ION TRAJECTORIES AND CORONA EFFECTS AT CONVERTING ONE CIRCUIT OF A DOUBLE CIRCUIT AC LINE TO DC

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ABSTRACT: This paper considers a typical 220 kV Egyptian double circuit line, in which one circuit of a normal double circuit is converted to ±220 kV bipolar dc line. Four different alternatives of circuit conversion are considered. Field patterns are presented with and without ac voltage presence. Distortion of the dc patterns is investigated and analyzed. The lateral average radio interference and audible noise profiles due to one cycle of ac voltage phasor for each alternative are computed and compared with the other alternatives to choose the optimum arrangement. The influence of ac circuit voltage on the average radio interference and audible noise under the line is discussed.

I. INTRODUCTION

Recent advances in the overhead HV transmission technology have significant enhanced the prospects of bulk power transfer over long distances using ac and dc circuits running in parallel or even sharing the same tower [1-3]. This could be done either by an additional line or by converting an existing ac line. In the latter case the parallel ac and dc lines are very close to each other. Design of such lines requires considerations of possible interactions between the ac and dc sides. Some of the more important interactions are those of the electromagnetic fields generated by the two circuits.

Owing to the close proximity of both the ac and dc circuits, the electromagnetic fields at any one point in the surrounding space will be composed of an alternating component superimposed on a direct component. The relative magnitudes of the two components depend on the parameters of both circuits and the location of the point of concern with respect to the ac and dc circuits.

A serious aspect of hybrid line interactions which require significant consideration is the corona-generated space charges and their associated trajectories. For the dc circuit, the corona generated space charge travels along the field lines and fills the entire space between the conductors and the ground. The basic assumption commonly used for a space charge analysis, that has been repeatedly questioned in literature, is that the dc ions trajectories will not be influenced by the presence of either the ac electric field or ions-generated electric field.

Design of such hybrid transmission lines require consideration of possible interactions between the ac and dc circuits. The mutual impact of the electric fields on the corona performance of the two circuits are important from the point of view of environmental impact. The important corona performance parameters are the radio interference and audible noise. Corona effects became an important factors in the design of the transmission lines, and the choice of the right-of-way as well.

This paper considers a typical hybrid line configuration, in which one circuit of a normal double circuit 220 kV line is converted to ±220 kV bipolar dc line. Various arrangements of the ac and dc circuits are possible. Two circuit arrangements were investigated in this work. The first arrangement is with the ac and dc circuits on separate sides of the tower. The second is an intermixed arrangement with the ac circuit on the bottom of the tower and the dc circuit on the top. Four different alternatives of converting one circuit of a double circuit ac line to dc are considered in this work, namely, separate circuits with two negative polarity bundles, separate circuits with two positive polarity bundles, intermixed circuits with two negative polarity bundles and intermixed circuits with two positive polarity bundles, as shown in Fig.1.

```
   o              o
  C +            C -
 B   -          B    +
  A  -           A  +

  (a)             (b)

   o              o
 +  -             -  +
 A    -         A     +
  B  C            B  C

  (c)             (d)
```

Fig.1 Conversion of one circuit of ac line to dc.
(a) Separate circuits with two negative polarity bundles
(b) Separate circuits with two positive polarity bundles
(c) Intermixed circuits with two negative polarity bundles
(d) Intermixed circuits with two positive polarity bundles

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II. ION TRAJECTORIES

The charge simulation technique is applied to determine the field pattern in the space surrounding the line. Different emanating angles are chosen on the surface of the outermost dc pole to trace the field lines pattern. The field lines are terminated at the ground boundary. Suppose that a point (x_i,y_i) is reached after executing I prior steps. The next step, i.e. the i+1 step, is executed as follows; calculate the field components E_x, E_y, then an angle α is calculated as $\alpha = \tan^{-1}(E_y/E_x)$. It is evident that the coordinates x_{i+1}, y_{i+1} are possible as:

$$x_{i+1} = x_i + R\cos(\alpha)$$

$$y_{i+1} = y_i - R\sin(\alpha)$$

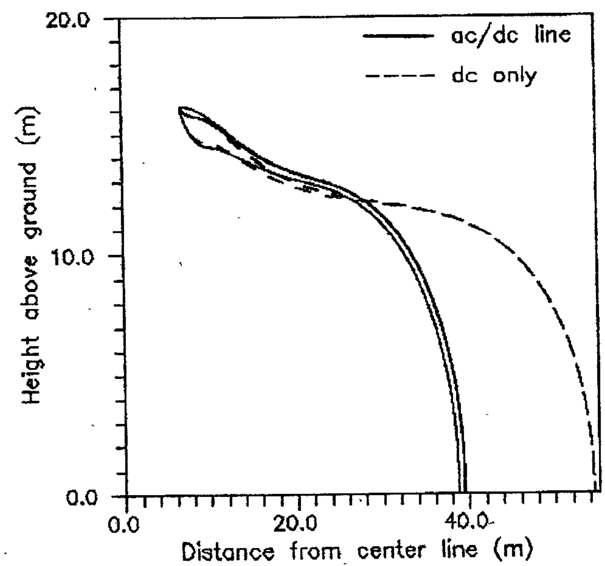

Fig.2 Patterns of the field lines trajectories for arrangements (a).

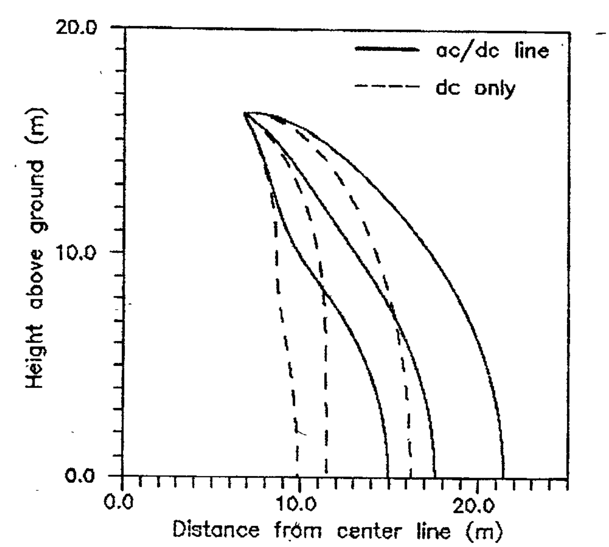

Fig.3 Patterns of the field lines trajectories for arrangements (c).

where, R is the subconductor radius.

Patterns of the field lines trajectories emanating at angles 0, 45 and 90° from the outermost conductor of the dc poles for arrangements (a) and (c) are shown in Figs.2 and 3. In order to demonstrate the possible effects of the ac circuit, the trajectories in the presence of the dc circuit alone were traced by assuming the ac voltages equal zero. It is clear from the figures that the ac voltage has a significant influence on the dc circuit and causes significant distortion of its trajectories. Also the figures show that in arrangement (a) the influence of the ac circuit is greater than that in arrangement (c).

The relation between the distance along the ground measured from the center line of tower at which a particular field line intersects the ground of the dc circuit alone, X_g of dc line, and the corresponding distance when the ac voltage is present, X_g of ac/dc line, for different emanating angles and different instants on the ac voltage phasor of the ac circuit is studied in this work.

The effect of the ac voltage value on the field pattern at ground level, X_g, for arrangements (a) and (b) is shown in Fig.4. It is clear that the ac voltage have a significant influence on the dc circuit and causes a distortion of its trajectories. As the ac voltage increase a trend towards saturation occurs.

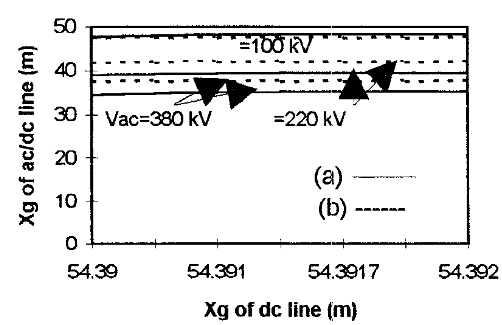

Fig.4 ac voltage effect on ac/dc lines (a) and (b) ion trajectories

Fig.5 shows the X_g of dc line versus X_g of ac/dc line at different instants on the ac voltage phasor of the ac circuit for arrangements (a) and (b) is shown in Fig.5. The ac voltage is considered 220 kV_{rms}. It is seen that the field pattern varies significantly during the cycle of the ac voltage phasor rotation occurs.

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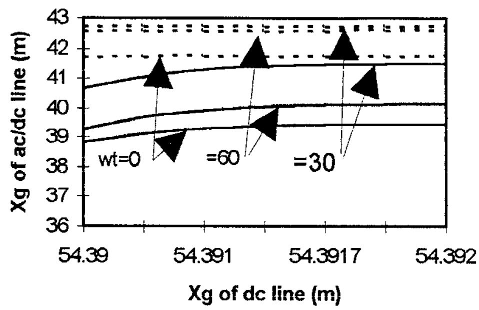

Fig.5 Phase shift effect on ac/dc lines (a) and (b) ion trajectories

The effects of the ac voltage value and the instant of the ac voltage phasor on the field pattern at ground level, X_g, for arrangements (c) and (d) are shown in Figs.6 and 7. It is seen that the field lines are contracted in the area underneath the line in case of arrangements (c) and (d) than in cases of other arrangements.

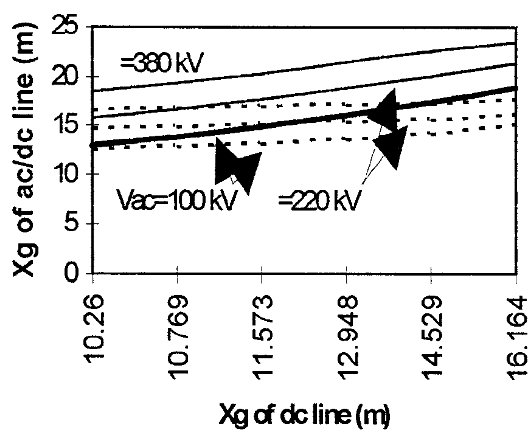

Fig.6 ac voltage effect on ac/dc lines (c) and (d) ion trajectories

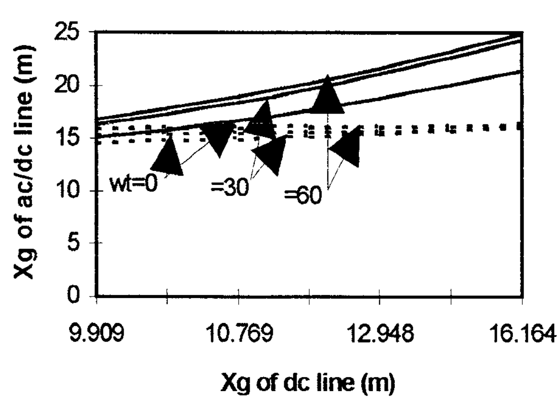

Fig.7 Phase shift effect on ac/dc lines (c) and (d) ion trajectories

III. CORONA EFFECTS

The mutual impact of the electric fields on the corona performance of the ac and dc circuits are important from the point of view of environmental impact. Corona effects became an important factors in the design of transmission lines and the choice of the line right-of-way as well. The important corona performance parameters are the radio interference (RI) and the audible noise (AN).

III.1 Radio Interferencc

While the ac RI occurs around the peak of the positive half cycle of the power frequency voltage wave, the dc RI for an equivalent gradient occurs all the time. The dc RI is primarily a fair weather phenomena, while the ac RI is usually considered as both a fair and a foul weather phcnomena.

Thc ac RI at fair wcathcr is [4]:

$$RI=120 \, Log_{10} E_{av} + 40 \, Log_{10} d + 20 \, Log_{10}(h/D^2) + 10(1-(Log_{10}(10f))^2)-150.4 \qquad (1)$$

where, E_{av} is the average surface gradient in kV/cm, d is the conductor diameter in mm, D is the aerial distance from phases to the measuring point in meters, h is the conductor height in meters and f is the frequency in Mhz. The foul weather RI is higher by about 17 dB than the fair weather RI, while the heavy rain RI is higher by about 24 dB than the fair weather RI.

The dc RI per positive pole is:

$$RI=214 \, Log_{10}(E_m/14) - 278 \, (Log_{10}(E_m/14))^2 + 40 \, Log_{10}(d/2) + 20 \, Log_{10}((h/15.2)(30.5/D)^2) \qquad (2)$$

where, E_m is the maximum surface gradient in kV/cm

The RI of negative pole is lower by about 4 dB than the RI of the positive pole.

The average radio interference of the four arrangements during a complete cycle of the voltage phasors is shown in Fig.8. It is seen that the average RI of the separate circuits arrangements are approximately the same under the dc circuit. The same result is shown for intermixed circuits arrangements. Also the separate circuits arrangements have lower values of RI underneath the dc circuit. At the lcft hand sidc right-of-way (25 m from ccntcr linc of tower) the RI of the intermixed circuit is lower than that of the separate circuit.

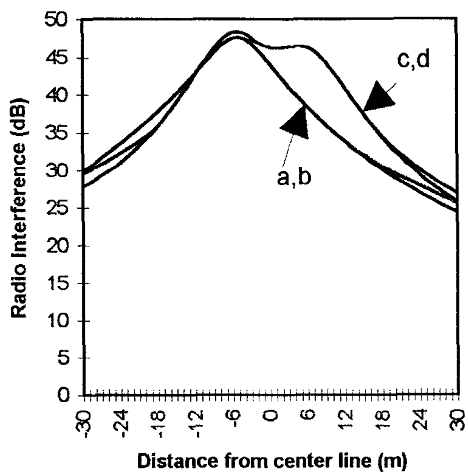

Fig.8 Average RI for different ac/dc line arrangements

The standard deviations of the RI values in lateral direction, X, during a complete cycle of the ac voltage phasor for the different line arrangements are shown in table 1. The standard deviation of RI of the separate circuits arrangements are approximately the same under the ac/dc line and away from the center line from the left hand side, while a small difference is shown away from the line from the right hand side. The standard deviations of intermixed circuits arrangements are the same under the line, while a difference is noticed away from the line from both sides especially from the left hand side.

Table 1 Standard deviation for different arrangements

X	(a)	(b)	(c)	(d)
-30.0	1.93	1.93	2.20	0.66
-25.0	1.82	1.82	1.73	0.73
-20.0	1.81	1.81	1.39	1.30
-15.0	2.29	2.29	1.61	1.61
-10.0	3.50	3.49	1.61	1.61
-5.0	3.99	3.99	1.61	1.61
0.0	3.57	3.57	1.98	1.98
5.0	2.50	2.50	5.38	5.38
10.0	1.92	1.92	5.83	5.84
15.0	1.94	1.78	5.51	5.51
20.0	2.40	1.81	4.72	4.91
25.0	2.77	1.89	3.96	4.27
30.0	2.99	2.01	3.50	3.67

III.2 Audible Noise

Design considerations of EHV lines are now governed by the need to limit audible noise levels, which become a serious problem from psycho-acoustics point of view.
The L_{50} A-weighted acoustic sound level of the ac phases in a rainy weather is [4] :

$$AN(i) = 120\ Log_{10}\ E_{av} + 55\ Log_{10}\ d_{eq} - 11.4\ Log_{10}\ D(i) - 188.5 \quad dB \qquad (3)$$

where, E_{av} is the average maximum surface gradient (kV/cm)

$d_{eq} = d$ for N=1,2
$d_{eq} = (0.58d)\ N^{0.48}$ for $N \geq 3$
d is the subconductor diameter in mm
N is the number of subconductors per bundle

The L_{50} A-weighted AN level of the dc positive poles in fair weather is :

$$AN(i) = 86\ Log_{10}\ E_m + 40\ Log_{10}\ d_{eq} - 11.4\ Log_{10}\ D(i) - 133.4 \quad dB \qquad (4)$$

where, E_m is the maximum surface gradient in kV/cm

$d_{eq} = d$ for N=1,2
$d_{eq} = (0.66d)\ N^{0.64}$ for $N \geq 3$

The negative pole produces a negligible audible noise.
The fair weather AN of ac circuit is higher by about 25 dB than the foul weather, while the fair weather AN of dc circuit is higher than the rainy weather AN by about 6 dB. The total AN of the ac/dc line is:

$$AN = 10 Log_{10} \sum_{i=1}^{n} 10^{0.1AN(i)} \qquad (5)$$

Fig.9 shows the average audible noise of the different line arrangements during a complete cycle of the voltage phasors. It is seen that the average AN of the separate circuits arrangements are approximately the same. The same result is shown for intermixed circuits arrangements. The separate circuits arrangements have lower values of AN underneath the ac/dc line. The deviation between the separate and intermixed circuit arrangements audible noises is larger under right hand side conductors than that under left hand side.

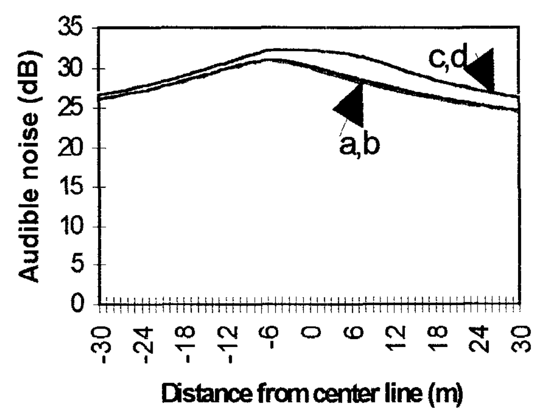

Fig.9 Average AN for different ac/dc line arrangements

Table 2 shows the standard deviations of the AN values in lateral direction, X, during a complete cycle of the ac voltage phasor for the different line arrangements. The maximum values of the standard deviation of AN of the separate circuits arrangements are under the ac/dc line, while for intermixed circuits the maximum values are underneath the right hand side of the ac/dc line.

Table 2 Standard deviation for different arrangements

X	(a)	(b)	(c)	(d)
-30.0	2.02	1.91	1.40	1.32
-25.0	2.05	1.95	1.36	1.28
-20.0	2.11	2.02	1.31	1.24
-15.0	2.23	2.14	1.27	1.20
-10.0	2.42	2.34	1.24	1.19
-5.0	2.55	2.47	1.35	1.30
0.0	2.43	2.30	1.85	1.84
5.0	2.26	2.07	2.52	2.52
10.0	2.16	1.93	2.64	2.65
15.0	2.10	1.88	2.47	2.47
20.0	2.07	1.85	2.31	2.31
25.0	2.06	1.84	2.19	2.18

IV. CONCLUSIONS

1. The dc field lines pattern is significantly distorted due to the presence of ac voltage.
2. The field lines are contracted in the area underneath the line in the case of intermixed circuits than the separate circuit lines.
3. Separate circuits produce lower radio interference underneath the ac/dc line.
4. Separate circuits produce lower audible noise underneath the ac/dc line.

V. REFERENCES

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