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Corona Detection Using Wide Band Antenna and Time Delay Method

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Abstract

IEEE Std 100-2000 defines corona as a luminous discharge due to ionization of the air surrounding a conductor caused by a voltage gradient exceeding a certain critical value. It occurs when the insulating material begins to ionize or conduct due to voltage stress. Corona brings a lot of damages such as corrosion, loss inoverhead transmission lines and electromagnetic interference. Monitoring of corona may reduce the maintenance and replacement cost of electrical equipment. The motivation of this experiment is to calibrate corona detector antennas in the future. The error obtained will determine the efficiency of the antenna to detect and locate potential coronas in electrical equipment in a substation with switchgears or transformers. The operation bandwidth of the antenna is 320MHz to 1.20GHz making it useful to detect and corona. The measurement method of utilizing delay between signals first peak is effective with average 4.76% error with maximum 10.0% error recorded. This may be used to develop a corona online measuring system in the future.

Keywords*: corona, corona generator*

1. Introduction

In a uniform electric field, exceeding the dielectric strength of the surrounding media usually leads to a complete electric breakdown [1]. If the field distribution between electrodes is strongly non-uniform, for example sphere or coaxial cylinders, electrical discharges are detected before a complete failure occurs. These discharges, or partial breakdowns, are commonly described by the term ‘corona’. Certain conditions must be met for corona discharge to take place. As mentioned above, the field distribution must be non-uniform, thus preventing complete breakdown of gap. The voltage applied to the corona electrode must be high enough to ensure electric field strength high enough to initialize ionization of the insulating gas medium. In practice, corona discharges are commonly found at high voltage power lines, or in apparatus being exposed to high voltage stress and are usually considered to be a problem as shown in Figure 1 and 2. Corona occurs at sharp corners, points, edges of conductors and also thin wires. Corona inception voltage is the lowest voltage at whereby corona is generated [2]. For two wires in Air, corona will not form when ratio $PW_{AIR}<5.85$; whereby [3].

$$PW_{AIR} = X/r \tag{1}$$

X= Distance between wires,
r = Wire radius,
For equal spheres in Air, corona will not form when $SP_{AIR}<2.04$. Arcing is difficult to avoid when ratio $SP_{AIR}<8$; whereby

$$SP_{AIR}=X/R \tag{2}$$

R=Sphere radius

Arcing will occur instead if voltage is too high for both setups.

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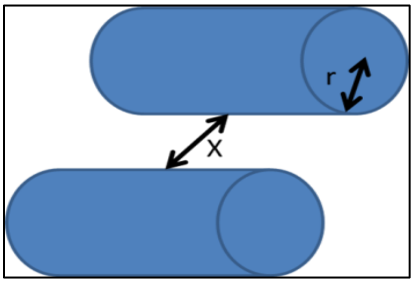

Figure 1. Corona between two parallel wires

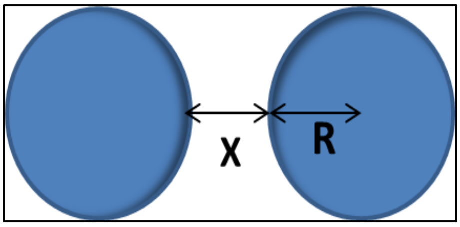

Figure 2. Corona in spheres wires

1.1. Drawbacks of Corona

Electromagnetic interference in communication systems, audible noise, insulation degradation and power loss in overhead transmission lines are few ill-effects of corona. Corona also causes loss of energy. This affects the transmission effectiveness. Corona produces ozone. The chemical reaction that takes place may cause deterioration of the conductor. Corona causes a non-sinusoidal current to be drawn by the line (Figure 3). This will eventually create avoltage drop which has the non-sinusoidal characteristic to transpire. Inductive interference between adjacent communication lines is the by-product of this.

Figure 3. Corona discharge on an insulator string of a 500 kV overhead power line [4]

1.2. Corona Detection

Corona detection is a useful technique which is applicable for various purposes. Monitoring of corona may reduce the maintenance and replacement cost of electrical equipment and, also, controls the quality of corona production at various stages. In fact, corona tests are used to know under what conditions corona occurs and if it happens, collect the information on nature of corona, frequency spectrum, amplitude, recurrence frequency and the duration.

Corona discharge emits ultrasound at the source of the problem thus can be located using an ultrasound detection system. Current system in the market receives ultrasound waves and converts them to the audible range and amplifies them so they can be heard. The output may be viewed on a meter or heard through a speaker or headset.

When corona occur, the discharge will emit large amounts of ultraviolet radiation which can be used as an indirect assessment of insulation condition of operating equipment and the detection of insulation defects [5]. Another method used is the optical method with the highest sensitivity, resolution and suitability is selected. By using a high sensitivity ultraviolet radiation receiver, corona can be recorded to evaluate equipment condition through data processing and analysis. Electromagnetic sensing can be utilized in corona detection [6,7]. This method is common in Partial Discharge detection and since corona is associated with the emission of electromagnetic pulses same method can be used. Since corona occurs in VHF/UHF, The E-shaped patch antenna designed with partial ground plane or the Wide Band slotted patch antenna may be selected.

Any corona measurement units have to be calibrated and tested before being used in the field for diagnosis. This is to ensure the units delivered provide consistent and accurate measurement results in the field when measuring switchgears or transformers. Bringing the system to the site for calibration is redundant and there are very limited known locations to be used for calibration. This is the limitation of on-site calibration. Therefore a calibration method has to be established utilizing simulated pulses which represent the corona in the field. This calibration method will be conducted in the lab environment.

2. Experiment Setup
2.1. Selected antennas for experiment
2.1.1. Wide band slotted patch with partial ground plane

The antenna designed for wide band slotted patch with partial ground plane is shown in Figure 4. The topology of the antenna was designed on a Flame Retardant Grade 4(FR4) substrate with a 1.6 mm thickness and a dielectric constant ε_r of 4.3 [8]. The antenna was designed and optimized to detect partial discharges emitted from underground LV power cables. In order to expand its bandwidth, two parallel slots were incorporated into this patch. The antenna operates in the impedance bandwidth range of 219.5MHz to 385.5 MHz with return loss of -37dB.

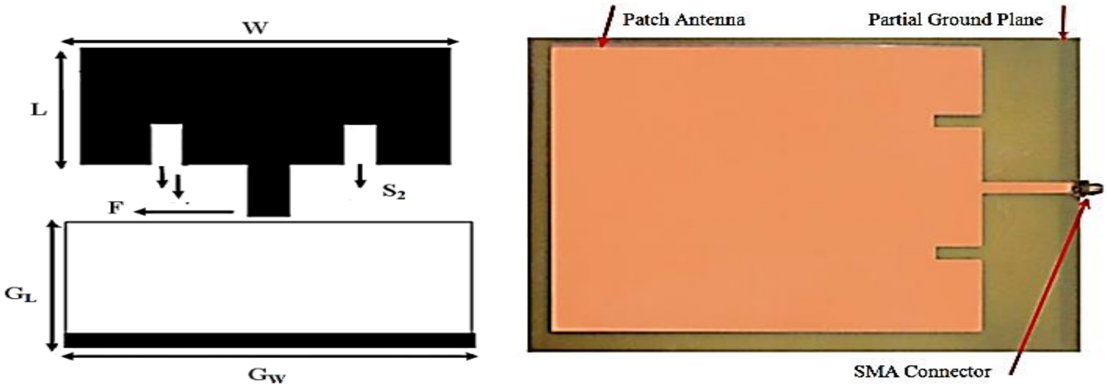

Figure 4. Basic configuration of wide band slotted patch antenna with feed line and partial ground plane

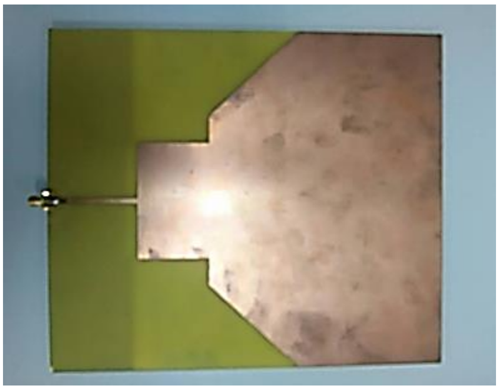

Figure 5**.** Fabricated Wide Band slotted patch antenna

The topology of the antenna in Figure 5 was designed on an FR4 substrate with a 1.6 mm thickness and a dielectric constant ε_r of 4.4 [9]. The antenna operates in the impedance bandwidth range of 320MHz to 1.20 GHz with return loss of -12dB return loss (S11).

2.1.2. Selected equipment *corona generator*

A smaller version of high voltage generator was used to ensure safety to the tester and mobility. The high voltage generator was used to generate corona discharge in the air. The high voltage circuit was developed to be portable and powered by 9-12 V DC source. The discharge voltage was measured as 20kV. A high voltage up to 20kV is sufficient to generate corona inside the transformer oil. The whole circuit was placed inside a plastic container for safety purpose as in Figure 6.

Figure 6. Corona Generator

There were 2 identical circuits developed for emergency purpose. The high voltage terminals of the circuits are separated by 10cm. This is to avoid any air ionization as well as sparking across the terminals. In addition, the sharp edges at the terminals were trimmed to prevent partial discharge/corona. The levels of partial discharge at the terminals were measured by using ultrasonic partial discharge and transient earth voltage detector. The terminals were trimmed until there is no partial discharge at the terminals. The corona was generated by placing a thin wire at a distance of 11mm across the high voltage terminals. The ultrasound partial discharge detector was used to detect the presence of corona in the air. Once the ultrasound detector detects the corona, the high voltage generator was brought into a dark room to see the corona discharge. An intense corona was seen as the blue dots in the dark as shown in Figure 7.

Figure 7. Corona being generated from the wire

After a few while a complete discharge was noticed as the gaps at the high voltage terminals. This could be due to the intense ionization of the air wire gaps. The discharge has a frequency is 25 kHz with measured current of 1.8A.

3. Methodology

The EM wave propagation from corona in air is equivalent to the speed of light [10]. Therefore, the relationship between distance from the antenna and corona source can be related using Equation 3.

$$\Delta L = c\,\Delta t \tag{3}$$

Whereby
c = speed of light (2.99 x 10^8)
$\Delta L = change\ in\ distance$
Δt = time delay between both similar antenna

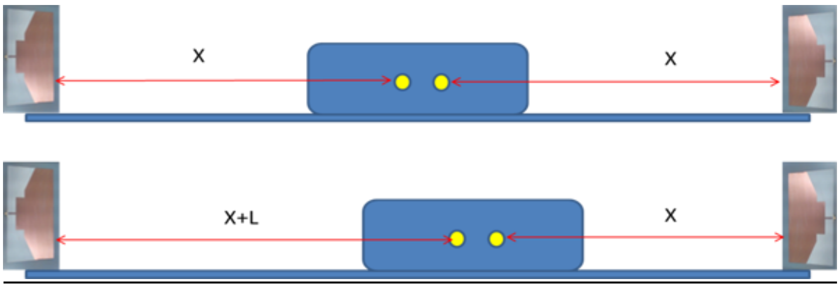

Figure 8. Experimental arrangement of antenna and corona generator

The distance of the corona source to the antenna can be equated as assuming that distance between two antennas is maintained at 3 meters.

$$X = 1.5 - 0.5L \tag{4}$$

Whereby
X = distance of the corona source to the antenna

Figure 9 illustrates the delay between the leading corona trace (closer to source) and the lagging corona trace. The delay between each signal will be used to interpret the distance between antenna and source.

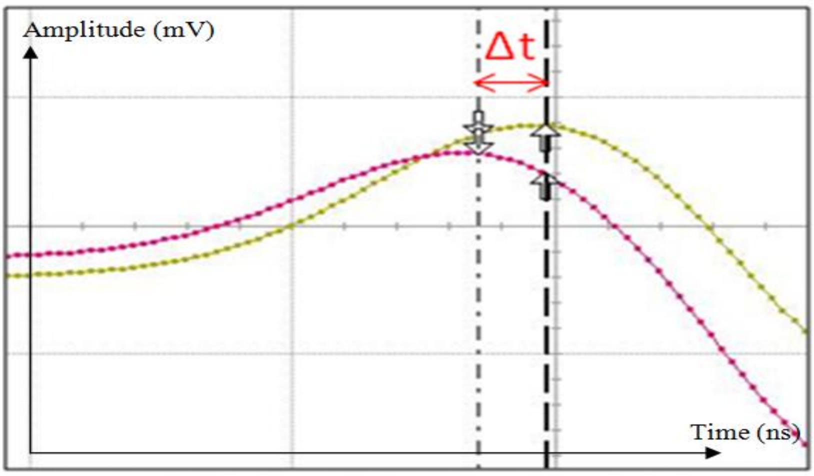

Figure 9. Oscilloscope trace of delay between the leading corona trace (closer to source) and the lagging corona trace

4. Results and Discussion

Figure 10 and Figure 11 are traces taken from the oscilloscope. Channel 1 represents the antenna on the left and Channel 2 represents the antenna on the right (refer to Figure 8). The time delay between first peaks of both traces is the Δt. This value will be used to determine L' (the difference of the displaced source). The distance between right antenna will be represented as X and the calculated value as X'. The distance between the left antenna and the source will be represented as X+L. L is the displacement from the source and L' is the calculated value. Figure 10 setup is when the corona source is at distance 1.5m from the antenna (left and right antenna). The source is at the center of both antennas. Δt is 0.35ns giving a measured distance of 1.45 meters with 3.33% error. Figure11 setup is when distance of corona generator is 0.8 meter from the right and 2.2 meters to the left. X' was calculated as 0.84 meters with 5.0% error. From Table 1, the error ranges from 1.54-10%.

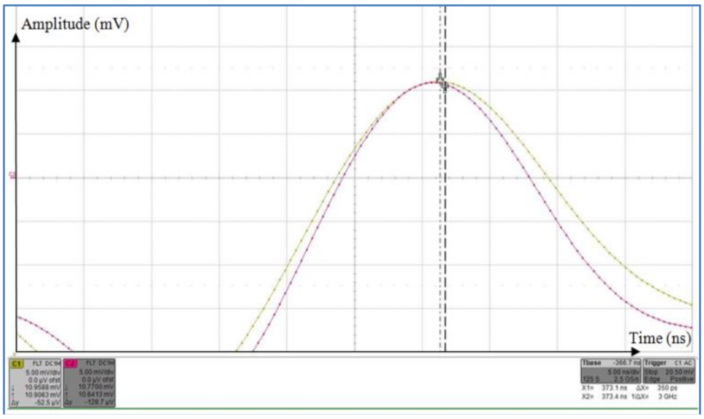

Figure 10. Trace when X =1.5m, L= 0m, Δt=0.35ns

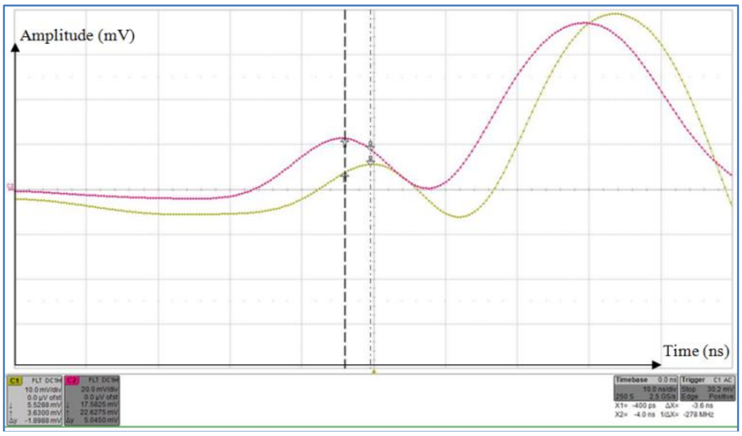

Figure 11. Trace when X=0.8m, L=1.4m, Δt=4.4ns

Table 1. X, L and % Error Between Measured and Actual Distance of Corona

X (m)	L (m)	t (ns)	L' (m)	X' (m)	Error (%)
0.0	3.0	11.0	3.29	-0.14	-
0.3	2.4	8.2	2.45	0.27	10.00
0.5	2.0	6.6	1.97	0.51	2.00
0.8	1.4	4.4	1.32	0.84	5.00
1.0	1.0	3.6	1.08	0.96	4.00
1.2	0.8	2.6	0.78	1.11	7.50
1.3	0.4	1.2	0.36	1.32	1.54
1.5	0.0	0.3	0.10	1.45	3.33

Figure 12 displays the calculated (X’) vs. measured distance (X) from the corona source. The average error recorded is 4.76% with the 98.81% confidence level. This gives a very close measurement for the antennas. Future corona detectors can be calibrated using this method to determine its performance.

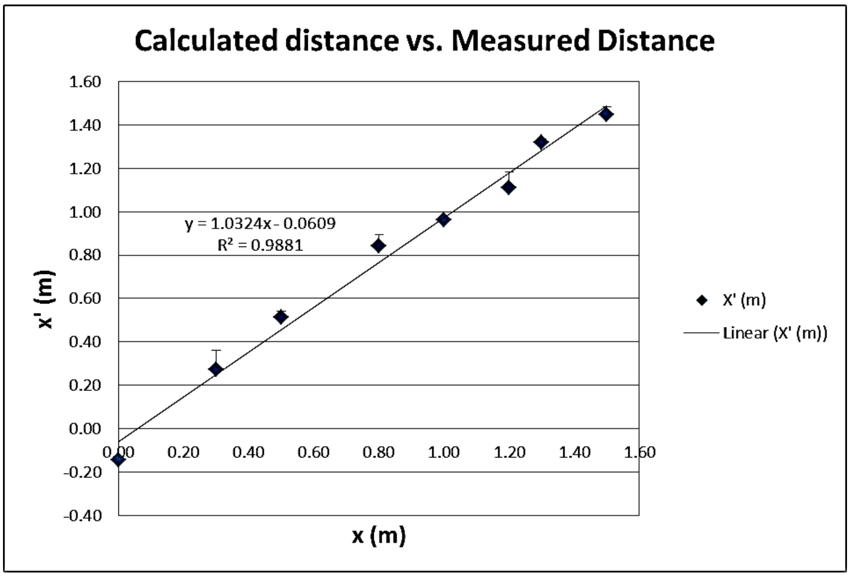

Figure 12. Calculated vs. measured distance of corona (error bar)

5. Conclusion

The 1d experimentation method concludes that the utilization of corona generator is substantial for calibration of antennas for corona detection. This method will compliment previous calibration method to ensure reliable and accurate field test results. Results show average 4.76% error with maximum 10.00%. The measurement method of utilizing delay between signals first peak proves is prevailing and may be used to develop an online corona measuring system in the future.

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