

CORONA EFFECTS ON EHV AC TRANSMISSION LINES

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ABSTRACT

Industrial minded countries of the world require a vast amount of energy of which electrical energy forms a major fraction. The distance between generating stations and load centres as well as the amount of power to be handled increased to such an extent that 220 KV was inadequate to handle the problem so extra high voltage lines of about 1200KV are used. But the problems posed in using such high voltages are different from those encountered at lower voltages. One of the major problems is due to Corona. This paper deals with properties of bundled conductors, corona loss formulae, factors affecting corona loss, corona effects on EHV AC transmission lines, applications of corona discharge and methods to reduce corona. The aim of this paper is to make review of corona effects on EHV AC transmission lines.

Keywords: Bundled conductors, corona, EHV AC transmission lines, radio interference.

I. INTRODUCTION

Extra High Voltage transmission lines are used mainly for bulk power transmission. Bundled conductors are exclusively used for EHV transmission lines. Only one line in the world that of the Bonneville Power Administration in the U.S.A, has used special expanded ACSR conductors of 2.5 inch diameter for their 525KV line. As of now a maximum of 8 sub- conductors have been used for 1150-1200 KV lines. Corona Discharge Effect in the transmission lines is a phenomenon in which ionization of the surrounding air of power conductors takes place at voltages, greater than critical break down voltage. When the potential between the power conductors of transmission lines in a Extra High Voltage (EHV) system goes on increases hissing noise, followed by the violet glow and the production of ozone gas and finally electrical breakdown and flash over is observed, all these constitutes the Corona Discharge Effect Phenomenon. Corona Discharge Effect is defined

as Self Sustained Electric Discharge in which the field Intensified Ionization is localized only over the portion of the distance between the electrodes. This paper will contribute in studying that how corona affects EHV lines and how can we minimize corona discharge.

II. PROPERTIES OF BUNDLED CONDUCTORS

(i) Bundle spacing and Bundle radius:

In almost all cases, the sub conductors of a bundle are uniformly distributed on a circle of radius R. there are proposals to space them non - uniformly to lower the audible noise generated by the bundle conductor, but we will develop the relevant geometrical properties of an N conductor bundle on the assumption of uniform spacing of the sub conductors. It is also reported that the flashover voltage of a long air gap is increased when a non – uniform spacing for sub conductors is used for the phase conductor.

The spacing between adjacent sub conductors is termed ‘ Bundle spacing’ and denoted by B. the radius of the pitch circle on which the sub conductors are located will be called the ‘Bundle radius’, denoted as R. The radius of each sub conductor is r with diameter d. The angle subtended at the centre by adjacent sub conductors is $2\pi/N$ radians.

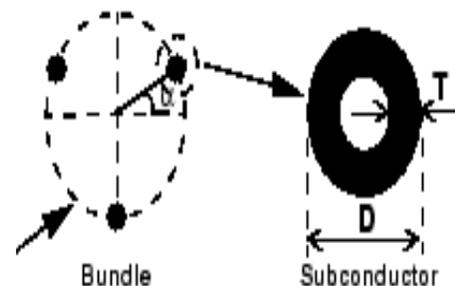


Fig.1

$$B/2 = R \sin[\pi/N] \text{ giving } B = 2R \sin[\pi/N]$$

(ii) Geometric mean radius of Bundle (Equivalent Radius):

Except for calculating the surface voltage gradient from the charge of each sub conductor, for most other calculations the bundle of N sub conductors can be replaced by a single conductor having equivalent radius. This is called ‘Geometric mean radius’ denoted by r_{eq} .
 $r_{eq} = R(N.r/R)^{1/N}$

III. HOW CORONA DISCHARGE EFFECT OCCUR

In a power system transmission lines are used to carry the power. These transmission lines are separated by certain spacing which is large in comparison to their diameters. In Extra High Voltage system when potential difference is applied across the power conductors in transmission lines then air medium present between the phases of the power conductors acts as insulator medium however the air surrounding the conductor subjects to electro static stresses. When the potential increases still further then the atoms present around the conductor starts ionize. Then the ions produced in this process repel with each other and attracts towards the conductor at high velocity which intern produces other ions by collision. The ionized air surrounding the conductor acts as a virtual conductor and increases the effective diameter of the power conductor. Further increase in the potential difference in the transmission lines then a faint luminous glow of violet colour appears together along with hissing noise. This phenomenon is called virtual corona and followed by production of ozone gas which can be detected by the odor. Still further increase in the potential between the power conductors makes the insulating medium present between the power conductors to start conducting and reaches a voltage (Critical Breakdown Voltage) where the insulating air medium acts as conducting medium results in breakdown of the insulating medium and flash over is observed. All this above said phenomenon constitutes Corona Discharge Effect in electrical Transmission lines.

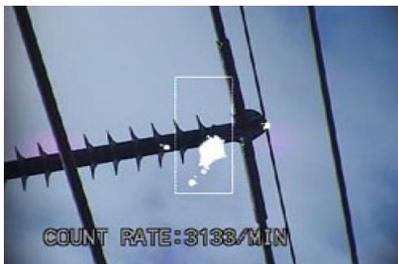


Fig.2

IV. CORONA LOSS FORMULAE

Corona loss formulae can be classified as:

(i) Those based on Voltages

- Linear relationship:

Skilling’s formula $P_c = V - V_o$

Where, V= actual voltage of conductor

V_o = corona inception voltage

- Quadratic relationship:

Peek’s formula $P_c \propto (V - V_o)^2$

Ryan and Henline formula $P_c \propto V(V - V_o)$

Peterson’s formula $P_c \propto V^2 \cdot F(V/V_o)$

where F=experimental factor

- Cubic relationship:

Foust and Menger formula $P_c \propto V^3$

Prinz’s formula $P_c \propto V^2(V - V_o)$

(ii) Those based on voltage gradients

- Nigol and Cassan formula $P_c \propto E^2 \ln(E/E_o)$
- Project EHV formula $P_c \propto V \cdot E^m, m=5$

We will here quote some formulas useful for evaluating 3-phase corona loss in KW/Km, which are particularly adopted for EHV lines.

1. Nigol and Cassan formula

$$P_c = K.f.r^3.\theta.E^2.\ln(E/E_o)$$

Where f = frequency in Hz

r= conductor radius in cm

θ =angular portion in radians of conductor surface where the voltage gradient exceeds the critical corona inception gradient.

E=effective surface gradient at operating voltage V, r.m.s

E_o = corona inception gradient for given weather and conductor surface condition, r.m.s

K= a constant which depends upon weather and conductor surface condition

2. Anderson, Baretzky, McCarthy Formula

An equation for corona loss in rain giving the excess loss above the fair weather loss in KW/3-phase Km is:

$$P_c = P_{FW} + 0.3606K.V.r^2 \ln(1+10\rho).\Sigma E^5$$

Where P_{FW} = total fair weather loss in KW/Km
 = 1 to 5 KW/Km for 500KV
 = 3 to 20 KW/Km for 700KV

$K = 5.35 \times 10^{-10}$ for 500 to 700 KV lines
 = 7.04×10^{-10} for 400 KV lines

V = conductor voltage in KV

E = surface voltage gradient on the underside of conductor, KV/cm, peak

ρ = rain rate in mm/hour

r = conductor radius in cm

N = number of conductors in bundle of each phase

V. FACTORS AFFECTING CORONA LOSS

(i) Electrical Factors:

Higher the frequency of supply, higher are corona losses. This shows that dc corona losses is less as compared to ac corona.

(ii) Field around the conductor:

The field around the conductor in addition to being a function of the voltage depends upon the configuration of conductors. If the formation is horizontal the field near the middle conductor is large as compared to the outer conductors, hence corona on the middle conductor is more than outer conductors. The height of conductors from the ground has its effect on corona loss. The smaller the height, the greater the corona loss.

(iii) Atmospheric Factors:

Corona loss is more on hilly areas where temperature is low and pressure is high. The particles of dust clog to the conductor, which increases corona. Similarly, bad atmospheric conditions such as rain, snow, hailstorm increases corona.

(iv) Heating of the conductors by load current:

The heating of conductor by load current has an indirect reducing effect on the corona loss. Without such heating the conductor would tend to have a slightly lower temperature than the surrounding air. In the absence of heating, dew in the form of tiny water drops would form on the conductor in foggy weather or at times of humidity, which induces additional corona.

VI. EFFECTS OF CORONA

1) Audible Noise:

When corona is present on the conductors, EHV lines generate audible noise which is specially high during foul weather. The noise is broadband which extends from very low frequency to about 20 KHz. Corona discharges generate positive and negative ions which are alternately attracted and repelled by periodic reversal of polarity of the ac excitation. Their movement gives rise to sound pressure waves at frequencies of twice the power frequency and its multiples, in addition to broadband spectrum which is the result of random motion of ions. Since audible noise is manmade, it is measured in the same manner as other types of manmade noise such as aircraft noise, automobile ignition noise, transformer hum, etc. therefore, it is measured in decibels.

Frequency Spectrum

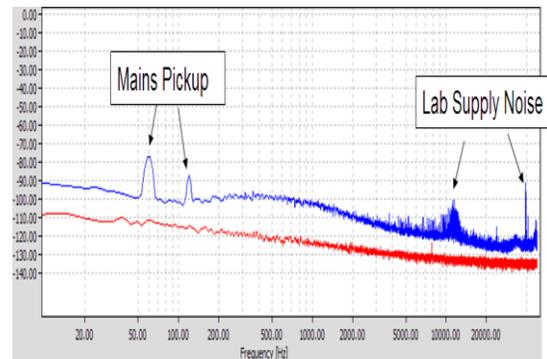


Fig.3

2) Radio Interference:

Pulse type of corona gives interference to radio broadcast in the range of 0.5 MHz to 1.6 MHz. In addition to corona generated on line conductors, there are spark discharges from broken insulators and loose wires which interfere with TV reception in the 80 – 20 MHz range. Corona on conductors also causes interference to Carrier Communication and Signaling in the frequency range 30-500 KHz.

As in most gas discharge phenomenon under high impressed electric fields, free electrons and ions are created in space which contain very few initial electrons. We can therefore expect a buildup of resulting current in the conductor from a zero value to maximum or peak caused by the avalanche mechanism and their motion towards the proper electrode. Once the peak value is

reached there is fall in current because of lowering of electric field due to relatively heavy immobile space charge cloud which lowers the velocity of ions. We can therefore expect pulses to be generated with short crest times and relatively longer fall times.



Fig.4

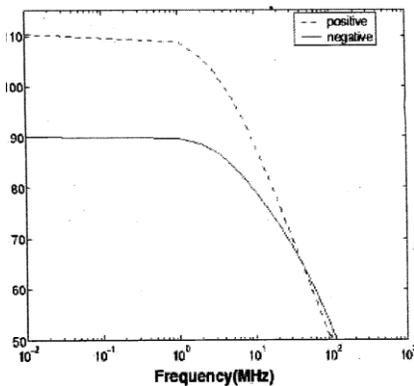


Fig. 5 Frequency spectrum

3) Induced Currents:

Electric currents can be induced by electric and magnetic fields in conductive objects near transmission lines. For magnetic fields, the concern is for very long objects parallel and close to the line. However, the majority of concern is related to the potential for small electric currents to be induced by electric fields in metallic objects close to transmission lines. Metallic roofs, vehicles, vineyard trellises, and fences are examples of objects that can develop a small electric charge in proximity to high voltage transmission lines. Under adverse circumstances these give rise to shock currents of various intensities.

Shock currents can be classified as:

- **Primary shock currents:** These cause direct physiological harm when the current exceeds about 6-10 mA. The normal resistance of human body is about 2-3 Kiloohms so that about 25 volts may be necessary to produce primary shock currents. The danger here arises due ventricular fibrillation which affects the main pumping chambers of the heart. This results in immediate arrest of blood circulation. Loss of life may

be due to arrest of blood circulation when current flows through heart, permanent respiratory arrest when current flows in the brain, and asphyxia due to flow of current across the chest preventing muscle contraction. The electrocution equation is $i^2t=K$, where $K= 165$ for a body weight of 50 Kg, I is in mA and t is in seconds. For $i=10$ mA, the current must flow for a time interval of 272 seconds before death occurs in a 50 Kg human being.

- **Secondary shock currents:** These can not cause direct physiological harm but may produce adverse reactions. They can be steady state 50 Hz or its harmonics or transient in nature. The latter occur when a human being comes into contact with a capacitively charged body such as parked vehicle under a line. Steady state currents upto 1 mA cause a slight tingle on the fingers. Currents from 1 to 6 mA are classed as, 'let go' currents. At this level, a human being has control of muscles to let the conductor go as soon as tingling sensation occurs. For a 50% probability that a let go current may increase to primary shock current, the limit for men is 16 mA and for women 10 mA. A human body has an average capacitance of 250 pF when standing on an insulating platform of 0.3m above ground. In order to reach the let go current value, this will require 1000 to 2000 volts. Human beings touching parked vehicles under the line may experience these transient currents, the larger the vehicle the more charge it will acquire and greater is the danger.

VII. METHODS TO REDUCE CORONA DISCHARGE EFFECTS

- 1) *Large Dia Conductors*
- 2) *Hollow conductors*
- 3) *Bundled conductors*

Large Dia and Bundled conductors reduce corona losses. The idea of using hollow conductors is again the same. In one of the designs one or more layers of copper wires are stranded over a twisted I-beam core. Another design consists of tounge and grooved copper segments spiralled together to form a self supporting hollow tube. This conductor has smooth surface. These special conductors are more effective in reducing corona.

VIII. APPLICATIONS OF CORONA DISCHARGE

1. Drag reduction over a flat surface

2. Removal of unwanted electric charges from the surface of aircraft in flight and thus avoiding the detrimental effect of uncontrolled electrical discharge pulses on the performance of avionic systems
3. Manufacture of ozone
4. Sanitization of pool water
5. Scrubbing particles from air in air-conditioning systems
6. Removal of unwanted volatile organics, such as chemical pesticides, solvents, or chemical weapons agents, from the atmosphere
7. Improvement of wettability or 'surface tension energy' of polymer films to improve compatibility with adhesives or printing inks
8. Production of photons for Kirlian photography to expose photographic film
9. EHD thrusters, Lifters, and other ionic wind devices
10. Ionization of a gaseous sample for subsequent analysis in a mass spectrometer or an ion mobility spectrometer
11. Solid-state cooling components for computer chips

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