The effective ionization region and its variation with geometrical and electrical properties of the HVDC transmission system

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Abstract. High Voltage Direct Current (HVDC) overhead power transmission trends are currently advancing toward high system voltages over very long distances in a bid to viably tap from remotely located renewable energy sources. Corona effect plays a very crucial role in the design of overhead power transmission systems. Through corona, part of the energy carried on the transmission line is expended through ionization and movement of charges in the air dielectric. Corona limitations influence selection of key line parameters such as diameter of phase conductors, the number of conductors per phase and conductor clearances to the ground. Since overhead transmission lines are installed in open air, the generated electric fields are non-uniform. As a result, the accompanying ionization in the surrounding air is non-uniform and does not occur throughout the inter-electrode gap. Instead, the ionization is confined to a very small region around the high voltage fitting referred to as the Effective Ionization Region (EIR). As such, corona power loss is proportional to the size of the EIR. This paper discusses the concept of effective ionization region from a theoretical perspective. Computer modeling was used to investigate the effect of geometrical as well as electrical line parameters on the size of the EIR. A comparison is made between single and bundled conductor configurations. Results show that the radius of the EIR of a single conductor that is energized at 800 kVDC drops by about 75% if the conductor were a sub-conductor in a four-bundle configuration.

1. Introduction

Corona ionization in open air occurs by three processes, namely; impact ionization, photoionization and metastable effect. Of the three, impact ionization so dominant that it is often considered to be the only ionization process in open-air corona. In regions very close to the high voltage (HV) line, electric field intensity is large enough to propel electrons to very high velocities over their *mean free paths* hence such electrons are highly likely to have sufficient kinetic energy to cause ionization on impact. The *mean free path* of an electron is defined as the average distance that the electron travels between any two successive collisions. Electric field intensity drops sharply with distance away from the HV line and accordingly acceleration of electrons over the mean path, hence their kinetic energies and ability to ionize on impact tumble. As a result, open air corona can be considered to be effectively taking place within a small region surrounding the HV line and it is this region that is being referred to here as the effective ionization region (EIR). Figure 1 is an illustration of the *effective ionization region* (EIR) in a positive point-plane gap. In the figure E_c represents the visual corona inception gradient described by equation.

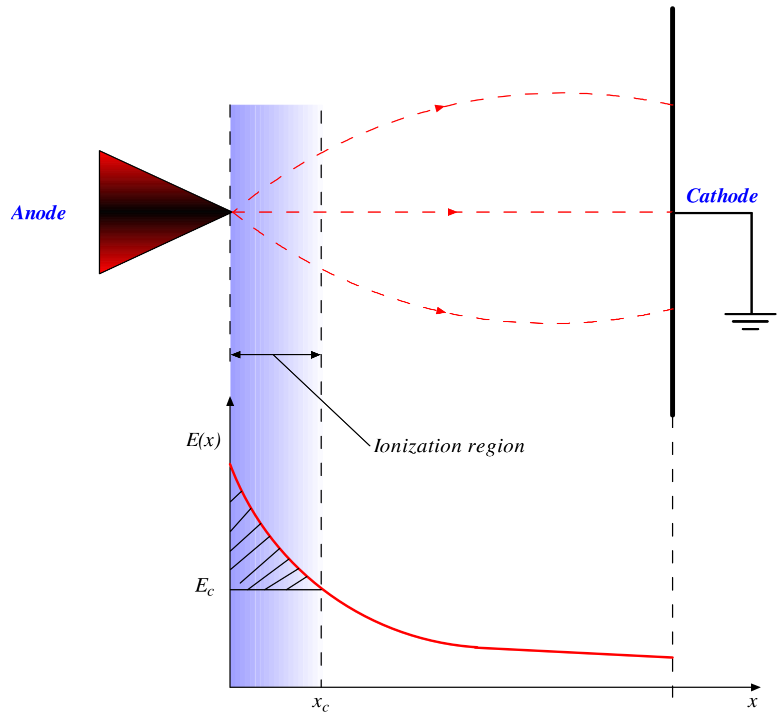

Figure 1. Electric field distribution in a non uniform point plane gap [1].

Corona ionization does not begin at visual corona discharge gradient. In fact, corona ionization starts at disruptive critical gradient (DCG) when electrons have gained sufficient kinetic energy to cause ionization of other molecule by impact. Mathematically, the electric field at any point P (E_P) within the EIR must satisfy the following expression:

$$E_P \geq E_0 \tag{1}$$

In equation (1) E_0 is the DCG given by the following expression [2]:

$$E_0 = 30\delta \text{ kV/cm} \tag{2}$$

where: δ = relative air density expressed as:

$$\delta = \frac{293p}{760(273+T)} \tag{3}$$

where: p = site pressure in millimetres of mercury;
T = site temperature in °C.

2. Parameters affecting the extent of the EIR (x_{eir}) in open air corona

The parameters can be broadly categorized into electrical as well as geometrical types. Based on equations (1) - (3), it can also be argued that ambient conditions (or more precisely air dielectric conditions) of pressure and temperature also play a significant role in influencing the extent of the

EIR. However, this study only focuses on “artificial” parameters, i.e. parameters that can be varied or pre-set at design stage.

2.1.1. Electrical parameters
The main electrical parameter is the actual line voltage referred to as the system voltage (*V*). For any given geometrical parameter settings, system voltage determines the conductor surface gradient. If the magnitude of existing conductor surface gradient exceeds the strength of the air dielectric at any given pressure and temperature condition corona ionization occurs. Other electrical parameters result from actual configuration of the HVDC link (monopolar, bipolar or homopolar [3]). This study only looked at a monopolar configuration at positive polarity.

2.1.2. Geometric parameters
These can be referred to as the physical HVDC system attributes. For a single conductor system, the parameters include average height (*H*) of conductor above the ground plane and radius (*r*) of the conductor. For a system that employs bundled conductors, parameters such as average height (*H*) of conductor bundle above ground, bundle radius (*R*) and radius of subconductors (*r*) become significant.

3. Method of analysis
Using finite element method, an analysis of the distribution of electric fields around the HV conductor and into the inter-electrode gape was done while varying *V*, *H*, *R* and *r*. Figure 2 shows the schematic of single and bundled conductor systems used in the simulation. The the relative air density was assumed to be 0.7, which gave a DCG of approximately 21 kV/cm or 2.4 MV/m.

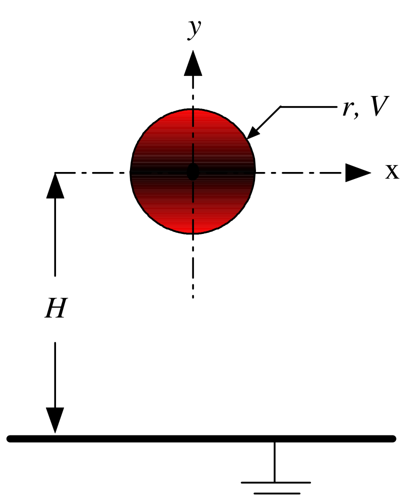

Figure 2a. Simulation geometry for single conductor system.

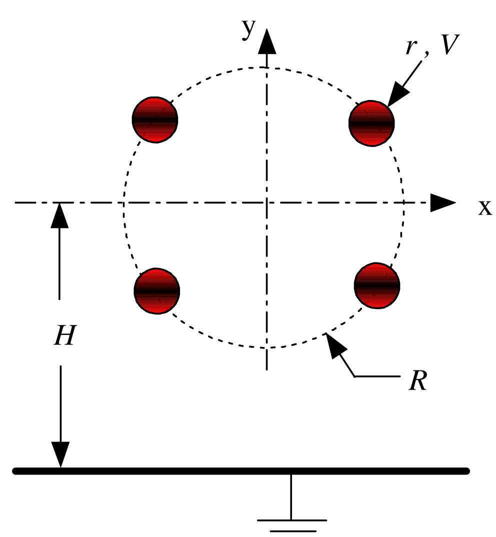

Figure 2b. Simulation geometry for a four bundle system.

4. Results and discussion

Figure 3 shows the effect of V on x_{eir}. System voltage has a more significant effect on the x_{eir} in a single conductor system than in a bundled system. This is the reason that makes bundled system favourable for bulk power transmission when extra high voltages (EHV) are employed.

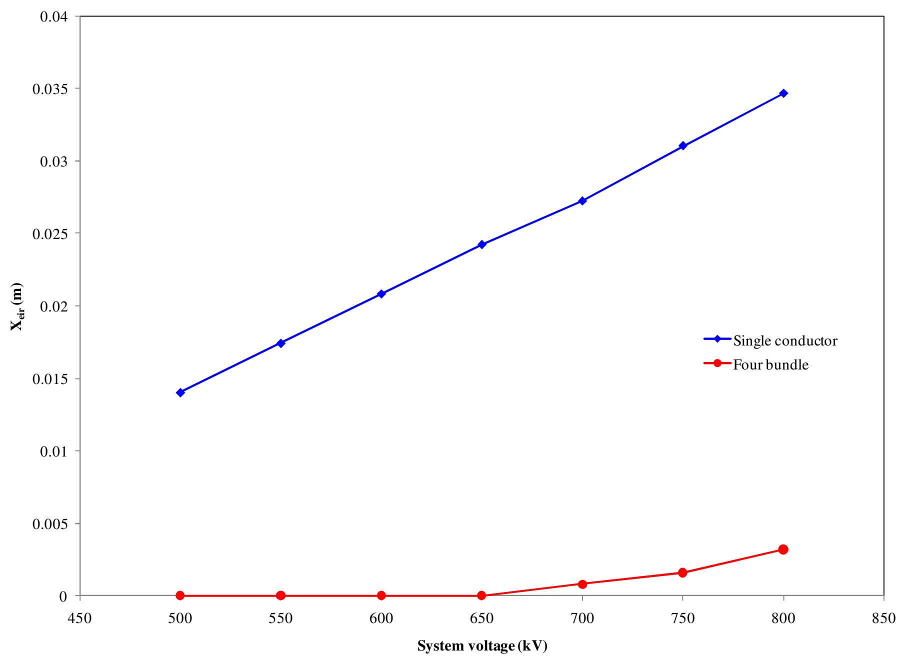

Figure 3. Plot of x_{eir} vs. V for a single conductor and a four bundle.

Figures 4 shows the dependence of x_{eir} on H in a single conductor as well as a four bundle system. The results in figure 4 show that H has the same effect on x_{eir}, however, having a conductor in a four bundle can a actually bundle reduce the x_{eir} by over 75%.

Figure 5 is a plot of conductor or sub-conductor radius, r versus x_{eir}. Again, r has similar effect as H has on x_{eir} in both single and bundled conductor systems. Figure 6 shows the effect that bundle radius, R has on x_{eir}. Clearly from these results, a smaller bundle radius results in a larger x_{eir}. Also a, larger bundle radius destroys the bundling effect. As a matter of fact, at bundle radii above 40cm, each sub-conductor will now behave more like a solitary conductor.

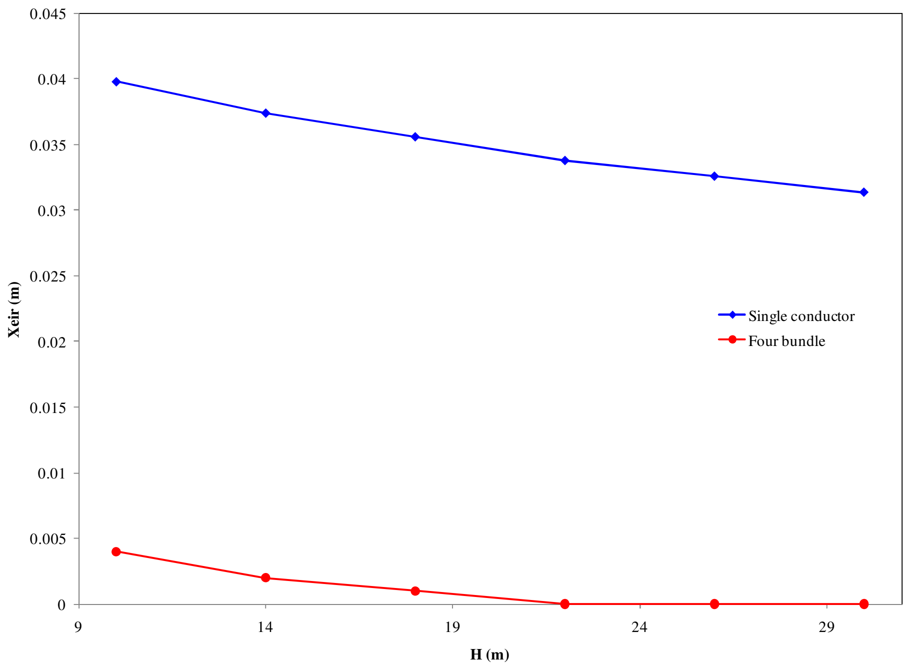

Figure 4. Plot of x_{eir} vs. H for a single conductor and a four bundle.

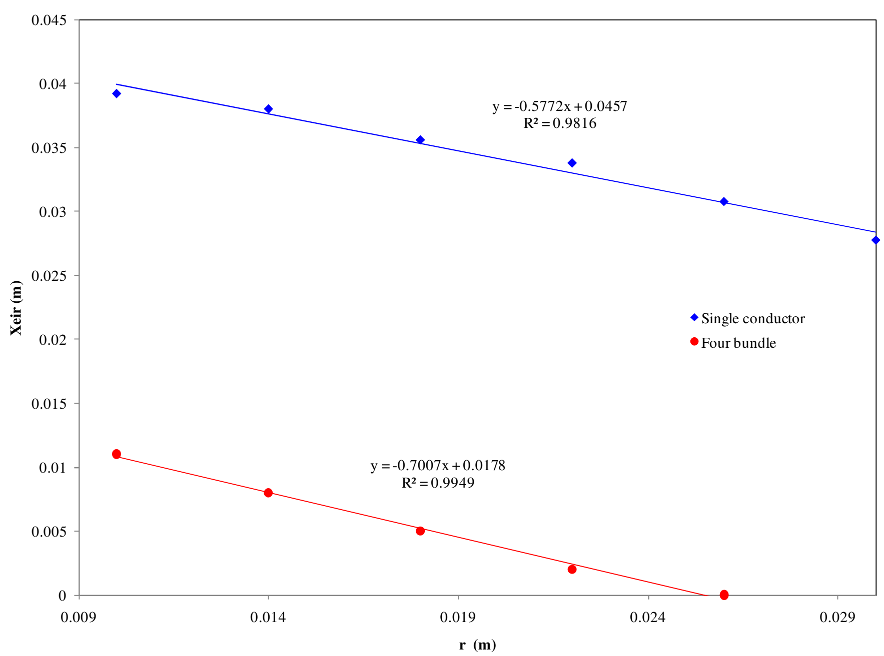

Figure 5. Plot of x_{eir} vs. r for a single conductor and a four bundle.

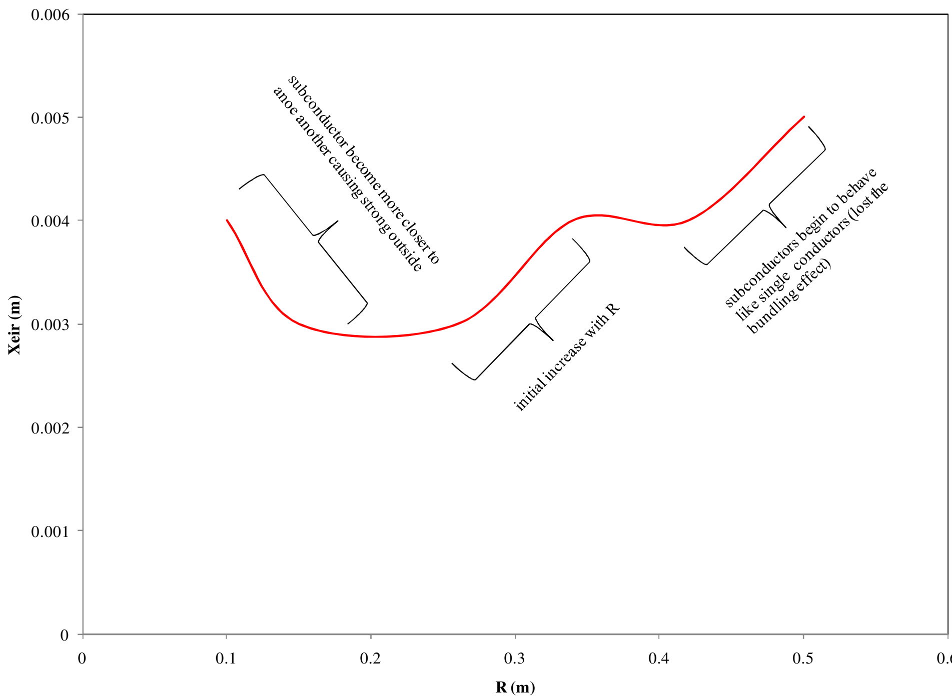

Figure 6. Plot of x_{eir} vs. R for a four bundle.

5. Conclusions

The paper has managed to highlight the effect that key system parameters have on the size of the effective ionization region around HVDC conductors. Each of these key parameters should be carefully considered in order to minimize corona power loss and ensure optimum performance of the energy trade business. Usually during optimization of these parameters, overall cost of the system plays a major role. For instance, the height of conductors might have desirable corona performance. However, this would mean larger and taller pylons which might offset the cost benefit brought on by the improved corona performance.

6. References

[1] Kuffel E., Zaengl W S and Kuffel J 2000 *High Voltage Engineering Fundamentals* (Oxford: Butterworth-Heinemann) p 343

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[3] Ijumba N and Sibilant G 2005 *High voltage direct current (HVDC) transmission -Eskom power series vol. 1* (Johannesburg Crown Publications) p 72 – 73