Problem Solving of Partial Discharge on the Distribution Line

NARONG MUNGKUNG[1], TANES TANITTEERAPAN[1],WERACHAI CHAOKUMNERD[2], KARUN MORASILP[3], PANUMAT LIMSUWAN[3], WARAWUT POOLPERM[4] AND TOSHIFUMI YUJI[5]

[1]Department of Electrical Technology Education
King Mongkut's University of Technology Thonburi,Bangkok
[2]Dhurakij Pundit University, Bangkok
[3] Provincial Electricity Authority , Nakhon Sri Thammarat
[4] Provincial Electricity Authority , Suratthai ,
THAILAND
[5]Faculty of Education and Culture, University of Miyazaki ,JAPAN
Email:narong_kmutt@hotmail.com

Abstract: - This paper presents the mitigation methods of PD on PIC in distribution line system. The area located near the coast will be selected as the pilot project because of having strong occurrence of PD which is mainly caused by salt contamination. The methods applied in this experiment consist of using tie wires made from an insulation sheath of low voltage cable, the sheath of PIC itself; composite tie wire and aluminium tie wire (reverse loop binding). Following the trial results, there are two methods that considered as the most effective ways for PD solving; binding PIC by using the PIC's insulation sheath and the composite tie wire instead of aluminium tie wire (conventional binding).

Key-Words: - Partial discharge, Partially Insulated Cable, Tie wire, Burn down, Mitigation

1. Introduction

The electrical partial discharge process is one of the causes of insulation failure in electrical machines, cable joints, bushings and gas insulated switchgear. Electrical transmission discharge is a long term failure mechanism, where fine erosion channels grow in high electrical stress (metal inserts, cracks, voids etc.) within the insulator. Failure of the insulator occurs when the tree channels join the electrodes and allow large destructive currents to flow. Insulation damage is frequently related to partial discharges (PDs).

The results of PDs in electrical transmission system insulation has sometimes been referred to surface tracking. Electrical discharges at the interface of two media are commonly called surface discharges and produce the well-known surface tracking [1-3]. Surface tracking at the interface contact between insulation and air frequently result from the following process. At each end of the potential gradient, any sharp surface will have a stronger electric field. This stronger electric field ionizes the surrounding air, therefore causing this air to be conductive. PDs may exist in this region. The ozone smell is more common for surface discharges and commonly is absent if internal discharges only are present[4-5]. Both "surface tracking" and that which is sometimes referred to as "traditional corona damage" begin as PD sparking. Detection of PDs can identify insulation deterioration long before traditional methods of insulation testing and analysis. In addition, PD testing is completed online, while conventional testing methods require an outage. According to occurrence position, partial discharge can be classified as three kinds, which occur outer, inner and surface of the insulation dielectric respectively. The first type, Partial discharge occurred outer of the insulation dielectric mainly means discharge in atmosphere or electric insulating oil, that is relative to solid insulation. The second type, inner partial discharge means air void discharge in solid or liquid insulation. The last type, discharge occurs along the surface of the insulation. The classification above is universal not only for solid but also for liquid and gas insulation. Therefore, it is significant to PD source location and PD pattern recognition that research on Partial discharge signal characteristic based on the UHF method for above three type PD.

At present, this study applies the PIC instead of bare aluminium conductor in the 22 and 33 kV distribution line in order to increase the reliability of the distribution system and decrease the outages and the risk of people who work near the line. However, the insulation thickness of PIC is typically not provided for full system line voltage. Consequently, some discharge in the distribution line can occur. The results of the discharge will produce some noise and light appearing at night and cause not only the corrosion of conductor but also the loss of electrical energy. This study figures out that there are two solutions to solve these PIC problems, which is binding with its insulation sheath and using the composite tie wire instead of aluminium tie wire.This paper presents the cause and the pattern of PD, the problems of using PIC and the solution of these problems. The case studies in this paper are the 33 kV distribution system in the southern area of Thailand. In southern of Thailand, the humidity and equivalent salt are very high value.

2. Theory of Partial Discharges

PD theory involves an analysis of materials, electric fields, sparking characteristics, pulse wave propagation and attenuation, sensor spatial sensitivity, frequency response and calibration, and noise and data interpretation. PD can be described as an electrical pulse or discharge in a gas-filled void or on a dielectric surface of a solid or liquid insulation system. This pulse or discharge partially bridges the gap between phase insulation to ground, or phase-to-phase insulation. A full discharge would be a complete fault between line potential and ground. The other area of PD, which can eventually result, is insulation tracking. This usually occurs on the insulation surface. These discharges can bridge the potential gradient between the applied voltage and ground by cracks or contaminated paths on the insulation surface.

These discharges might occur in any void between the copper (or aluminium) conductor and insulation wall, internal to the insulation itself, or between the outer insulation wall and the grounded frame. The pulses occur at high frequencies; therefore, they attenuate quickly as they pass a short distance. The discharges are effectively small sparks occurring within the insulation system, which deteriorate the insulation, and result in eventually complete insulation failure. These discharges might occur in any void between the copper conductor and insulation wall, internal to the insulation itself, or between the outer insulation wall and the grounded frame. The pulses occur at high frequencies; therefore, they attenuate quickly as they pass a short distance. The discharges are effectively small sparks occurring within the insulation system, which deteriorate the insulation, and result in eventually complete insulation failure. The possible locations of voids within the insulation system are illustrated in Fig.1. The other area of PD, is insulation tracking. It usually occurs on the insulation surface. These discharges can bridge the potential gradient between the applied voltage and ground through cracks or contaminated paths on the insulation surface. They are illustrated in Fig.2. The details of PD void modeling, PD testing and more information are described in [6] and [7] respectively. Besides, surface discharges are readily detected in term of the ultraviolet (UV) radiation emitted by the discharges, using remote direction UV detection devices [8]. Actual failure modes may indicate a drop in PD intensity shortly prior to complete failure. This would occur when the internal arcing had carbonized to the point where the resistive component of the model was low enough to prevent a buildup of voltage across the void. This new low resistive component would also allow higher current flows, and additional heating and resultant insulation damage. The above model, including the resistive component correlates to the actual failure mode of a PD void, with the resistive component passing more leakage current as the PDs increase with time.

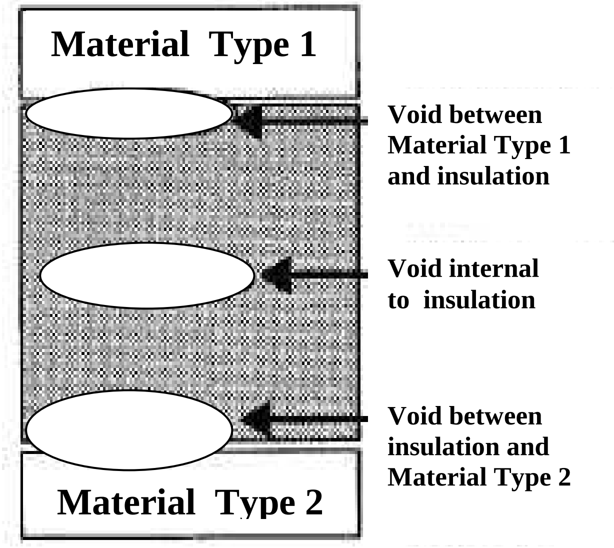


Fig.1. PD within insulation system

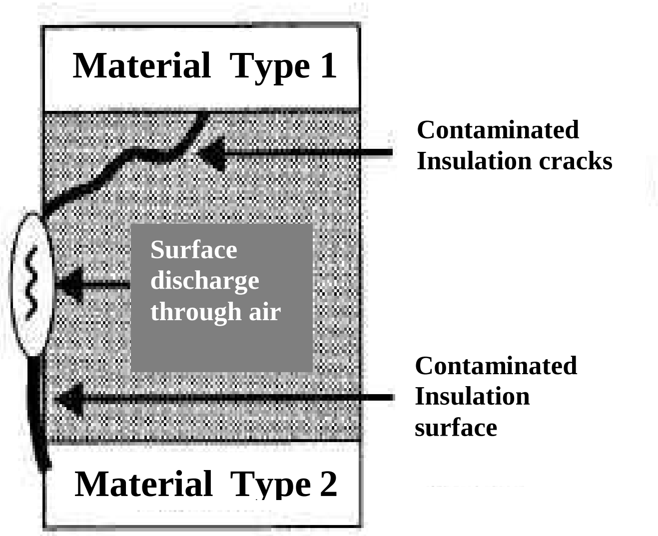
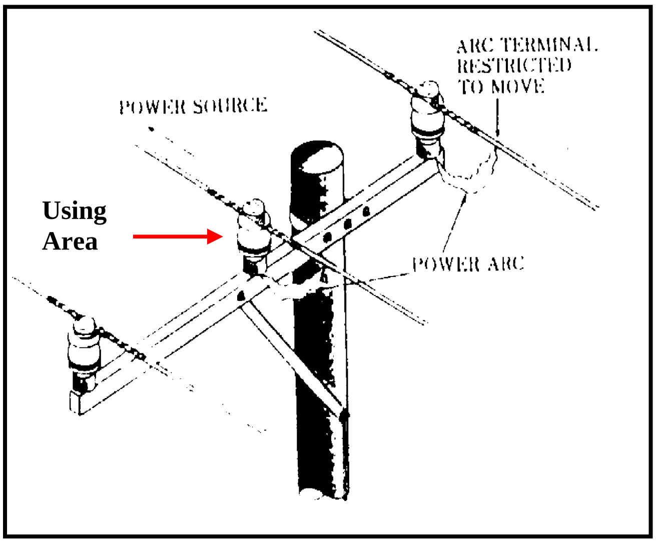
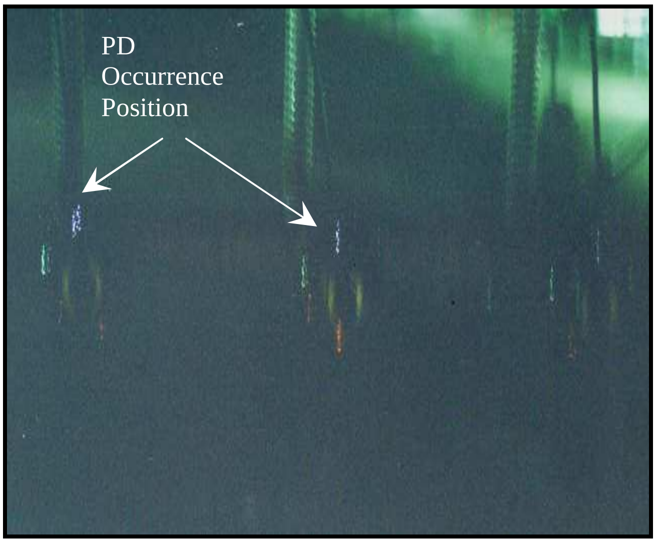


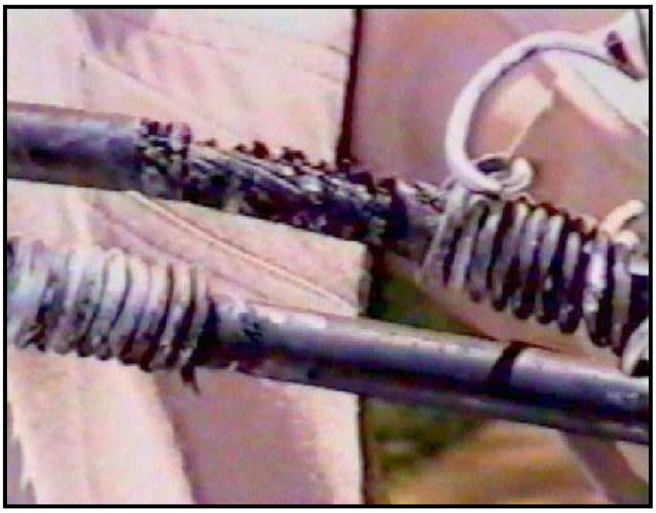
Fig.2. Surface PDs



a) Using area



b) PD occurrence position



c) Damaged area part

Fig.3. Insulation of PIC was damaged by PD

3. The Problem of PD on PIC

PEA has used PIC instead of bare conductor in the industrial area and high density of plantation area to reduce the interruption caused by trees and animals (snakes and birds etc.), which increase the system reliability and diminish an accident of people who work near the line. However, there are some problems of PIC line i.e. conductor burn down (which can be solved by several methods [9-12]), the wrong tripping of protective devices, and the occurrence of PD. This paper concentrates on the problem of PIC caused by PD. The PD will occur between tie wire and the conductor due to the difference of voltage level of both surfaces. It will produce the track on the insulation and result in complete insulation failure as show in Fig.3.

4. The Effect of PD in Distribution Lines

This study has accumulated the effects of PD on PEA distribution system and found that PD will result in topic 4.1 - 4.3 and the positons of PD occurrence are also observed and listed in topic 4.4 - 4.10 as the following :

4.1 Deteriorating of PIC insulation PD and causing the puncture in the insulation.

4.2 Disturbing radio/TV signal in the nearby area.

4.3 Producing the light and noise. Corrosion of aluminium conductor and causing the conductor to be worn out.

4.4 The insulator supported lead line to transformer.

4.5 The insulator at double deadend pole (DDE).

4.6 The insulator supported lead line at the crossing pole (BA).

4.7 The insulator at the pole in the angle structure.

4.8 The insulator at the pole in the tangent structure.

4.9 The ended line point using a preformed line guard.

4.10 The ended line point using strain clamp

5. The Mitigation of PD Problem

There are several methods to relieve the PD problem.

5.1 Prevent the damage of PIC and the percolation of water into the conductor which decrease AC breakdown voltage.

5.2 Use non-metal material instead of aluminium tie wire such as:
1. low voltage insulation (PVC)
2. insulation of PIC
3. rope
4. composite tie wire.

5.3 Use the technical approach to tie the insulator to reduce the electric field strength.

5.4 Use the high property insulation such as Line post type, Pin post type instead of Pin type insulator.

5.5 Avoid using PIC in the high pollution area such as seaside and dusty area etc. or cleaning the insulation frequently.

5.6 Reduce the system voltage level.

The designer and constructor were advised to use the approach 5.1), 5.4) and 5.5) in the distribution line construction to reduce PD problem as they can be applied without the experiment. The procedure 5.6) is the best solution to solve the PD problem but the investment cost is too high. For these reasons, it shall be considered in the policy process. For the method 5.2) and 5.3) that use the non-metal instead of aluminium tie wire and use the technical method in binding need to be tested before applying them to eliminate the PD problem in the distribution system.

6. The Trial of PD Problem

As mentioned in section 5, the method 5.2) and 5.3) will be tested before applying them to mitigate the PD problems as a standard. In this experiment, the several cases will be set up.

6.1 Cases and Number of Samples

The cases using in the trial compose of:

Case 1: Binding by using PEA's standard
1.1 Overall system: 1,000 points
1.2 Only on insulators that support lead line to distribution transformer: 30 points

Case 2: Binding by using aluminium tie wires (reverse loop binding) .
2.1 Overall system: 1,245 points
2.2 Only on insulators that support lead line to distribution transformer: 111 points

Case 3: Binding by using low voltage cable insulation on the insulators that support lead line to distribution transformer: 24 points

Case 4: Binding by using the insulation of PIC on the insulators that support lead line to distribution transformer: 45 points

Case 5: Binding by using composite tie wires: 36 points.

Case 6: Binding by using the insulation of PIC on the insulators at the poles, which is the tension loaded location and the tensionless location: 10,000 points.

6.2 Binding Methods

The approaches used in the experiment can be explained as follow:

6.2.1 Binding by using PEA's standard

The binding following by the existing PEA's standard is adopted to use in this study [13] and illustrated in Fig. 4 - 5.

6.2.2 Binding by using aluminium tie wires (reverse loop binding: RLB)

The RLB method is similar to the one as described in section 6.2.1, but the tie wire is bound backward to short circuit all wires in order to reduce the voltage across the wires and to distribute the strength of electrical field as much as possible. The method of RLB is illustrated in Fig.8. After applying this method, the end of tie wire should be joined together on the insulator as shown in Fig.9. As a result, it is tighter than the previous method

6.2.3 Binding by using low voltage cable insulation (PVC insulated)

This approach will use non-metal material as tie wire instead of aluminium tie wire because the property of PVC insulated is similar to the PIC especially, the permittivity value. Therefore, it can alleviate the effect of PD. The binding by using this method will use the PVC insulated that is made from 2 m , 50 mm^2 of low voltage cable insulation as shown in Fig.7 and Fig.8.

6.2.4 Binding by using the insulation of PIC

Because the material of PIC insulation and PIC conductor are homogeneous, it can lessen the problem of PD. PIC insulation that is used as tie wire is made from the remained PIC conductor peeling into 8 mm thick and 50 mm long. The detail of this method is shown in Fig.9 and Fig.10.

6.2.5 Binding by using composite tie wire

PEA has purchased the composite tie wire for trial. Binding by using composite tie wire on the insulators that support overall system : 36 points as shown in Fig. 11.

6.3 Experimental Results

The results of the trial as shown in table 1 and Fig 12.

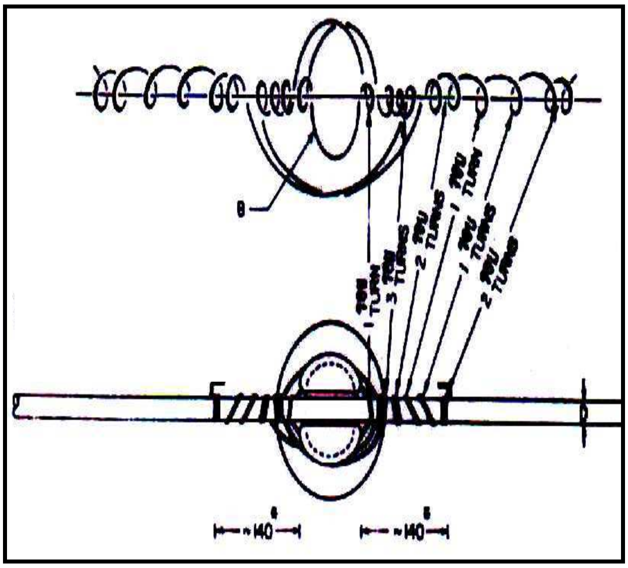
Table 1: The trial results in each case.

Case Study	PDs Occurrence (%)	Remarks
Case 1.1 Case 1.2	48 100	• Problems occur after 4 months. • The problems occur rapidly in the pollution area. • Most of PD problems occur when used Pin type insulator following by Fog type.
Case 2.1 Case 2.2	30 69	• Problems occur after 6 months. • No problem when use this method with Line Post and Pin Post.
Case 3	0	• PIC insulation deteriorating, color change.
Case 4	0	• PIC Insulation is normal
Case 5	0	• A little change in color
Case 6	0	• PIC insulation is normal

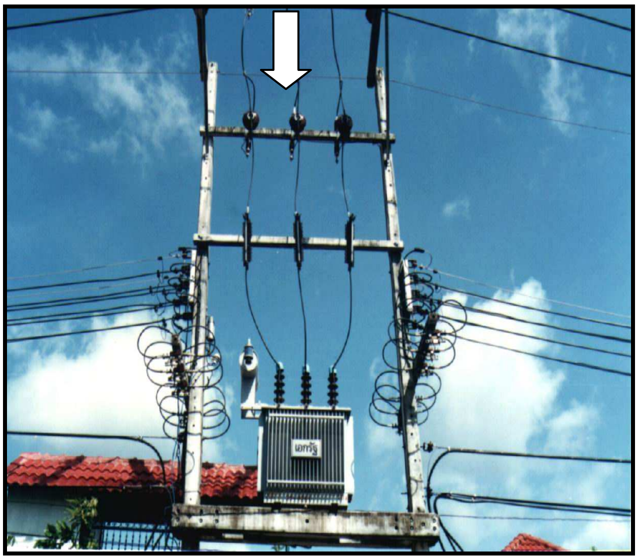
The endurance of the application of PIC insulation as tie wire is also considered to test in the laboratory as shown in table 2.

Table 2: Testing results of the endurance of PIC's insulation sheath as tie wire binding on line post type insulator.

Sizes of PIC	Tension force (kgf)	
	PIC's ins. sheath	Al. tie wire
185 sq.mm.,22 kV	137	41
185 sq.mm.,33 kV	165	45
50 sq.mm.,33 kV	105	89



a) Winding Method



b) Using Area

Fig.4. Binding by using PEA's standard

6.4 Summaries and Recommendations

6.4.1 Analysis and Summary Results

a) insulation is selected as tie wire because of more durability. The testing results shown in table2. However, PIC insulation can be breakdown by UV. Therefore, it should be used in the low strength area. To prove the endurance of PIC insulation, we install about 10,000 sets in distribution system (including tension loaded and tensionless points). There is no problem during the two years of the experiment. For composite tie wire, it can distribute the strength of magnetic field and reduce PD problems. From the experiment, no problem with composite tie wire is shown. In addition, Phuket office used to use composite tie wire without problem in the new lines but in the old lines, the PD problems are still taking place.

b) insulation is selected as tie wire because of more durability. The testing results shown in table2. However, PIC insulation can be breakdown by UV. Therefore, it should be used in the low strength area. To prove the endurance of PIC insulation, we install about 10,000 sets in distribution system (including tension loaded and tensionless points). There is no problem during the two years of the experiment. For composite tie wire, it can distribute the strength of magnetic field and reduce PD problems. From the experiment, no problem with composite tie wire is shown. In addition, Phuket office used to use composite tie wire without problem in the new lines but in the old lines, the PD problems are still taking place.

c) The quality of insulator affects to PD. The low quality insulators such as pin type and fox type will produce PD faster than pin post type and line post type insulators.

d) Binding method will also affect PD. The use of the method that can reduce the strength of electrical field such as backward binding can mitigate the PD problem.

e) The angle points easily produce PD such as at DDE, BA and the pole with a transformer.

f) The pollution area such as the region near coast or dusty area can be yielded PD easier than other places.

g) Deteriorated conductor and the old lines can easily cause PD.

h) The humidity will affect PD i.e. at peeled cable, the position of insulation supported lead line to transformer, lead line at BA and DDE.

i) At present, not only PIC but also spaced aerial cable (SAC) has PD problem, and it extends to performed deadend.

6.4.2 Recommendations

a) If noise caused by PD occurs at the position of the insulator support lead line to transformer, lead line at BA and DDE or the new PIC installation, PIC insulation should be used. In addition, if there are some damages on the old cable, peeling the cable at damage point and binding the cable with high voltage tape should be done before using the PIC insulation. However, at the high tension loaded point, the composite tie wire should be used as tie wire.

b) During the construction, try to avoid the damage of PIC and the percolation of water into

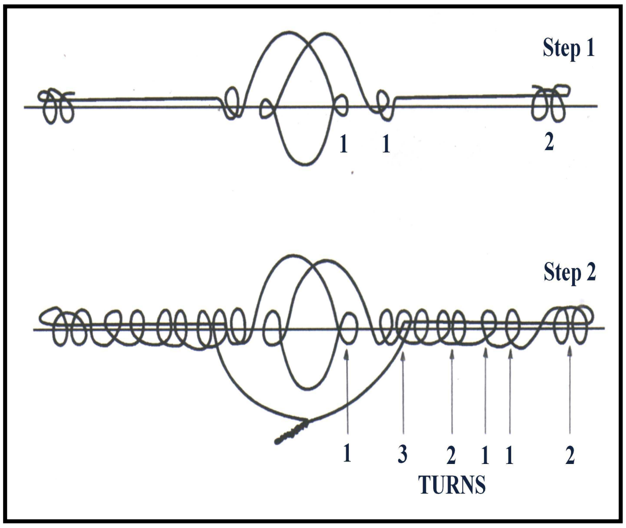


Fig.5. Binding method by using RLB

Fig.6. Application of RLB on the Pin type insulator

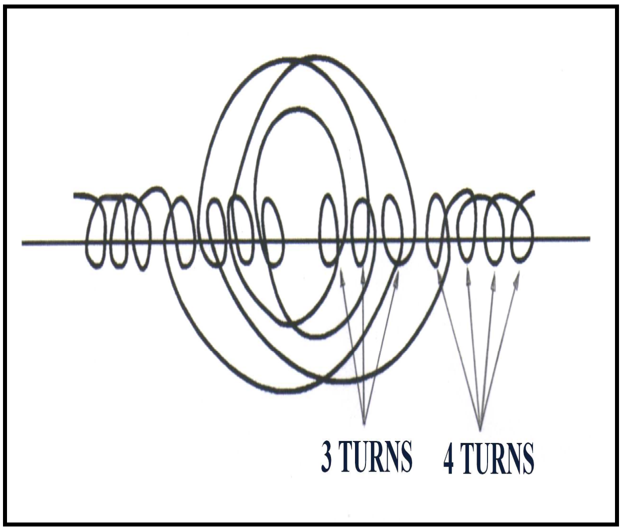


Fig.7. Binding method by using PVC insulated

cable because it will reduce AC breakdown voltage and produce high PD.

c) Avoid using PIC in pollution area.

d) Avoid bending at the binding point as much as possible to reduce the strength of electrical field, especially the insulator at DDE, BA and insulator supported lead line to transformer.

e) In PIC deadend assembling with strand clamp, PIC must be peeled according to the standard.

f) Use the high quality insulator in the pollution area.

g) For PD problem at the deadend of PIC and SAC using preformed line guard (PLG), it can be reduced by peeling the insulation of conductor about 50 mm at the bending point as shown in Fig. 13 .and then binding with tie wire cover PLG about 50 mm. As a result, the potential of PLG is conducted to the potential of aluminium conductor, and PD will be vanished.

6.4.2 Recommendations

a) If noise caused by PD occurs at the position of the insulator support lead line to transformer, lead line at BA and DDE or the new PIC installation, PIC insulation should be used. In addition, if there are some damages on the old cable, peeling the cable at damage point and binding the cable with high voltage tape should be done before using the PIC insulation. However, at the high tension loaded point, the composite tie wire should be used as tie wire.

b) During the construction, try to avoid the damage of PIC and the percolation of water into cable because it will reduce AC breakdown voltage and produce high PD.

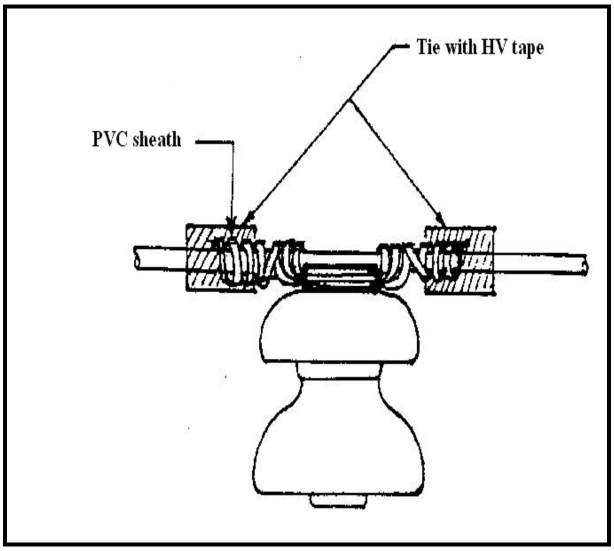
c) Avoid using PIC in pollution area.

d) Avoid bending at the binding point as much as possible to reduce the strength of electrical field, especially the insulator at DDE, BA and insulator supported lead line to transformer.

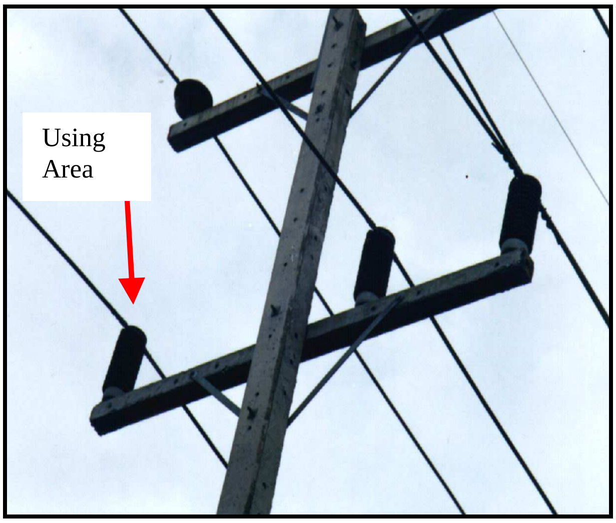
e) In PIC deadend assembling with strand clamp, PIC must be peeled according to the standard.

f) Use the high quality insulator in the pollution area.

g) For PD problem at the deadend of PIC and SAC using preformed line guard (PLG), it can be reduced by peeling the insulation of conductor about 50 mm at the bending point as shown in Fig. 13 .and then binding with tie wire cover PLG about 50 mm. As a result, the potential of PLG is conducted to the potential of aluminium conductor, and PD will be vanished.



a) Position of PVC Sheath



b) Using Area of PVC Insulator

Fig.8. Application of PVC insulated on the insulator

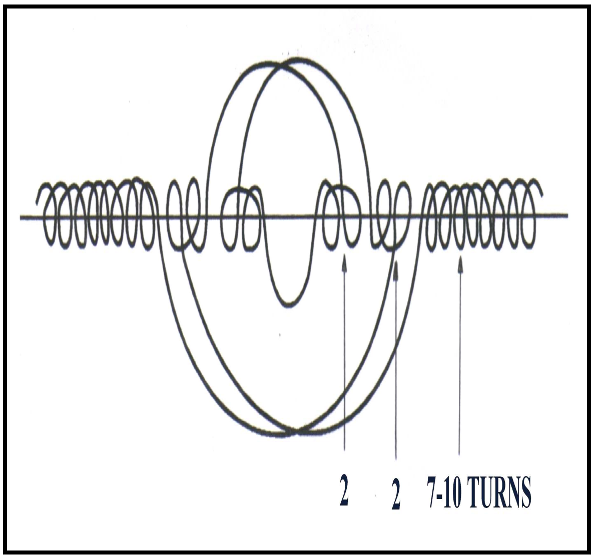


Fig.9. Binding method by using PIC insulation

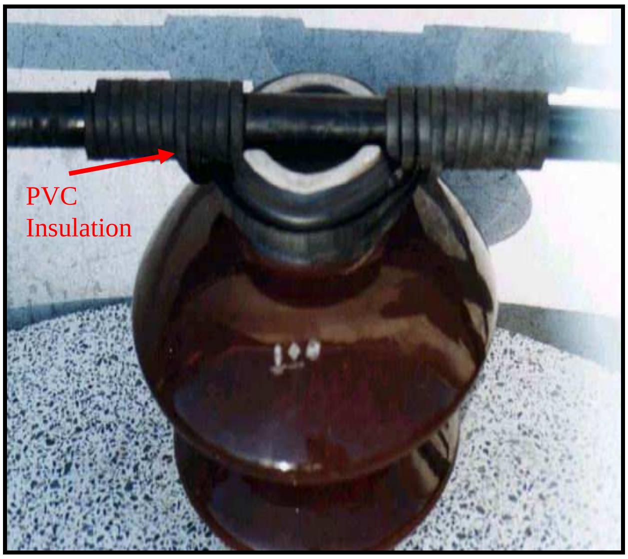


Fig.10. Application of PIC insulation as tie wire

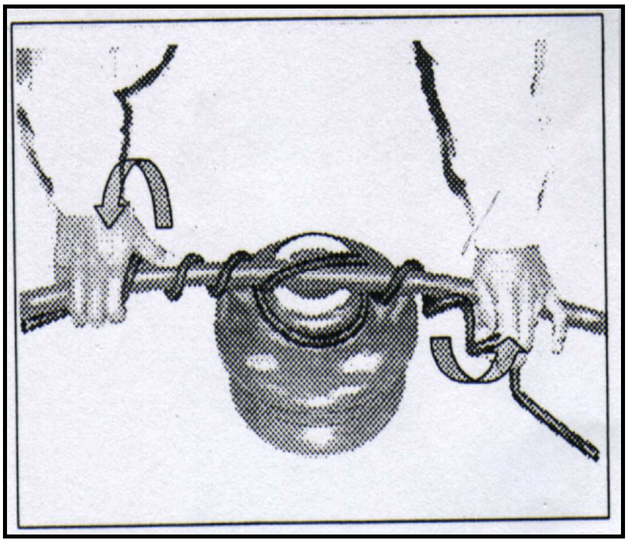


Fig.11. Binding by using composite tie wire

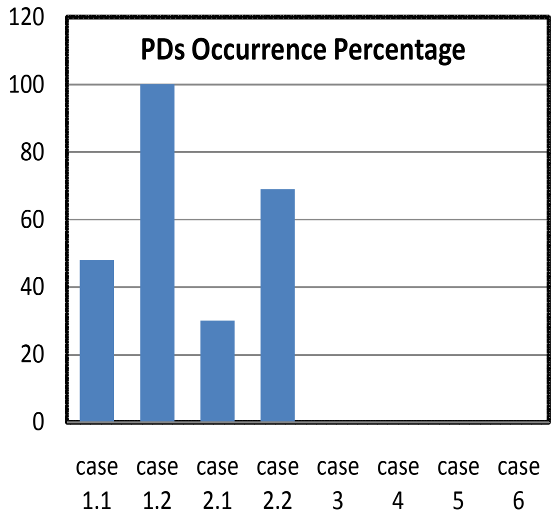


Fig. 12 PDs Occurrence Percentage

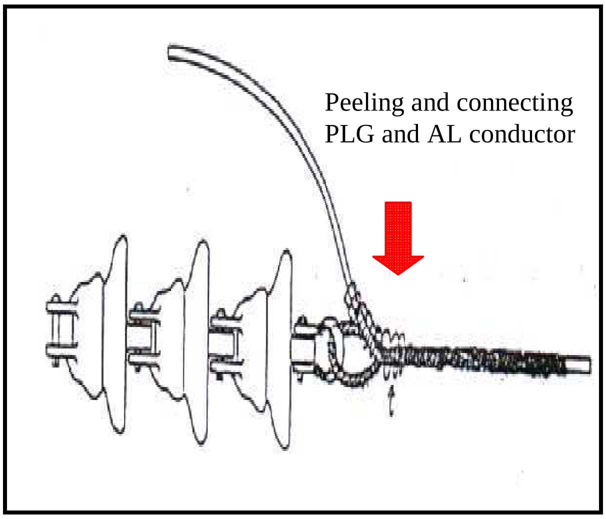


Fig.13. The PD mitigation at the dead end point

7. Conclusions

The PD can occur on the overhead distribution line using the partially insulated cable particularly in the high pollution area. The reason of selecting the insulator which supports lead line at distribution transformer is plenty of PD problems. This study has set up the experiment to solve the PD problem into several cases. It can be concluded that there are two methods that are the most effective ways for PD mitigation. The first is binding PIC by using the PIC's insulation sheath and the second is applying the composite tie wire instead of aluminium tie wire (conventional binding). Because the cost of composite tie wire is relatively high, this study has considered using the PIC's insulation sheath as tie wire in the locations where there are slightly mechanical tension force and use the composite tie wire particular in the areas where mechanical force is high. However, this study has applied this method in the southern area about 25,000 points for fairly mechanical tension force location and about 4,800 points for slightly mechanical tension force location. From history record, PEA has not experienced the problem of PD on PIC any more. However, in order to reduce the magnitude of PD, the partial discharge intensity, the number of PD pulse and the induced voltage in PIC loop are consider for solving this problem in more accuracy and more reliability. The need to apply a considered partial discharge control in power system can be controlled by choosing optimum materials of construction and using on-line partial discharge monitoring. Knowledge-Based Diagnosis of Partial Discharges should be considered for more accuracy. Captured knowledge system describing the visual inspection of these characteristics can be applied for defect diagnosis and position. The knowledge-based system can provide on-line transmission condition assessment of PD activity detected and classification of the defect source.

References:

[1] J.C. Devins, "The Physics of Partial Discharges in Solid Dielectrics", IEEE Trans. of Electrical Insulation, Vol.19, No. 5, pp 475-495, 1984.

[2] S.A. Boggs, “Partial Discharge: Overview and Signal Generation”, IEEE Electr. Insul. Mag., Vol.6, No.4, pp33-39, 1990.

[3] G.P. Cleary and M.D. Judd, “UHF and current pulse measurements of partial discharge activity in mineral oil”, Science, Measurement and Technology, IEE Proc., Vol. 153, No. 2, pp. 47 – 54, 2006.

[4] M.D. Judd, L. Yang and I.B.B. Hunter, “Partial discharge monitoring for power transformers using UHF sensors Part 2: Field Experience”, IEEE Electr. Insul. Mag., Vol. 21, No. 3, pp. 5-13, 2005.

[5] Samruay Sangsa-ad, High Voltage Engineering, 3rd Impression, Bangkok, 2006.

[6] G. Paoletti and A. Golubev, “Partial discharge theory and technologies related to medium-voltage electrical equipment”, IEEE Transactions on Industry Application, Vol.37, No.1, pp. 90-103, Jan/Feb 2001.

[7] F.H. Kreuger, “Partial Discharge Detection in High-Voltage Equipment”, Butterworth&Co. (Publishers) Ltd, 1989.

[8] R. Bartnikas, “Partial discharges, their mechanism, detection and measurement”, IEEE Transactions on Dielectrics and Electrical Insulation, Vol.9, No.5, pp. 763-807, October 2002.

[9] R.E. Lee, D.E. Fritz, P.H. Stiller, D.F. Shankle, “Prevention of covered conductor burndown on distribution circuits -Arcing Protection devices” IEEE Transaction on PAS Vol. 101 No.8, pp. 2434-2438, August 1982.

[10] M. Washino, A. Fukuyama, K. Kito., K. Kato, “Development of current limiting arcing horn for prevention of lightning faults on distribution lines” IEEE Paper 86 SM 363-6,1986.

[11] R.E. Lee, D.E. Fritz, P.H. Stiller, L.A, Killar, D.F. D.F. Shankle “New device reduces conductor burndown on distribution circuits” Electric Light and Power, pp.52-54, August 1980.

[12] K. Nakamura, P.J. Mckenny, M.S. A.A. Hamman, G. Adams, R. Fernandes, F. Rushen, “Impulse Breakdown characteristic of 13.2 kV. covered conductor insulator/tie configurations” IEEE Transaction on Power Delivery, Vol. PWRD-1 No.4, pp. 250-258, October 1986.

[13] Provincial Electricity Authority(PEA),“The Standard of Distribution System Construction”.

BIOGRAPHIES

Narong Mungkung was born in Lopburi Province, Thailand, in 1965. He received the B.S.Ind.Ed. degree in electrical engineering from King Mongkut’s University of Technology, Thonburi, Thailand, in 1992, the M.S.Tech.Ed degree in electrical technology from King’s Institute of Technology, North Bangkok, Thailand, in 1998, the M.S. degree and D.Eng in electrical engineering from Nippon Institute of Technology, Saitama, Japan, in 2000 and 2003. Currently he is Assoc Prof. of Department Electrical Technology Education, Faculty of Industrial Education and technology , King Mongkut’s University of Technology Thonburi, Thailand. His main research interests are in engineering education, electrical discharge, energy conversion system and high voltage.

Tanes Tanitteerapan was born in Yala, Thailand, in 1971. He received the B.S.Ind Ed. in electrical engineering in 1994 from King Mongkut's University of Technology Thonburi, Bangkok, Thailand, the M.S degree in High Voltage Measuring System from Department of Electrical and Electronics Engineering, Nippon Institute of Technology, Saitama, Japan in 2000 and the Doctor of Engineering in Power Electronics Engineering at Mori Shinsaku Laboratory, Nippon Institute of Technology, Japan in 2003. Currently he is Assistant Professor of Department Electrical Technology Education, Faculty of Industrial Education, King Mongkut’s University of Technology Thonburi, Thailand. His research interests include soft-switching power factor correction converters, simple wave shaping techniques for high power factor rectifiers in CCM operation, single-stage power factor correction converters, Photovoltaic Powered Applications, Electrical Teaching Methods.

Weerachai Chaokumnerd is with the telecommunication management , Graduate school, Dhurakij Pundit, Bangkok, Thailand

Karun Morasilp was born in Nakhon Sri Thammarat, Thailand in 1971. He recieved his B.Eng.(in Electrical Engineering) at Prince of Songkla University, Songkhla in 1995 and MBA degree at Ramkhamhaeng University in 1999. Since graduation he has been working for Provincial Electricity Authority (Nakhon Sri Thammarat Office) as an electrical engineer. His responsibility concerns engineering and safety.

Panumat limsuwan has been working for Provincial Electricity Authority at Nakhon Sri Thammarat Office.

Warawut Poolperm has been working for Provincial Electricity Authority at Suratthani Office.

Toshifumi Yuji was born in Miyazaki, Japan, on June 2, 1976. He received the M.E. degree from the University of Miyazaki, Miyazaki, Japan, in 2003 and the Ph.D. degree from the Tokyo Institute of Technology, Tokyo, Japan, in 2007. He became a Research Associate at Hiroshima National College of Maritime Technology in 2005 and Assistant Professor at Oita National College of Technology in 2006. He is currently a Lecturer in Faculty of Education and Culture, University of Miyazaki, Miyazaki, Japan. His research interests are plasma application and electric power installation. He is a member of the Institute of Electrical Engineers of Japan and the Japan Society of Applied Physics.