

Numerical Calculation of Voltage Distribution in an Insulator String Comparison with Measurements

Peder Hansen, Wendy Massey, Jose Chavez
SPAWAR Systems Center Code 285, San Diego 92152

Introduction

High power transmitting antennas, especially in the lower frequency ranges (VLF, LF, MF, and the low end of the HF band), are required to operate with high voltages and currents. The design of the insulator systems for these antennas is an interesting problem and has significant impact on the overall cost for any given system [1]. Many of these antennas are supported by guyed insulated masts requiring fail-safe insulators. Most fail-safe insulators are designed such that they will not fail structurally even if the insulating component does fail. They are usually composed two interlocking loops of structural steel separated by an insulator in compression. Fail-safe insulators are significantly heavier than non fail-safe types and they have lower voltage ratings. It is often the case that the required voltage for a particular insulator location cannot be achieved with a single insulator. In this case multiple insulators in a string are used.

The voltage distribution along a string of insulators is not uniform, so the rating for the string is not equal to the rating of a single insulator times the number of insulators in the string. Typically, the insulator at the high voltage end of the string has the most voltage, making it the voltage limit for the whole string. Grading techniques exist to make the voltage distribution more uniform, increasing the overall rating for the string. One of these techniques, the use of grading rings at the string ends, will be shown in this paper.

Design of fail-safe insulator strings in the past has been primarily based on empirical methods, including scale model and full-scale measurements as well as electrostatic model measurements. Numerical calculations using thin-wire method-of-moment codes provide a method for estimating insulator voltages but little data is available to validate calculated voltages, consequently large safety factors are often used. It is desirable to have a validated method for estimating the voltage distribution in an insulator string.

Insulator String

The US Navy is in the process of putting new fail-safe insulators in the 2MW transmitting facility at Cutler Maine. As a part of the design process for these insulators a string of 10 insulators was tested at the Hydro Quebec Research Institute (IREQ) high voltage test facility outside of Montreal Canada. The insulator string was tested with two large grading rings at each end to make the voltage distribution more uniform. The larger grading ring was on the high voltage end. The string of 10 insulators with the end rings is shown in Figure 1. One objective of these tests was to measure the voltage distribution along the string in so that the overall voltage rating of the string could be determined. The voltage distribution was measured for two configurations. One with all insulators active and the second with two of the insulators shorted.

The insulators and rings were also modeled numerically using a thin wire Method of Moments (MOM) program. The calculated results were in excellent agreement with the measurements leading to the conclusion that, with the appropriate technique, numerical

methods can be used to estimate the voltage distribution on fail-safe insulator strings with accuracy sufficient for engineering design.

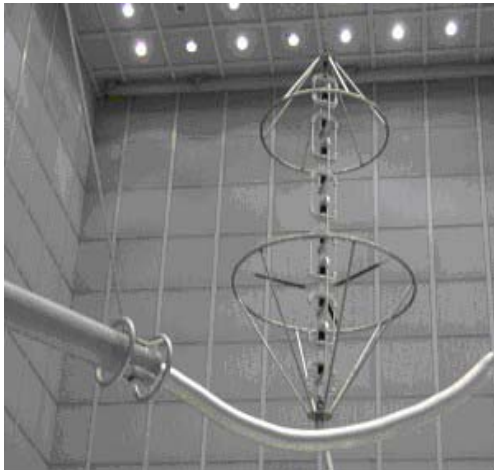


Figure 1. Insulator string at IREQ

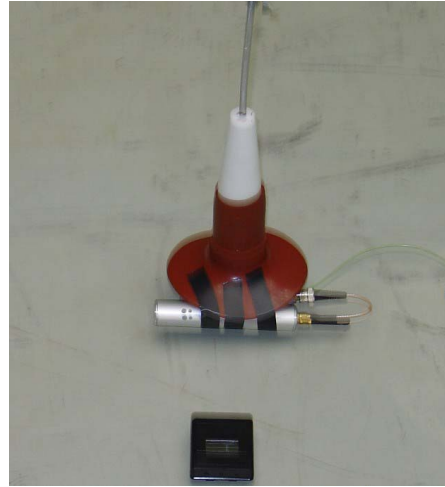


Figure 2. IREQ voltmeter

Measurement of Voltage Distribution

The voltage distribution along an insulator string is the result of a voltage divider effect due to the capacitance of the individual insulators and the capacitance of the individual insulators to free space (leakage capacitance). The measurement of the voltage distribution has some significant challenges, not the least of which is to get the insulator string far enough away from ground to approximate the actual installation. The voltage distribution was measured at the Hydro Quebec Research Institute (IREQ) high voltage test facility outside of Montreal Canada. The insulator string suspended at IREQ is shown in Figure 1. A remotely telemetered voltmeter (Figure 2), having an input capacitance of 4 pF, was used to make voltage measurements across individual insulators. Two readings were taken for each insulator. One measurement is taken with the voltmeter by itself, and a second measurement taken with a dummy voltmeter, having the same capacitance, connected in parallel with the active voltmeter. This technique allows for correction of the loading effect of the voltmeter. The correction factor is given by the formula below.

$$V_{oc} = \frac{V_1}{2 - V_1/V_2}$$

Where V_1 is the voltage measured by the voltmeter alone,
 V_2 is the voltage measured by the voltmeter with the dummy in parallel
 V_{oc} is the voltage for a meter with infinite impedance.

Figure 3 shows the measured voltage distribution on the 10-insulator string normalized to one volt total across the string. The voltage distribution is relatively uniform for such a long string because of the large grading rings at the ends. The first insulator has the largest voltage equal to 13% of the total. This implies that the overall rating of the string with the grading rings will be:

$$V_{string} = \frac{1}{0.13} \cdot V_{ind} = 7.79 \cdot V_{ind}$$

Where V_{string} is the rating of the string and
 V_{ind} is the rating of the individual insulators in the string.

A second configuration was measured with insulators #3 and #7 shorted out, simulating an 8-insulator string. The results are shown in Figure 4.

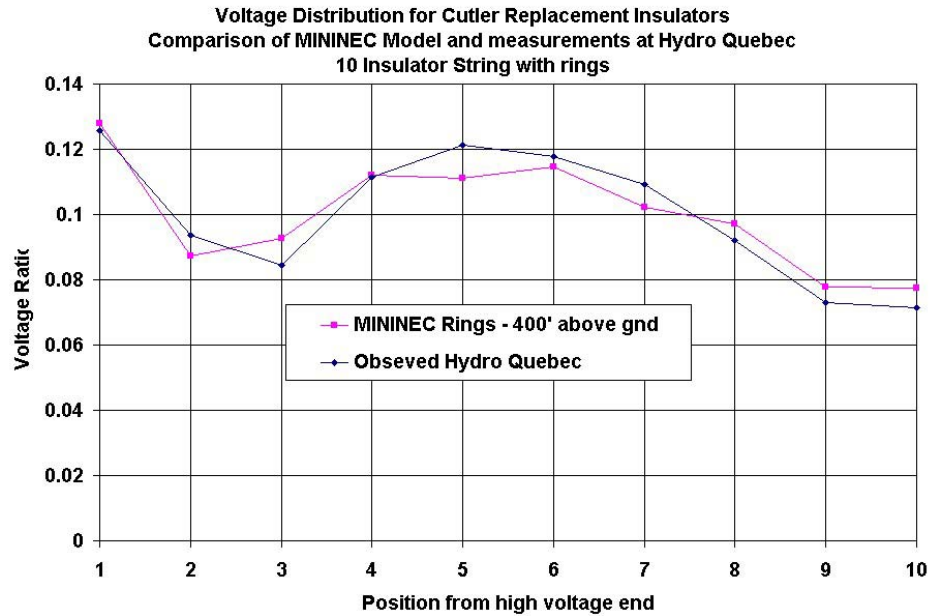


Figure 3. Cutler fail-safe insulator string voltage distribution

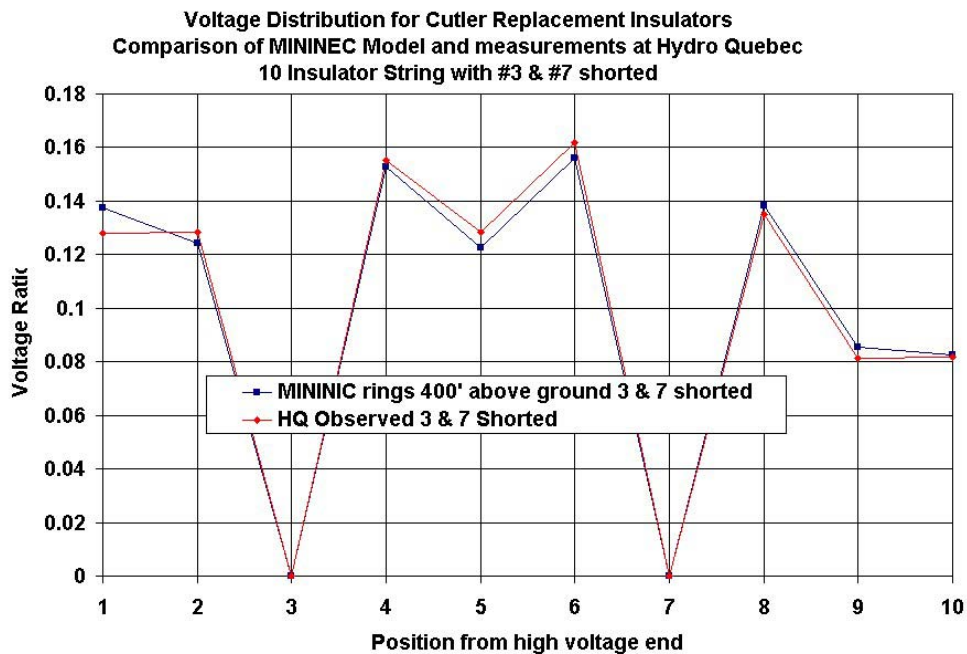


Figure 4. Insulator string voltage distribution with #3 and #7 shorted

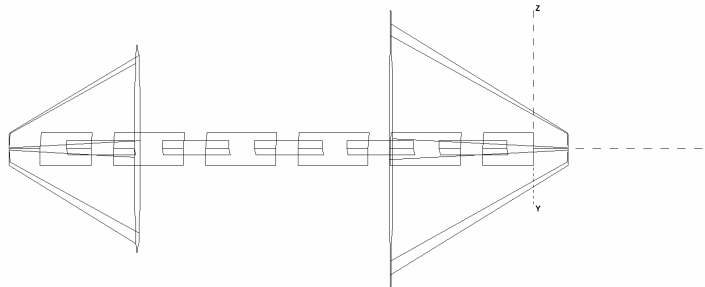
Calculations

A computer model was developed using MININEC [2], a thin wire MOM code, and used to calculate the voltage across the insulators in the string. The metal parts of the insulators and the end rings were modeled using wires. The porcelain insulators were modeled using a thin wire loaded with a 100 Mohm resistor. This resistance must be large enough so that it does not affect the voltage distribution and this is determined by trial and error. Figure 5 shows the graphical representation of the computer model. The MININEC results are compared with the measurements in Figures 3 and 4. The agreement is striking.

Conclusions:

Comparison of measurements and calculations of the voltage distribution along a large insulator string have been given. The results show that numerical techniques can be used to calculate the voltage distribution in insulator strings with the accuracy required for engineering design. Considerable art is required in constructing the details of the computer model. The technique of using a very large value resistor to measure the voltages has been applied with excellent results.

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perspective view, free space



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Figure 5. Computer model of failsafe insulator string.

References:

- [1] Hansen, P.M. and W. Massey, "Numerical Calculation of Insulator Voltages in Transmitting Antennas - Comparison with Measurements", IEEE APS Symposium Albuquerque, NM July 2006
- [2] MININEC is available from EM Scientific Inc. at <http://www.emsci.com/>