 minutes. The soot particles polluted air was introduced to simulate the industrial pollution environment for 10 minutes. The polluted insulators were transferred to the test facility following the same procedure used in the sandstorm conditions. The experiment was repeated under dry and wet conditions.

3. RESULTS AND DISCUSSIONS

3.1. Effect of Deposited Sand Particles on the Flashover Voltages of Insulators

Fig. 2 shows the flashover test under dry conditions for clean porcelain and polymeric insulators. It is seen that both insulators were exposed to same voltage profile, and both insulators show no sign of air breakdown (flashover) under the test conditions. The maximum applied voltage was 182 kV and the total time of the test was 101 minutes. The test profile is divided into two zones. Zone I is characterized of relatively short duration step 3 minutes and high amplitude step 15 kV, while zone II is characterized of relatively long duration step 8minutes) and low amplitude step 7 kV. This test was considered a reference test to be used for comparison with other tests.

After exposing both porcelain and polymeric insulators to simulated environment of sandstorm, their flashover voltages were measured using Rising Voltage Test. Figs. 3 and 4 show two different conditions of sandstorm pollution. Fig. 3 shows the flashover voltages of porcelain and polymeric insulators under 10minutes exposure of sandstorm simulated conditions. It was found that flashover voltages of both insulators show small degradation 2% from clean insulators measurements. Fig. 3 demonstrates the simulated conditions of 10 minutes' exposure to sandstorm followed by 1hr dry air flow to simulate wind effect on the erosion of the deposited sand particles. The obtained results show no significant voltage degradation from clean insulators measurements (flashover of Porcelain insulator took place at 168kV and flashover of Polymeric insulator took place at 175 kV, suggesting that winds can erode deposited sand particles under dry conditions unless the particles get charged and stick to the surface of the insulators. The effect of charging sand particles was studied elsewhere [3]. However, wet conditions test shown in Fig. 4 clearly shows significant drop in the values of flashover voltages in comparison with dry conditions test (flashover of Porcelain insulator took place at 140kV and flashover of Polymeric insulator took place at 161kV). This is due to formation of thick layers of deposited sand on the surfaces of both insulators under wet conditions. It was also noted that the flashover voltages of

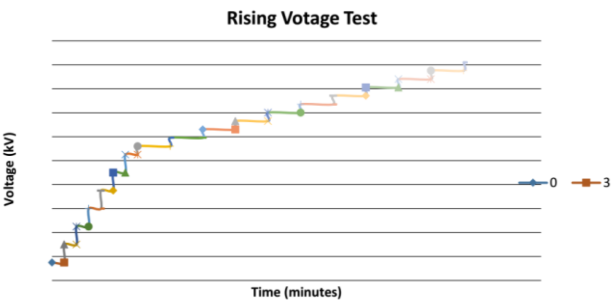

Fig. 2. Rising voltage test for porcelain and polymeric HV insulators.

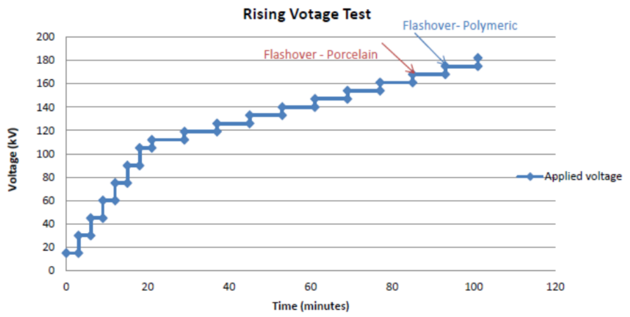

Fig. 3. Dry conditions sandstorm simulated test.

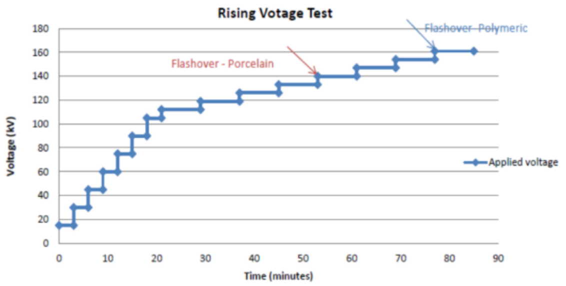

Fig. 4. Wet conditions sandstorm simulated test.

Porcelain and Polymeric insulators diverged from each other. The interpretation of this divergence is due to the hydrophobicity of Polymeric insulator.

3.2. Effect of Subsequent Deposition of Sand and Soot Particles on the Flashover Voltages of Insulators

Dry and wet conditions tests were conducted to simulate subsequent deposition of sand and soot on the surfaces of Porcelain and Polymeric insulators. Fig. 5 shows that both insulators had witnessed same flashover voltage at 161 kV. The effect of the deposition of soot on both contaminated insulators under dry conditions was only 4% less than sandstorm pollution.

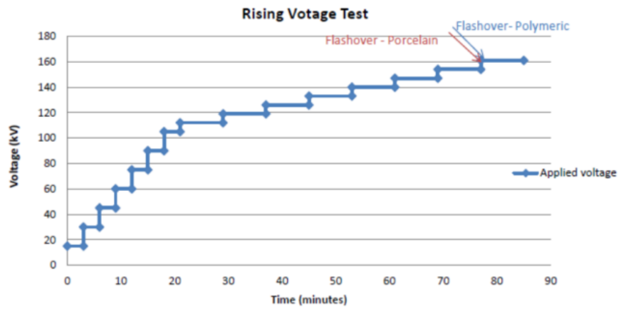

Fig. 5. Dry conditions subsequent sandstorm and soot deposition simulated test

Wet conditions test is shown in Fig. 6. It is clearly shown that the subsequent deposition of sand and soot particles under wet conditions significantly reduces the flashover voltages of both insulators. However, the flashover voltage of Porcelain insulator was 11% lower than the flashover voltage of Polymeric insulator. This is also may be attributed to the hydrophobicity phenomena of Polymers. The flashover voltages of Porcelain and Polymeric insulators under wet conditions of subsequent deposition were 112 kV and 126 kV respectively.

These voltages are considered very low in comparison with the withstand voltages of high voltage insulators. The obtained results reflect the sever effect of subsequent exposure of HV insulators to sandstorms and black carbon particles under moistening conditions. The dew conditions during the sandstorm season may cause a formation of an irregular sand layer on the surface of insulators. This layer will degrade the smoothness of the surface of insulator and increases the deposition rate of other pollution particles.

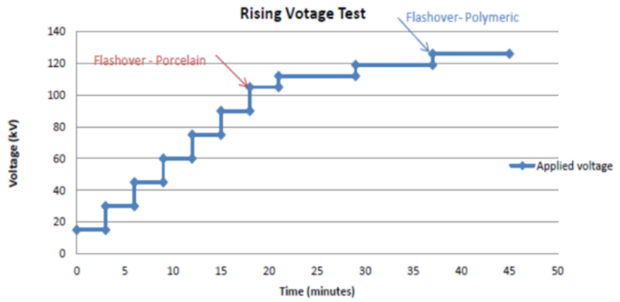

Fig. 6. Wet conditions subsequent sandstorm and soot deposition simulated test.

4. CONCLUSIONS

The effect of subsequent deposition of sandstorm and soot particles was investigated. Results show that moistening the initial deposited layer of contaminant increases the deposition rate of the second subsequent contaminant (carbon particles). The study compares the behavior of Porcelain and Polymeric insulators under dry and wet subsequent exposure of polluted environments. The polymeric insulator was found to better repulse sand particles and consequently keeps flashover voltage higher than porcelain insulator. The simulated results reflect the sever drop of air breakdown (flashover) voltages of HV insulators under polluted environments. Moistening the sandstorm deposition particles was found to increase the rate of carbon particles deposition. This leads to lower flashover voltage. Washing insulators after sandstorm season could reduce the thickness of sand layer and consequently reduces the probability of industrial contaminants accumulation.

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