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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 2.14×1016 Ω-cm and surface resistivity about 5.56×1016 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

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[1] Hileman, A.R., 1999, Insulation Coordination for Power Systems, Boca Raton, Florida, USA: CRC Press.

[2] Reece, A.B.J. and Preston, T.W., 2000, Finite Element Methods in Electrical Power Engineering, New York: Oxford.

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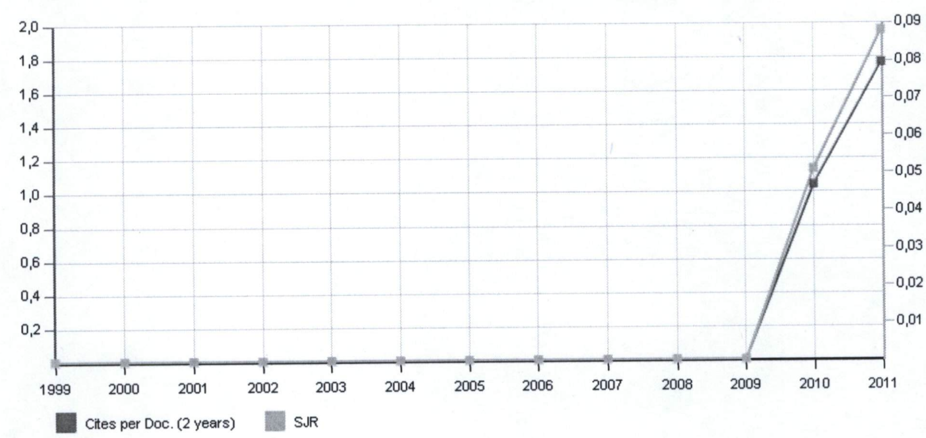

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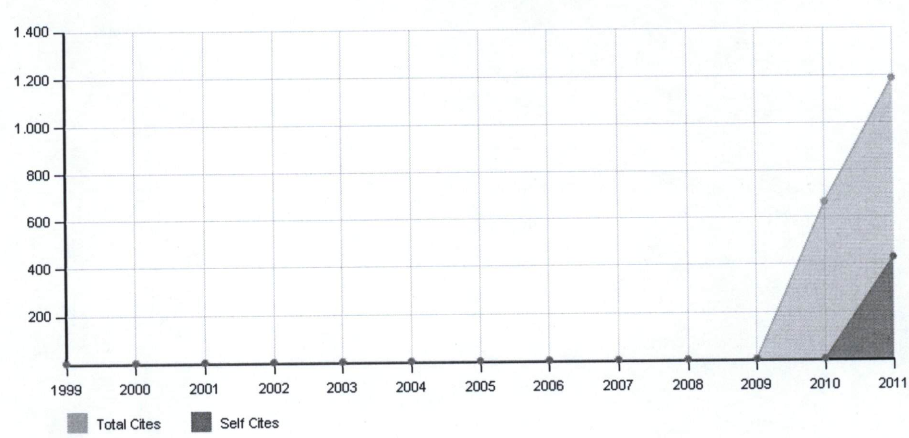

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9th Eco-Energy and Materials Science and Engineering Symposium, Chiang Rai, Thailand 25-28 May. 2011

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Design of 33kV Transformer Bushing Insulator from NR and HDPE

N. Panklang, N. Phankong and K. Bhumkittipich

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). HDPE has been used to increase a weather resistance properties of natural rubber such as ultraviolet resistance, temperature and heat resistance etc. The blend ratio of materials is natural rubber 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, we used a finite element method(FEM) to analyze the electric field distribution around the bushing insulator. 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 33kV distribution system 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. Most of high voltage distribution system in Thailand is overhead wire system. These systems have so many connections without insulation and risk to undesirable short circuit. Wire terminal of distribution transformer is one of connections that risk to short circuit due to reptiles or poultries such as bird, sneak, squirrel ect. This paper shown a novel design and development of protect insulator for transformer busing. A developed busing insulator in this research will be protected a wire terminal. Insulation material is compound rubber between natural rubber(NR) and high density polyethylene(HDPE). For certain on material properties, it will be test by ASTM D2240, ASTM D412, ASTM D257-99 and ASTM D149-05 standard. Also, finite element analysis has been used for simulation a distribute electric potential and electric field.

2. INSULATION MATERIAL

The most wire connection of distribution transformers doesn't have protect insulator, which probably short circuit phenomenon. Fig. 1 illustrate a wire connection at high voltage side of distribution transformers.

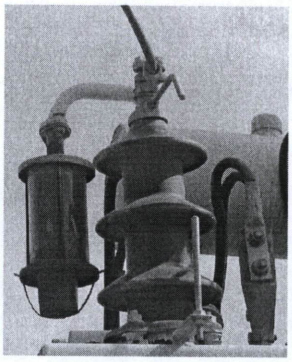

Fig. 1. A wire connection of distribution transformer at primary side.

The initial of solving a short circuit problem used a simple cover insulation as a PVC water tube. They are a sufficient insulator but don't be engineering standard and not beautiful. The insulator can storage some dust particles, water moisture and leaf on top of connection. A protective insulator from PVC tube shown in Fig. 2.

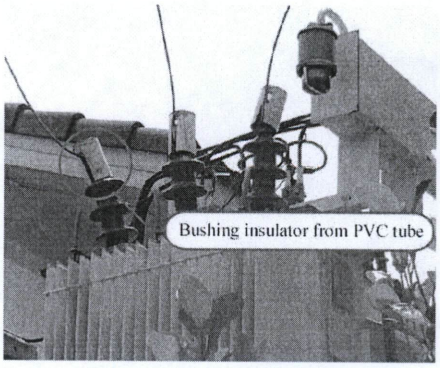

Fig. 2. Used of PVC water tube for protected a primary wire connection

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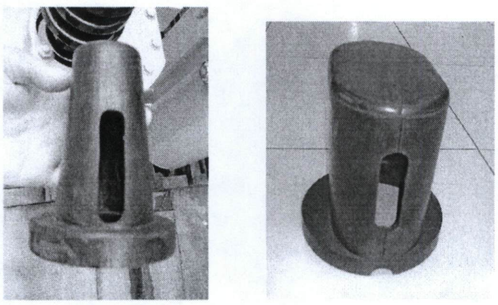
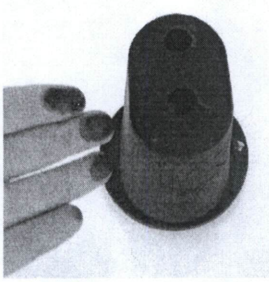
From simple PVC insulator, specific bushing insulator has been developed to protection purpose in many shape upon to design and production company. Ethylene-Propylene Diene Monomer Rubber(EPDM) is a major insulation material. They have a limit of weather resistance properties. Fig. 3 illustrated a current EPDM bushing insulator for single and three phase distribution transformer.

The EPDM bushing insulator has many problems, black powder from surface degradation, EPDM can't resist a heat and ultraviolet from sunlight. The surface degradation and thermal damage is show in Fig. 4. In additional, current EPDM bushing insulator is uncomfortable design for maintenance. When bushing insulator has been damaged, the operators will necessary to reassembly wire terminal for install a new one that used much more time.



(a) (b)

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



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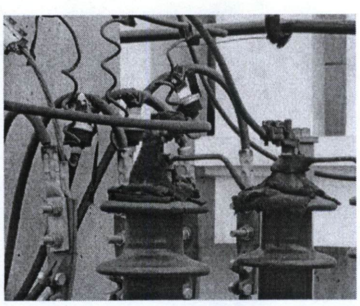


(b)

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

This research developed insulation from compound material, natural rubber(NR) and high density polyethylene(HDPE). The HDPE used for increasing weather resistance properties of natural rubber. The compound rubber consist of 60% NR and 40% HDPE ratio. Materials and chemical substances are using to blend a compound rubber shown in Table 1.

Table 1. Materials and chemical substances for compound rubber

Materials	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

The compound rubber has been process to vulcanized rubber sheet dimension 150 x 150 x 2 mm for mechanical and electrical testing. The insulation testing topics are hardness, tensile strength, surface and volume resistivity and dielectric strength. In the testing process refer ASTM D2240, ASTM D412, ASTM D257-99 and ASTM D149-05. Testing results will be compare with other material such as EPDM, NR and EPDM rubber with a same ratio of blending. Table 2 shown properties of NR+HDPE material when compared with 100% EPDM rubber and 60% NR, 40% EPDM rubber.

Table 2. Properties of vulcanized rubber from testing

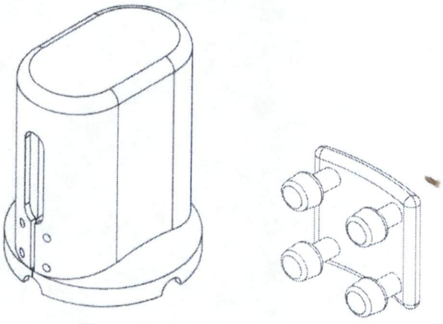
Material Properties	EPDM	NR+EPDM (60:40)	NR+HDPE (60:40)
Hardness, Shore A	30 - 90	46.7 $\pm$ 3	83.7$\pm$0.9
Tensile Strength, MPa	10 - 20	8.82 $\pm$ 1.58	4.28 $\pm$ 5.4
Elongation at Break , %	200 - 500	548 $\pm$ 29	92 $\pm$ 29
Surface Resistivity, Ω /square	N.A.	1.9×10^{17}	5.56×10^{16}
Volume Resistivity,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

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 a hardness 83.7$\pm$0.9 shore A which more than NR+EPDM rubber about 56%. But, NR+EPDM rubber able to support more tensile force. NR+EPDM rubber and NR+HDPE rubber has a tensile strength about 8.82 $\pm$ 1.58 MPa and 4.28 $\pm$ 5.4 MPa respectively. For surface and volume resistivity, The testing shown that NR+HDPE rubber has surface resistivity 5.56×10^{16} Ω /square, volume resistivity 2.14×10^{16} Ω - cm. Volume resistivity of NR+HDPE rubber more than NR+EPDM rubber about 92.5%. While, surface resistivity of NR+HDPE rubber less than NR+EPDM rubber about 70.7%. From testing properties, NR+HDPE rubber is a good electric insulator because of there is a more electric resistance[1]

3. DESIGN AND COMPUTER SIMULATION

The design and development of bushing insulator used a computer aided design to create a 3-D model. First step, we're build a 3-D model of porcelain bushing by using realistic dimension. After that, bushing insulator was designed to compatible dimension with porcelain bushing. 3-D models of bushing insulator shown in Fig. 5. A bushing insulator is composed with two part. A first part is main body insulator with dimensional about 113x113x131 mm and insulator sheet thickness equal to 4 mm. Later part is strap plate insulator with dimensional about 32x32x18 mm. Strap plate insulator has a four pins for holding with as shown in Fig. 5(b). The assembly of both insulator parts shown in Fig. 5(c).

In this article, we used 2-D model of bushing insulator to make a mathematical model. This math model has been used to analyze electric field strength and voltage distribution by mean of finite element analysis(FEA)[2]. A simulation model shown in Fig. 6. A 2-D model composed with porcelain bushing, spark gap, wire terminal and NR+HDPE busing insulator. Spark gap and wire terminal defined as a perfect conductor, voltage equal to 33kV, neglect a join of both conductors. NR+HDPE bushing insulator and porcelain bushing are isotropic material and no space charge was formed. NR+HDPE bushing insulator has a relative permittivity equal to which calculated from relative permittivity of NR and HDPE[3]. While, porcelain bushing has relative permittivity equal to . The external boundary of model is simulated as vacuum and it has relative permittivity equal to 1 and no external electric field. For computation electric potential and electric field used a tolerance of solution less than 1×10^{-6}. Fig. 7 and Fig. 8 are shown simulation results from FEA.



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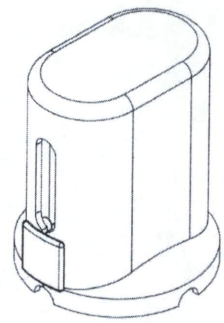


(c)

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

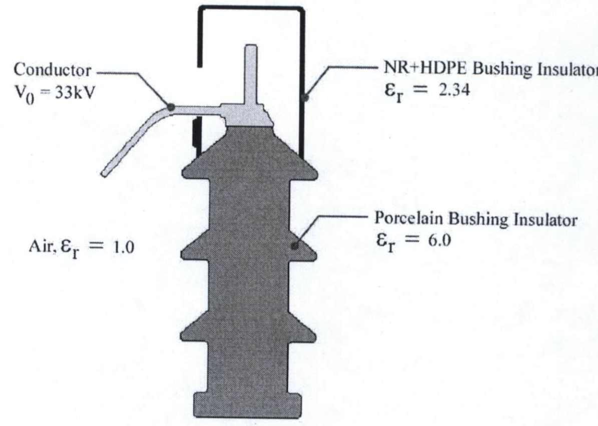


Fig. 6. 2-D model for finite element analysis

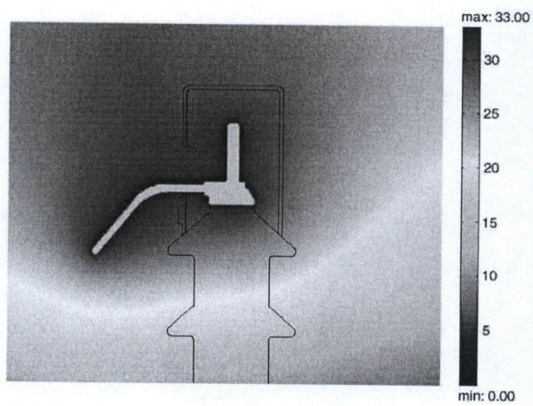


Fig. 7. Voltage distribution around porcelain bushing and bushing insulator

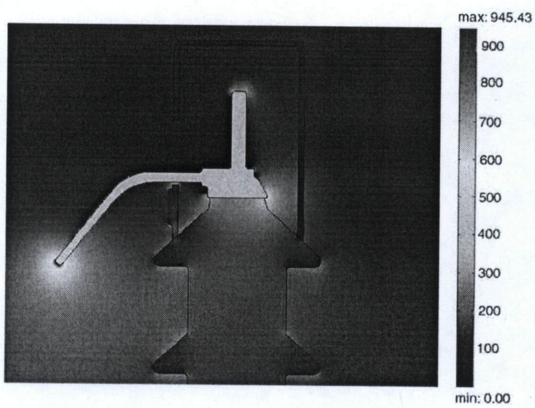


Fig. 8. An electric field strength that distributed around insulator

Fig. 7 is a simulation result of voltage distribution when applied voltage at wire terminal and spark-gap equal to 33kV. Highest electric field strength arise at tip of spark-gap, 0.95kV/mm. But, NR+HDPE bushing insulator received lower electric field strength about 80V/mm by location. From the maximum electric field strength, when comparisons with a dielectric strength of material, see in Table 2. Since, a NR+HDPE bushing material can withstand a electric field strength under normal usage situation.

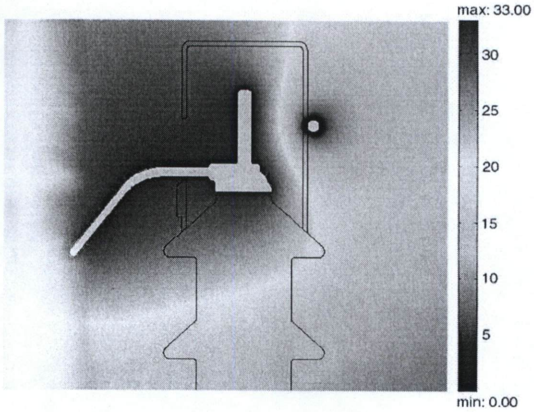


Fig. 9. Voltage distribution around porcelain bushing and bushing insulator when bushing insulator contacted with grounding tree branch.

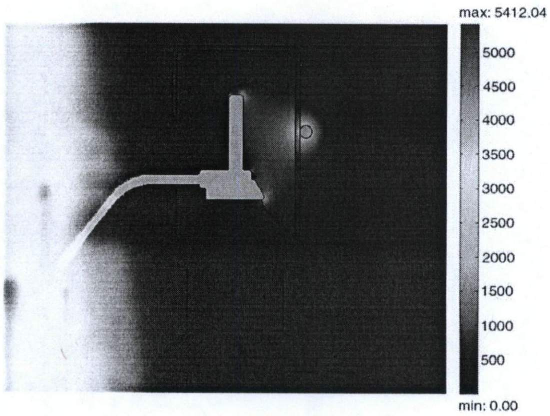


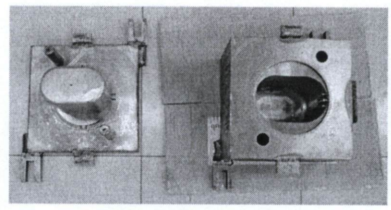
Fig. 10. Electric field strength when bushing insulator contacted with grounding tree branch.

Furthermore, the worst case simulation is using a tree branch model with contacted to surface of NR+HDPE bushing insulator. A tree branch defined as circle shape has a radius 10 mm and voltage equal to zero. The simulation neglected an electric conductivity, surface and volume resistivity and relative permittivity of tree branch. Voltage and electric field simulation results show in Fig. 9 and Fig. 10 respectively.

A grounding tree branch contacted to surface of bushing insulator increasing electric field strength and changing voltage distribution as shown in Fig. 9 and Fig. 10. Electric field strength at contact point is increased to 5.4kV/mm. A bushing insulator is design a wall thickness of main body insulator about 4 mm. Since, from dielectric strength of material in table 2, the wall sheet of bushing insulator can be withstand AC power frequency voltage about 78.8kV. In this case, bushing insulator can withstand maximum electric field strength at contact point.

4. BUSHING INSULATOR INSTALLATION

From computer design and simulation, the building of metal molds for thermal compression process use 3-D computer model. The metal mold has two set. A first set use for main body insulator, which composed two metal parts. Second set is a strap plate mold with there metal parts. Both mold shown in Fig. 11. By thermal compression manufacturing, a finish-bushing insulator from NR+HDPE material shown in Fig. 12(a) and installation example with porcelain bushing shown in Fig. 12(b). Developed busing insulator has been installed in 33kV distribution system of Provincial Electricity Authority(PEA) at Saraburi province. Installed area is nearly cement plant, which has a lot dust particles. Form installation as shown in Fig. 13, A novel bushing insulator has comfortable to install when compare with old design because of PEA operator don't remove a wire connector. The installation used timeless and shortly shutdown electrical system.



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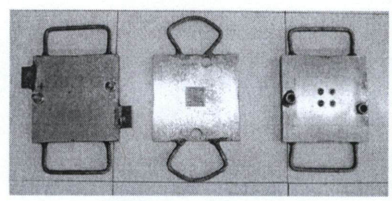
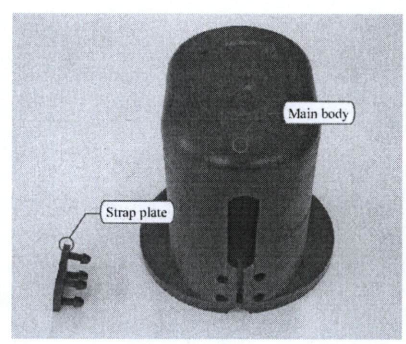


(b)

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



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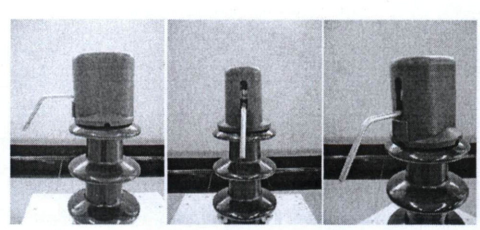
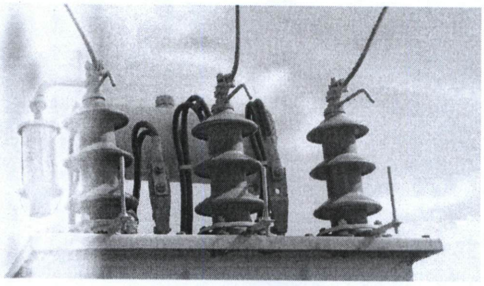


(b)

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



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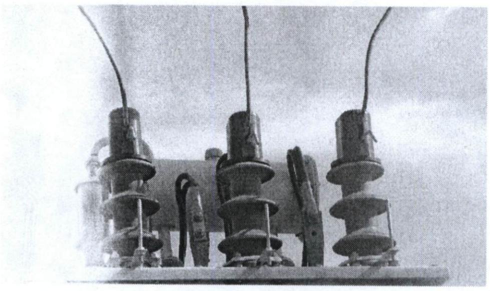

(b)

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

5. CONCLUSION

This research presents a novel design and development of bushing insulator. Developed bushing insulator is use to protect a primary wire connection of distribution transformer at maximum AC voltage 33kV. Insulation material is composite from natural rubber and high density polyethylene by blending ratio 60:40. Insulation material has been test by using ASTM D2240, ASTM D412, ASTM D257-99 and ASTM D149-05 standard. From test results shown that 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 33kV distribution system of PEA at Saraburi province.

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Abstract

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Keywords—Transformer Bushing, Natural Rubber, High Density Polyethylene, Finite Element Method.

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