Mississippi State UNIVERSITY

HIGH VOLTAGE LABORATORY
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
MISSISSIPPI STATE, MS 39762

Research Report

STUDY OF THE BASIC INSULATION LEVEL (BIL) OF CALVERT NEW THREE-PHASE 15 kV BAR BUS DESIGN

Investigation performed
for
Calvert Company
120 Aztec Drive
Richland, MS 39218

Principal Investigator

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Measurements performed on February 15, 2005

1. PURPOSE

The purpose of the tests was to determine whether the lightning withstand voltage of the new 3-phase, 15 kV bar bus designed by Calvert Company was greater than 95 kV.

The evaluation of the bus bar insulation was performed:

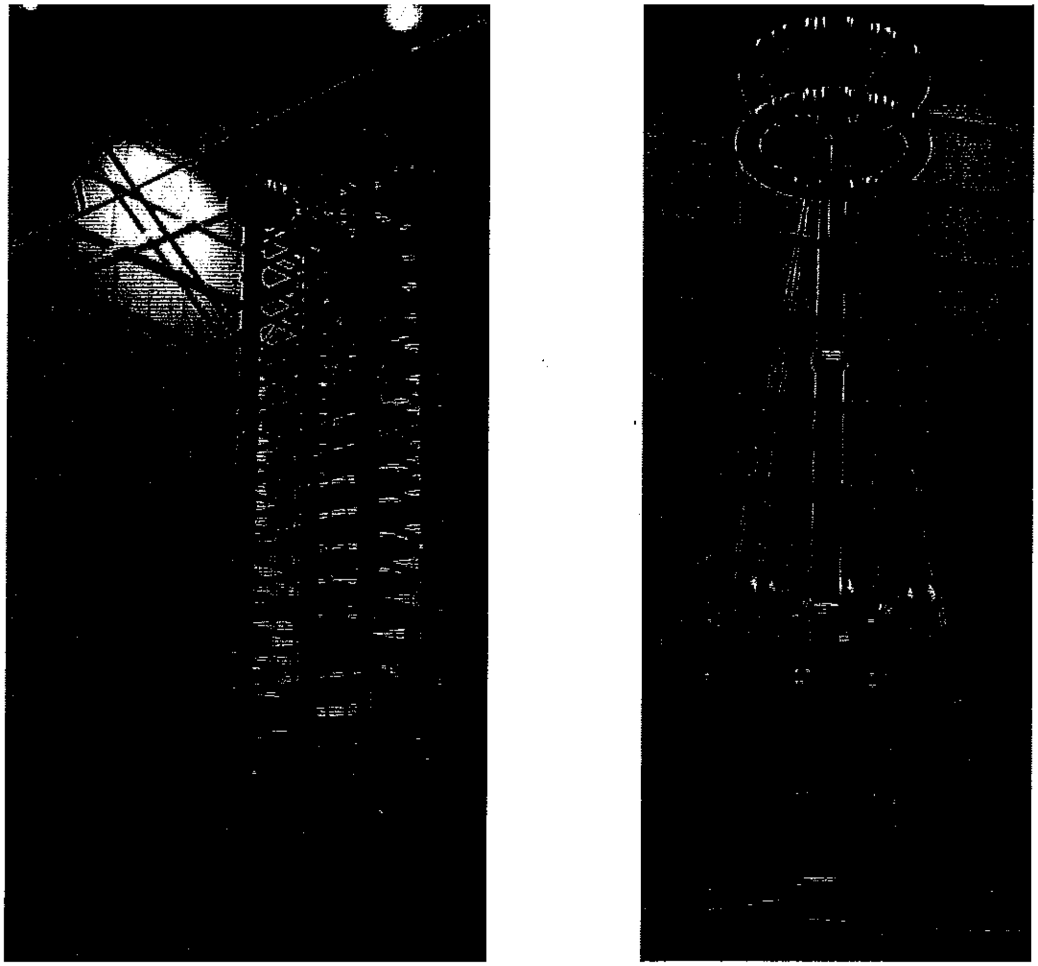
1. phase and ground (enclosure)
2. phase to phase

2. LIGHTNING IMPULSE GENERATOR AND MEASUREMENT SYSTEM

The lightning impulses were obtained from a 20-stage, 57 kJ impulse generator (Figure 1). The generated lightning impulses in the study (Figure 2) had a virtual front time of 0.99 μs and a time-to-half-value of 60.6 μs, both positive and negative polarity.

The lightning impulses were measured for voltage magnitude and shape using a voltage divider system connected to the test object. The voltage from the divider is displayed on a Tektronix TDS 7104 digital storage oscilloscope, which displays each waveform as it is applied to the test object and indicates whether the effect of the impulse was a flashover or a withstand.

The impulse measurement system was calibrated with the laboratory's reference sphere gap set according to Section 17 of IEEE Std. 4-1995 (Appendix 1). The manufacturer calibrated the TDS 7104 digital storage oscilloscope.



(a) (b)
Figure 1- (a) Impulse Generator, (b) Capacitor Voltage Divider

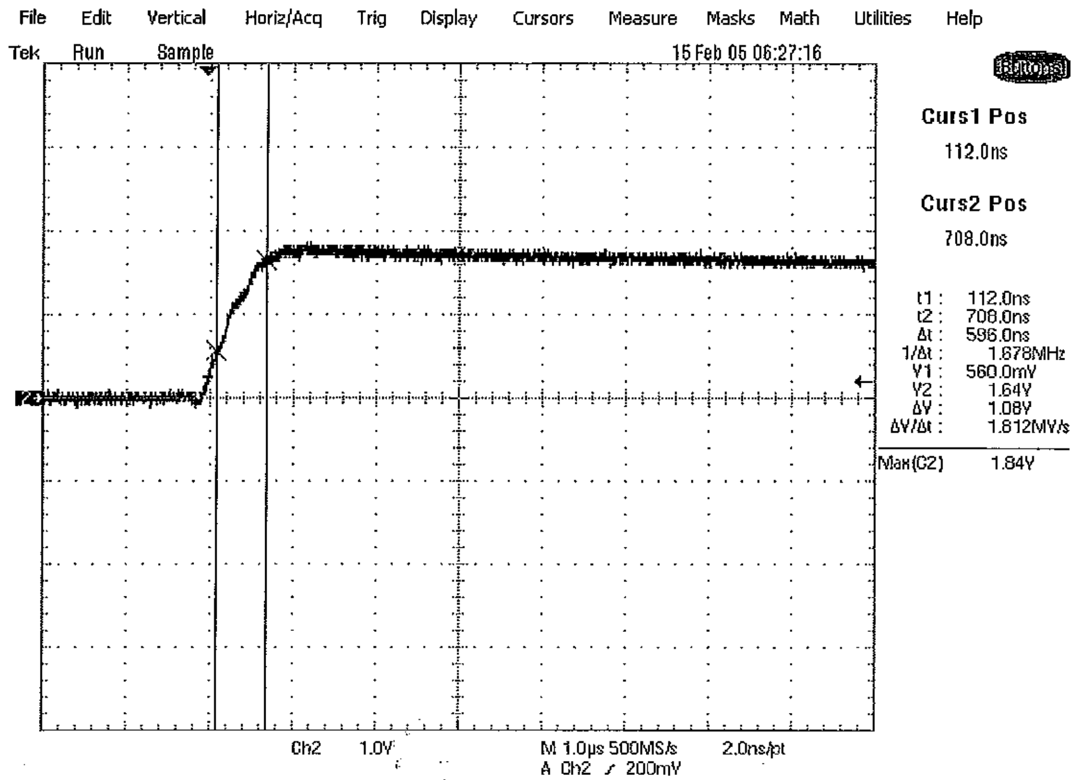


Figure 2a - Lightning impulse wave shape used in the study, time to virtual front 0.99 μs.

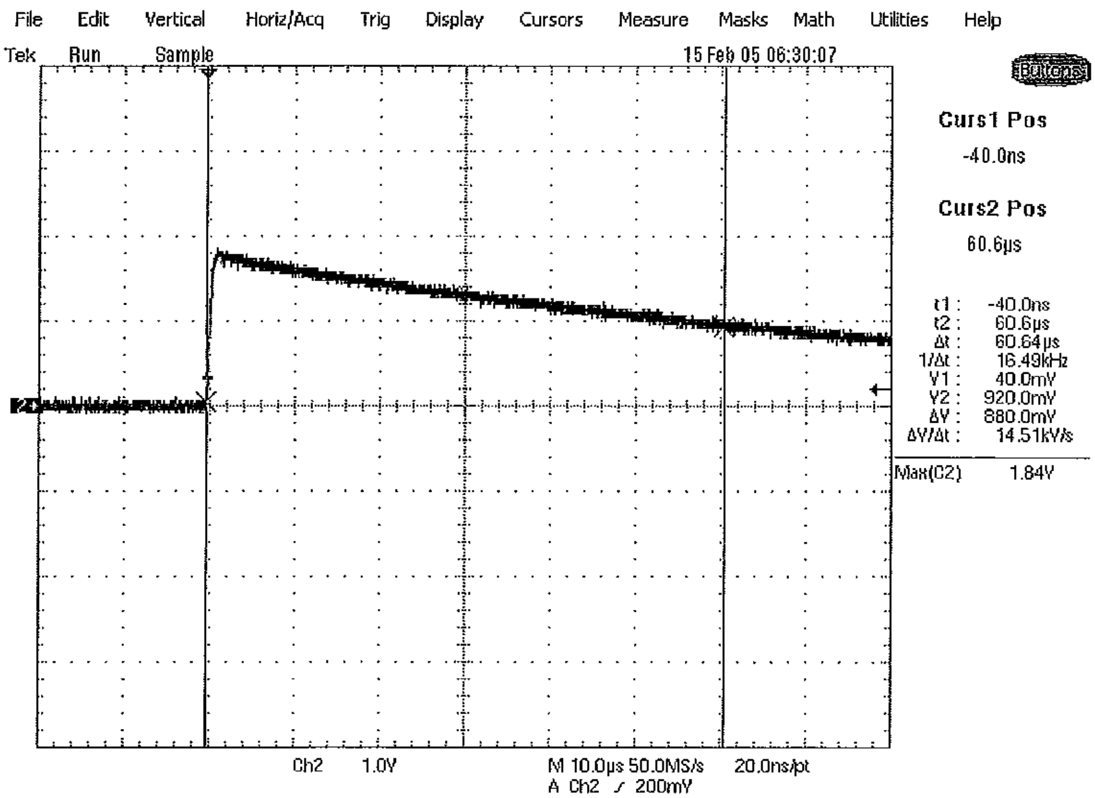
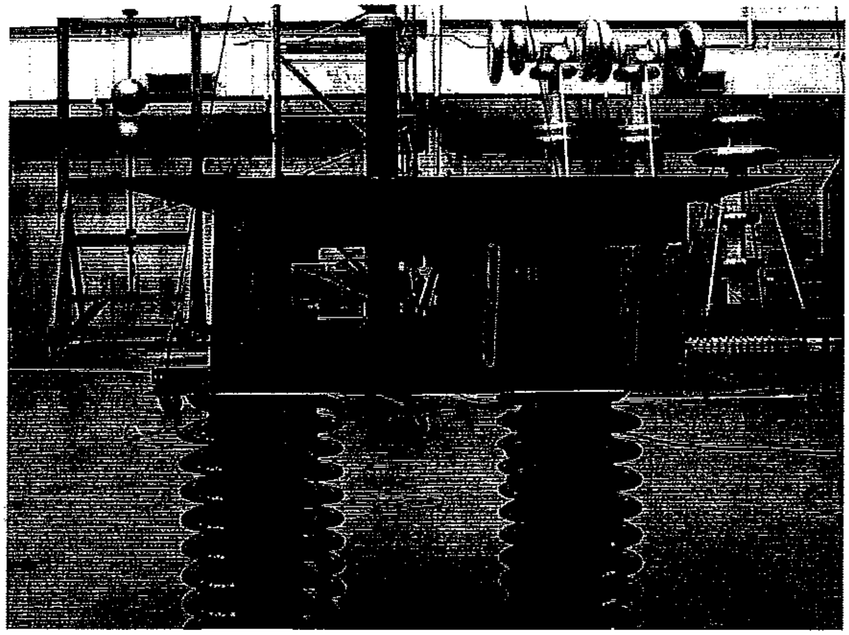


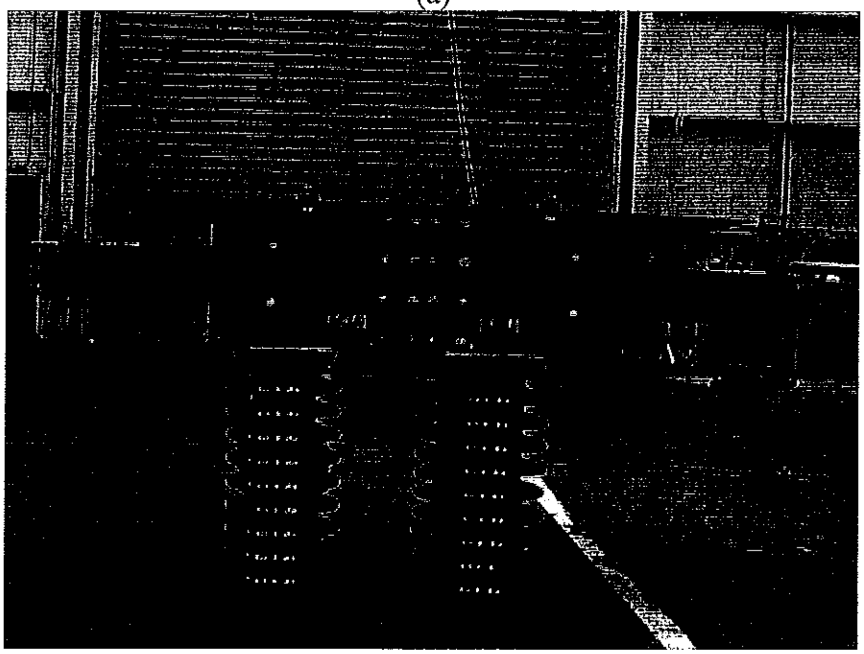
Figure 2b - Lightning impulse wave shape used in the study, time to half value 60.6 μs.

3. TEST SETUP

The bus bar was located in the High Voltage Laboratory mounted horizontally 70 cm above the grounded laboratory floor (Figures 3 and 4). The bus enclosure was elevated from the floor by four cylindrical isolators in such a way that observations could be made from a safe location within the laboratory.



(a)



(b)

Figure 3 - The bus enclosure located in the High Voltage Laboratory: (a) front view, (b) side view.

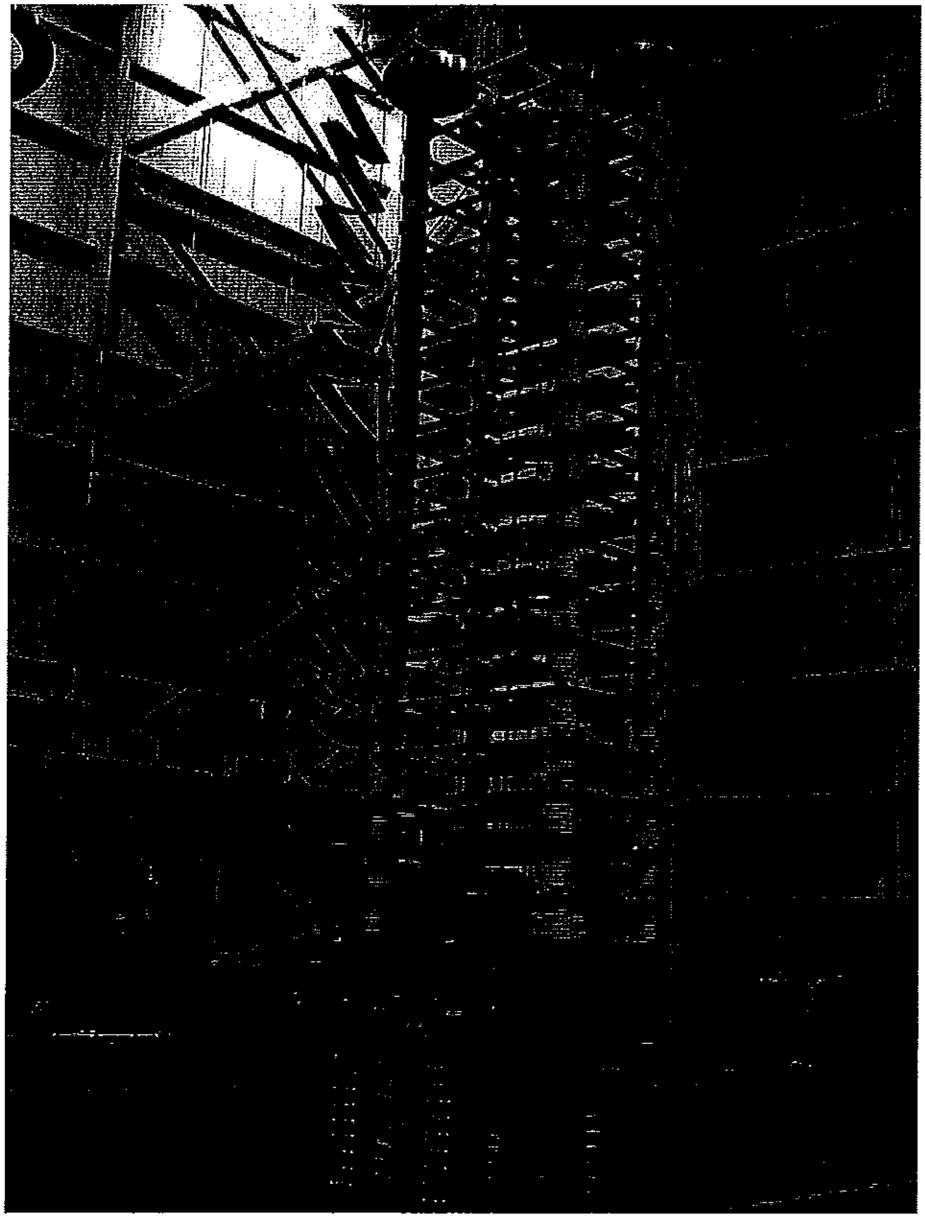
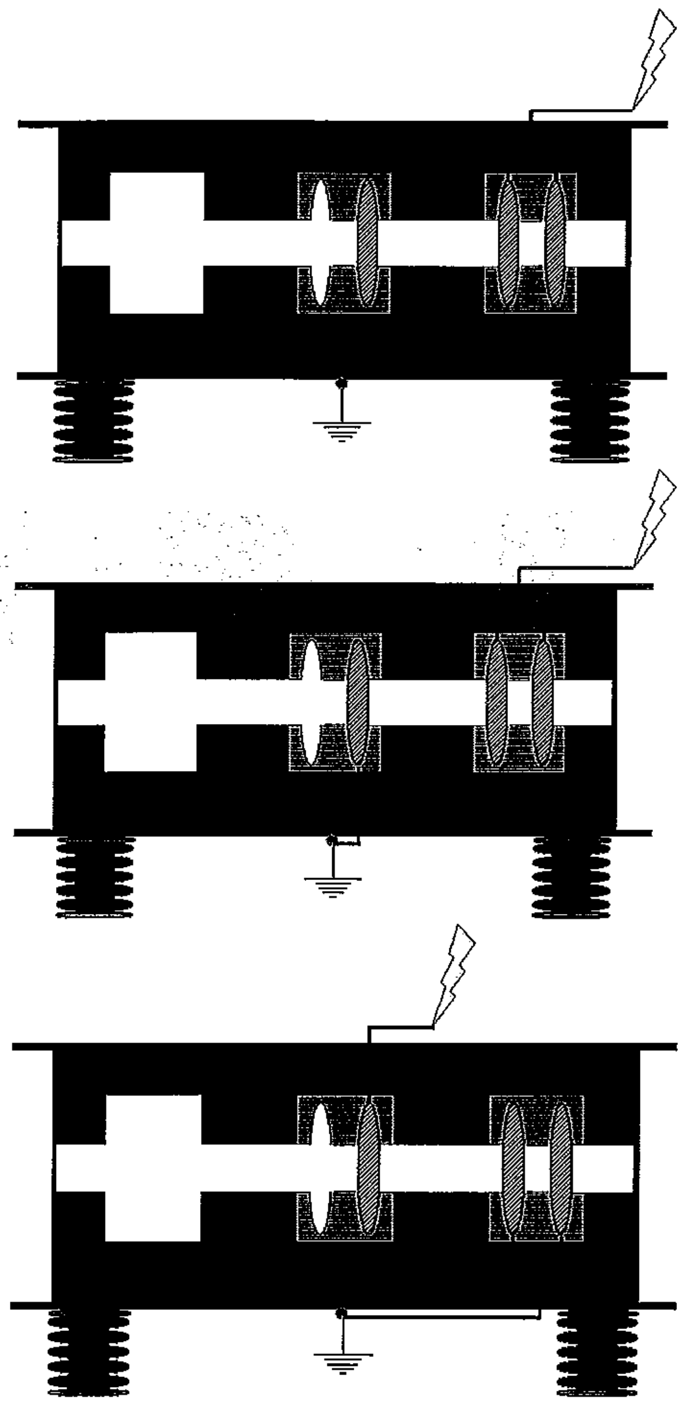


Figure 4- The three-phase bus with the lightning impulse generator in the background.

In the MSU High Voltage Laboratory three test configurations were implemented to study the BIL of the three-phase bus. These test configurations evaluated the withstand capability of each phase with respect to ground, and between phases (see Figure 5). The evaluated three-phase bar bus had only two buses in phase A and one bus in phase B as delivered by Calvert Company.



(a)

(b)

(c)

Figure 5 – Representation of the test configurations implemented in the study: (a) Phase A energized, enclosure grounded; (b) Phase A energized, enclosure and phase B grounded; (c) Phase B energized, enclosure and phase A grounded.

4. TEST CONDITIONS

The atmospheric conditions were observed to apply measurement corrections as specified in the IEEE Std. 4-1995. Once applied the adjusted measurement should correlate to the laboratory and other laboratories at any point in time. Measured voltages were corrected by an air density correction factor (k_1) and a humidity correction factor (k_2). The correction factor parameters measured in the laboratory at testing time include barometric pressure, dry bulb temperature, and wet bulb temperature. Application of the correction factors was as follows:

$$V_{Rated} = \frac{V_\delta}{K} \tag{4.1}$$

where

$$K = k_1 \cdot k_2 \tag{4.2}$$

The air density correction factor (k_1)

$$k_1 = \delta^m \tag{4.3}$$

$$\delta = \left(\frac{b}{b_0}\right)\left(\frac{273°C + t_0}{273°C + t_d}\right) \tag{4.4}$$

Where m was the exponent as specified in the IEEE 4-1995 standard, b_0 and t_0 were standard atmospheric pressure and temperature constants, and the measured parameters:

Barometric pressure: $b = 773$ mm Hg
Dry bulb temperature: $t_d = 21.7°$ C

Therefore, from equation 4.4 we computed δ to find the parameter g:

Relative Air Density: $\delta = 1.0112$

$$g = \frac{V_b}{500 \cdot L \cdot \delta \cdot k} \tag{4.5}$$

Parameter k was computed from δ and the absolute air humidity (h) as specified by the curves, Figure 35 of the IEEE Std. 4-1995 using the dry bulb and wet bulb temperatures:

Wet bulb temperature: $t_w = 17.5°$ C
Absolute air humidity: $h \approx 13$ g/m^3

Because the term h/δ was in excess of 15 g/m^3 a weighting factor was applied to account for error in the linear approximation of k:

$$k = \left[1 + 0.01 \cdot \left(\frac{h}{\delta} - 11\right)\right] \tag{4.6}$$

Additionally, the parameters V_b and L were determined in the laboratory as:
Applied test voltage: $V_b = 138$ kV
Minimum discharge path: $L = 50.0$ mm

The parameters g and k were computed from (4.5) and (4.6):
Humidity correction parameter: $g = 5.3597$
Humidity correction parameter: $k = 1.0185$

Consequently, the parameter k was required for the computation of the humidity correction factor (k_2):

$$k_2 = k^w \qquad (4.7)$$

Where parameter g computed from equation (4.5) was used to find the exponent terms m and w from curves specified in the IEEE Std. 4-1995, Section 16. Then equations (4.3) and (4.7) were applied respectively to compute k_1 and k_2:
Exponent estimation: $m = 1.0$
Exponent estimation: w = 0.0
Air density correction factor: $k_1 = 1.0112$
Humidity correction factor: $k_2 = 1.0$

Then equation (4.2) was computed to: $K = k_1 \cdot k_2 = 1.0112$

5. MEASURED PARAMETERS

Measurements were recorded for each of the two phases that were present on the three-phase bus. In each test visual observation were conducted and oscillogram measurements were recorded. Three negative and three positive impulses were applied for each test voltage level. The bus is considered to have a A, B, or C phase. Phase 'A' is the right-most terminal when facing the bus as shown in Figure 5. Phase 'B' is the center terminal, and phase 'C' is the left-most terminal opposite from the phase 'A' terminal. The delivered bar bus consisted only with two buses in phase A and one bus in phase B

The results of the measurements are presented in the Appendices 2 and 3. Each appendix contains the measurement results for positive and negative polarity respectively. The appendices are presenting results of measurements as follows:

- **Appendix 2, Positive Polarity**
  1. 95 kV Results
  2. 110 kV Results
- **Appendix 3, Negative Polarity**
  1. 95 kV Results
  2. 110 kV Results

6. RESULTS OF STUDY

The evaluated three phase, 15 kV bar bus withstands the 95 kV BIL level for positive and negative polarity of the lightning impulse.

When the tests were performed at 110 kV lightning impulse flashovers appeared between phase A and ground as well as phase B and ground.

- For positive polarity, when phase B was energized, case 3, flashovers appeared for three out of four applied impulses.

  The boot on the phase B was changed and the test continued

  The next two flashovers appeared out of three shots

  The top of the enclosure was raised by one inch and the test continued

  The next nine applied impulses did not cause flashovers

- For negative polarity, when phase A was energized, case 1, flashovers appeared for three out of four applied impulses.

  The enclosure side at phase A was stretched out by one inch.

  The next four applied impulses did not cause flashovers

7. CONCLUSIONS

Calvert Co. new three-phase bar bus design was tested to study its basic insulation level. The performed primary tests at 95 kV positive and negative polarity impulses confirmed that three-phase 15 kV bar bus is good for 95 kV BIL level.

According to the standards the evaluated 15 kV bar bus have to be tested with busses installed in all three phases.

Additional testing and bar bus modification is recommended for the 110 kV BIL level. .

8. REFERENCES

[1] IEEE Standard for Metal-Enclosed Bus; IEEE Std. C37.23-2003.

[2] IEEE Standard for Metal-Clad Switchgear; IEEE Std. C37.20-1999.

[3] IEEE Standard Techniques For High-Voltage Testing; IEEE Std. 4-1995.