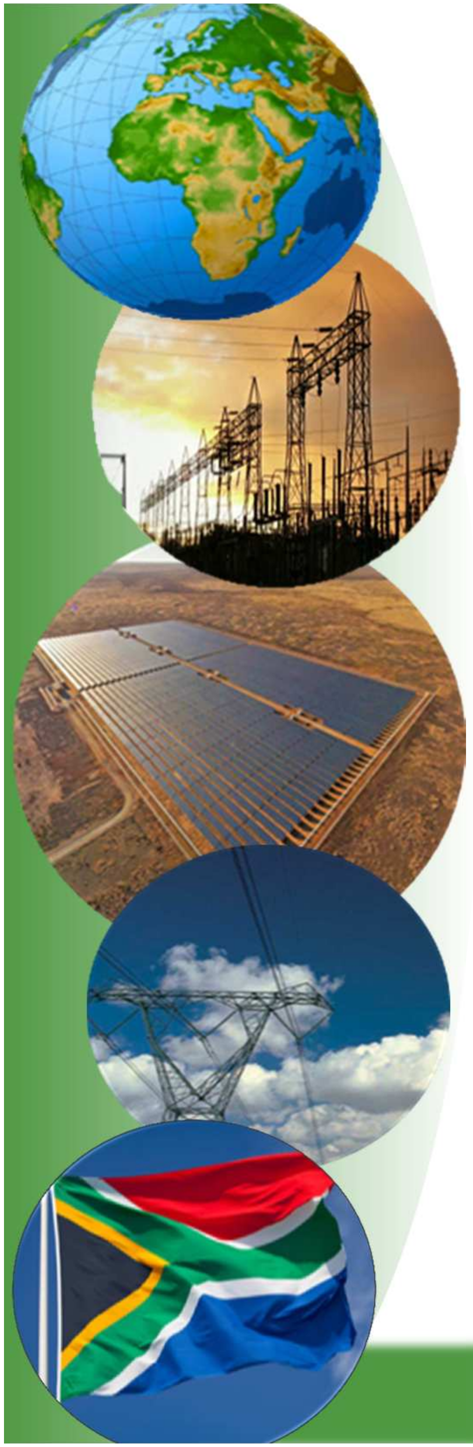

Air Breakdown Voltage Decreases As Altitude Increases

A Review of HV Insulator Test Results from Chinese Experiments

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Paper 2.06
Session 2
15 November 2017

Electricity Supply to Africa and Developing Economies: Challenges and Opportunities

Synopsis

Air : Free Insulation of Excellence

- Electrical Plant and Equipment
  - ✓ Design Specification
  - ✓ Operational Performance

- Dielectric Strength of Air is Influenced by
  - ✓ Air Density : Pressure and Temperature
  - ✓ Humidity

Synopsis

Air Breakdown

- ✓ Concurrent of Factors in the Discharge Process
- ✓ Varies from time to time; from locality to locality

❖ ***Case : Increasing Altitude***

- ✓ Air Pressure Decreases
- ✓ Air Breakdown Voltage Decreases

The Engineering Practice

IEC Guidelines

- ✓ Apply Correction Factors

People's Republic of China

- ✓ Embarked on Large Scale Transmission Expansion
- ✓ Promoted Laboratory and Field Experimentation at Varying Altitudes
- ✓ Found limitations to the mechanical application of the IEC factors
- ✓ "Fine tuned" their design standards for UHVAC and UHVDC schemes

The Study Approach

Literature Review

Collate and review the Chinese experimental results and findings

(Focus on the work done with respect to HV external insulators)

Fundamentals for Insulation Design

- ✓Identify the Pollutant
- ✓Determine the Severity of the Pollution Level
- ✓Specify the Weather Conditions
- ✓Add Operating Experiences

- ➢Specific creepage at nominal voltage; mm/kV

Xiang Sheng & Jianqun [3]

- ☐ Transmission Line Insulation Design
- ☐ Altitude range of 0m to 2500m

- ❖ Simple Laboratory Experiment : One insulator disc and applied HV for varying altitude levels
- ❖ Finding : Flashover voltage for a polluted insulator decreases as altitude increases
- ❖ Result : N = 1.1 U_1/U_2

N = Number of Insulators, 1.1 FOS - broken insulator, U_1=Max Ph./E Operating Voltage, U_2 = Max withstand voltage for a single insulator

Shi et al [4]

Built upon the earlier work; reduction in flashover voltage as a result of decreasing air density caused by increasing altitude is given by:

$$Vf/Vo = \left(\frac{P}{Po}\right)^{n}$$

Vf = pollution flashover voltage at reduced pressure P

Vo = pollution flashover voltage at standard pressure Po (101.3 kPa)

n = 0.47

Zhang et al [6,7]

Conducted actual field tests at

2820m, 3575m and 4484m

n = 0.52 – 0.56 (field)

n = 0.52 – 0.59 (laboratory)

n = 0.5 to 0.6 for AC voltages

Concluded that both pressure and temperature have a role in the breakdown process.

International Factors for n

Institution	AC	DC (-)	DC (+)
Japan	0.5 – 0.55	0.35	0.4
USSR	0.5 – 0.6	0.5	-
Sweden	0.29	0.5	-
Canada	0.5	0.35	0.4
Chongqing University	0.36 – 0.9	0.14 – 0.3	0.23 - 0.63
Tsinghua University	0.18 – 0.6	0.4 – 0.84	0.6 – 0.72

Chongqing University

Employed high speed photography

Observation : Partial arc had 2 components

- An air gap component
- A surface arc component

Rao et al [9] : Similar Finding : Effective saturation of the flashover voltage for the case of alternating shed diameters

The Research Question

What initiates and sustains the gas discharge process in the very small air gap (mm) between consecutive insulator sheds?

Depending on air pressure, temperature, humidity and gap distance, the air dielectric strength can either support or inhibit the growth of leakage current between consecutive sheds.

The Research Hypothesis

The hypothesis is that with increasing altitude, air pressure, temperature and humidity changes and given the presence of a sufficiently high electric field across the insulators, corona is initiated in the air gap between sheds and grows to become a self sustaining streamer between sheds thereby presenting an electric circuit having two paths; one along the surface of the insulator and one through the air between the sheds.

The Research Hypothesis

Corona initiated gas discharge, air gap by air gap, sets in motion a cascading avalanche of consecutive air gap breakdown that eventually leads to the full length insulator breakdown.

Meng et al [11]

"Corona inception voltage decreases as air pressure lowers with increasing altitude; a linear relationship exists"

- ✓ Classical corona cage & DC Conductors
- ✓ Tests at 4 different altitudes
  - 23m, 2250m, 2829m, 3800m asl

- ➢ Attributed this finding to the enlargement of the ionization zone as a result of the increase in the ionization coefficient

Meng et al [11]

Ionization zone is the small volume of air space surrounding the energised conductor

Given : High electric field

$$\alpha > \eta$$

α : coefficient of ionization by electron collision

η : electron attachment coefficient

Meng et al [11]

electron collision → primary e avalanche

→ photons emitted in all directions

→ photons are absorbed by air

→ leads to photoionization of air inside the ionization zone

Meng et al [11]

Photoelectrons in the air stimulate

→ second generation successor avalanches

→ these start at various distances from the primary avalanche

→ contributing to an accumulation of positive ions

→ inception streamer develops

Meng et al [11]

For a self propagating streamer

$$N_2 \geq N_1$$

N_1 : number of electrons in the primary avalanche

N_2 : number of electrons in the secondary avalanche as generated by photoionization

Meng et al [11]

Number of electrons in the primary avalanche

$$N_1 = \exp\left(\int_o^{yi} [\alpha(y) - \eta(y)]\, dy\right)$$

y^i : radius of the ionization zone

Meng et al [11]

Number of electrons in the secondary avalanche

$$N_2 = \int_{r1}^{yi} A(y)\, dy$$

$$r_1 = \sqrt{6 \int_0^{yi} (De/Ve)\, dy}$$

r_1: radius of the head of the primary avalanche

(assumed spherical)

De : electron diffusion coefficient

Ve : electron drift velocity

A(y) : Defined as equation 6 in the paper

Meng et al [11]

To determine the inception voltage:

Employed Charge simulation method

Calculate α and η

Calculate N_1 and N_2

Check for $N_2 \geq N_1$ for a self propagating streamer; if no, then

Increase voltage and repeat

Study Recommendation : Employ Meng et al [11] findings to study small (mm) air gap discharges for the case of varying air pressures, temperature and humidity. Construct a small scale corona cage model for laboratory experimentation.

Swanson and Jandrell [12]

Air : Oxygen + Nitrogen

Investigated the role of singlet oxygen in air for positive corona

Concluded

When excited, singlet oxygen does not contribute to the production of seed electrons

Swanson and Jandrell [12]

Ionization, attachment and photoionization mechanisms remain dominant in the breakdown process

Singlet oxygen and negative ions produce high electron densities close to the anode

Space charge dominates and influences the collapse of the electric field

Meng et al [11] findings sustains

Maruvada [13]

"Mass motion of charged particles is governed by diffusion and drift"

Diffusion emanates from the existence of a density gradient

Drift emanates from the presence of an electric field

Maruvada [13]

Charged particle current : τ

$$\tau = -\nabla D_n + \mu E_n$$

Diffusion Component

Drift Component

μ : particle mobility
D : diffusion coefficient
E : electric field vector
τ : particle flow vector

Maruvada [13]

From experimental work;

Maruvada records that particle mobility is a function of the applied electric field and gas pressure (p)

$$\mu = f\left(\frac{E}{p}\right)$$

Maruvada [13]

For ions; diffusion coefficient and mobility are related to each other by the Einstein equation:

$$\frac{D}{\mu} = \frac{kT}{e} = 0.862 \text{ x}10^{-4}\ \mathrm{T}$$

k : Boltzmann Constant (k = 1.3806 x 10^{-23}Joule/K)
e = charge of an electron (e = 1.602 x 10^{-19}Coulombs)
T = absolute temperature of the gas (K)

Conclusion

- ✓ Literature Review (foundation; the building upon the work of others to continue)
- ➢ Next steps : start with computational analysis
  - Ionization, Primary and secondary electron avalanches
  - Self propagating inception streamer
  - Charged particle current, drift and diffusion
  - Particle mobility as a function of electric field and gas pressure; incorporating Einstein's equation on diffusion and mobility
- ➢ Next steps : start with lab experiments : HV corona cage/conductor chamber having variability for air pressure, temperature and humidity; focus on small air gaps; multiple electrode configurations
- ➢ Contribution to continuous research into air insulation

Thank You

Acknowledgement

WITS : Professors Nyamupangedengu and Jandrell

Cigre SA: Kurt Dedekind and Roger Cormack

Thank You