Recent Improvements in K-Factor Models

Yixin Zhang
NEETRAC, Georgia Institute of Technology

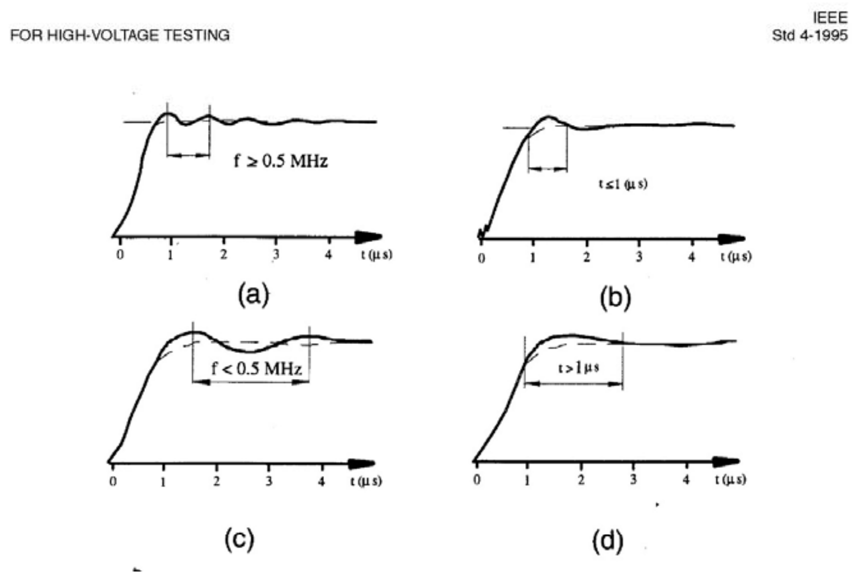
2014 IEEE PES Panel Session

Discussions on IEEE Std.4-2013: High-Voltage Testing Techniques

Related Standards besides IEEE4

- *IEC 60060-1 Ed. 3.0 – 1973, 1992, 1989 , 2010*
  - *IEC 60060-1 Ed. 3.0: High-voltage test techniques.*
  - *Part 1: General definitions and test requirements (K-Factor)*
- *IEC 60060-2 Ed. 3.0 - 1973, 1994, 1996, 2010*
  - *High-voltage test techniques*
  - *Part 2: Measuring Systems*
- *IEC 61083-1 Ed. 2.0 – 1991, 2001*
  - *Instruments & Software Used For Measurement in HV Impulse Tests*
  - *Part 1: Requirements for Instruments*
- *IEC 61083-2 Ed. 2.0 -1996,2013*
  - *Instruments & Software Used For Measurement in HV Impulse Tests*
  - *Part 2: Evaluation of Software Used for the Determination of the Parameters of Impulse Waveforms (TDG Software)*

Problems with IEEE 4 - 1995 Impulse Voltage Overshoot Definition



f < 0.5 MHz => Peak of Recorded Curve

f > 0.5 MHz => Peak of Mean Curve

- *No gradual transition between selection of Peak Values of Recorded Curve and Mean Curve*
- *No well defined method to generate the Mean Curve*
- *No Clear Definition of Overshoot*

New IEEE 4-2103 Impulse Test Voltage Definition

- *Test Voltage V_i : The peak value of the* ***test voltage curve*** *(Note, not the peak value or maximum value of recorded curve anymore)*
- *Test Voltage Curve : The summation of the base curve and the residual curve after it has been processed by a filter whose frequency response is defined by the* ***test voltage function***

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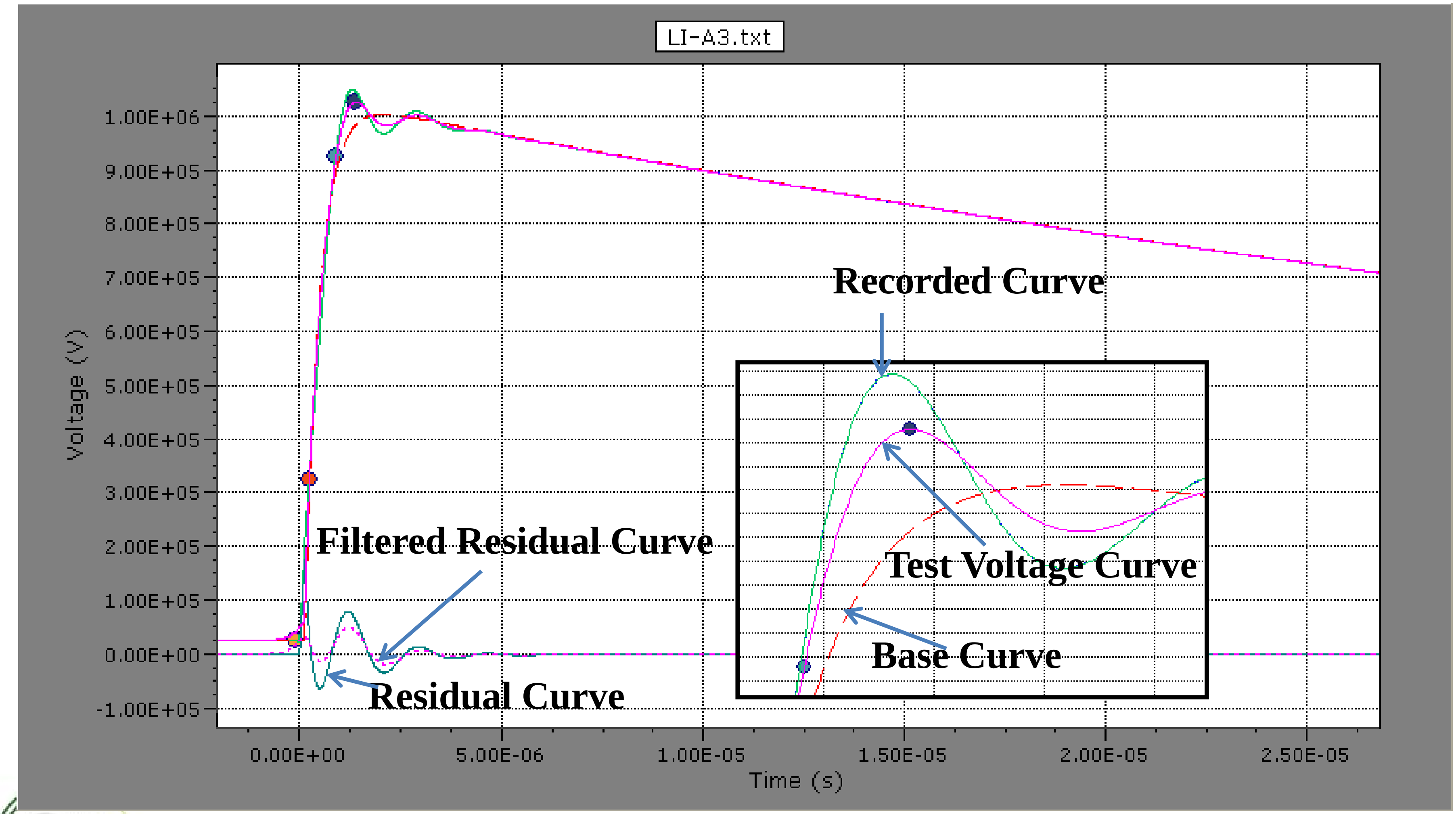
New Definitions for Test Voltage Curve, Base Curve, Residual Curve, and Filtered Residual Curve



New IEEE 4-2103 Overshoot Definition

- *Overshoot magnitude β : Difference in peak values between the* ***recorded curve*** *and the* ***base curve***
- *Relative Overshoot magnitude β': The ratio of the overshoot magnitude to the extrme value (The maximum value of the* ***recorded curve****), usually expressed as a percentage*
- *β' can be limited to 5%. In any case shall be limited to 10%, which can be a problem for UHV tests as test loop dimensions become very large*

K-Factor or Test Voltage Function

An amplitude – frequency function that defines the response of the insulation to impulses with overshoot

IEEE P4/D007, January 2012

The graphic expression of the $k(f)$ function is shown in Figure 1

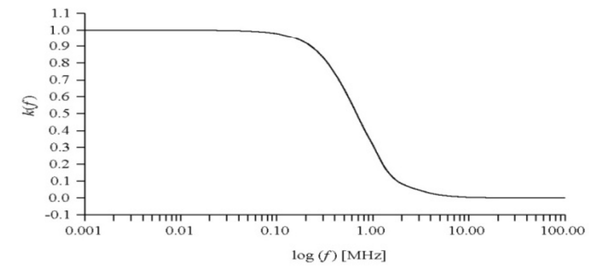


Figure A.1—Frequency dependency of the test voltage function $k(f)$

The test voltage equation, (A.1) is applicable to impulses both with and without overshoot. For impulses without overshoot the applied voltage is a smooth curve and has the form of a base curve without any residual oscillations to process. Such curves are unaffected by the residual filter function and yield impulse parameters that are unaffected by that function. The procedures are therefore transparent to smooth curves and so it is not necessary to pre-sort impulse prior to parameter derivation.

The frequency dependent function of the test voltage factor is given by:

$$k(f) = \frac{1}{1 + af^2}$$

where f is the frequency in MHz and a is a coefficient with a value of 2.2.

Steps to Perform K-Factor Overshoot Analysis

1. *Perform double exponential curve fit to a recorded curve to generate a "**Base Curve**".*
2. *Subtract the Base Curve from the recorded curve to generate a "**Residual Curve**"*
3. *Filter Residual Curve with **K-Factor Filter** （Test Voltage Function）*
4. *Add the Filtered Residual Curve to the Base Curve to generate a "**Test Voltage Curve**"*
5. *Calculate impulse parameters from the Test Voltage Curve*
6. *Determine overshoot magnitude from the peak values between the recorded curve and the base curve*

Factors Influence on K-Factor Function

- *Type of dielectric media such as oil, SF6, air…*
- *Overshoot magnitude*
- *Oscillation frequency*
- *Test voltage*
- *Test object's electric field geometry such as gap spaces and homogeneity*
- *The base curve to be used. Which fitting function to use and which parts of recorded curve to be removed before fitting*

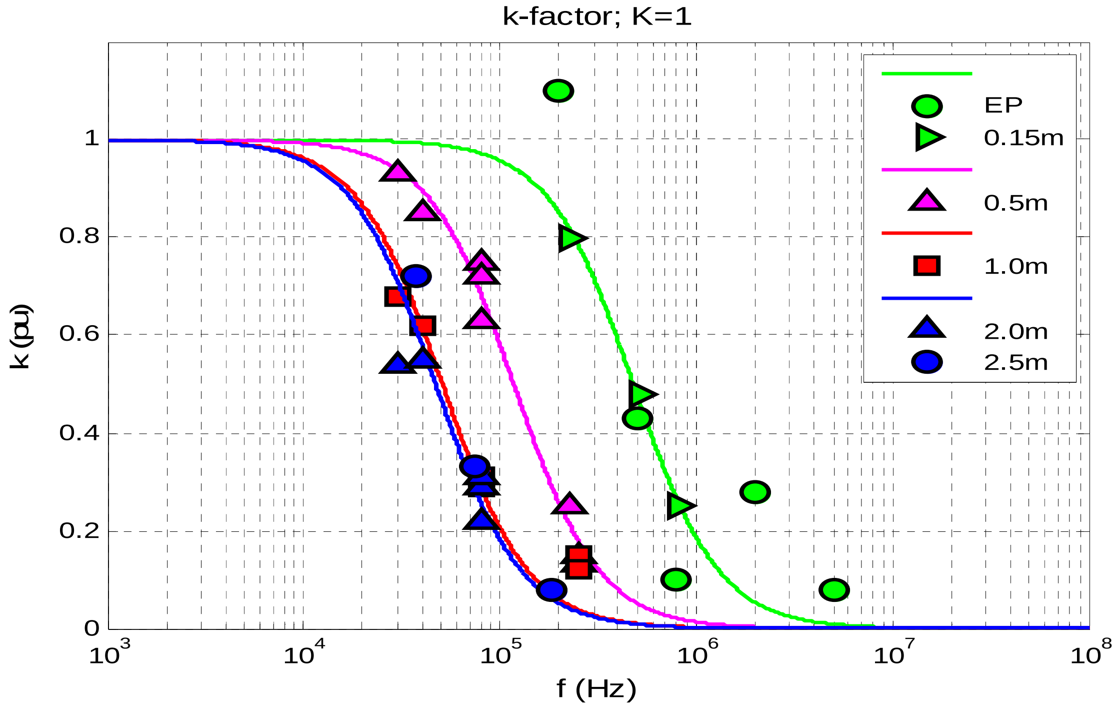
How Was the Current K-Factor Created?

- *Via almost two decades of studies by CIGRE WG D1.36 (Formally 33.03) members with participation from IEEE HVTT members*
- *Experimental work primarily done by Prof. Fernando Garnacho from LCOE, Spain and Dr. Sonja Monica Berlijn from Netherlands.*
- *The air gap, oil gap, and SF6 gap models were extensively tested at 100 kV or below with many combinations of the waveforms.*

Recent Work in K-Factor Models

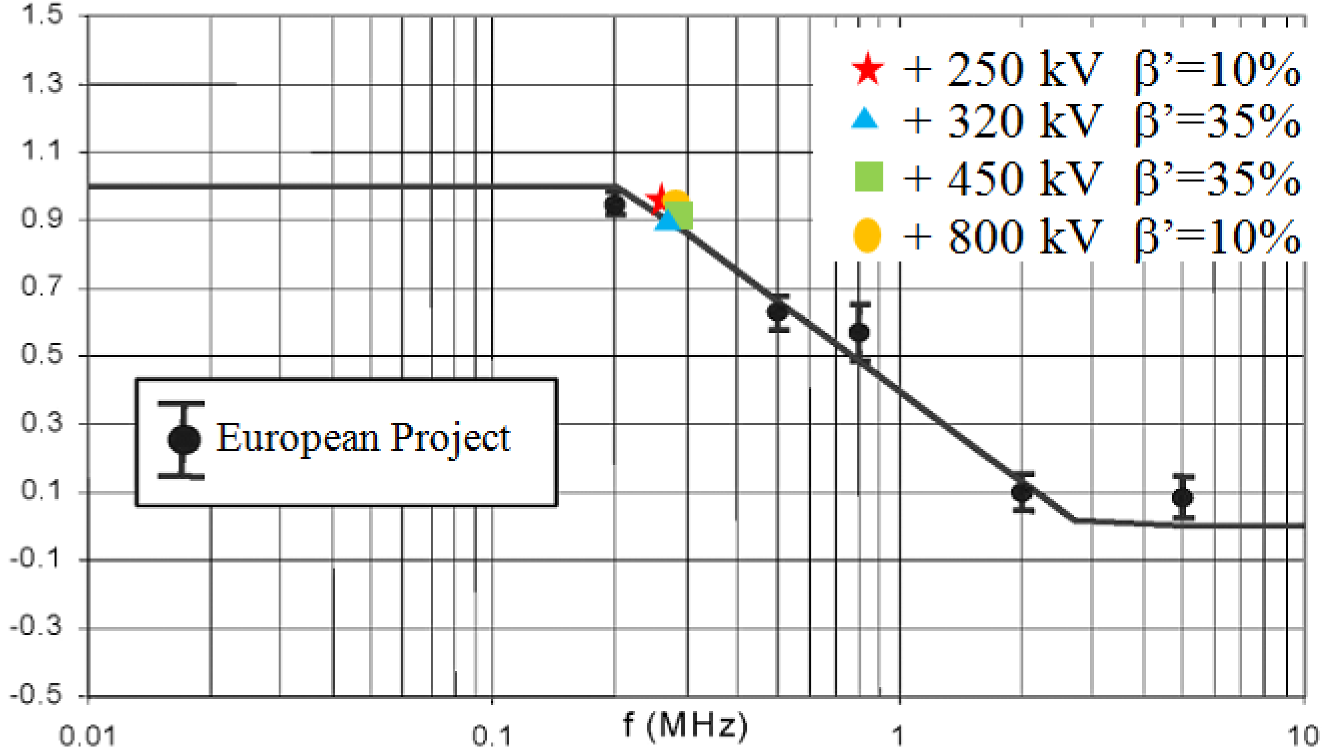
- *For UHV systems, issues are open on applicability of K-Factor function*
- *Additional tests to obtain k-factor functional equivalency for higher voltages were carried out in recent research projects by Japanese and Spanish researchers (European Project)*
- *More complicated test samples with large size were tested at higher voltage than 100 kV*
- *New different K-factor curves were generated*

Results from Recent Studies -1



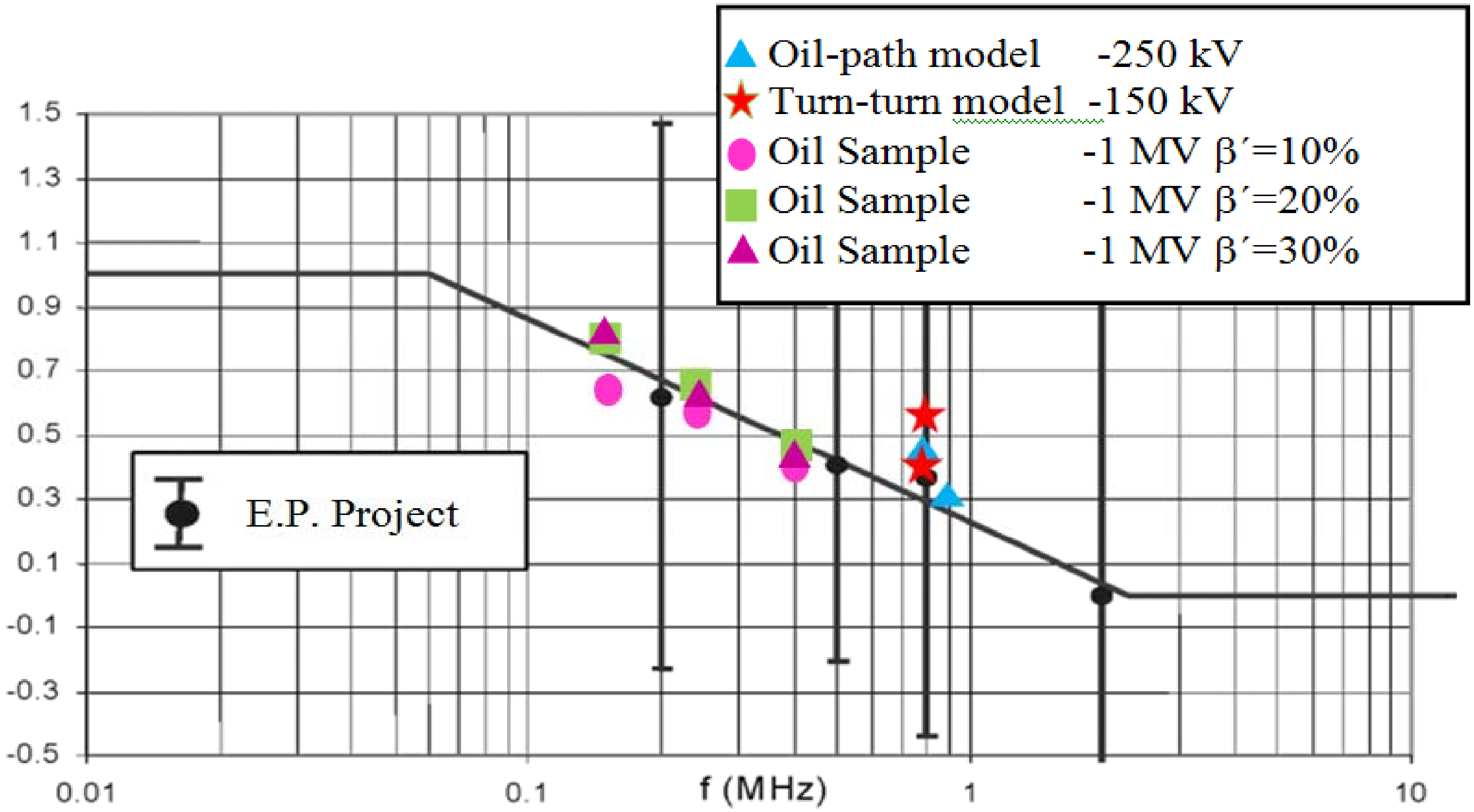
Family of the test voltage function (K-factor) curves for **rod plate** samples with different air gap spaces. The larger the gap space is, the smaller the K-factor Is. Air gap may not be an issue for UHV apparatus under lightning impulse. However, for nonhomogenous air gap with spaces larger than **0.15 m**, the current K-factor does **not** represent the dielectric breakdown behaviour.

Results from Recent Studies -2



Experimental test voltage function (K-factor) for air gap in homogenous field from 250 kV to 800 kV

Results from Recent Studies -3



Experimental test voltage function (K-factor) for oil samples in homogenous field ($\eta = 1$) from -150 kV to -1000 kV

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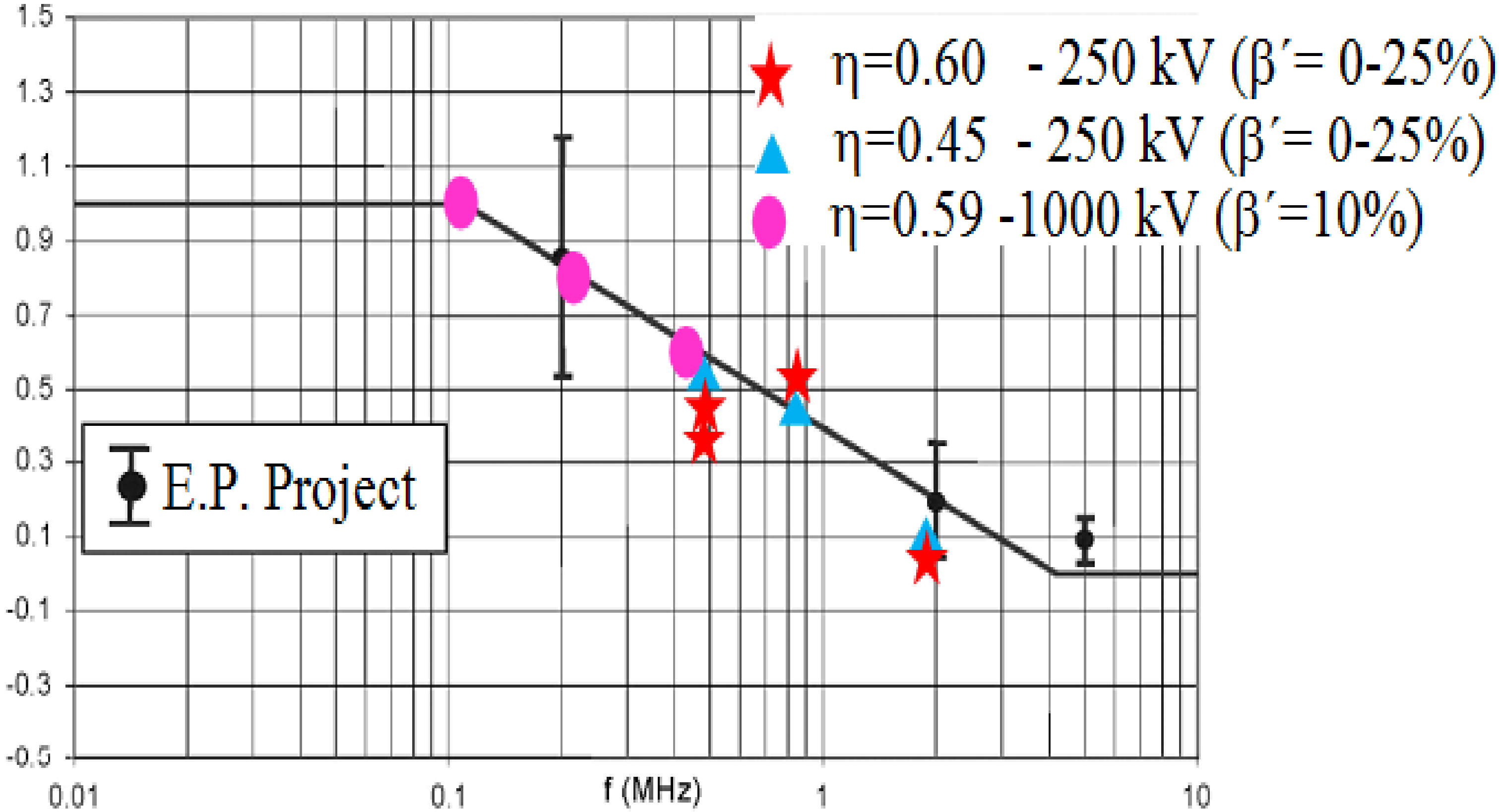
Results from Recent Studies -4



Experimental test voltage function (K-factor) for SF6 samples in quasi-homogenous field from -250 to -1000 kV

Results from Recent Studies -5

Summary by Japanese researchers via UHV Tests

- *Base curves extraction method may make significant difference*
- *Relative error of the test voltage increased with higher β and lower oscillation frequency*
- *K-factor function for GIS and oil immersed transformers were close to EP test results*
- *K-factor function is lower when gap space is longer so for UHV it needs to be reviewed*

Suggestions from the Japanese Researchers

- *Smaller β is desirable. β' should be < 10%*
- *Increase front time T_1 of standard lightning impulse from 1.2 μs to 2.2~3.6 μs to cover 5 nF to 15 nF capacitance of UHV class transformers and / or GIS. T_1 extension to 3.6 μs has only minor influence on insulation but will significantly reduce overshoot*
- *Use a new proposed base curve extraction method*

SUMMARY

- *The current K-factor function in IEC 60060 and IEEE 4 standards is an improvement on impulse voltage test that produces more consistent test voltage peak values worldwide*
- *The K-factor function needs to be enhanced for different dielectric media, different electric field homogeneity, and higher test voltage levels*
- *We should work more closely with the related apparatus standard committees in the future to define new K-factor functions*