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Insulation Effects and Characteristics of XLPE Covered Overhead Conductors in Low and Medium Voltage Power Distribution Systems in Iran

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***Abstract*- Advantages of XLPE covered conductors in comparison with bare conductors of low voltage and medium voltage power distribution networks are introduced. The configuration, production and application of these conductors in Iran are discussed and the electromagnetic effects of them are studied through the simulation results carried out by finite element methods.**

I. Introduction

Reliability and safety considerations are one of the most significant problems about the electric power distribution systems. Increasing the reliability of the power distribution networks depends on many factors from network configuration, relaying strategy and weather condition to social and cultural factors. Among these, the overhead distribution networks due to their widespread, being near to customers, passing through different areas and weather dependence considerations have the most important effect on the reliability of electric power distribution networks. Most of the overhead distribution networks consist of bare conductors with high possibility of their faults which can cause power outages or hazards for the personals working on distribution networks where application of non-bare overhead conductors would be a great step to overcome reliability and safety problems.

Among several non-bare overhead Low Voltage (LV) and Medium Voltage (MV) distribution lines, application of Covered Conductors (CC) seems to be the most economic one [1]. The first researches in this field begun in about 1970s in Scandinavian countries where the first covered conductor line began to operate in 1984 in Finland [2,3]. After that, they were utilized in other countries where e.g. nowadays, there are more than 2200 kilometer LV or MV distribution network installed in Norway, 2800 km in Sweden, 3200 km in Finland, 864 km in Slovenia and about 96% of MV distribution overhead lines in South Korea.

Application of CC in great amounts is based on its noticeable technical [4,5] and economical advantages in comparison with conventional bare conductors [8,9] such as:
- Reduction of power interruptions and outages
- Increasing the power distribution network reliability
- Decreasing Energy Not Supplied (ENS)
- Increasing the safety of people and animals
- Reduction of current leakage of bare conductors
- Reduction of fires in jungles due to bare conductors
- Reduction of phase-to-phase and phase-to-earth clearances
- Reduction of Right of Way (ROW) of overhead lines
- Reduction of tree trimming problems
- Reduction of Operation and Maintenance (O&M) costs

The first researches on CC in Iran began in 2004 after a technical meeting of Eastern Azarbayjan Electric Power Distribution Company (EAEPDCO) from Korean Electrical Power Company (KEPCO), South Korea. It is somehow difficult to say exactly about the length of installed CC lines in Iran but it seems to be more than 310 km of LV and 466 km MV since then. Anyway, there is a growing interest in installation of CC where some experts also believe in substituting most of the installed bare conductors with CC [6,7]. Some pictures of the recently installed CC distribution networks in Iran are shown in Fig. 1.

After introducing the main advantages of CC in comparison with conventional bare conductors and the great interest in their application in LV and MV distribution networks, briefly, CC production in Iran and its installations are talked where a finite element analysis has been applied for simulation of electromagnetic fields of CC which has led to describe electrical field around CC in comparison with bare ones.

II. Structure and Production of CC in Iran

Covered conductors consist of two main parts as the conductor and the cover. From technical point of view the conductor could be any type of well-known conductors in overhead distribution lines such as All Aluminum Conductor (AAC), Aluminum Conductor Steel Reinforced (ACSR), All Aluminum Alloy Conductor (AAAC) or Copper Conductor (for LV). On the other hand, covered conductors are divided into two categories depending on their cover thickness as: Covered Conductor (CC) and Full Thickness Covering (CCT). The conductor are covered with a track resistant UV stabilized cross linked polyethylene (XLPE) in CC, while there is an inner non UV resistant XLPE and an outer layer of UV stabilized high density polyethylene (HDPE) in CCT [5,6] as shown in Fig. 2. The thickness of XLPE is usually constant (2 mm) for all working LV and MV while CCT has a specified thickness of covering for each working voltage. CC can withstand intermittent contacts between two phases or one phase to ground, while CCT can remain for extended periods.

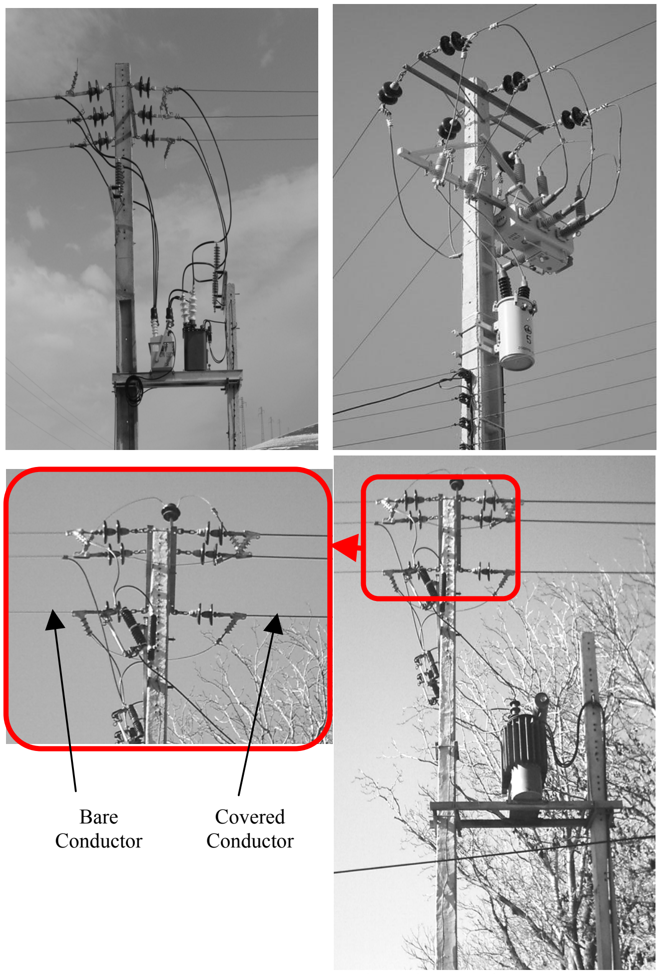

Fig. 1. Pictures of CC distribution networks with covered junctions in Iran.

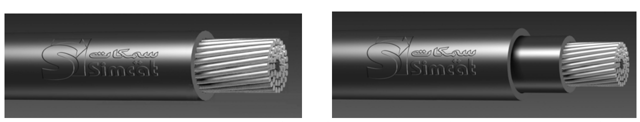

Fig. 2. Construction of covered conductors as CC (left) and CCT (right) produced in Iran.

CC is covered with cross-linked polyethylene (XLPE) as a has a well known insulation for LV and MV cables and wires with the maximum operation temperature of 90^{oc} and resistivity of more than 10^{16} Ω.cm which has good stability against different kinds of acids and oils. Therefore, XLPE cover of CC has better electrical, mechanical and chemical properties. Three common methods for cross-linking of polyethylene (PE) and covering bare conductors with XLPE includes Peroxide method, Vinilsilan method and Betta Ray Radiation where both Peroxide and Vinilsilan methods are utilized in Iran [6].

In peroxide method, the cross-linking of PE occurs due to existence of peroxide materials which are activated by heating for cross-linking of PE molecules in temperature of $180–220^{oc}$. This process can be done by extruders only in one stage. In Vinilsilan method, the Vinilsilan molecules should be used for cross-linking of PE which is done in two stages. In the first stage, the Vinilsilan mixtures inside the Extruder with other additives in special conditions and the resultant material cover the conductor and in the second stage, the covered conductors are stayed in a high temperature steam room. The picture of an extruder utilized in SIMCAT Co. as one of the pioneer CC producing companies in Tabriz, Iran applied for covering bare conductors with XLPE is shown in Fig. 3. This extruder is capable of producing 40 meters of CC per minute. Comparing these methods, it should be noticed that peroxide method need higher initial investment, lower production speed and more wasted materials compared with Vinilsilin method but its advantage is single stage operation. On the other hand, Beta ray radiation method needs high technology apparatuses and its production cost is very high compared with other methods [6].

The main standards for production of CC in the world are the Finish standards, SFS 5790, 5791 and 5792 and the Australian standard, AS/NZS 3675 where in Iran Finish standard SFS 5791 is utilized.

Fig. 3. Pictures of an Extruder used for CC production in Iran.

III. Finite Element Analysis of CC Electromagnetic Field

Finite Element Methods (FEM) are widely used in many engineering applications. Indeed, FEM studies have been used for a number of years in the cable manufactory industry in general and the insulation technology in particular to develop accessories. This is evident by the wide rang of modern cable of improved design and performance. A main salient advantage of FEM in CC performance is its capability for electric and magnetic field analysis around and within CC in all cases such as: transient and short circuits, unbalanced conductors or polluted by water or moisture, water ingress [8] and etc.

The assumptions that were used in the calculation of magnetic fields are the following:

- The length of CC is of 1m, so that magnetic field is treated as 2D. Charges and displacement currents are neglected.
- The conductors and the sheath have constant conductivity and relative permeability.
- The phase current is sinusoidal and balanced.
- All analysis is based on magneto-static.
- Because of symmetrical topology of CC, all simulations are based on axis-symmetric simulation.

These assumption model leads to a linear, steady state electromagnetic field which is governed by Maxwell's equations:

$$\nabla \times \vec{H} = \vec{J} \qquad (1)$$

$$\nabla \bullet \vec{B} = 0 \quad (2)$$

Ohm’s law at a point:

$$\vec{J} = \sigma \vec{E} \quad (3)$$

The continuity relation:

$$\nabla \bullet \vec{J} = 0 \quad (4)$$

And the constitutive relation:

$$\vec{B} = \mu_0 \mu_r \vec{H} \quad (5)$$

Introducing the magnetic vector potential with:

$$\nabla \times \vec{A} = \vec{B} \quad (6)$$

$$\nabla \bullet \vec{A} = 0 \quad (7)$$

From above equations we get:

$$\nabla \times (\vec{E} + jw \vec{A}) = 0 \quad (8)$$

Fig. 4 shows the cross section and topological configuration of considered CC.

The boundary conditions are defined using (18) and (19) [9,10]:

$$\hat{n} \times (A_2 - A_1) = 0 \quad (9)$$

$$\hat{n} \bullet (A_2 - A_1) = 0 \quad (10)$$

where A is a magnetic potential vector. Eq. (9) describes the behavior of the tangential components of the field and Eq. (10) states that the normal component is continuous. Thus saying that the tangential and normal components of A are continuous and we have chosen $A_2 = A_1 = 0$ at the boundary.

This boundary condition is a Dirichlet condition and is used as definition of infinity and axis-symmetry. Fig. 5 shows these boundary conditions in axis-symmetry considered CC. Fig. 6 shows considered CC using tri-angular first order mesh. Figures 7 and 8 show the magnetic field density around and within of CC respectively. Note that unit system is CGS. Fig. 9 shows the magnetic field intensity around CC in GGS. Fig. 10 shows the electrical field intensity around the CC.

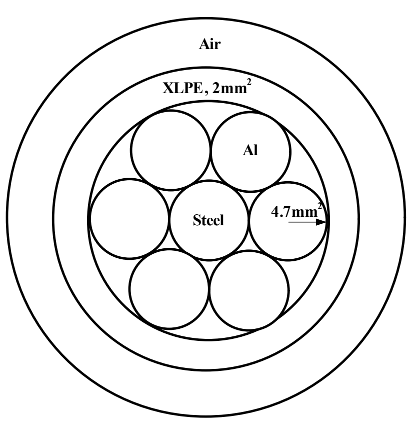

Fig. 4. Cross section of the simulated CC.

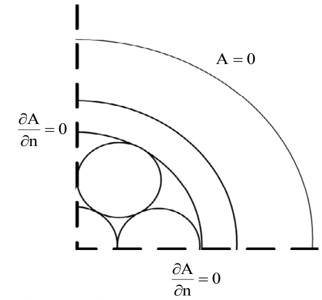

Fig. 5. Boundary condition in axis-symmetry considered CC.

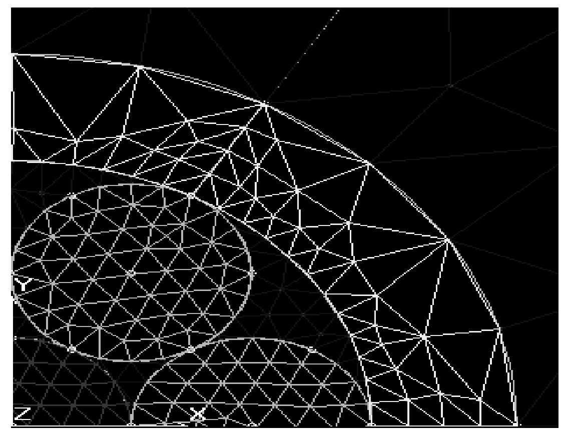

Fig. 6. Meshed CC using tri-angular first order mesh.

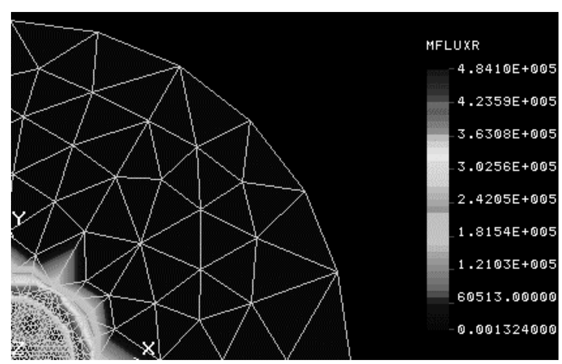

Fig. 7. Magnetic field density around CC in CGS.

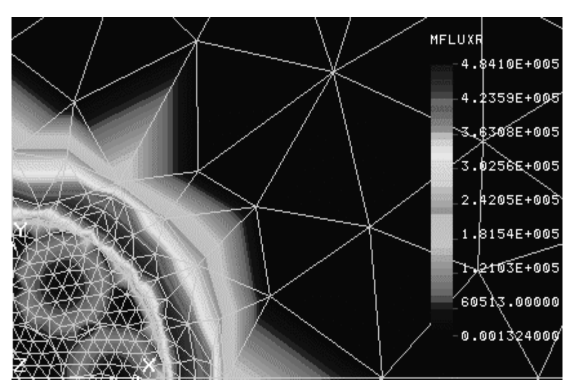

Fig. 8. Magnetic field density within CC in CGS.

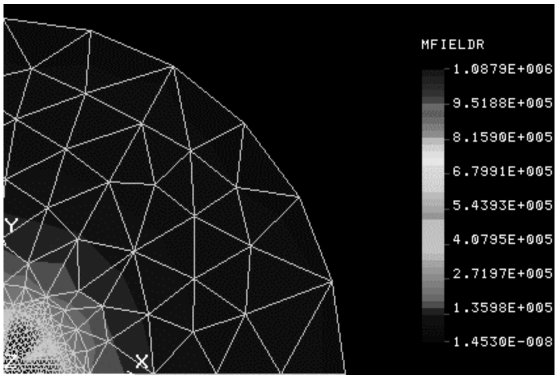

Fig. 9. Magnetic field intensity around CC in GGS.

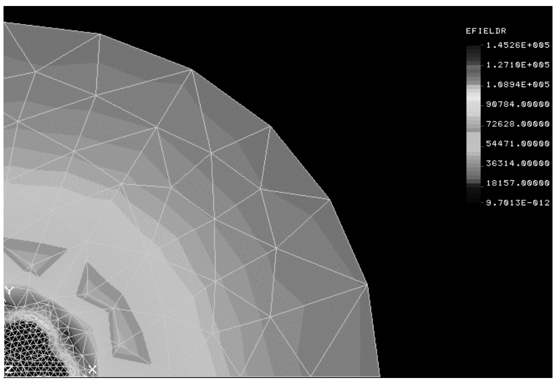

Fig. 10. Electrical field intensity around the CC.

IV. Conclusion

The characteristics of XLPE covered conductors for LV and MV power distribution systems as new increasing insulation equipment in the power distribution system of Iran were discussed. XLPE covered conductors can lead to a decrease in phase clearances, ROW, O&M costs, power outages and increase the reliability and safety of the power distribution networks. Studying configuration and production procedure of CC, it is expected that it would be capable of replacing the bare conductors in the distribution networks greatly. Meanwhile, the electromagnetic field characteristics inside and outside of CC were studied through FEM simulations for studying the XLPE characteristics on the conductors.

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