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Comparative Studies on Different Laboratory Investigations of Ionic Current Environment of HVDC Lines

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Abstract

Corona on HVDC transmission lines generates the ionic current and electric field environment under the transmission lines. The corona generated ionic current are drifts towards the ground causes electric shock to the any living organism which present under the transmission lines. In view of this designing of HVDC transmission lines at EHV/ UHV levels plays a vital role. The magnitude of these ionic current flows under the transmission lines depends on the line design considerations. Therefore, the major factors which affect the magnitudes of ionic currents are applied voltage, conductor diameter, space between lines to ground etc. Not only the design factors, but atmospheric parameters such as atmospheric temperature, pressure, humidity etc. are also have profound influence on generation of ionic current magnitudes under the lines. This authenticates that, need of significant studies on corona generated ionic currents under the HVDC lines before designing the new DC lines at EHV/UHV levels. In view of this authors are conducted different laboratory investigations on corona generated ionic current of HVDC lines at indoor and outdoor climatic conditions. Therefore, this paper presents the different laboratory experiments conducted for different conductor diameter in indoor and outdoor weather conditions. Also, this paper discussed the different observations during the measurements observed at different weather conditions.

Key words: *HVDC lines, corona, ionic current, electric field environment.*

1. Introduction

HVDC offer greatly for bulk power transmission over longer distances. Recent advances in the development of terminal equipment have increased the technical and economic feasibility of DC transmission. HVDC overhead lines operating up to ±600kV are in operation or under construction and lines of higher voltages are under consideration. Now in India the construction of a ±800kV with power transfer capability of 6000MW is under progress. The major effects associated with this corona discharge on the conductors are power loss of the conductor and drifting of space charge density in the inter electrode space surrounding the HVDC transmission line [1] [2]. In addition to corona power loss, it also leads to undesirable effects of generation of electromagnetic interference, audible and radio noise. The major effects influencing corona discharge of the HVDC transmission lines are its conductor surface gradients at given operating voltage levels, corona onset gradients, and ambient weather conditions such as temperature, pressure, wind, humidity, presence of aerosols, ambient electric fields produced by atmospheric electricity etc [3] [4]. In AC transmission lines, during the positive half cycle, the newly generated positive ions by means of corona phenomenon moves away from the line conductor due to repulsion force where as negative ions attracts the line conductor and vice versa. This authenticates that, the space charge ions created by the corona phenomenon is constrained in the vicinity of the line conductors only due to the periodic reversal of the applied voltage. Hence, the evaluation of these effects using corona cage studies was possible due to the reason that the space charge created by corona is

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constrained in the vicinity of the conductors only [5] [6]. In case of DC transmission lines, this space charges fill the inter electrode region between conductor to ground plane is shown in figure 1.

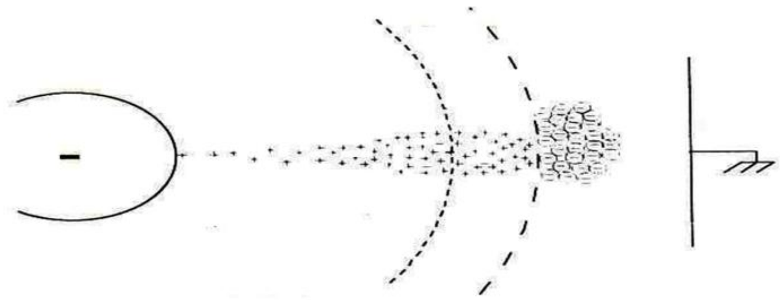

Figure 1: Ionic Current flow of a unipolar and Bipolar HVDC transmission lines

The presence of any human body or any living organisms at UHVDC levels under DC transmission lines, the ionic current density and ionized fields are perturbed with an enhancement. [7] [8] [9]. Therefore, the ionic current through a human body that stands on ground plane under the transmission lines and also the people who lives in the vicinity of the UHVDC lines are always attended by the government. Although the proposed safe limits of electric field and ionic current densities at ground level under the HVDC transmission lines using analytical methods such as Charge simulation method (CSM) [10], Finite Element Method (FEM) [11], Flux tracking Method (FTM) [12] etc. was not fully analyzed and also by line designers due to the limitations of analytical methods up to now. Since these parameters are a disturbance and can be sensed by personnel, acceptable levels have to be established to guide the transmission line designers. However, it is observed from literature [1] [2] [3] [4], to analyze the ionic current environment of HVDC transmission lines by conducting long term full scale experiments solely is tedious process and time consuming. On account of this fact, scale down models of experimental findings at actual atmosphere, that is, under outdoor conditions can provide significant help to evaluate the performance of ionic current densities at ground levels. The authors have made an attempt to investigate the ionic current environment at ground levels under HVDC transmission lines under actual atmospheric conditions using the scale down models at indoor and outdoor conditions. The measured experiment results of scale down models and their performances at different experimental setups are presented in this paper.

2. MEASUREMENT SYSTEM OF IONIC CURRENT DENSITY

Since HVDC transmission lines generally allow operation with slight corona discharge above onset voltage, considerable positive and negative ions are generated around the lines, which flow between the conductors and toward the ground [13]. To estimate the ion-current density on the ground, a collecting plate usually called a Wilson plate [14] is used to intercept the ions which migrate from the lines to the ground. The schematic diagram of measurement system of ionic current flow at ground plane is shown in Figure 2. The value of the ion-current or its density can be measured by using the digital DC nanoammeter [15]. This digital DC nano ammeter can read current from sensing electrode under the line conductor directly.

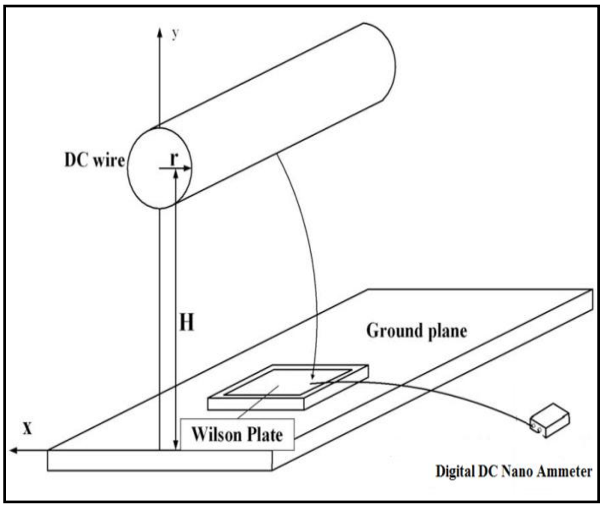

Figure 2: Schematic Diagram of Ionic Current Measuring System

3. EXPERIMENTAL RESULTS

Case A:

A unipolar dc wire comprising of copper material with 1.015 mm in radius and 1.73m in height is built in outdoor atmosphere condition is shown in Figure 3. Wilson plate is put on the ground under the centre of the test wire. The line conductor was energized with negative polarity of dc voltage in the range of 60 kV to 160 kV with increment of 20 kV. The experimental set up is shown in Figure 3. The measured values of ionic current under actual atmospheric conditions are listed in Table 1. The ionic current was measured directly under the line and also at lateral distances of 1m, 2m 3m, 4m from the centre of the line at different voltage levels using the digital DC nano ammeter.

Figure 4: Schematic view of unipolar DC line experimental line setup.

Table 1: Ionic current magnitudes of DC line conductor comprising of copper material at a heights of 1.73m and 1.24 m.

Applied Voltage In kV (-ve polarity)	Ionic current at ground level in μA							
	Below the conductor		Lateral profiles in Meters					
	At H= 1.73 m	At H= 1.24 m	1 m		2m		3m	
			At H= 1.73 m	At H= 1.24 m	At H= 1.73 m	At H= 1.24 m	At H= 1.73	At H= 1.24

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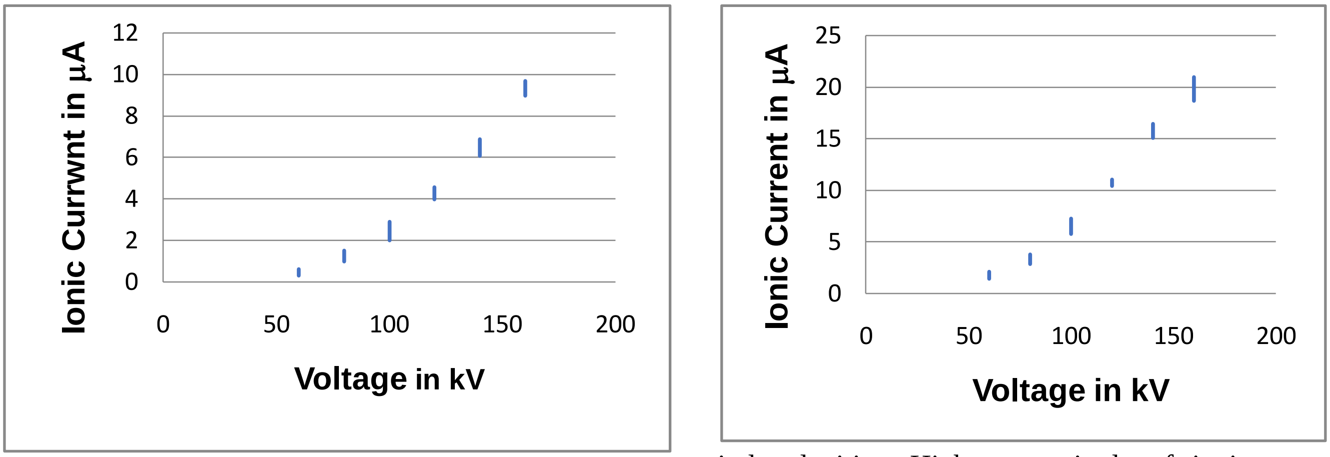
							m	**m**
60	0.31 to 0.62	1.45 to 2.12	0.26to 0.36	0.56 to 0.71	0.15 to 0.28	0.18 to 0.37	0.02 to 0.09	0.04 to 0.13
80	1.0 to 1.5	2.88 to 3.82	0.38 to 0.61	1.73 to 1.9	0.39 to 0.62	0.42 to 0.60	0.08 to 0.14	0.16 to 0.24
100	2.0 to 2.9	5.8 to 7.29	1.65 to 2.25	2.9 to 3.75	0.62 to 0.86	0.95 to 1.18	0.11 to 0.20	0.38 to 0.52
120	4.0 to 4.48	10.45 to 11.1	2.98 to 3.85	5.4 to 6.2	1.25 to 1.58	1.7 to 2.28	0.21 to 0.41	0.56to 0.71
140	6.0 to 6.9	15.1 to 16.5	4.05 to 4.77	10.1 to 10.7	1.61 to 1.98	2 to 3.11	0.5 to 0.71	0.81 to 1.1
160	9.0 to 9.7	18.74 to 21.01	5.9 to 6.3	16.95 to 18.10	2.2 to 2.6	4.1 to 5.05	0.82 to 1.14	1.8 to 2.6

It can be observed from Table 1 that the recorded values of ionic currents have wide variation. The maximum magnitude is recorded at low wind velocities and minimum values are recorded at high wind velocities. Higher magnitude of ionic current during voltage rise of the DC line due to rate of change of voltage with respect to time i.e. dv/dt.



(a) (b)

Figure 5. Variation of ionic current for applied DC voltage for conductor at a height at (a) H=1.73 m and (b) H=1.24 m.

It is observed that the magnitude of ionic current is higher during the dv/dt as compared to the maximum value recorded during the duration of one minute observation. The variation of ionic current for different applied DC voltages for this conductor configuration under the line is shown in figure 5 and figure 6. It is clearly observed that the variation of ionic current for a given DC voltage is in non linear in nature. All these measured values are recorded at two different atmospheric temperatures conditions of 32ºC and 28ºC for time duration of 1 minute. It is also observed that, the ionic current magnitude variation is higher at higher atmospheric temperature and is lower at lower atmospheric temperature. This can be attributed to the movement of ions at higher temperatures is faster as compared to the movement of ions at lower temperatures. Faster movement of ions may result in generation of ions due to more collisions in their expedition and this phenomenon is observed from [16].

Case B:

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The experimental set up [8] used for measurement of DC electric field and ionic current is shown in figure 6. In this case the experiments are carried in indoor laboratory set ups for two conductor diameter variations kept at same height 1.5 m from the ground.The line conductor was energized with DC voltages of 90kV, 100 kV, 110 kV and the ionic current magnitudes are measured using the ionic current meter designed in the Central Power Research Institute. The ionic current was measured directly under the line and at a distance of 1m laterally from the centre of the line at all the different voltage levels using the ionic current meter and is observed from the table 2

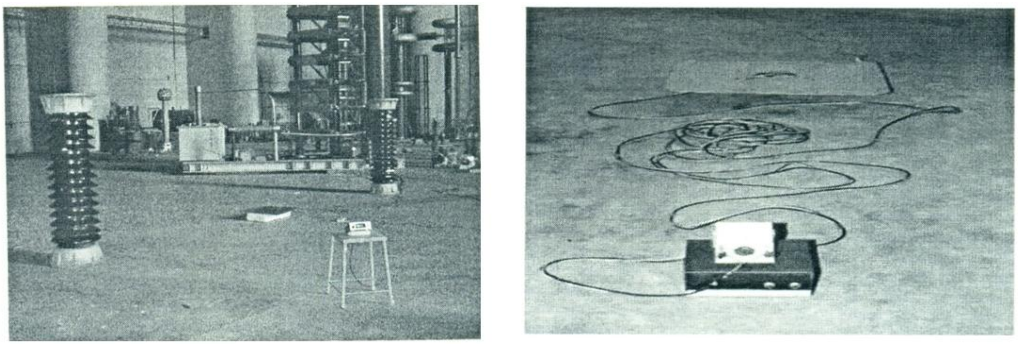

Figure 6: Schematic view of indoor unipolar DC line experimental line setup.

Table 2: Ionic current magnitudes of DC line conductor comprising of copper material at a heights of 1.5 m.

Applied Voltage In kV (-ve polarity)	Ionic current at ground level in µA					
	At H = 1.5 m		Lateral profiles in Meters			
			1 m		3m	
	At D= 4.3 cm	At D = 1.7 cm	At D= 4.3 cm	At H= 1.27 cm	At D= 4.3 cm	At H= 1.7 cm
60	90-140	815-820	52-53	324-329	13.4-16.5	36.4
80	380-410	980-985	150-160	401-405	19.4-22.6	46.3
100	727-740	1178-1183	290-310	523-528	26.4-29.9	58.8

It is observed that the measured values in table 2 shows that minimum variations and this may be attributed to the fact that the experiment was conducted inside the laboratory where the effect of wind and other atmospheric conditions on the measured values is minimum. The larger deviations at higher voltage may be due to the undesirable corona discharges from sharp points of the experimental setup. The ions generated during this corona discharge will add up to the ions generated by the DC conductor and thus will not only increase the interaction between the two parameters.

Case C:

In this case, again the indoor laboratory measurements are conducted for fixed energised voltage of 30 kV at different conductor heights. The experiments are conducted at two different conductor diameters of 0.27 mm and 0.51 mm to measure ionic current values for both HVDC and HVAC voltage applications. The experimental set ups for measuring the ionic current of HVDC and HVAC lines in laboratory set ups are shown in figure 7 below

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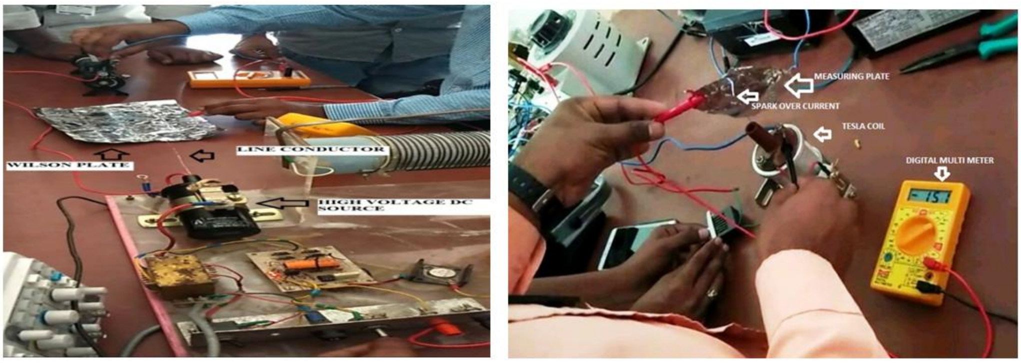


Figure 4: Schematic view of unipolar DC & AC line experimental line setup

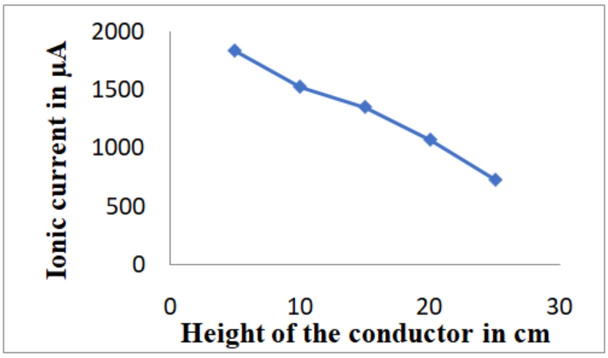
The measured values and variation of corona generated ionic currents are observed from the table 3, 4 and figure 5 below

Applied voltage in kV	Height of the conductor in cm	Ionic current in µA	
		DC	AC(at fixed height)
30	5	1832	
30	10	1523	
30	15	1349	24650
30	20	1069	
30	25	726	

Figure.3. ionic Current Magnitudes of Dc line conductor line conductor

Applied voltage in kV	Height of the conductor in cm	Ionic current in µA	
		DC	AC(at fixed height)
30	5	1562	
30	10	1312	
30	15	1079	17250
30	20	816	
30	25	591	

Figure.4. ionic Current Magnitudes of DC



(a)

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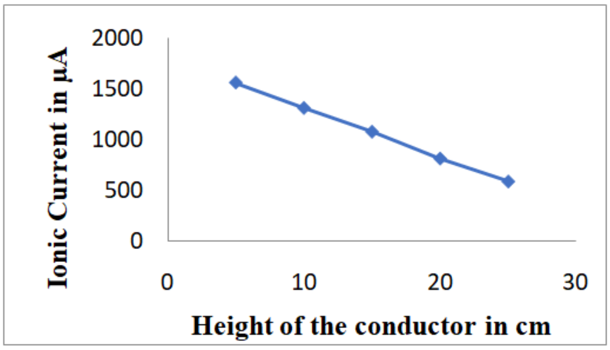

(b)

Figure 5. Variation of ionic current for conductor diameters of (a) d = 0.27 mm and (b) at d = .051 mm

It can be observed from Table 3 and table 4, the recorded values of ionic currents are lower in magnitudes as height of the conductor increases under DC supply conditions. This shows the ionic current of the line conductor is in inversely in relation with conductor height. It is also observed that, higher magnitude of ionic current during voltage rise of the DC line due to rate of change voltage with respect to time i.e. dv/dt.The variation of ionic current at different conductor heights under the line is shown in Figure 5. It is clearly observed that the variation of ionic current for a given DC voltage is in non linear in nature. Whereas, corona generated space charges are envisaged by spark over current in the vicinity of line conductor only. This clarifies that unlike DC supply, the corona generated space charge ions are absent at ground levels. This spark over current may vary with minor variation in height of the conductor and also atmospheric conditions. All these measured values are recorded at two different atmospheric temperatures conditions for short time duration.

4. Discussion

From the experimental studies carried out in indoor and outdoor laboratory conditions for ionic current measurements for both aluminium conductor and copper conductor, it is observed that, the magnitude of ionic currents are higher for smaller conductor diameter irrespective of polarity and vice versa. It is observed from the experimental conducted at two different atmospheric temperatures of 32ºC and 28ºC, that the ionic current reduces as height of the conductor is increased and vice versa. Whereas, in case of lateral profile the ionic current decreases as the lateral distance increases. It is observed that ionic current flow of a HVDC line at actual field conditions has large variations in magnitudes and depends on atmospheric conditions. This indicates that the atmospheric parameters such as temperature, pressure, wind velocity, aerosols, humidity etc., have the significant influence in generation of ions in the vicinity of the HVDC transmission lines. It is also observed from the experimental presented that the ionic current densities are higher in magnitude initially and lower magnitudes are measured after prolonged time duration. This may be due to the life span of the generated ions in the corona discharge which has significant influence in magnitude of the ionic current flow at ground levels. This phenomenon is also observed by [11]. Whereas, under AC supply conditions, the space charge ions are generated and observed in view of spark over current at nearer to the line conductor only in spite of at ground levels. This corroborates that corona phenomenon for HVAC transmission lines constrained in the vicinity of the line conductor only. This attests that, corona cage studies are only possible to analyze the ionic current environment of HVAC line conductors.

Conclusion

The scale down models of experimental study on different HVDC & HVAC line conductors by various experimental setups at laboratory conditions was conducted. From the experimental results of the study, it is concluded that:

1. The ionic current flow at ground level is nonlinear in nature due to life span of the generated ions in ionization layer.
2. The ionic current varies inversely with height of the conductor.
3. Atmospheric parameters like temperature, humidity, pressure, aerosols, wind velocity etc., have the profound influence on the ionic current flow at ground levels.
4. The ionic current environment for HVAC lines compared to the HVDC lines is constrained in the vicinity of line conductor only.

5. Considerable amount of space charge was observed during the voltage raise, this attributes during voltage fluctuations at UHV levels of the line results in deposition of the space charge ions in form of surface charges on the tower end insulators causes short term flashes.

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