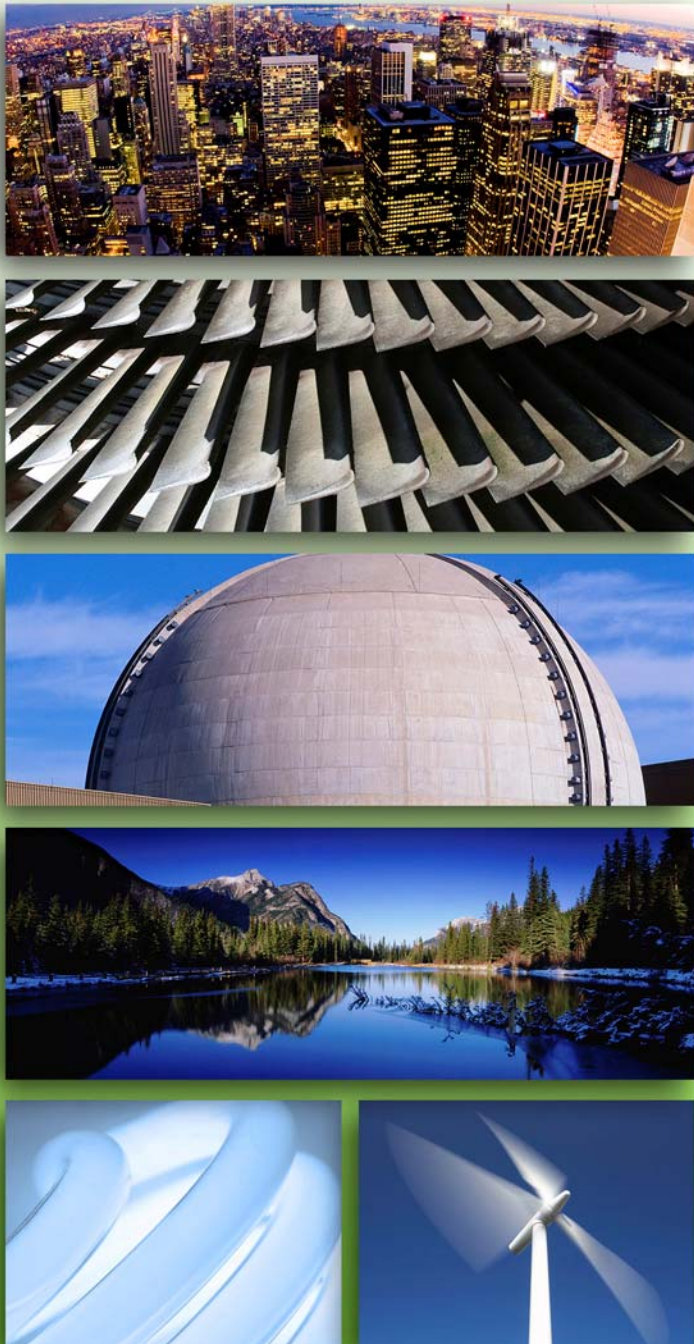

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# Corona Performance of Conductors at High Temperatures

**IEEE PES Joint Technical Committee Meeting**

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# Power Industry's Needs

**Issues**:

- Growth in Power Demand outpaced New Construction
- Bottlenecks created by De-regulation

**Challenges**:

- Difficulties in acquiring Rights-of-Way
- Immediate need to raise Capacity
- Longer term solution to address Right-of-Way acquisition problem

# Solutions to Increase Transmission Capacity

- Find additional capacity in existing system
- Develop methodologies and tools to:
  - Raise Current (one option: raise conductor operating temperature)
  - Raise Voltage
  - Optimize Power Flow
- Conduct Research for longer-term and higher-gain Solutions such as AC to DC conversion, superconductors

# Raise Conductor Temperature Issues

- Existing conductors are not designed for temperature higher than $93^0$C.
- Is there any mechanical problem for the conductor and its connection at high temperature?
- In addition, new materials for HTLS conductors have been introduced which may behave differently - electrically, thermally, and mechanically.
- Is the thermal model correct for high temperature operation?
- Corona model developed when $75^0$C was considered a high operating temperature.
- Will we experience corona problems where there were not problems previously?



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# Corona Onset Gradient

Corona effects (AN, RI, TVI, EMI, corona loss, ozone, etc) are calculated using empirical formulas based on the corona inception gradient, $E_0$)

Peek's empirical formula:

$$E_0 = 21.07\, m\, \delta \left( 1 + \frac{0.301}{\sqrt{\delta\, r_c}} \right)$$

Where:
$E_0$ is the inception gradient in $kV_{rms}$/cm of a cylindrical conductor of radius $r_c$
$m$ is the conductor surface roughness factor and
$\delta$ is the relative air density, given as

$$\delta = \frac{273 + t_0}{273 + t} \cdot \frac{p}{p_0}$$

Where:
$t$ is the ambient temperature in °C
$p$ is the atmospheric pressure in mm Hg and
$t_0$ and $p_0$ are reference values ($t_0$ = 25°C and $p_0$ = 760 mm Hg)





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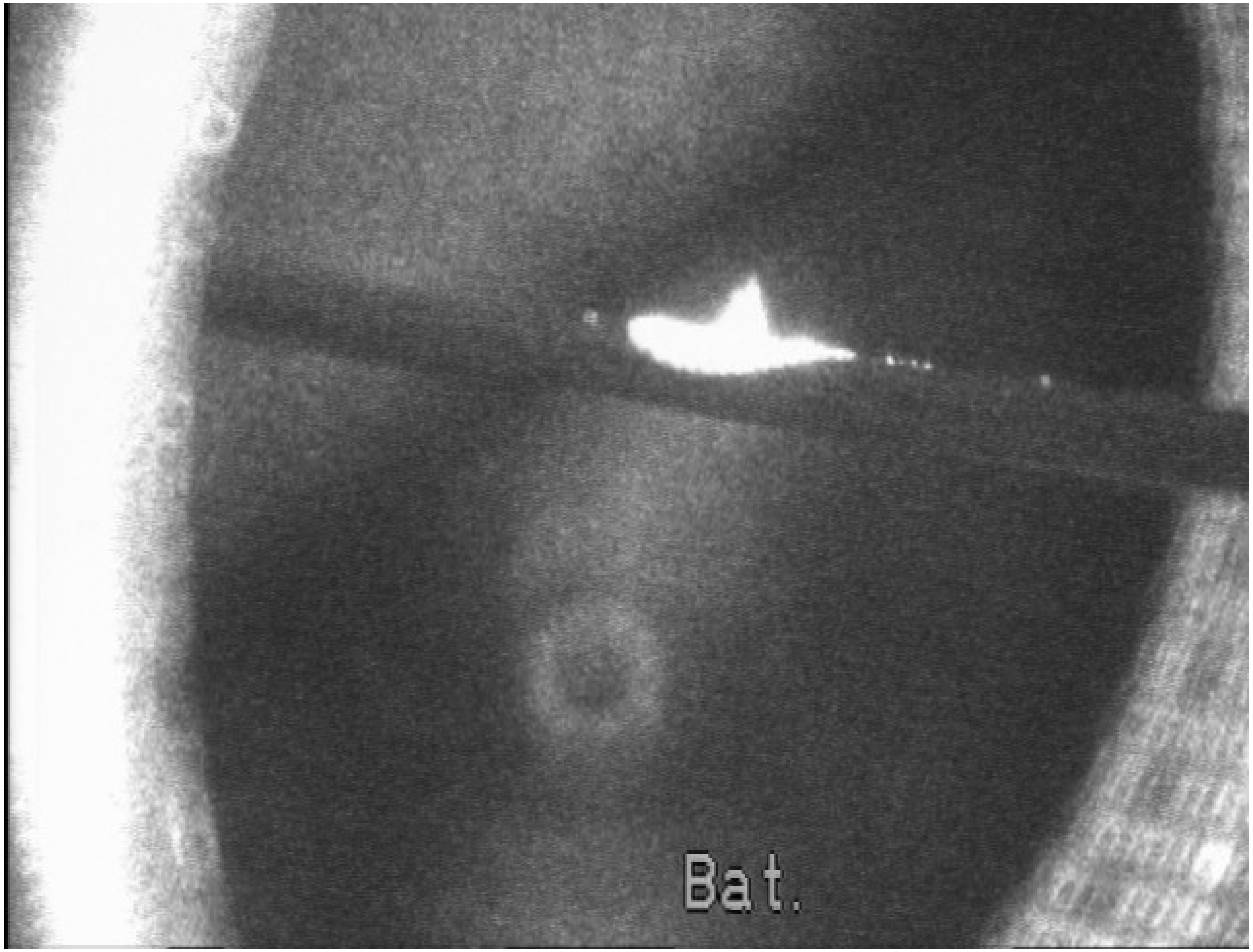
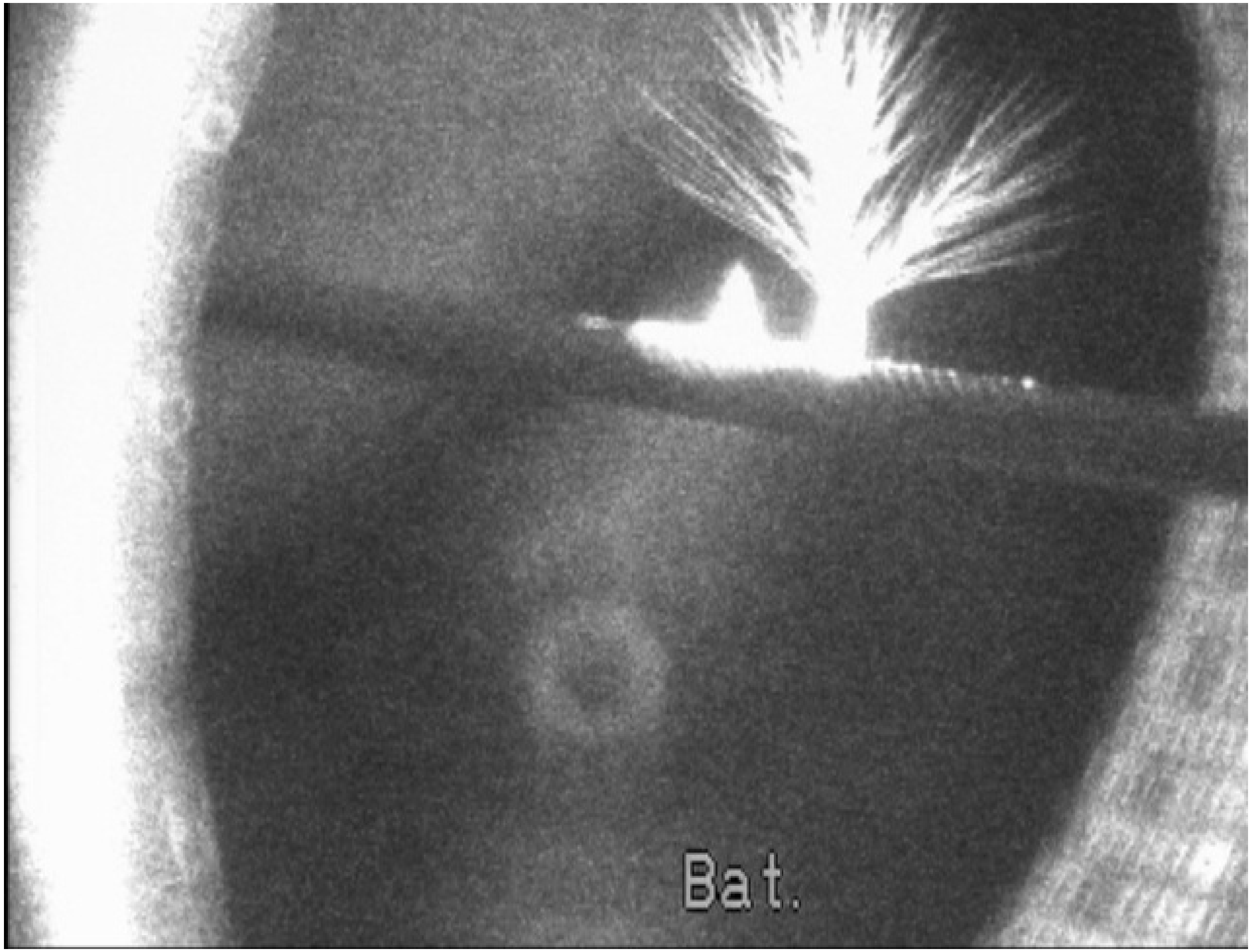
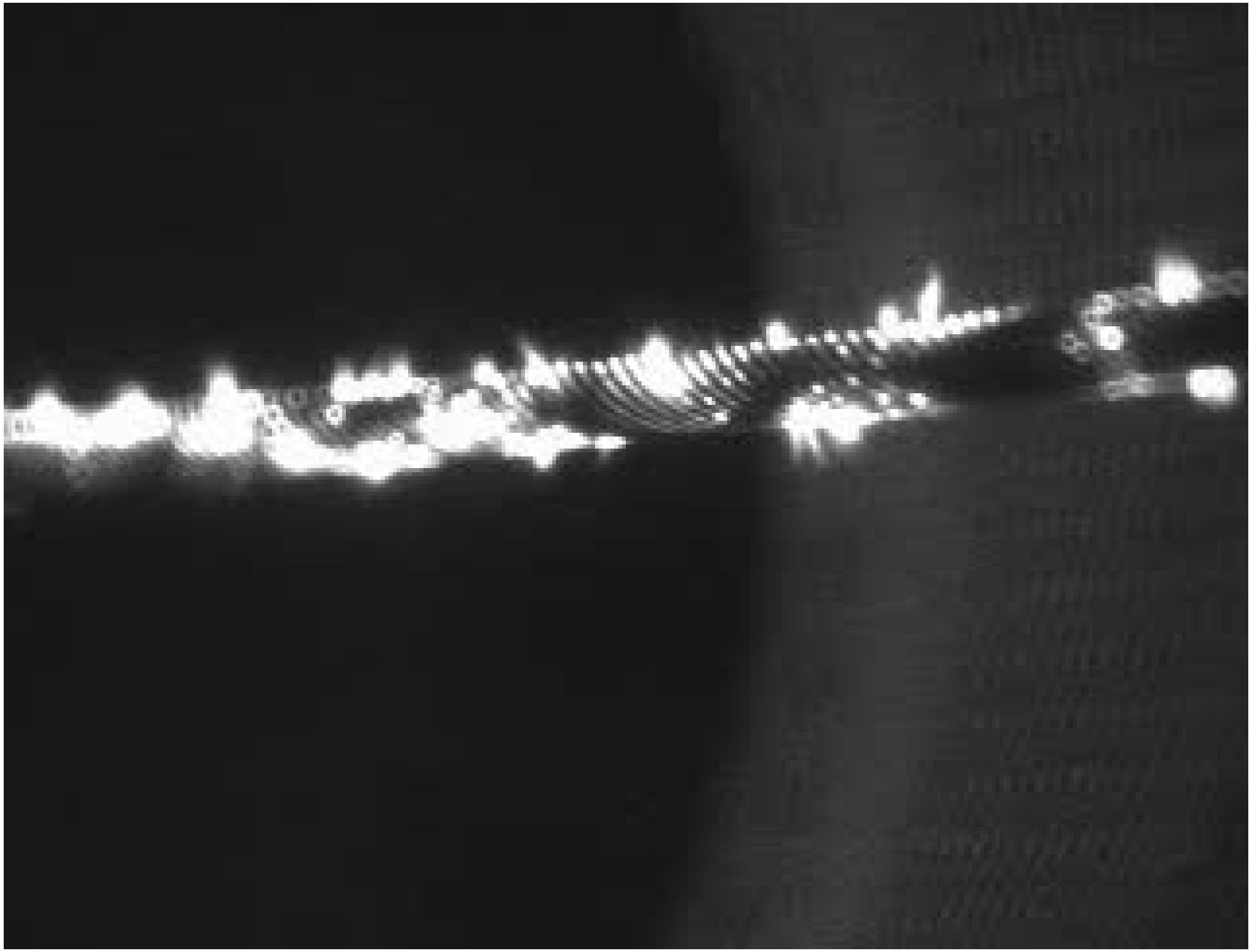
# Negative Corona



# Positive Corona



# Negative and Positive Corona







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# Corona Tests

First Phase:

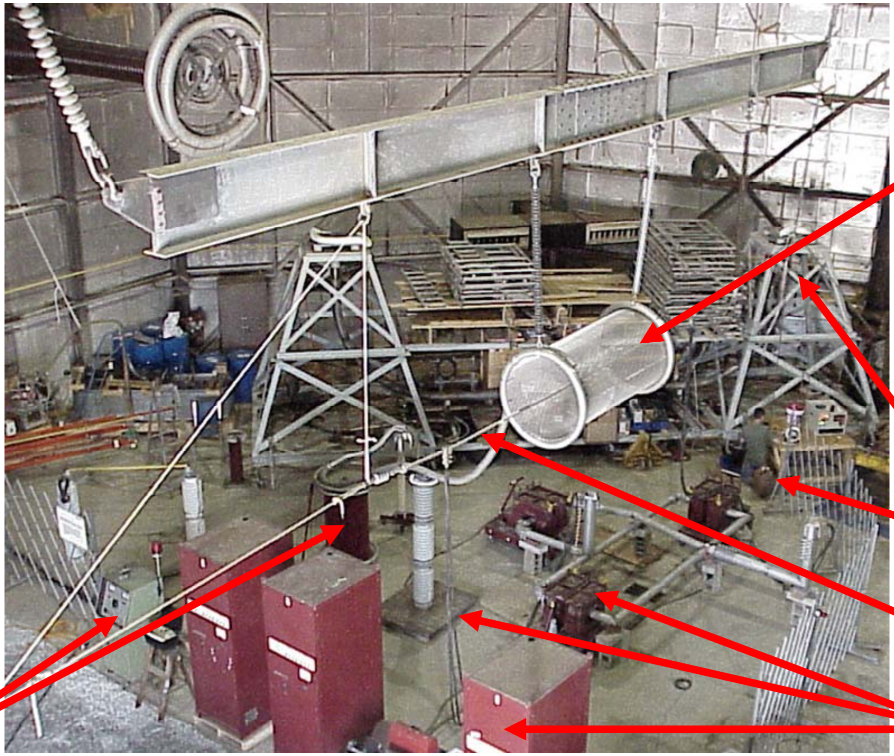
- Outdoor in a tent
- Smooth tubes used as test samples
- Heating elements embedded inside tube

Second Phase:

- Test cage setup moved inside the high-voltage laboratory at Lenox.
- Gap and ACSR conductors used as test samples
- Conductor heating accomplished by circulating a high current from a current transformer in the test conductor and the conductor temperature is controlled by controlling the circulating current.

# Outdoor Cage Test Set-up

# Indoor Cage Test Set-up



Cage around conductor

500 lb Weight and pulley arrangement

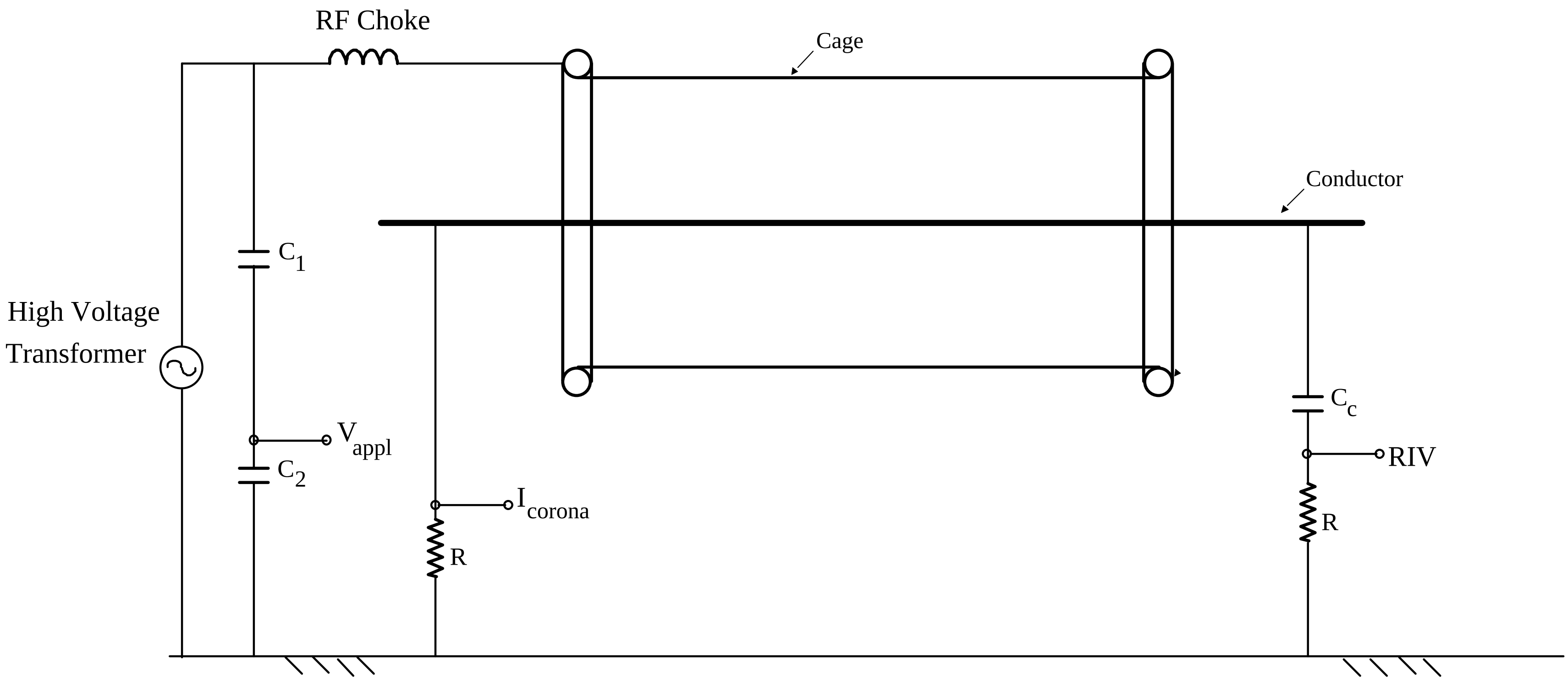
ACSR Conductor

High-Current inductive supply, controllers and connection cables to heat conductor under test

VAC 150 kV supply

# Measuring Circuit

- **The measuring circuit is shown in the figure below:**





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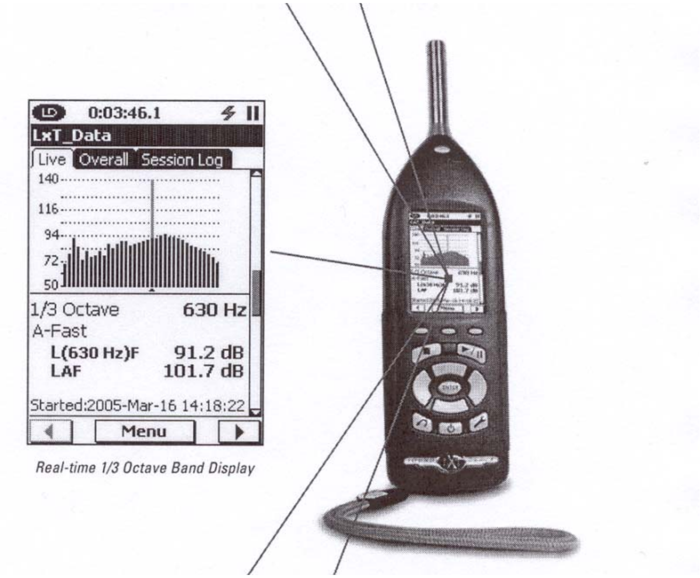
# Instrumentation and Measurement

- Conductor surface temperature is measured using an infra-red camera. Other atmospheric variables are also measured at the test location.
- Corona onset on the test conductor is measured by gradually raising the applied voltage up to and above the onset of corona on the conductor. The onset of corona on the conductor is detected using a Corocam (instead of a Daycor) camera.
- Corona loss (CL) is measured by digitally multiplying the applied voltage and corona current signals obtained as shown in the figure.

# Instrumentation and Measurement

- RI is measured using a NEMA circuit and a Stoddart NM-25T radio noise meter on the test conductor, as shown in the figure. Some measurements are made using a NM-21 FFT meter
- AN is measured using a Larson-Davis SoundTrack LxT sound-level meter.




Real-time 1/3 Octave Band Display

# Test Procedure

- First Phase:  Tests were carried out on smooth tubes of outside diameters of 2.64 cm and 2.13 cm.
- Second Phase:  Tests were carried out on three Gapped HTLS (3.16 cm, 2.77 cm and 2.28 cm diameter) and one ACSR (3.36 cm diameter) conductors.
- For each of the conductors installed in the cage, the following tests were carried out:

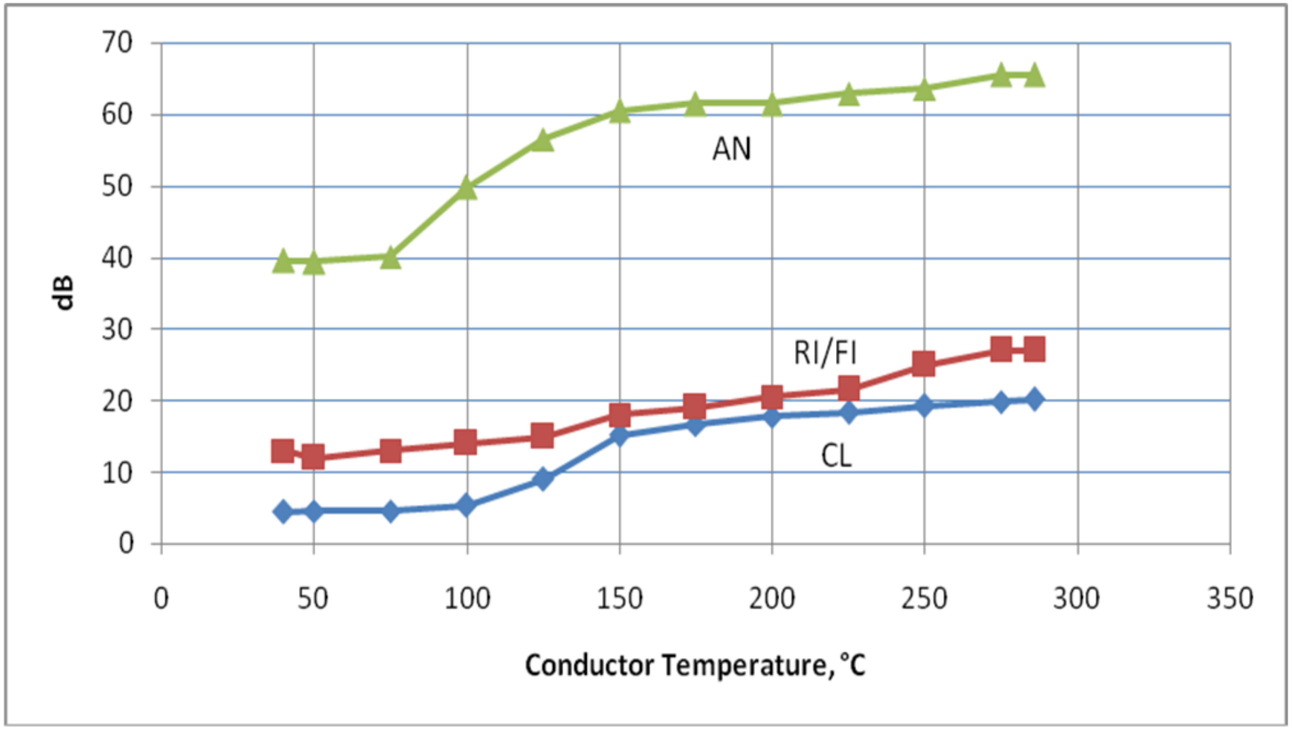
1. Determination of the corona onset voltage for different conductor surface temperatures varying in steps of 50ºC from ambient to 250ºC or 300ºC.

# Test Procedure

2. Dry HT corona measurements, with a constant voltage applied to the cage and the conductor surface temperature brought up to the highest value (250ºC or 300ºC) and then switching off the heater power supply. The corona measurements CL, RI and AN were made at different conductor surface temperatures, in steps of 50ºC, as the conductor cools down to the ambient value. Similar corona measurements were carried out at three voltage levels applied to the cage.
3. For one stranded conductor selected, a study was carried out to observe the behavior of water drops falling on the hot conductor surface, with and without voltage applied to the cage.

# Preliminary Results

- **Corona Phenomena Measured as a Function of Conductor Temperature on a 2.64 cm Smooth Tube.**



# Temperature Correction Terms

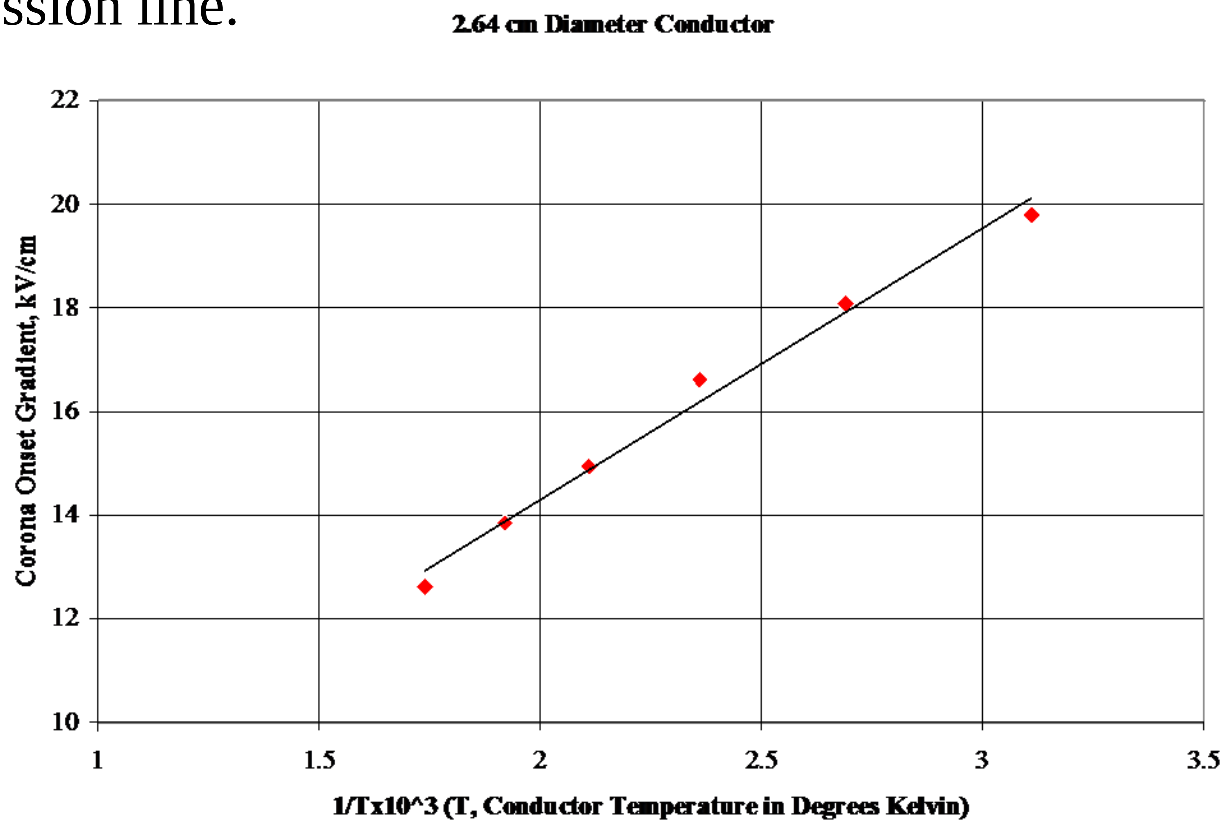
- A simple equation of the form

$$E_0 \quad = \quad c_1 + \frac{c_2}{T}$$

is proposed to determine the influence of surface temperature on the corona onset gradient for the two conductors tested.

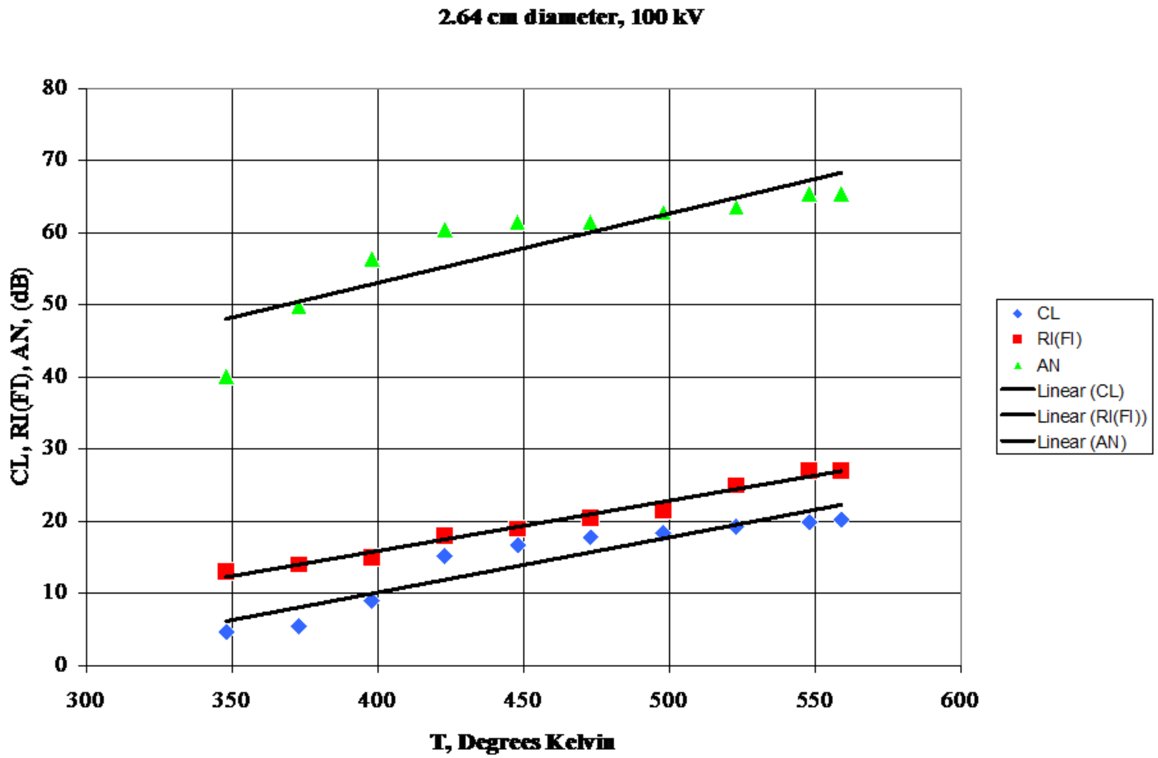
# Temperature Correction Terms

- Figure shows the corona onset gradient as a function of $(1/T)x10^3$ for the 2.64 cm diameter conductor tested, along with the regression line.



# Temperature Correction Terms

- The following simple empirical formula is proposed for CL, RI and AN, $$\left(CL, RI, AN\right) = k_1 + k_2 T$$ where T is the conductor surface temperature in ºK.



# Temperature Correction Terms

Mean Slopes of Regression Analysis Curves

| Conductor | CL | RI | AN |
|---|---|---|---|
| 2.64 cm | 0.0792 | 0.084 | 0.113 |
| 2.13 cm | 0.0477 | 0.0777 | 0.0437 |
| Both | 0.0634 | 0.0808 | 0.0782 |

# Conclusions

1. On dry conductors, the corona onset gradient decreases with increasing conductor surface temperature, mainly as a result of a decrease in the air density in the immediate vicinity of the conductor. However, additional studies on smooth as well as stranded conductors using well-defined corona onset criteria are required to obtain the appropriate temperature correction term in empirical prediction formulas.
2. The influence of corona wind in cooling the surfaces of dry conductors, particularly at high conductor surface temperatures, has been confirmed. The cooling effect ranged from 10ºC to 20ºC.

# Conclusions

3. On dry conductors, CL, RI and AN increase significantly with conductor surface temperature.
4. Regression analysis of the test results obtained on dry conductors indicates that a temperature correction term of the order of 0.7 dB per 10ºC increase in conductor surface temperature applies to CL, RI and AN.
5. Compared to unheated conductors, rain tends to decrease the CL, RI and AN levels of heated conductors, particularly at high conductor temperatures.
6. There is no measurable influence of wind of the order of 1 m/s on the corona performance of high temperature conductors.

# Conclusions

7. If existing line generates fair weather AN close to the limit, the additional increase could result in complaints
8. The effects of high temperature on electrical effects must be evaluated to avoid potential problems

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