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# Power Loss Assessment in Polymer and Ceramic Insulators due to Aging: An Experimental Study

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ABSTRACT

*The objective of this study is to analyze the influence of smog on polymer and ceramic insulators, which can lead to flashovers in the distribution network. An experimental chamber was designed to conduct an aging test on the insulators, where in the chamber was subjected to five different types of artificial environments, including rain, temperature, smog, and dust. The chamber was set to replicate the environmental conditions of a smoggy region based on the last five years data for all environmental factors, such as rain, temperature, humidity, smog, and dust. The accelerated aging test was conducted on 11KV-rated polymer and ceramic insulators. The polymer insulator developed contamination of 0.09 gm, while the ceramic insulator showed contamination of 0.13 gm. Furthermore, a leakage current test was performed on the aged insulators, which resulted in 37uA on the polymer insulator and 201uA on the ceramic insulator. The findings suggest that ceramic insulators are more susceptible to the adverse effects of a smoggy environment compared to polymer insulators. Thus, replacing ceramic insulators with polymer insulators in the distribution network not only reduce losses due to the leakage current but it also improve the cost of installation of new distribution networks that can improve the network's reliability.*

*Keywords: Distribution system; polymer insulator; power loss*

## INTRODUCTION

The rising need of energy in advanced countries that convince them to adopt unique ways to meet their energy requirements. Similarly less developed regions are in crisis and encountered different issues that includes power loss, unidentified energy consumption, power theft, less technological advancement that results in severe flash backs and burden on distribution network Ali (2023).

Insulators are one of the basic and most important equipment of transmission and distribution system for electric power Zaiman (2023). The system reliability is highly affected due to the performance of the insulator. Insulators are materials that inhibit the flow of electrical current, opposite of conductor, which allows current to flow freely. Insulators possess high resistivity and low conductivity Lambeth (1971). They play a vital role in maintaining the accuracy of the power supply system. For a longer period of time, they have been widely used in power transmission and distribution lines Tanaka (1978). Due to its better insulating properties, when it comes to pollution resistance, polymer insulators are mainly used compared to ceramic insulators. When airborne particles and other environmental factors settle on the surface of insulators installed in different areas such as coastal, industrial and agricultural areas, a layer of pollution will form on the insulators Hussain (2017). Therefore, when the pollution layer becomes wet in humid weather conditions such as fog or drizzle, the pollution layer allows leakage current to flow.Due to the deposition of salty dew on the insulation surface in the vicinity of the coast in the morning, a pollution layer starts to deposit on the insulator Fahmi (2017). When the layer dries with heat due to the increase in temperature or heat is generated when an insulator is deposited on it, layer hardens and deposits on the surface Cherny (1999). Contaminants deposited on the surface of insulation are harmless in dry climates, but this is particularly important in humid conditions such as rain and high humidity.

Meteorological conditions play a crucial role in the deposition rate of pollutants and the role of pollutants and insulators, because they are different from inland marine areas near land Fauziah (2017). Due to the strong wind, the evaporated salt existing in the environment is deposited on the surface of the insulator Over the period of time Liu (2017) Yao (2017), salt and contaminant layer will thicken, and on the surface of the insulator will increase Akbar (2019) Ali (2022). Due to this continuous leakage current could pose a shock hazard to someone and becomes the reason for someone's death. After the continuous leakage current causes, a huge flashover, these flashovers destroy the whole transmission line and disturb the whole system.

## INSULATING MATERIAL

Starting in the early 1800, DC generation started for use along with that latestly developed telegraph technologies Mizutani (2000). During the era of 1840-1897 glass sheets are used to insulated the DC lines.In 1902-1965 insulation qualities increased in voltage application. The development of the insulator Ceramics (ceramic, glass) was developed in this era. AC transmission system developed that required high insulation capabilities. Different types of design approved in this era for high voltage transmission system Cherney (2005).

During 1970-2010 era, NCI insulator industry is actually beginning field trials in the US.Ceramic manufacturers were not idle either with the production of ceramic, RG glazes, higher strength, and hydrophobic strength Rice (2007).New polymers having distinctive and desirable blend of properties have been developed over the last decade. These materials include thermoplastic Elastomers, ultra-high molecular weight polyethylene and liquid crystal polymer. Some of the properties for polymers are related to the structure of the molecule show ever, it is essential to adjust the physical, mechanical and chemical properties. To render the properties of polymers additives are introduced to modify and enhanced the properties of the material which ultimately make it more compatible to new applications Fukushima (2006).

Insulating material such as ceramic serves culture for over many decades. High voltage applications use different type of insulations for protection of the transmission tower. The development of ceramic insulation involves quartz, feldspar, clay or alumina. For water shedding smooth glazing is used. The mechanical strength of the ceramic is very high due to highly rich alumina content in it. The dielectric strength of these insulators is high that ultimately enhances its use in high voltage application. Polymeric insulators are widely used in transmission and distribution power system. It covers the market in very short time due its extra ordinary capabilities. The main impulsion for their enlarged recognition in electrical utilities is their advantages as compared with inorganic insulators (glass, ceramics etc). The low surface energy of the polymers added more advantage for the use in different weather conditions such as rain, dust, dew and fog Marotta (2006).

The expected failure mode when an internal fault occurs that ultimately damage the core and add crack in to it. Polymer insulators has some weakness that identified in various literatures. The mechanical strength of the polymer insulator is not that robust as compared with ceramic insulator, jackets clamping is used to support the cables Fuller (2001). The bond of the polymer insulator is stronger than ceramic. Some comparative analysis has been done in past few years. Recycled insulation material was on the ceramic insulators to protect them from fire and overheating Wi (2019). An insulation coating was also developed by performing the experiment in the Canadian Aluminum industry that shows different pollutants have different impact on the type of insulator Fofana (2020). New coatings were tested that use alumina trihydrate for ceramic insulators the results shows that deterioration decreases after performing 10,000 hrs multi stresses in the laboratory Israr (2022). Aerogels materials are used for the insulation purposes that shows the promising results Pontinha (2023). Similary some recent work was also done to increase the performance of polymer insulators. Oil paper composites and nano particles were used to strengthen the electrical properties of polymer insulators Adekunle (2023). Nano materials was used to achieve the super hydrophobicity in snow regions. The materials show prominent results that includes reduction in wet flashovers Liu (2023). Installing anti-thunder and anti-icing composite insulators (AACIs) reduces shielding failure rates on non-shield-wired 110 kV transmission lines in mountainous areas Hu (2023). The laboratory and field tests on snow-covered insulators reveal variations in flashover performance and discharge characteristics, indicating that the electrical performance of composite insulators is superior to glass insulators, with a higher snowing flashover voltage Sun (2023). A high-demand polymer composite with electrical insulation and high thermal conductivity is achieved through the synthesis of Ag@SiO/GNP core-shell hybrids, leading to a significant improvement in thermal conductivity (457.2% higher than pure epoxy resin) and good electrical insulation (>1010Ω) at a low filler loading Wang (2023). Different experiments and aging's methods are discussed in various literature that sums up a performance difference between ceramic and polymer insulator. Various tests have been performed to validate physical, chemical and mechanical properties of the high voltage insulators. Different parameters of the polymer and ceramic materials are tested and quantified in testing chamber. Comparative analysis between polymer and ceramic insulator are depicted in Table 1.

TABLE 1. Comparison of Ceramic and Polymer insulators

| Property | Ceramic | Polymer |
|---|---|---|
| Compression | High | Low |
| Size | High | Low |
| Weight | Low | High |
| Breakage | High | Low |
| Ageing | Low | High |
| Hydrophobicity | Low | High |
| Pollution Flashover | High | Low |

## METHODOLOGY

### EXPERIMENTAL CHAMBER DESIGN

Experimental chamber is designed to perform the aging analysis on the polymer and ceramic insulators. It is designed using ultra poly vinyl chloride sheets of 5 mm thickness and temperature strength of 90°C. The dimensions are 1.5(L) x 1.5(W) x 3(H) ft. acrylic has excellent optical clarity, weather withstanding capability, and heat resistance. Figure 1 shows the experimental methodology and Figure 2 shows experimental aging chamber.

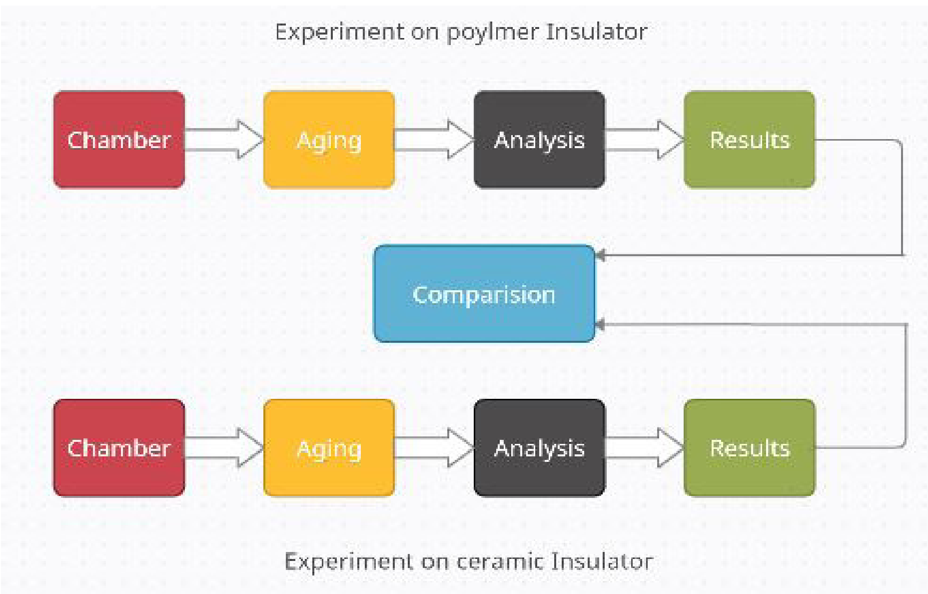


FIGURE 1. Experimental Methodology

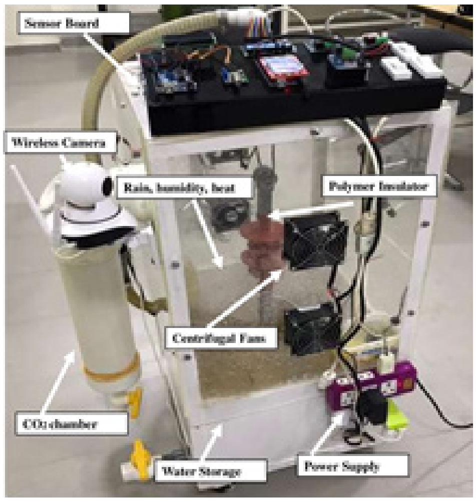


FIGURE 2. Experimental Chamber for Aging Analysis

The complete accelerated aging process of the ceramic and polymer insulator is controlled by the control panel that access all the input of the desired environmental condition to be modeled. Figure 3 shows the complete image of the control board for experimental chamber.

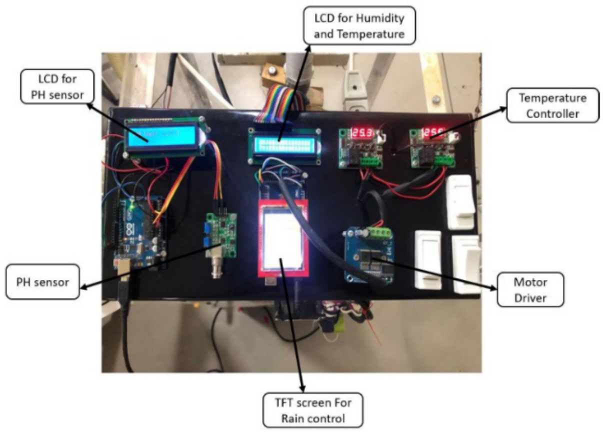


FIGURE 3. Control board for the Experimental Chamber

## TEMPERATURE EFFECT ON INSULATOR

In this experimental chamber artificial temperature setup has been created to perform temperature effect. For artificial temperature effect, cooling fans on left and right side of the experimental chamber has been installed with a 500W halogen light on top of the chamber that is facing downward in chamber. The insulator is placed in the top center of experimental chamber and both centrifugal fans and light are being controlled by w1209 controller. Light source will automatically turn off and cooling fan will automatically start to maintain the desired temperature.

## RAINING EFFECT ON INSULATOR

To model the washing effect of rainfall on contamination of ceramic and polymer insulators, an artificial rainfall setup has been designed and tested in experimental chamber with water storage component at the bottom of the chamber that are equipped with DC submersible pump. Flow sensor are installed to measure the flow rate of water, by this flow rate the rain rate value can be set in mm/hr. The rain rate input value can be given through TFT screen. It can control rainfall's intensity and duration. PH sensor is used to measure the PH value of the water to control the salts in it.

## FOG EFFECT ON INSULATOR

The artificial fog effect was created by using the Ultrasonic Humidifier mist maker (Air Humidifier Fogger), that utilizes water to create fog and, the DHT11 sensor measures the amount of humidity.

## SMOG EFFECT ON INSULATOR

In this experimental chamber for artificial smog effect, Ultrasonic mist maker have been installed that uses water to create fog, later on baking soda and vinegar are used to produce carbon dioxide. The composition of $CO_2$ production is mentioned in table 2.

TABLE 2. $CO_2$ Production

| Months | Average Temperature °C | Average Rainfall mm | Average Humidity % |
|---|---|---|---|
| January | 17 | 35.7 | 53 |
| February | 21 | 36.2 | 45 |
| March | 26 | 28.7 | 36 |
| April | 36 | 18.2 | 21 |
| May | 40 | 14.7 | 20 |
| June | 40 | 56.1 | 29 |
| July | 38 | 38.6 | 40 |
| August | 38 | 29.5 | 39 |
| September | 37 | 9.9 | 30 |
| October | 35 | 3.3 | 18 |
| November | 26 | 49.6 | 24 |
| December | 21 | 11.3 | 27 |

## DUST EFFECT ON INSULATOR

Total failure of the insulator along with different problems like erosion and surface degeneration can occur as a resultant of pollution accumulated on surface and adherence to outdoor insulators. For Dust effect in the experimental chamber, Fans have been used that are mounted on both sides with controlled wind speed capability. Figure 4 shows the images for control panel and different environmental effects.

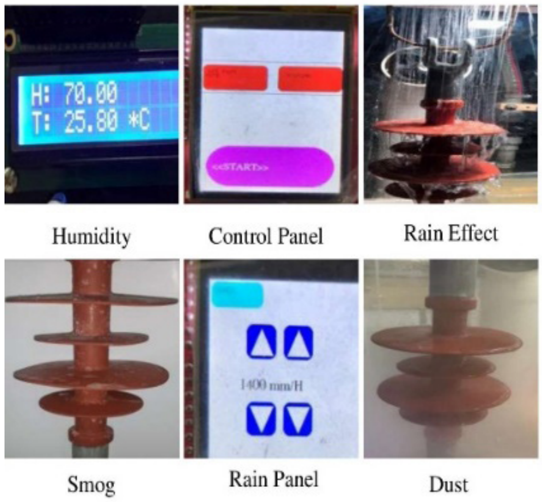


FIGURE 4. Control Panel and Environmental Effects

To perform accelerated aging on the polymer and ceramic insulator, a period of five years (2017-2021) was selected having a geographical location of concentrated smoggy area of Lahore, Pakistan. Figure 4 shows the complete block diagram of the process in which accelerated aging was done for both of the insulator over a period of five years modeled time span. The comparison of the polymer and ceramic insulator was done on the basis of dust accumulated and leakage current measured after accelerated aging.

## EXPERIMENTAL RESULTS

An experimental study was carried out to investigate the performance of a polymer insulator over a period of five years within a controlled chamber. The study included measurements of smog, fog, rain, temperature, and dust. The experimental conditions were regulated by a control panel and documented via camera. Table 3 outlines the prescribed weather conditions for each month of the experimental process. Additionally, Figure 5 presents images of the polymer insulator at each year of the aging process.

TABLE 3. Average Weather data for Accelerated Aging (Insulators 2017-2021)

| Baking Soda | Vinegar | $CO_2$ |
|---|---|---|
| 14 Grams | 200 ml | Gallon |


FIGURE 5. Polymer insulator after five years of accelerated aging

After the aging process on polymer insulator, the experimental process for a ceramic insulator will be done for five years in the experimental chamber by applying same weather conditions given in table 3. The complete experiment is controlled by the control panel and recorded through camera. Figure 6 shows the images of ceramic insulator with each year of aging.


FIGURE 6. Ceramic insulator after five years of accelerated aging

## COMPARISON OF CONTAMINATION DEPOSITION ON CERAMIC AND POLYMER INSULATORS

After performing the complete analysis for the aging of ceramic and polymer insulators, figure 7 shows the contamination collected from both insulators surfaces.

Afterward, weighing contamination and obtaining the difference in the tray weight from the total weight of tray (i.e., including contamination), the contamination weight is 0.09 gm for polymer insulators and 0.13 gm for ceramic insulators.


FIGURE 7. Contamination collected from Ceramic insulator after five years of accelerated aging

## COMPARISON OF LEAKAGE CURRENT IN CERAMIC AND POLYMER INSULATORS AFTER ACCELERATED AGING

An accelerated aging experiment was conducted over a period of five years on both polymer and ceramic insulators. The experiment involved collecting a certain amount of contamination from both insulators. The data on contamination showed that the polymer insulator was less contaminated than the ceramic insulator. Subsequently, the leakage current was measured for both insulators after each year of the aging process. Table 4 provides a comprehensive comparison of the leakage current values obtained from the polymer and ceramic insulators following each year of aging.

TABLE 4. Leakage current comparison between polymer and ceramic insulator (2017-2021)

| Year | Polymer Insulator | Ceramic Insulator |
|---|---|---|
| | Leakage Current (uA) | Leakage Current (uA) |
| 2017 | 23 | 140 |
| 2018 | 26 | 162 |
| 2019 | 31 | 173 |
| 2020 | 33 | 189 |
| 2021 | 37 | 201 |

According to a comparative analysis, there is a difference in the effect of contamination development and leakage current flow between polymer and ceramic insulators. The results show that polymer insulators are less affected by contamination compared to ceramic insulators, leading to a greater amount of leakage current in ceramic insulators. This increase in leakage current contributes to distribution system losses. Table 5 presents a comparison between the level of contamination development on insulator surfaces and the amount of leakage current that flows due to such contamination.

## COMPARATIVE ANALYSIS

According to a comparative analysis, there is a difference in the effect of contamination development and leakage current flow between polymer and ceramic insulators. The results show that polymer insulators are less affected by contamination compared to ceramic insulators, leading to a greater amount of leakage current in ceramic insulators. This increase in leakage current contributes to distribution system losses. Table 5 presents a comparison between the level of contamination development on insulator surfaces and the amount of leakage current that flows due to such contamination.

TABLE 5. Comparison of leakage and Contamination

| Type | Contamination Weight (gm) | Leakage Current (After 5 Years) uA |
|---|---|---|
| Polymer Insulator | 0.09 | 37 |
| Ceramic Insulator | 0.13 | 201 |
| Difference | 0.04 | 164 |

## CONCLUSION

This study aimed to analyze the impact of environmental factors, particularly smog, on ceramic and polymer insulators used in power distribution networks. The experiment was conducted using an artificial chamber, which simulated five different artificial environments, including rain, temperature, humidity, smog, and dust conditions. Both insulators underwent accelerated aging tests, based on the environmental data of the smoggy region of Pakistan from 2017 to 2021.

The results of the study indicated that ceramic insulators were more susceptible to contamination than polymer insulators, leading to higher leakage currents and increased distribution power losses, flashovers, and power outages. In contrast, polymer insulators were found to be more reliable and efficient in power distribution networks, reducing the risk of power loss and outages.This study provide conclusive evidence that the use of polymer insulators in power distribution networks can improve system reliability and efficiency, while reducing the risk of power outages and flashovers, making them a better alternative to ceramic insulators.

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Nil

## DECLARATION OF COMPETING INTEREST

None

## REFERENCES

Adekunle, A. A., Oparanti, S. O., & Fofana, I. 2023. Performance Assessment of Cellulose Paper Impregnated in Nanofluid for Power Transformer Insulation Application: A Review. *Energies 16*(4): 2002.

Akbar, M., R. Ullah, and S. Alam. "Aging of silicone rubber-based composite insulators under multi-stressed conditions: an overview." *Materials Research Express* 6, no. 10 (2019): 102003.

Ali, B., Rizwana, M., Fatimab, K., Shafqata, A., & Abbasia, S. 2023. Impact Computation of Electric and Magnetic Field on Farmers Working Near High Voltage Transmission Lines in Pakistan by Developing Software. *Jurnal Kejuruteraan 35*(1): 123-132.

Ali, Basit, Abdul Attayyab Khan, Ahsan Ali, Marya Maqsood, and Rohma Nisha. Power loss reduction of distribution network in densely industrialized coastal belt by development of hydrophobic coating applying accelerated aging for ceramic insulator. *ASEAN Engineering Journal* 12(1): 111-117.

Cherney, E. A., and R. S. Gorur. 1999. RTV silicone rubber coatings for outdoor insulators." *IEEE Transactions on Dielectrics and Electrical Insulation* 6(5): 605-611.

Cherney, Edward A. 2005. Silicone rubber dielectrics modified by inorganic fillers for outdoor high voltage insulation applications. *IEEE Transactions on Dielectrics and Electrical Insulation* 12(6): 1108-1115.

Fahmi, Daniar, I. Made Yulistya Negara, Anisa Kusumaningrum, and Dirman Hariono Santosa. 2017. Analysis of contaminant effect on ceramic & polymer insulator surface under artificial environmental condition. In *2017 International Seminar on Intelligent Technology and Its Applications (ISITIA)*, pp. 161-164. IEEE, 2017.

Fauziah, Dini, and Heldi Alfiadi. 2017. The effect of coating on leakage current characteristic of coast field aged ceramic insulator. In *2017 4th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI)*, pp. 1-7. IEEE, 2017.

Fofana, I., N'cho, J. S., Betie, A., Hounton, E., Meghnefi, F., & Yapi, K. M. L. 2020. Lessons to learn from post-installation pollution levels assessment of some distribution insulators. *Energies 13*(16): 4064.

Fukushima, Keiji, et al. 2006. High thermal conductive resin compounds with controlled nanostructures for electric devices. *IEEJ Transactions on Fundamentals and Materials* 126(11): 1167-1172.

Fuller, Jason John, and E. E. Marotta. 2001. Thermal contact conductance of metal/polymer joints: an analytical and experimental investigation. *Journal of Thermophysics and Heat Transfer* 15(2): 228-238.

Hu, J., Zhu, T., Hu, J., Fang, Z., & Zhang, R. 2023. Study on the lightning protection performance for a 110 kV non-shield-wired overhead line with anti-thunder and anti-icing composite insulators. *Energies* 16(2): 815.

Hussain, Muhammad Majid, Shahab Farokhi, Scott G. McMeekin, and Masoud Farzaneh. 2017. Risk assessment of failure of outdoor high voltage polluted insulators under combined stresses near shoreline. *Energies* 10(10): 1661.

Lambeth, P. J. 1971. Effect of pollution on high-voltage outdoor insulators. In *Proceedings of the Institution of Electrical Engineers*, vol. 118, no. 9R, pp. 1107-1130. IET Digital Library, 1971.

Liu, Junpeng, Zaid A. Janjua, Martin Roe, Fang Xu, Barbara Turnbull, Kwing-So Choi, and Xianghui Hou. 2016. Super-hydrophobic/icephobic coatings based on silica nanoparticles modified by self-assembled monolayers. *Nanomaterials* 6(12): 232.

Liu, S., Liu, S., Wang, Q., Zuo, Z., Wei, L., Chen, Z., & Liang, X. 2023. Improving surface performance of silicone rubber for composite insulators by multifunctional Nano-coating. *Chemical Engineering Journal* 451: 138679.

Mizutani, Yoshinobu, et al. "Investigation of deterioration mechanism of inorganic insulation under high temperature." *Electrical Insulation and Dielectric Phenomena, 2000 Annual Report Conference on*. Vol. 1. IEEE, 2000.

Pontinha, A. D. R., Mäntyneva, J., Santos, P., & Durães, L. 2023. Thermomechanical Performance Assessment of Sustainable Buildings' Insulating Materials under Accelerated Ageing Conditions. *Gels*, *9*(3), 241.

Rice, John A., and Hannah M. Rice. 2007. Moldable ceramic putty for high field magnet applications. *IEEE Transactions on Applied Superconductivity* 17.2 (2007), pp. 1015-1018.

Sun, J., Hu, Y., Jiang, X., Wu, Y., Li, T., Zhao, Y., & Rong, Y. 2023. Discharge development process and flashover performance of snow-accreted insulators under natural environment. *International Journal of Electrical Power & Energy Systems*, *146*, 108678.

Tanaka, T., K. Naito, and J. Kitagawa. 1978. "A Basis Study on Outdoor Insulators of Organic Materials." *IEEE Transactions on Electrical Insulation* 3 (1978), pp. 184-193.

Ullah, I., Akbar, M., & Khan, H. A. 2022. Enhancement of electrical, mechanical and thermal properties of silicone based coating with aluminatrihydrate/silica for ceramic insulators. *Materials Chemistry and Physics*, *282*, 125972.

Wang, Z. Y., Sun, X., Wang, Y., Liu, J. D., Zhang, C., Zhao, Z. B., & Du, X. Y. 2023. A high-performance thermally conductive and electrically insulating silver@ siloxane/graphene/epoxy composites at low filler content: Fabrication, mechanism study of insulation and thermal conductivity enhancement. *CeramicsInternational*, *49*(2), 2871-2880.

Wi, S., Yang, S., Berardi, U., & Kim, S. 2019. Assessment of recycled ceramic-based inorganic insulation for improving energy efficiency and flame retardancy of buildings. Environment international, 130, 104900.

Yao, Tao. "Preparation of super hydrophobic coating for insulator against icing flashover." In *2017 2nd International Conference on Materials Science, Machinery and Energy Engineering (MSMEE 2017)*, pp. 1032-1038. Atlantis Press, 2017.

Zaiman, N. F. H. N., Shaari, N., & Ramli, Z. A. C. 2023. Carbon Based-Materials/Metal-Organic Framework for Catalytic Oxidation in Direct Borohydride Fuel Cell Application. *Jurnal Kejuruteraan*, *35*(1), 203-213.