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Design of 33 kV Transformer Bushing Insulator from NR and HDPE

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Abstract

This research presents a design of transformer bushing insulation at high-voltage wire connection side. The bushing insulator is made from composite materials between natural rubber (NR) and high-density polyethylene (HDPE). The HDPE has been utilized to increase a weather resistance property of natural rubber, such as ultraviolet resistance, temperature, heat resistance, and so on. The blend ratio of materials depends on NR 60% and HDPE 40%. To study properties of insulator material, it is tested by using ASTM D2240, ASTM D412, ASTM D257-99 and ASTM D149-05 standard. The test results shown that the composite material has a tensile strength equal to 4.28±5.4 MPa, volume resistivity more than 2.14×10^{16} Ω-cm and surface resistivity about 5.56×10^{16} Ω/square. This insulation material can be withstanding a maximum AC power frequency voltage about 19.7 kV/mm. In additional to design, the electric field distribution around the bushing insulator is analyzed by using a finite element method (FEM). The highest electric field strength occurs at wire connector and equal to 0.95 kV/mm. Finally, the developed bushing insulator has been installed on 33 kV distribution systems at Saraburi province.

Keywords: Transformer bushing; Natural rubber; High density polyethylene; Finite element method

1. Introduction

Stability and reliability are the most important of electrical power distribution system. Power outage is affecting to customers especially a manufacturing industry. The most of high voltage distribution systems

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in Thailand is overhead wire system. These systems have so many connections between wire terminals without insulation and risk to undesirable short circuit. The wire terminal of distribution transformer is the one of connections that risks to short circuit due to reptiles or poultries, such as bird, sneak, squirrel, and etc. This paper shows a novel design and development of protected insulator for transformer busing. A developed busing insulator in this research will be protected a wire terminal. The insulation material combines the natural rubber (NR) and the high density polyethylene (HDPE). To certain the material properties, the material will be tested by ASTM D2240, ASTM D412, ASTM D257-99 and ASTM D149-05 standard. Also, the finite element analysis has been used for simulation of a distributed electric potential and electric field.

Nomenclature

EPDM	ethylene-propylene diene monomer rubber
FEA	finite element analysis
FEM	finite element method
HDPE	high-density polyethylene
NR	natural rubber

2. Insulation Material

Usually, the most wire connection of distribution transformers, which is shown in Fig. 1, has not protected with insulator. The short circuit phenomenon is probably occurred by animals and etc. The solving of the short circuit problem is initially utilized with PVC water tube as simple cover insulation. The insulator is sufficient to protect the wire terminal in the systems, but it is not engineering standard and beautiful. The insulator can storage some dust particles, water moisture, and leaf on top of connection. The protective insulator from PVC tube is shown in Fig. 2.

Fig. 1. A wire connection of distribution transformer at primary side.

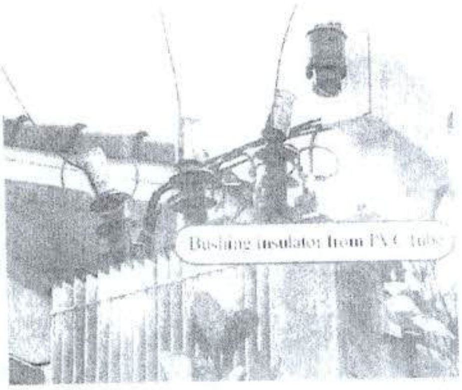
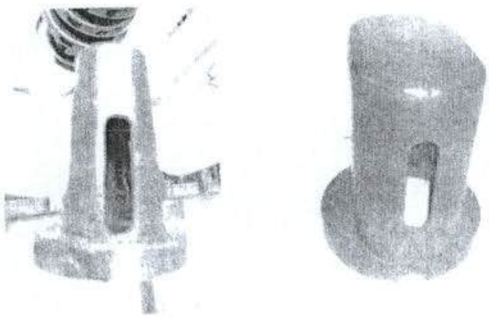
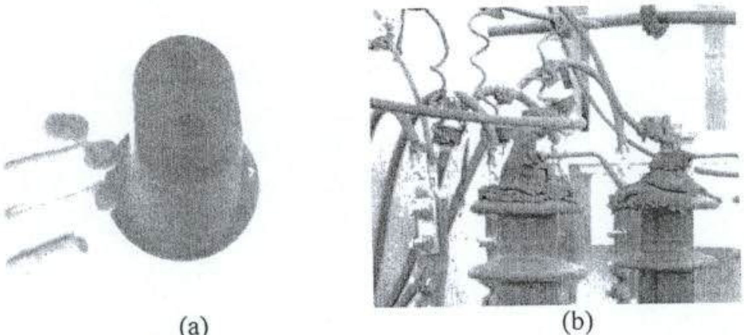


Fig. 2. Using PVC water tube for protected a primary wire connection.



(a) (b)

Fig. 3. Current EPDM bushing insulator for (a) single-phase transformer and (b) three-phase transformer.



(a) (b)

Fig. 4. Damage of EPDM bushing insulator (a) black powder from surface degradation and (b) thermal damage from heat and ultraviolet.

In the case of the simple PVC insulator, the specific bushing insulator has been developed for protection purpose. It has many shapes depending on design and production company. Ethylene-Propylene Diene Monomer Rubber (EPDM), which has a limit of weather resistance properties, is a major insulation material. A current EPDM bushing insulator for single and three phase distribution transformer is shown in Fig. 3.

The EPDM bushing insulator has many problems, such as black powder from surface degradation. And also, it cannot resist heat and ultraviolet from sunlight. The surface degradation and thermal damage of the EPDM is shown in Fig. 4. In additional, the current EPDM bushing insulator is inconvenient design for maintenance. When bushing insulator has been damaged, the operators/technicians will necessary to take time for reassembling a new insulator into the wire terminal extensively.

The insulation compounding material, which is the natural rubber (NR) and the high density polyethylene (HDPE), is developed in this research. The HDPE is used for increasing weather resistance properties of NR. The compounding rubber consists of 60% NR and 40% HDPE ratio. The materials and chemical substances are utilized to blend a compounding rubber as shown in Tab. 1.

The compounding rubber has been proceeded to be the vulcanized rubber sheet. It has the dimension about 150x150x2 mm for mechanical and electrical testing. The insulation tests are composed of hardness, tensile strength, surface and volume resistivity, and dielectric strength. The testing process refers to ASTM D2240, ASTM D412, ASTM D257-99 and ASTM D149-05. The testing results will be compare properties with other materials, such as EPDM, NR, and EPDM rubber with a same ratio of blending. Table 2 shows the properties of NR+HDPE material that has 60% NR, 40% EPDM rubber.

As shown in Table 2, a 60% NR and 40% HDPE rubber has similarity properties with a 60% NR and 40% EPDM rubber. NR+HDPE rubber has the hardness 83.7±0.9 shore A, which is more than NR+EPDM rubber about 56%. But NR+EPDM rubber is capable to support more tensile force. NR+EPDM rubber and NR+HDPE rubber have the tensile strength about 8.82±1.58 MPa and 4.28±5.4 MPa, respectively. For surface and volume resistivity, the testing results shown that NR+HDPE rubber has the surface resistivity $5.56\times10^{16}\,\Omega$/square, volume resistivity 2.14×10^{16} Ω- cm. The volume resistivity of NR+HDPE rubber is more than NR+EPDM rubber about 92.5% while the surface resistivity of NR+HDPE rubber is less than NR+EPDM rubber about 70.7%. From the testing properties, NR+HDPE rubber has qualified electric insulator because there is the more electric resistance [1].

Table 1. Materials and chemical substances for compounding rubber.

Material	phr
Natural Rubber STR 5L	60
High-Density Polyethylene	40
Zinc Oxide	3
Stearic Acid	1.2
Cyclohexylbenzothiazolesulfonamide	0.6
Tetramethylthiuramdisulfide	0.12
Sulphur	1.08
Carbon Black	1

Table 2. Properties of vulcanized rubber from testing.

Material Properties	EPDM	NR+EPDM (60:40)	NR+HDPE (60:40)
Hardness, Shore A	30-90	46.7 ± 3	83.7±0.9
Tensile Strength, MPa	10-20	8.82 ± 1.58	4.28 ± 5.4
Elongation at Break , %	200-500	548 ± 29	92 ± 29
Surface Resistivity, Ω /square	N.A.	1.9×10^{17}	5.56×10^{16}
Volume Resistivity, Ω - cm.	1×10^{17}	1.6×10^{15}	2.14×10^{16}
Dielectric Strength, kV/mm.	0.9	17.9	19.7

2. Design and computer simulation

The bushing insulator was designed and developed by using a computer aided design for creating a 3-D model. Firstly, the realistic dimension of the insulator was built with the 3-D model of porcelain bushing. After that, the insulator was designed to be compatible dimension with porcelain bushing. The 3-D models of the insulator are shown in Fig. 5. The bushing insulator is composed of two parts. The part I is the main body insulator that has the dimension about 113x113x131 mm. The insulator sheet thickness is equal to 4 mm. The part II is the strap plate insulator with dimensional about 32x32x18 mm. The strap plate insulator has four pins for holding the bushing insulator as shown in Fig. 5(b). The assembly of both insulator parts is shown in Fig. 5(c).

In this article, the 2-D model of bushing insulator can be explained with a mathematical model that used to analyze the electric field strength and voltage distribution by mean of the finite element analysis (FEA) [2]. The simulation of 2-D model of the bushing insulator, which is shown in Fig. 6, is composed of porcelain bushing, spark gap, wire terminal, and NR+HDPE busing insulator. The spark gap and wire terminal are defined as a perfect conductor because the joint of both conductors is neglected. The rated voltage of them is equal to 33 kV. The NR+HDPE bushing insulator and porcelain bushing are the isotropic material with no space charge. The NR+HDPE bushing insulator has the relative permittivity that is equal to the calculated relative permittivity of NR and HDPE [3] while the porcelain bushing insulator has relative permittivity equal to the NR+HDPE. The external boundary of model is simulated as vacuum that its relative permittivity is equal to 1 and no external electric field. For computation, the tolerance of solution for electric potential and electric field is less than 1×10^{-6}. Figures 7 and 8 show the simulation results of porcelain bushing and bushing insulator from FEA.

(a) (b) (c)

Fig. 5. 3-D model of designed bushing insulator (a) part I: main body, (b) part II: strap plate, and (c) assembly of those insulators.

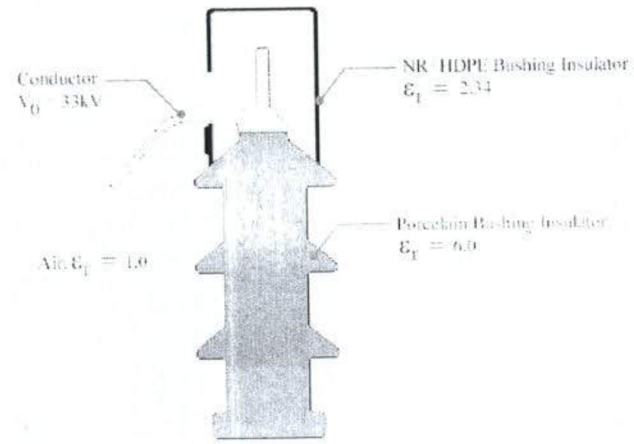


Fig. 6. 2-D model for finite element analysis.

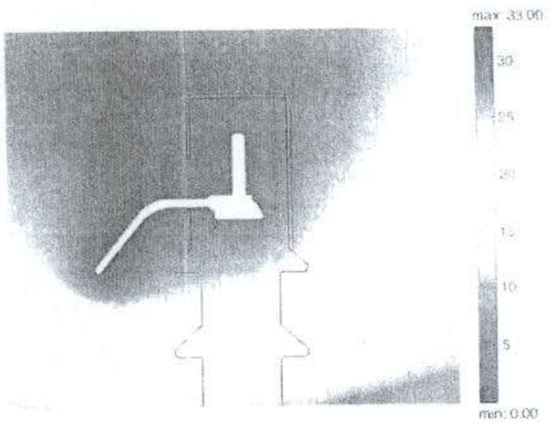


Fig. 7. Voltage distribution around porcelain bushing and bushing insulator.

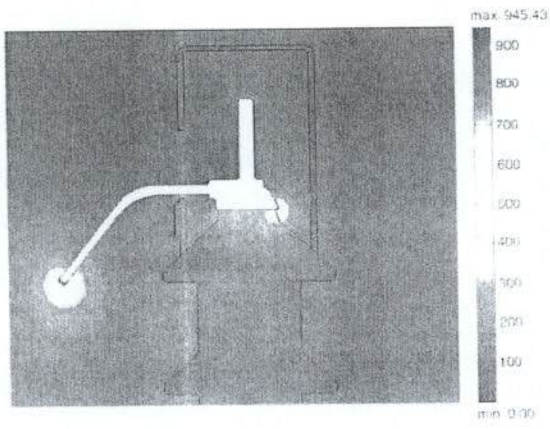


Fig. 8. An electric field strength that distributed around insulator.

Figure 7 shows the simulation results of the voltage distribution when applied voltage at wire terminal and spark-gap are equal to 33 kV. The highest electric field strength arises at tip of spark-gap to 0.95 kV/mm. But the NR+HDPE bushing insulator received low electric field strength about 80V/mm by location. From the maximum electric field strength, the dielectric strength of materials was compared between them, which are shown in Tab. 2. The NR+HDPE bushing material can withstand electric field strength under normal usage situation. Furthermore, the worst case simulation is using a tree branch model with contacted to surface of the NR+HDPE bushing insulator. The tree branch defined as circle shape, which has a radius 10 mm and voltage equal to zero. The simulation results neglected an electric conductivity, surface and volume resistivity and relative permittivity of the tree branch. The simulation results of voltage and electric field are shown in Figs. 9 and 10, respectively.

A grounding tree branch contacted to surface of bushing insulator increasing electric field strength and changing voltage distribution is shown in Figs. 9 and 10. The electric field strength at contact point is increased to 5.4 kV/mm. The bushing insulator was designed to be a wall thickness of main body insulator about 4 mm. The dielectric strength of materials is shown in Tab. 2. The wall sheet of bushing insulator can withstand the AC power frequency voltage about 78.8 kV. In this case, the bushing insulator can withstand the maximum electric field strength at contact point.

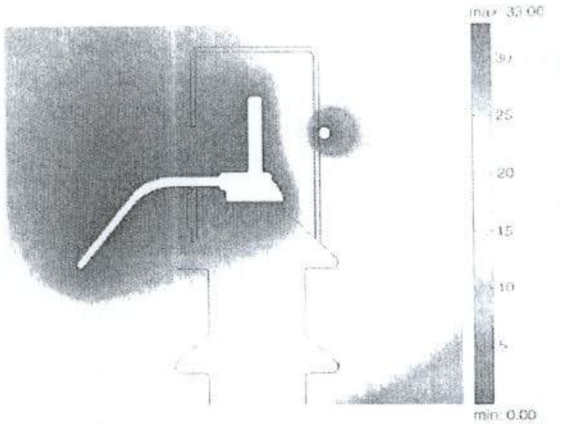


Fig. 9. Voltage distribution around porcelain bushing and bushing insulator when bushing insulator contacted with grounding tree branch.

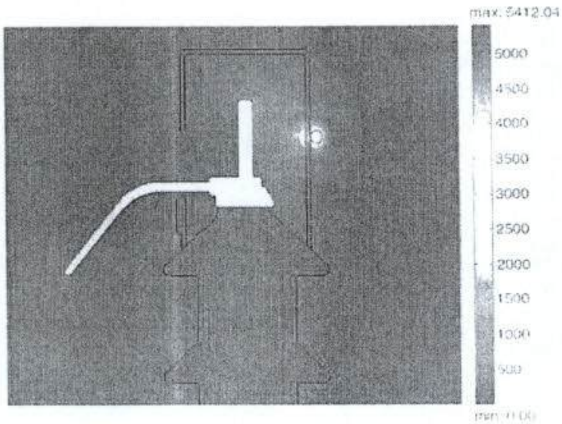
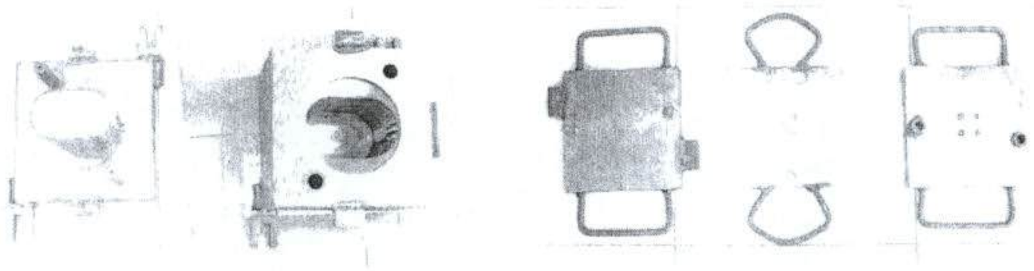


Fig. 10. Electric field strength when bushing insulator contacted with grounding tree branch.

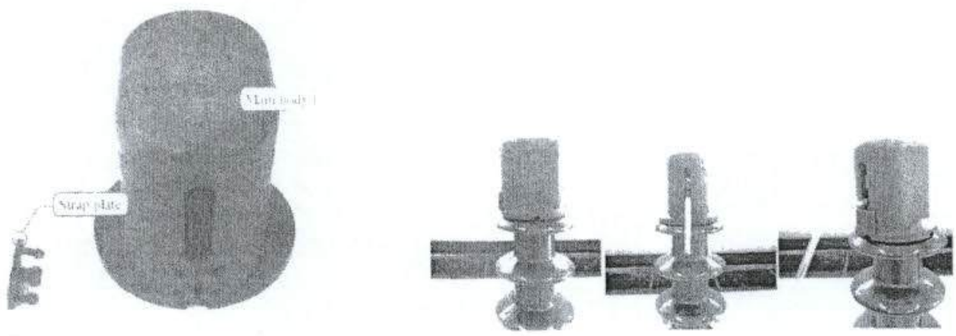
4. Bushing insulation installation

From design and computer simulation, the building of metal molds for thermal compression process uses 3-D computer model. The metal mold has two sets. The first set uses for main body insulator, which is composed of two metal parts. The second set is a strap plate mold with their metal parts. Both of molds are shown in Fig. 11. By thermal compression manufacturing, the finished bushing insulator from the NR+HDPE material is shown in Fig. 12(a) and the installation example with porcelain bushing is shown in Fig. 12(b). The developed busing insulator has been installed in the 33kV distribution system of Provincial Electricity Authority (PEA) at Saraburi province. The installed area is nearly cement plant, which has a lot of dust particles. Figure 13 shows the installation of the bushing insulator on the distribution system. The novel bushing insulator was conveniently installed to the system that was compared with the old design. Because PEA operator cannot remove the wire connector. The installation of the bushing insulator is faster than the old one. Therefore, the electrical distribution system is shut down shortly.



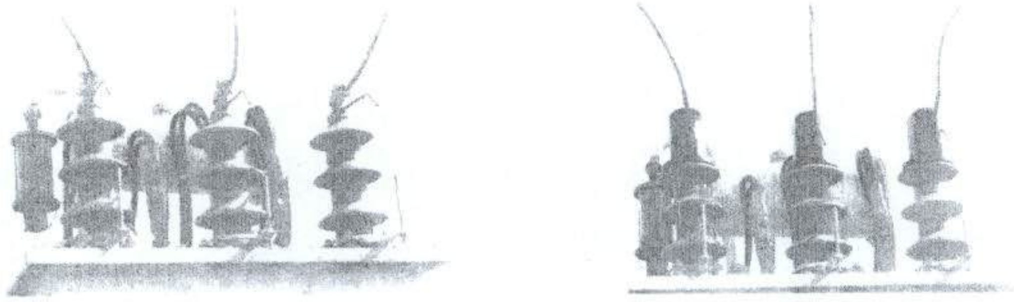
(a) (b)

Fig. 11. Metal molds of bushing insulator for heat compression molding (a) main body mold and (b) strap plate mold.



(a) (b)

Fig. 12. Developed NR+HDPE bushing insulator (a) two part of insulator (b) installation example



(a) (b)

Fig. 13. Installation of NR+HDPE bushing transformer with distribution transformer (a) before and (b) after.

5. CONCLUSION

This paper presented the novel design and development of bushing insulator. The developed bushing insulator is used to protect a primary wire connection of distribution transformer at maximum AC voltage 33kV. The insulation material is composited from natural rubber and high density polyethylene by blending ratio 60:40. The insulation material has been tested by using ASTM D2240, ASTM D412, ASTM D257-99 and ASTM D149-05 standard. From test results shown that the developed insulator material has suitable properties to use for bushing insulator. This insulation material can be withstanding a maximum AC power frequency voltage about 19.7 kV/mm. In addition, the developed bushing insulator has been installed on the 33 kV distribution system of PEA at Saraburi province.

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