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A Study on Electrical Design Considerations of Power Transmission Lines

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ABSTRACT: The power is generated as a three phase for the reliable operation of the power system network and the generated power from the generation station end to the consumer end is transmitted as a three phase three wire. Such power which should be transmitted from source end to the load end should be made to be transmitted through conductors made of proper material coordinated with required insulation, conductor size and many more electrical designations. This paper presents the electrical design of such conductor through which the power is being transmitted by considering all the electrical requirements.

KEYWORDS: Bundled Conductor, Carona, Homogeneous Conductor, Line Conductor, Stranded Conductor.

I. INTRODUCTION

We will generate the power at the generating station and transmit the power through conductors or feeders to the consumer end called transmission lines. Though it is simple to think that the power is being transmitted through the conductor, it is quite time consuming and complex to design such conductors not for transmission of power but for better transmission of power. Such a design is however bothered by both mechanical and electrical theories; we here in this paper consider electrical theories majorly.

II. SELECTION OF MATERIAL

There are majorly four materials which can be used as a link between generation station and terminal end of consumer. They are Copper (Cu), Silver (Ag), Aluminum (Al) and Gold (Au). Gold however as being costlier can't be used as a transmission line as we can't effort such a huge gold regarding economy. Even silver is also not used as it is having high conductivity. The problem with high conductivity is that, it has high eddy current losses. Among the Copper and Aluminum, Aluminum is preferable as it having low cost compared to the copper. Though this is one of the reason for using the aluminum rather than copper, this is not the only one. The main reason for using aluminum conductor than copper conductor is because of the relatively large resistivity of the aluminum conductor. As the resistivity of the aluminum conductor is large, for fixed resistance the cross sectional area of the aluminum conductor will be more compared to copper conductor which makes the concentration of charge on the aluminum conductor surface lesser than the copper conductor. The concentration of charge on the surface of the conductor dictates the electric field intensity of that particular conductor. As the electric field intensity decides the Carona loss, the transmission line is designed with aluminum as the conductor material.

$$\rho_{Al} = 2.82 \times 10^{-8} \Omega - m$$

$$\rho_{Cu} = 1.68 \times 10^{-8} \Omega - m$$

$$\rho_{Al} > \rho_{Cu}$$

=>

$$a_{Al} > a_{Cu}$$

$$[R = \rho l/a]$$

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III. INSULATION

The voltage rating of the transmission line is measured as line to line rms voltage value. It means when the transmission line is in operation that much voltage is impressed between the transmission line and the ground. There is a chance of breakdown of the air in between the line conductor which transmits the power and the tower structure as the breakdown voltage of air is around 21 kv rms which is very much less than the operating voltage of the transmission line at that particular point between tower structure and the ground. This makes a conducting path between the line conductor and the tower structure and then to the ground which results shunt current or short circuit current or fault current as the current is through an undesirable path. To avoid this shunted paths insulation is placed between the line conductor and the tower structure. Note that though the transmission line is designed for line to line value, the insulation is designed for phase value of peak voltage as the shunted path is formed between the line conductor which is at higher potential and the tower structure which is grounded.

Though the level of transmission levels and conductor voltages are not mentioned in this paper, we should keep in mind that the level of insulation placed in the power system network differs according to the severity of the switching overvoltage or lightning overvoltage. For voltage level less than 400 kv the level of insulation is designed based on the lightning over voltages whereas the level of insulation is designed based on the switching overvoltage for voltage level of 400 kv or above. The readers should keep in mind that the lightning overvoltage in this paper is not mentioned whether it is direct lightning overvoltage or indirect lightning voltage because the problem of direct lightning voltage though mentioned or not, will be protected by using a ground wire or shield wire made up of galvanized steel. Similarly the conductor cross section also depends on the factor of comparison among the corona loss or normal power loss of the line. As a matter of fact the selection of conductor is done based on the current density or current rating for line voltage less than 220 kv and the selection of conductor is based on the corona loss for line voltage more than 220 kv.

overhead line insulation level \propto voltage rating

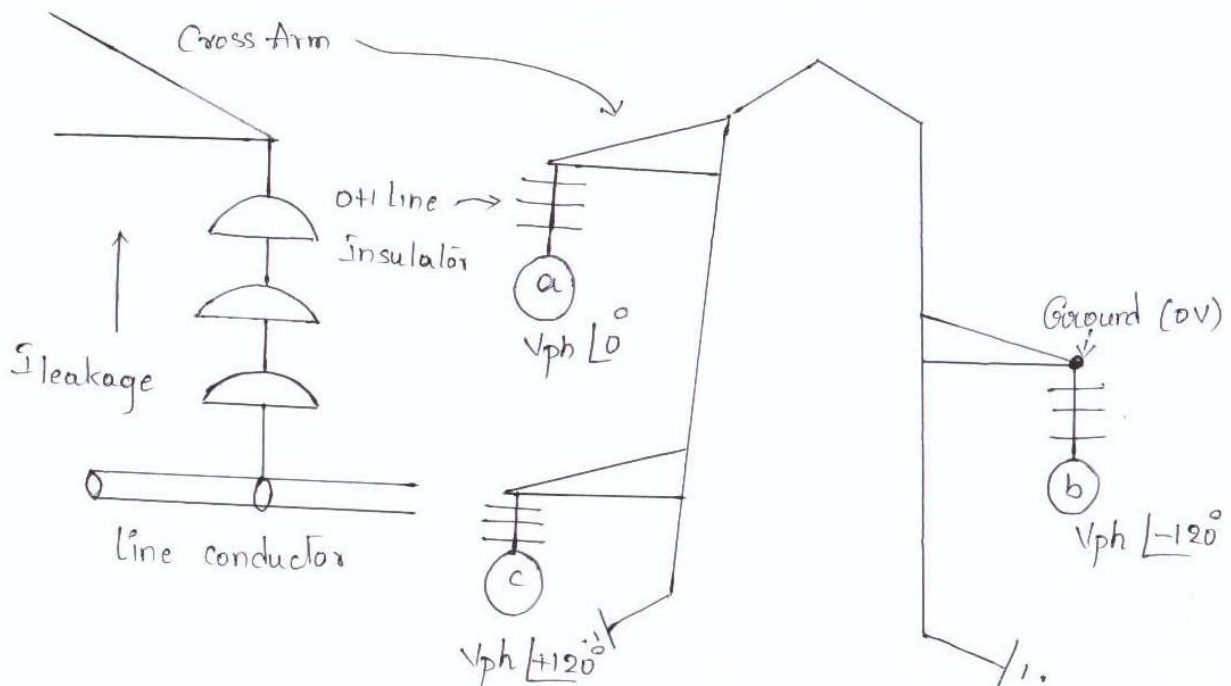


Fig. 1 Placement of conductors on a tower

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IV. TYPES OF INSULATORS

1. Pin type or Suspension type :- Though many of the authors mention or classify pin type and suspension type separate, they both can be referred as one type because the construction of both the insulators are same inspite of the voltage ratings they are used for. Generally these types of insulators have two shells called as top and bottom shell. The use of two shells is only for the sake of reliability such that the top shell provides protection for the bottom shell.

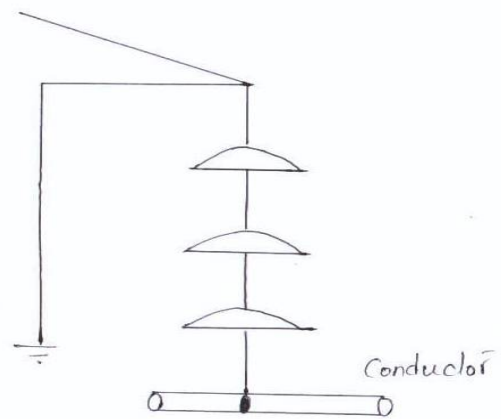
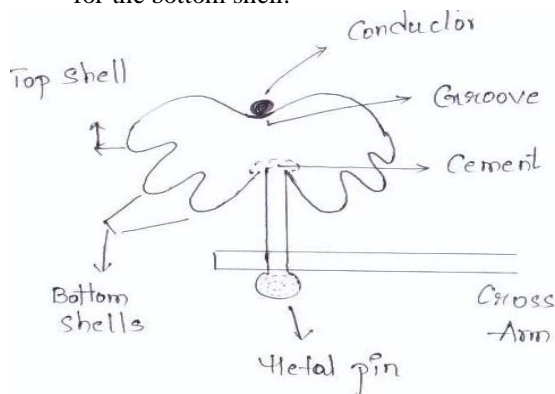


Fig. 2 Pin type insulator and its placement with associated tower and conductor

2. Shackle type or Strain type :- These are the insulators designed for the special purpose of taking strain away at the routes having bends and hence the name strain type insulators. Suspension type insulators are placed below the cross arm vertically whereas the strain type insulators are placed horizontally or perpendicularly to the tower structure and the line conductor is riveted at the other end. The use of suspension type insulator is more compared to the strain type but the efficiency is quite verse owing to the fact that as we move from the tower end to the conductor end the distance between the ground and the line conductor increases incase of the strain insulator. This decreases the capacitance and in turn decreases the charging currents between the top of the insulator disc and the tower structure (ground). Therefore the string efficiency of the string increases.

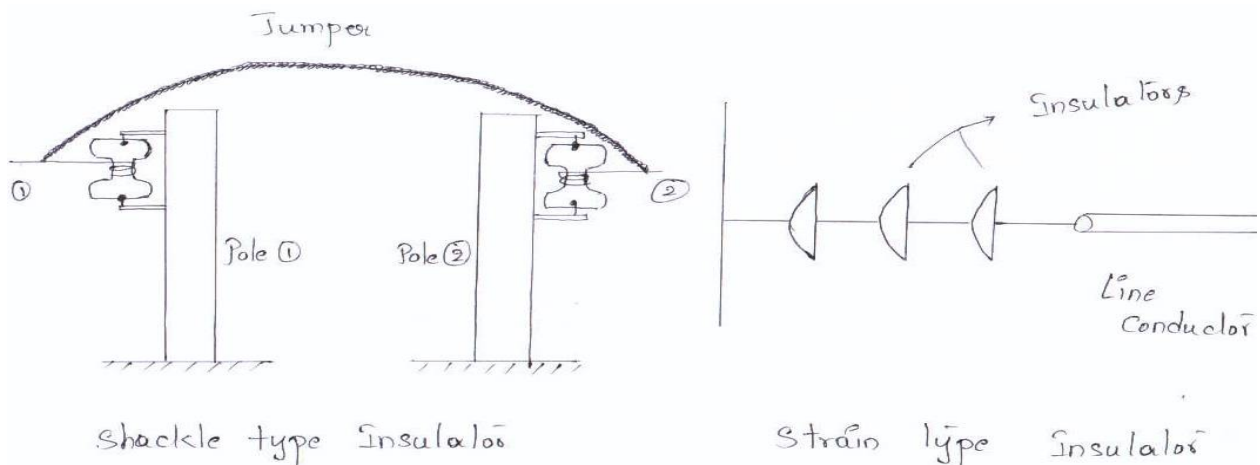


Fig. 3 Shackle type insulator and Strain type insulator

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- Besides the above two insulators there are some other types of insulators like aerofoil type which are used at the places where there is high air pollution, antifog type insulators which are used at the places where there is high fog deposition. There is also one more insulator majorly used in between the tower and the earth through earth wire which is called as stay wire insulator. This stay wire insulator serves the purpose of both maintaining the tower at equal geometrical distance from the ground and to ground the leakage currents through the ground.

V. CONDUCTOR

Besides the type of conductor materials and insulators used the alignment or geometry of the conductors placed decides the efficient transmission of the power generated. Before going to the geometry of the conductors used we should keep in mind that at the design stage the current carrying capability is proportional to the area of cross section of the conductor. For perfect understanding of the conductor design go through the second paragraph of section III.

$$\text{area of conductor} \propto \text{current rating} \Rightarrow a \propto I_L$$

Corona → Sound (Audible)



Light blue colour (or)
violet colour glow is visible
on the surface of the conductor.

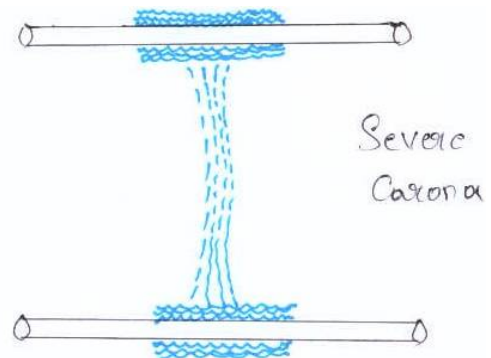


Fig. 4 Corona effect

VI. TYPES OF CONDUCTORS

- Single strand conductor :-** These are never used in the transmission systems because of the problem of the skin effect. Skin effect can be explained in many ways by many authors, but in this paper as my motive is to discuss about the conductor geometry in this section, I simply says that the skin effect is the property of the conductor to allow current to be flown over its surface. This is due to the fact that when we move from the centre point of the conductor to the surface (only in case of solid conductor) the radius of the conductor gets increased which inturn increases the area of cross section of the conductor (keeping length of the line as constant) and hence the resistance of the conductor will decrease as we move from centre to the surface of the conductor. Keep in mind that it is a disadvantage as skin effect is a type of loss as the complete conductor cannot be used for the power transmission.
- Stranded conductor :-** The alternative for reducing the skin effect in transmission system is to use the stranded conductor. A number of strands are taken and twisted together. Note that all the strands should be of same size and same material (homogeneous conductor or AAC). In addition to the benefit of reduction in skin effect it is also having a benefit of easy transportation as the string of this stranded conductor is easy. By using the stranded conductor the skin effect is decreased in the transmission system however there are certain disadvantages. The disadvantages of homogeneous conductor are as follows: 1. Reduced mechanical strength

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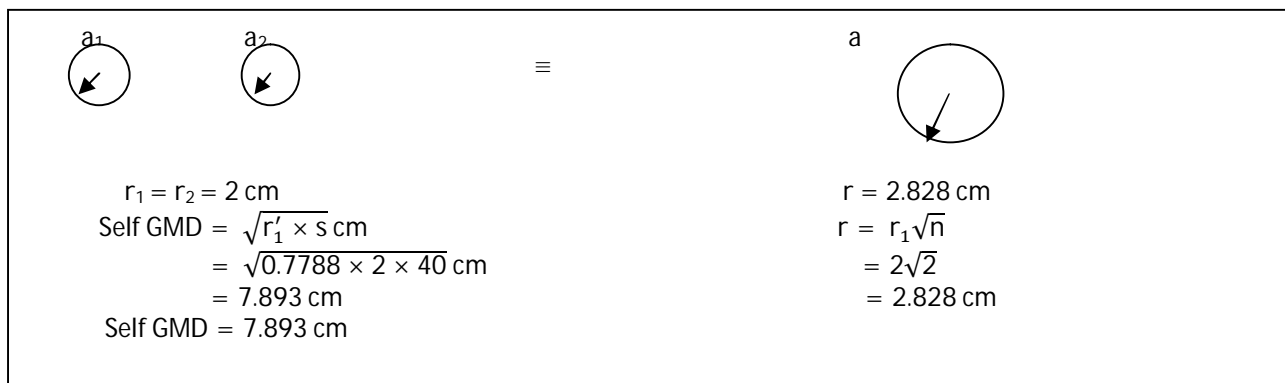
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as the strands are having gaps in between them, 2. increased carona effect as the surface is not smooth and 3. The conductor material used for the same power transfer in case of stranded conductor is more than solid conductor because of the spirality effect.

3. Composite stranded conductor :- By keeping the stranded conductor as it is the mechanical strength should be increased as this is of more importance compared to all other disadvantages. For this the central strand is replaced with the steel strand (ACSR) which is having high tensile strength compared to aluminum. The only disadvantage of the composite stranded conductor is increased skin effect compared to the AAC because the central steel strand as having high resistance doesn't carry any of the current where as it is not the case with the central being aluminum conductor in AAC case.
4. Expanded ACSR conductor :- This is same as the ACSR conductor except with a modification of keeping some insulation material between the already existing strands. The advantage of placing the insulation between the strands is the increased effective area. As it is already mentioned in the section II that the increased area reduces the carona effect, the same application for the reduction of carona loss is applied here.
5. Bundled Conductor :- As it has been explained already that the selection of conductor is done based on the carona for the transmission lines operating with or above 220 kv, our transmission line should consider the carona loss as of primary importance. Hence the replacement of all the above conductors makes the design of the new conductor called bundled conductor. Besides reducing the carona effect the following are the advantages of using the bundled conductors.
 - i. Reduction in inductance of the line and hence the reactive power requirement. (Observe equation 1)
 - ii. Increase in the capacitance of the line and hence the decrease in the reactive power requirement of the line. (Observe equation 2)
 - iii. Increase in the surge impedance of the line. (Observe equation 3)
 - iv. Increase in the power transfer capability of the line. (Observe equation 4)

One shouldn't be confused that how the use of the bundled conductors gives all the above advantages. To have a brief idea above all the above advantages the forgoing analysis helps the readers. Before going to the foregoing analysis the reader should keep in mind that though there are many other factors like reduction in voltage levels, increased cross arms length which reduces the carona the author is using this method because this method is the reliable one and the applicable one.



$$L/\rho h = 2 \times 10^{-7} \ln \frac{\text{GMD}}{\text{GMR}} \frac{H}{m} \rightarrow \text{equation 1}$$

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$$C_{/ph} = \frac{2\pi \epsilon_0 \epsilon_r F}{\ln \left(\frac{GMD}{GMR} \right) m} \quad \rightarrow \text{equation 2}$$

$$Z_c = \sqrt{\frac{L}{C}} \quad \rightarrow \text{equation 3}$$

$$P_{max} = \frac{V_S V_R}{Z_c} \quad \rightarrow \text{equation 4}$$

Hence because of the above advantages the line should be designed in such a way that the self GMD of bundle conductor system is greater than GMR of its equivalent single conductor system.

VII. CONCLUSION

It can be concluded that the link between the generating station and consumer station should be laid with aluminum as material, by placing proper insulation between the tower structures and the line conductors. In addition to this the conductor system used should be bundled conductor system for proper and efficient power transmission.

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