Journal of Southeast University (English Edition) Dec. 2001 Vol.17 No.2 ISSN 1003—7985

A Novel Insulator and Its Characteristics

Li Xiaofeng[1*] J.M.K. MacAlpine[2] Chen Junwu[1]
Wang Yan[1] Zhang Guosheng[1] Li Zhengying[1]

([1] Department of Electrical Engineering, Huazhong University of Science and Technology, Wuhan 430074, China)
([2] Department of Electrical Engineering, Hong Kong Polytechnic University, Hong Kong, China)

Abstract: Both the ceramic and the composite insulators have their own advantages and disadvantages when compared with each other. It is a reasonable idea to combine their merits together to design a novel insulator. The key measure of the novel insulator suggested in this paper is to add an annular metal sheet coated with high temperature vulcanisation (HTV) silicone rubber (SIR) at the base of the traditional ceramic insulator cap. The HTVSIR covering on the exterior of the metal sheet can lengthen the creepage distance. The metal sheet can uniform the electric stress, reduce its maximum value and modify its direction on one insulator unit and acts as equalizing ring on an insulator string. The factors stated above are the main reasons why the novel insulator has better insulating performance, including lower leakage current and flashover voltage, especially under polluted conditions. Simultaneously, the novel insulator can overcome the disadvantages of the ordinary remedies which have been widely used to improve the performance of ceramic insulators against pollution. The experimental results obtained in the laboratory were in good agreement with the theoretical analysis and demonstrated the novel insulator's effectiveness.

Key words: novel insulator, leakage current, pollution flashover, HTVSIR

The environment in which insulators are installed can have a significant impact on their performance. When insulators are situated in areas where they are exposed to severe contamination, their performance can deteriorate significantly, especially for traditional ceramic and glass insulators[1]. Because both ceramic and glass have high surface free energy which makes it easy for moisture and contamination to adhere, thus increasing the leakage current and initiating arc discharges that may lead to energy losses, flashover and outages[2,3]. In order to decrease the leakage current and increase the flashover voltages of ceramic and glass insulators, especially under severe contamination, the following methods are used:

- Periodic cleaning;
- Using insulators with optimised shapes;
- Grease coating;
- Resistive glazing;
- Room temperature vulcanizing (RTV) silicone coating;
- Attaching composite polymer skirts;
- Replacing ceramic and glass insulators with composite.

The first remedy requires much man power and pure water etc., and the accidents in the substations which sometimes occur during washing[4]. The second one is effective under clean conditions, but has not been successful under conditions of severe contamination and is difficult to obtain further improvement[5,6]. The third method has also been proven effective and has been in use for many years. But it is a maintenance-base solution, which must be periodically repeated. In most cases, both the application of the new and removal of the old grease are labor intensive and requires circuit outages[1]. As to the fourth, Whilst insulators coated with resistive glaze can provide excellent contamination flashover resistance, they suffer from glaze corrosion and deterioration at the junction point where electrical contact is made between the metal cap and pin of the insulator and the glaze[1]. About the fifth method, current information based on service experience and laboratory testing shows that these coatings perform well and will last for a number of years[7,8]. But RTV coatings can deteriorate more seriously in the presence of electrical discharges when compared with HTVSIR[9,10], quite apart from pure ceramic insulators, so care must be taken at higher voltage levels to ensure that the insulators are free of corona[1]. The sixth method is to attach composite polymer skirts around the insulator edge as sheds to increase the leakage distance. It is successful, but only in the short-term because of the poor bonding

Received 2001-09-03.
* Born in 1969, male, graduate.

between the polymer skirts and the porcelain surface. Finally, the use of composite fibreglass/silicone-rubber insulators as an alternative to ceramic or glass insulators in high-contamination areas has been growing since the early 1980s. However, because composite insulators are relatively new, the expected lifetime and their long-term reliability are not known[11]. Meanwhile, compared with porcelain and glass, it is well known that polymers are more readily damaged by degradation initiated from dry band arcing[12].

Furthermore, all the above methods just pay attention to the insulating material and configuration, but do not in general attack the problem of redistributing the electric stress on the insulator's surface[13].

1 Description of Novel Insulator

Since ceramic is still a prevalent material for overhead insulation application, it is necessary to design a novel insulator which can combine the merits of ceramic with the excellent antipollution ability of composite material.

Generally speaking, the novel insulator should pay much attention to the following aspects: basing on traditional ceramic insulators, ameliorating the electric field, using HTVSIR to lengthen creepage distance, excellent performance against pollution, long life and without frequent maintenance, stable, unsophisticated and inexpensive.

According to the aspects stated above, the structural sketch of our novel insulator is shown in Fig.1 where it is seen that the key element of this new method is the annular metal sheet coated with HTVSIR and fitted around the cap of a conventional insulator. Its inner diameter matches the outer diameter of the metal cap to ensure tightness and good electrical contact, its outer diameter is about three fourths of the insulator's diameter and can be adjusted when necessary. The main procedures of making the novel insulator are as follows:

- Firstly, an annular metal sheet was made of 2?mm thick metal plate with the configuration shown in Fig. 1;
- Secondly, a suitable mould was used to vulcanize a 3 mm thick SIR onto the metal sheet under high temperature;
- Finally, the coated annular metal sheet was fitted closely around the insulator cap. Its lowest torus was contact with the upper surface of the electric porcelain where a further sealing strip of insulation paste was added to prevent discharge.

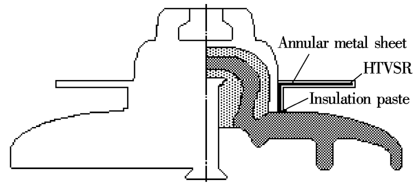

Fig.1 The structural sketch of the novel insulator

2 Comparative Analysis

2.1 Electric field

In addition to the effect of localised discharges on polluted surfaces, corona can in due course damage the surfaces, and increase pollution adherence. Both types of discharges are largely controlled by the electric field distribution.

In Fig.2 and Fig.3 the equipotential distributions for conventional and the proposed novel insulator unit are shown using ElecNet Software. From Fig. 2 it can be deduced that the field at the upper surface of the conventional insulator unit is largely parallel to the surface, thus encouraging surface discharges, particularly under polluted conditions. By contrast, in Fig. 3, it is clear that the field component normal to the surface is, for the most part, greater than the parallel component. It should lead to significantly improved flashover performance both under clean and polluted conditions[14].

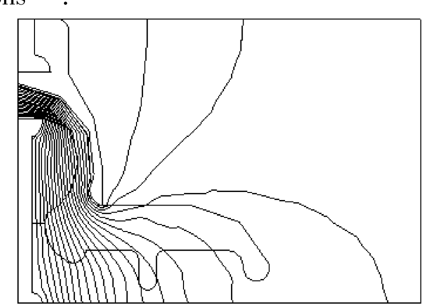

Fig.2 The equipotential distribution of the traditional ceramic insulator

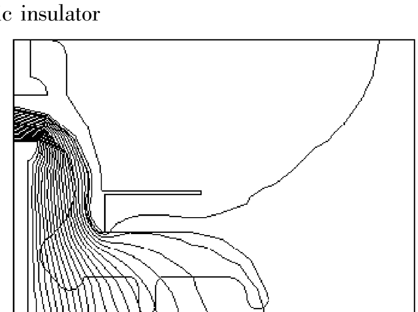

Fig.3 The equipotential distribution of the novel ceramic insulator

The maximum field (near the cap) is reduced largely and can be expected to result in an improved corona onset voltage. This merit is important for the ordinary ceramic insulator, and more important for the HTVSIR which can deteriorate quickly under corona, arc and flashover conditions.

To attenuate the effect of strong field stress on the edge of annular sheet, two measures are adopted: one is to shape the edge as semicircle, the other is to thicken the HTVSIR around the metal edge.

The metal annulus is an equipotential volume, thus the thin external surfaces of the HTVSIR have approximately same potential, regardless of under clean or polluted condition. It is well known that when the pollutants deposit on the ceramic and composite insulators, the potential distribution on the surfaces of these insulators can be distorted heavily, because of the uneven depositions. However, with the compelling effect of the metal annulus, the external surfaces of the novel insulator can keep nearly same potential whatever they are clean or unevenly polluted, which can prevent the arc from forming, and thus can increase the corona and flashover voltages.

2.2 The effect of the increased creepage distance

Porcelain is an excellent dielectric for use in relatively clean, outdoor, air-insulated systems, with adequate bulk dielectric strength and with excellent surface resistance to weathering, electrical tracking, and corona degradation. The primary limitation relates to its use under heavily contaminated conditions, where the combination of the hydrophilic nature of the surface with conducting pollution can cause highly non-uniform grading of the insulator, dryband arcing and surface flashover. Thus while porcelain has served the electrical industry well for many decades, there is still a need to seek novel method with improved performance under heavy pollution[15].

Composite systems, particularly those with HTV-SIR, are widely recognized as the preferred insulating material in heavily polluted environments. This is largely because of the hydrophobic properties of SIR and its ability to transfer these properties to the pollution layer[16]. Excellent hydrophobicity and self-repairability give HTVSIR an advantage when compared with porcelain as an insulating material for increasing the leakage distance[17]. The presence of the annular sheet covered with HTVSIR is therefore expected to improve the performance under polluted conditions drastically.

The elongated creepage distance l of the novel insulator is

$$l = 2(R_o - R_i) + h$$

where R_o represents the outside radius of the annular metal sheet; R_i represents the inside radius; and h represents the height from the upper surface of the metal sheet to the upper surface of the electric porcelain.

2.3 Other advantages

Apart from the advantages elucidated above, the HTVSIR coated on the annular metal sheet should have good stability and long life as HTVSIR insulators have been in service for more than 20 years without apparent deterioration[18]. From the Fig.4 in Ref.[19], we can find the HTVSIR insulators have higher flashover voltage than the RTV coating insulators.

Furthermore, the annular metal sheet increases the capacitance between insulator units, which should improve the voltage distribution along the insulator string[20], and thus reduce the maximum voltage across the individual units of the string.

3 Experimental Procedure and Results

3.1 Experimental insulators and apparatus

The ceramic insulator used for both the conventional and the novel insulators had an overall diameter of 260?mm, a creepage distance of 292?mm and an overall height of 160?mm. The annular metal sheet was made of 2?mm thick steel with an outer diameter of 210 mm coated with 3?mm thick HTVSIR. The clearance was 20?mm between the bottom of the annular sheet and the upper ceramic surface. The elongated creepage distance calculated by the formula in section 2.2 was 118?mm.

Besides the experiments taken under dry condition, the experiments in the wet condition simulated in a fog chamber were also tested. The fog produced by an ultrasonic humidifier was about 15?℃, liked the actual fog or drizzle. The fog input rate was 320?g · m^{-3}/h, and the condensation rate on the insulator surfaces was 22?mg · cm^{-2}/h.

The maximum output voltage of the testing transformer was ac 100?kV. Because the conventional ceramic insulators tested in these experiments were designed for very low voltage (for 11?kV transmission line under heavy pollution) for one unit, it is not necessary to test beyond 100?kV that they would seldom or never encounter.

3.2 Experimental procedure

Keeping atmospheric and other experimental conditions constant, the conventional and novel insulators were tested under ac voltage, for both clean and polluted conditions, to determine their leakage currents and flashover voltages.

As a relatively straightforward comparison test for polluted conditions, both insulators were immersed entirely in salt solutions, then taken out and allowed to dry naturally.

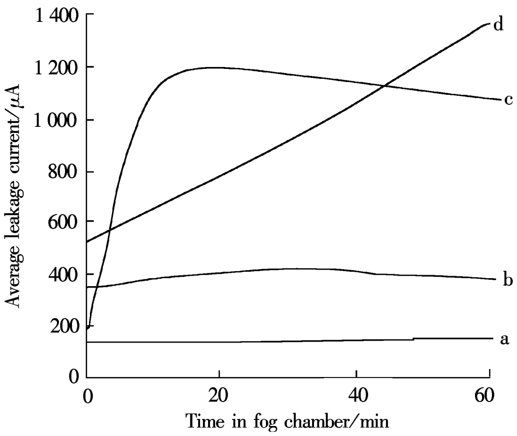

Fig.4 The leakage current comparison. a: Novel insulator under clean condition; b: Novel insulator polluted by 1?g/L salt solution; c: Ceramic insulator under clean condition; d: Ceramic insulator polluted by 1?g/L salt solution.

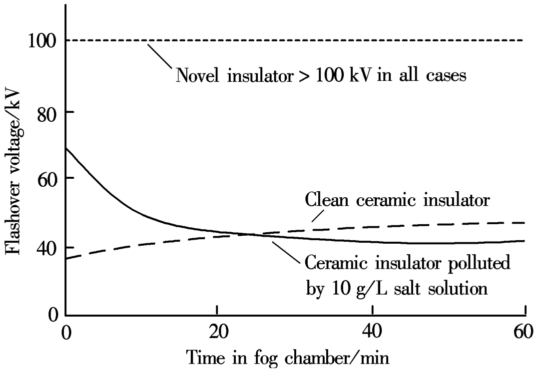

Fig.5 The flashover voltage comparison

3.3 Experimental results

The Experimental results are shown in Fig.4 and Fig.5, respectively. Both of the graphs were fitting curves for four measure result pairs. The figures using time as transverse axis were corresponding to four time measuring points, which were 0, 10, 30 and 60?min from the fog inputting.

The leakage current comparison is shown in Fig.4. The applied voltage was 10?kV, the salt solution concentration to pollute the insulators was 1?g/L.

The flashover voltage comparison is shown in Fig.5. The salt solution concentration to pollute the insulators here was 10?g/L. The flashover voltages of the novel insulators were all beyond 100?kV.

3.4 Experimental analysis

From Fig.4, it can be seen that the leakage current of novel insulator has been reduced significantly when compared with that of conventional ceramic insulator, for both clean and polluted conditions.

From Fig.5, it can be seen that the flashover voltage of the novel insulator shows at least a 45% increase when compared with the conventional one under clean condition. Under polluted condition, however, the improvement seen are even better, at least 170%.

4 Conclusion

The novel insulator described in this paper has the following advantages when compared with the conventional ceramic insulators:

- The annular metal sheet changes the electric field direction on the insulator upper surface rendering it mostly perpendicular, rather than parallel, to the insulating surface.
- The annular metal sheet also renders the electric field distribution more uniform and this reduces the maximum electric field value near the cap.
- The HTVSIR surfaces have approximately equivalent potential compelled by the metal sheet which is an equipotential volume, no matter whether the pollution layer is even or not.
- The HTVSIR has excellent hydrophobicity and self-repairability, thus providing enhanced antipollution performance whilst also lengthening the creepage distance, compared with the original ceramic insulator.
- The annular metal sheet increases the capacitance of the novel insulator and improves the uniformity of the voltage distribution along the insulator string, thus increases the corona onset and flashover voltages of the complete string.
- The novel insulator has other merits such as ease of manufacture, low cost, long life, strong mechanical strength and good stability.

The method described here can also be applied at the factory for designing and manufacturing new insulator.

References

1 E. Kuffel, W. S. Zaengl, and J. Kuffel, *High voltage engineering: fundamentals*, 2nd edition, Butterworth-Heinemann, p. 509, 2000

2 R. S. Gorur, E. Cherney, C. de Tourreil, and D. Dumora, et al., Protective coatings for improving contamination performance of outdoor high voltage ceramic insulators, *IEEE Transactions on Power Delivery*, vol. 10, no. 2, pp. 924 – 933, 1995

3 R. J. Chang, M. Shah, L. Mazeika, A. Tsai, and M. Takaseki, Design of insulators for severe contamination, In: *Proceedings of the 5th International Conference on Properties and Applications of Dielectric Materials*, Seoul, Korea, pp. 778 – 781, 1997

4 S. Goto, M. Nakamura, N. Nanayakkara, and T. Taniguchi, Reliable automatic decision making for washing the polluted insulators in coastal substations, *Electrical Insulation and Dielectric Phenomena*, 1995, *Annual Report*, *Conference on*, pp. 408 – 411, 1995

5 A. S. Farag, F. M. Zedan, T. C. Cheng, and C. Y. Wu, et al., New dc insulator design for use in the desert environment, *IEEE Transactions on Electrical Insulation*, vol. 25, no. 2, pp. 435 – 448, 1990

6 B. F. Dewey, Tests on insulators reveal danger signs for silicones, *Electrical World*, 1969

7 E. A. Cherney, and R. S. Gorur, RTV silicone rubber coatings for outdoor insulators, *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 6, no. 5, pp. 605 – 611, 1999

8 IEEE Dielectric and Insulation Soc. Committee s – 32 – 33, Round robin testing of RTV silicone rubber coating for outdoor insulation, *IEEE Trans. On Partial Discharge*, vol. 11, no. 4, p. 1889, 1996

9 S. M. Gubanski, Properties of silicone rubber housings and coatings, *IEEE Transactions on Power Delivery*, vol. 27, pp. 374 – 382, 1992

10 S. H. Kim, E. A. Cherney, and R. Hackam, Hydrophobicity behavior of insulators coated with RTV silicone rubber, *IEEE Transactions on Electrical Insulation*, vol. 27, pp. 610 – 622, 1992

11 Reuben Hackam, Outdoor HV composite polymeric insulators, *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 6, no. 5, pp. 557 – 585, 1999

12 H. Zhang, and R. Hackam, Electrical surface resistance, hydrophobicity and diffusion phenomena in PVC, *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 6, no. 1, pp. 73 – 83, 1999

13 S. Chakravorti, and H. Steinbigler, Boundary element studies on insulator shape and electric field around HV insulators with or without pollution, *IEEE Trans. on Dielectrics and Electrical Insulation*, vol. 7, no. 2, pp. 169 – 176, 2000

14 R. J. Chang, and Linas Mazeika, Analysis of electrical activity associated with inclined-plane tracking and erosion of insulating materials, *IEEE Trans. on Dielectrics and Electrical Insulation*, vol. 7, no. 3, pp. 394 – 400, 2000

15 K. Eldridge, J. Xu, W. Yin, and A. M. Jeffery, Degradation of a silicone-based coating in a substation application, *IEEE Transactions on Power Delivery*, vol. 14, no. 1, pp. 188 – 193, 1999

16 J. P. Reynders, I. R. Jandrell, and S. M. Reynders, Review of aging and recovery of silicone rubber insulation for outdoor use, *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 6, no. 5, pp. 620 – 631, 1999

17 L. Xi, S. Wang, J. Fan, and Z. Guan, Development of composite insulators in China, *IEEE Trans. on Dielectrics and Electrical Insulation*, vol. 6, no. 5, pp. 586 – 594, 1999

18 A. Bognar, P. Szaplonczay, Sz. Pinter, and G. Banhegyi, Investigation on a 20 years old composite insulator, *10th International Symposium on High Voltage Engineering* (ISH'97), Montreal, pp. 325 – 328, 1997

19 A. De La O, R. S. Gorur, and J. Chang, AC clean fog tests on non-ceramic insulating materials and a comparison with porcelain, *IEEE Trans. on Power Delivery*, vol. 9, no. 4, pp. 2000 – 2008, 1994

20 D. H. Zhu, and, Z. Yan, *High voltage insulation*, Tsinghua University Press, Beijing, 1992

新型绝缘子及其特性

李晓峰[1]　J. M. K. MacAlpine[2]　陈俊武[1]　王　燕[1]　张国胜[1]　李正瀛[1]

([1] 华中科技大学电气与电子工程学院,武汉 430074)

([2] 香港理工大学电机工程系,香港)

摘　要　以普通瓷质绝缘子为基础,并充分利用硅橡胶材料优良的防污性能,提出了一种新型绝缘子的设计方法,其主要措施是在普通瓷质绝缘子的铁帽中部加装了一个表面被覆高温硫化硅橡胶(HTVSIR)的金属环片.金属环片表面的 HTVSIR 可以达到增加爬距和防污的目的,金属环片本身除支撑 HTVSIR 外,还可以改变电场分布以抑制放电的发展,从而提高新型绝缘子的起晕和放电电压.清洁和污秽两种情况下的实验结果证明了新型绝缘子确实可以有效地减少表面泄漏和显著地提高闪络电压.

关键词　新型绝缘子, 泄漏电流, 污秽闪络, 高温硫化硅橡胶

中图分类号　TM854