TSDOS TRANSMISSION & SUBSTATION DESIGN & OPERATION SYMPOSIUM

THE UNIVERSITY OF TEXAS AT ARLINGTON

Role of Power Factor Testing and Dielectric Frequency Response Testing in Bushing Health Assessment

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Why bushings fail?

- Conduct current in and out of an apparatus
- Have to operate under high voltage
- Being located on top of the transformer, operate at high temperatures
- Can easily get damaged during transport, installation
- Exposed to harsh weather conditions
- Can be a target for vandalism

Image from reddit.com

Image from inmr.com

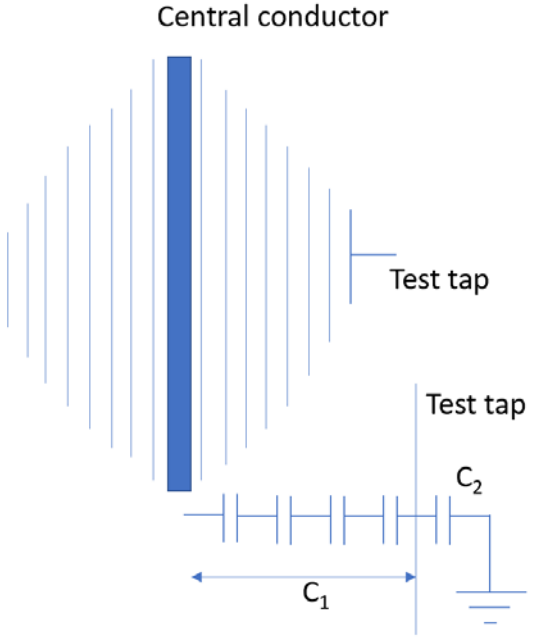
Testing on bushings

- Bushing failure one of the top reasons for transformer failure
- Bushing health needs to be monitored to ensure timely replacement

Continuous testing methods	Periodic testing methods
Capacitance and power factor	Capacitance and power factor
PD monitoring	Dielectric Frequency Response
Creepage current	Winding resistance
Internal pressure	IR scanning

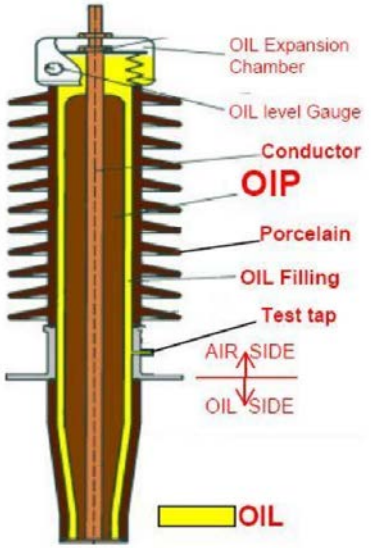
Condenser bushing design

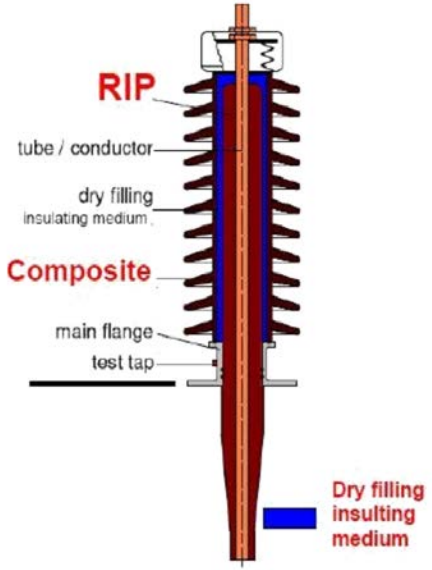
- Conductive foil in paper (or synthetic material) wrapped multiple times around the central conductor
- Outermost layer connected to test tap
- C_1 – capacitance between conductor and test tap
- C_2 – capacitance between test tap and grounded flange



Condenser bushing types

- Resin-Bonded Paper (RBP)
- Oil-Impregnated Paper (OIP)
- Resin-Impregnated Paper (RIP)
- Resin-Impregnated Synthetic (RIS)

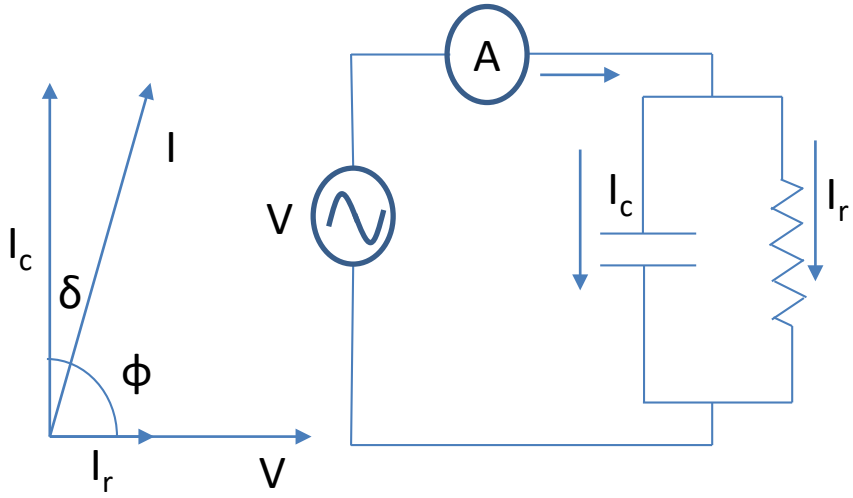




Images from http://www.ijpttjournal.org/

Power factor testing on bushings

- Dielectric losses measured on C_1 insulation at 10kV
- Measurement done on C_2 insulation at a lower voltage



$$X_C = {}^{V}/_{I_c}$$

$$C = {}^{1}/_{(2\pi f X_c)}$$

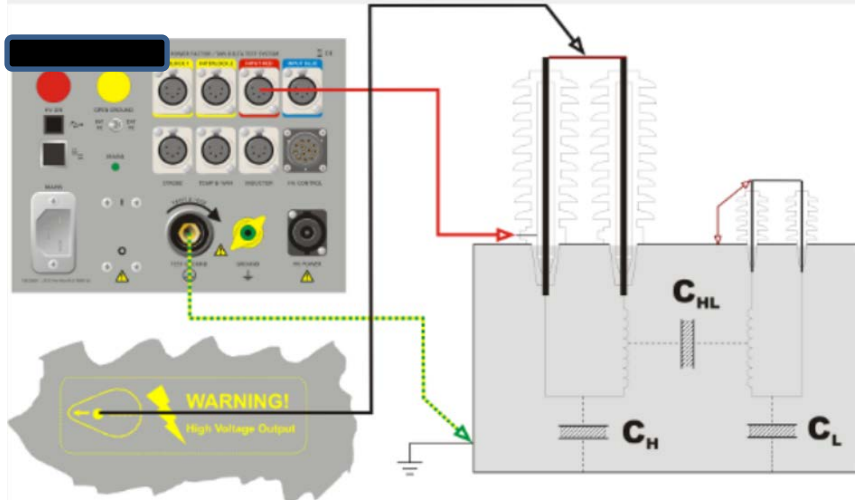
$$pf, \cos\emptyset = {}^{I_r}/_{I}$$

$$df, \tan\partial = {}^{I_r}/_{I_c}$$

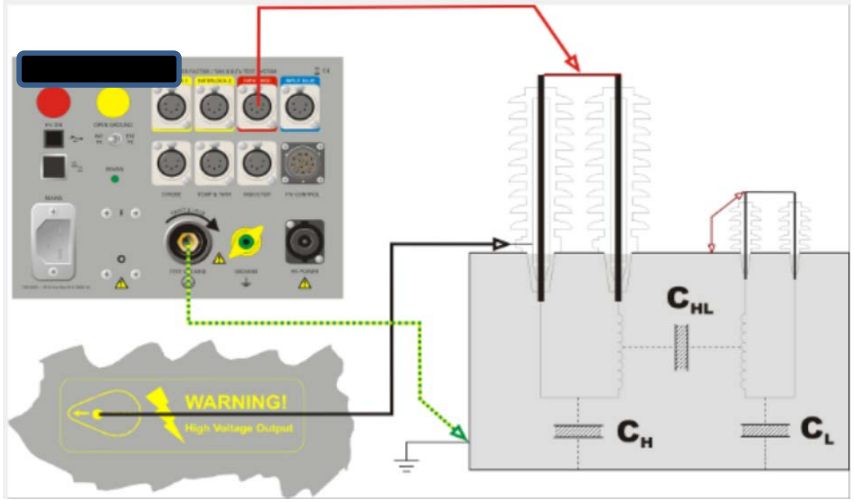
$$P = VI\cos\emptyset$$

Test Connections for Power Factor Testing

C_1 Power Factor
UST mode



C_2 Power Factor
GST-g mode



How to analyze power factor results?

- IEEE C57.152 – 2013
  - 7.3.3 (bushings) says –
    - If PF increases by 1.5 to 2 times its initial reading, frequency of testing should be increased, or bushing removed from service
    - If PF is triple the initial reading, bushing should be removed from service
  - Increase in capacitance of more than 5% is cause to investigate

- IEEE C57.19.01 says,

Bushing type	Acceptance PF limit at 20°C
OIP	0.5%
RIP	0.85%
RBP	2.0%

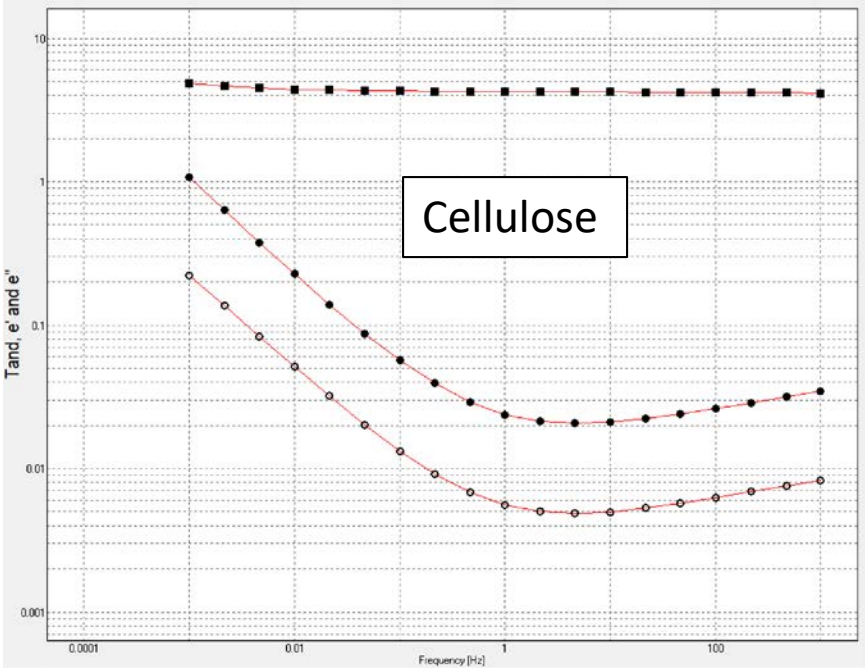
Temperature dilemma

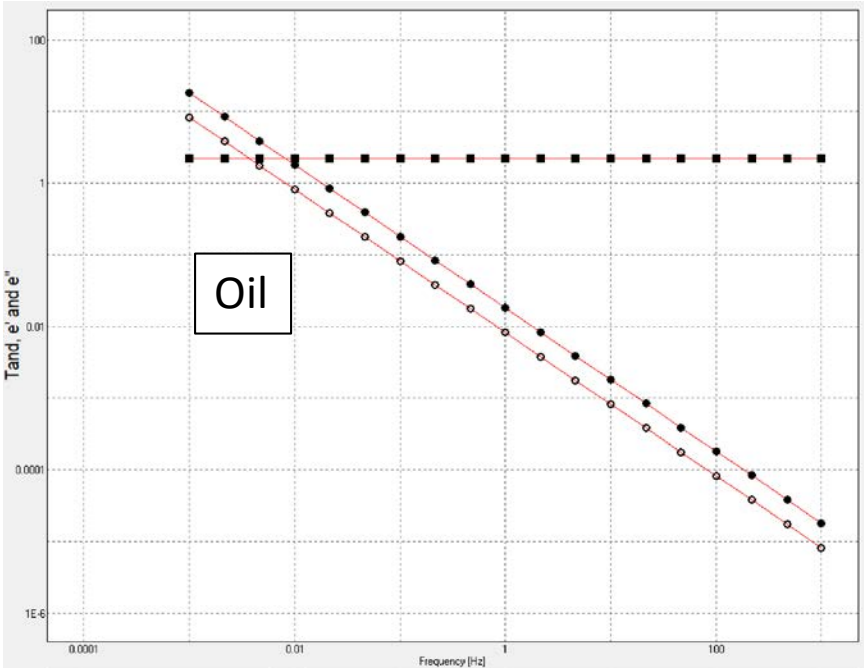
- Power factor is temperature dependent
- Correction to 20°C is essential for fair analysis
- Some generic temperature correction factors provided by manufacturers and some other references
- Factors can’t be relied upon in all cases
- Research has been done to determine temperature correction factor using dielectric frequency response

Dielectric Frequency Response - Theory

- Behavior of power factor / DF over a certain range of frequencies
- $\varepsilon^* = \varepsilon' - j\varepsilon''$
- $\tan\delta = \frac{\varepsilon''(\omega)}{\varepsilon\prime(\omega)}$

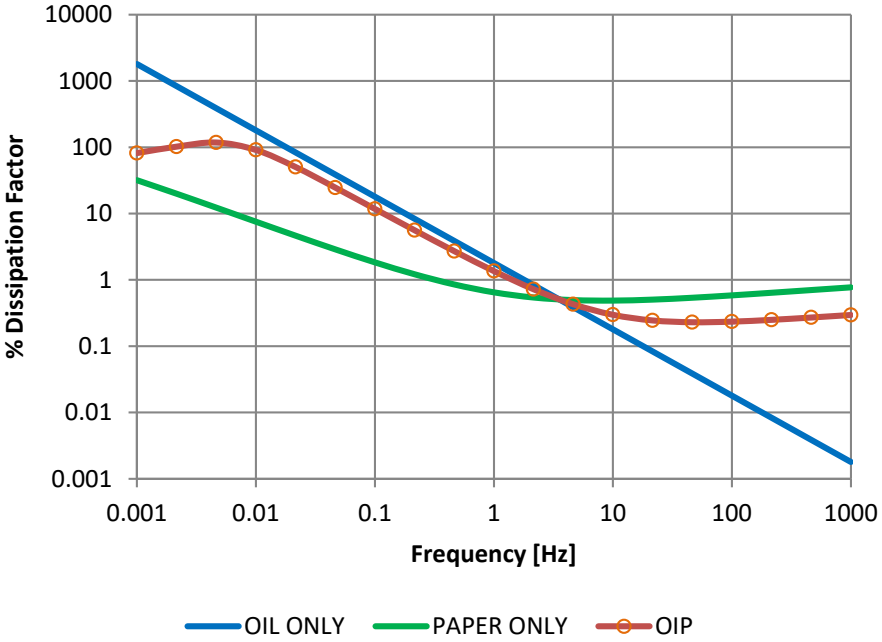
Dielectric Frequency Response - Theory

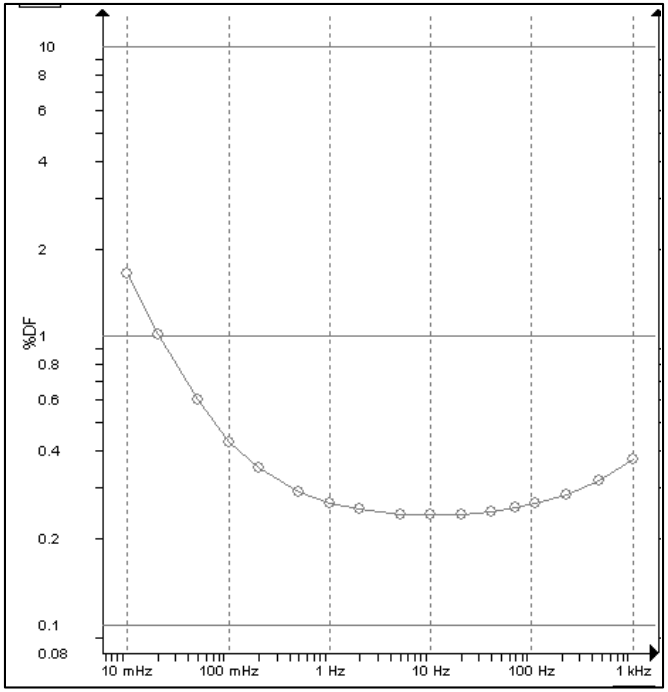




ε'' ● $\tan\delta$ ○ ε' ■

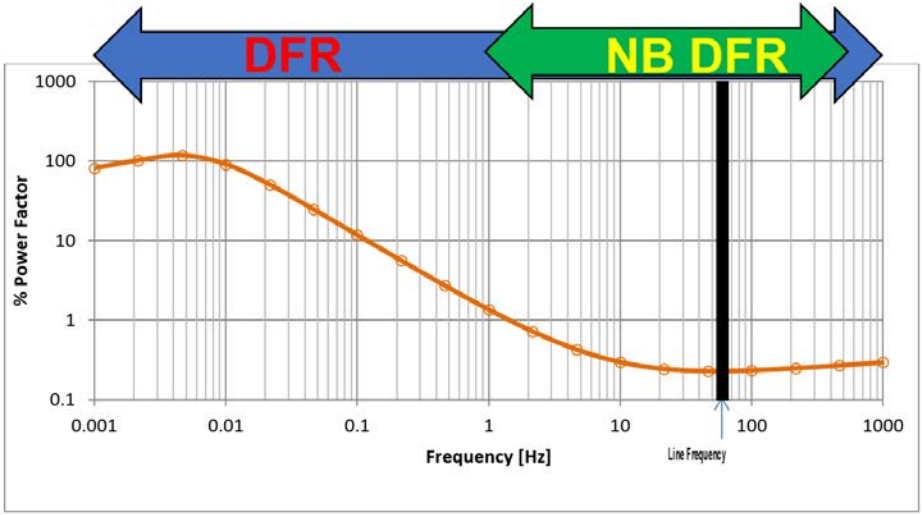
DFR of an OIP bushing





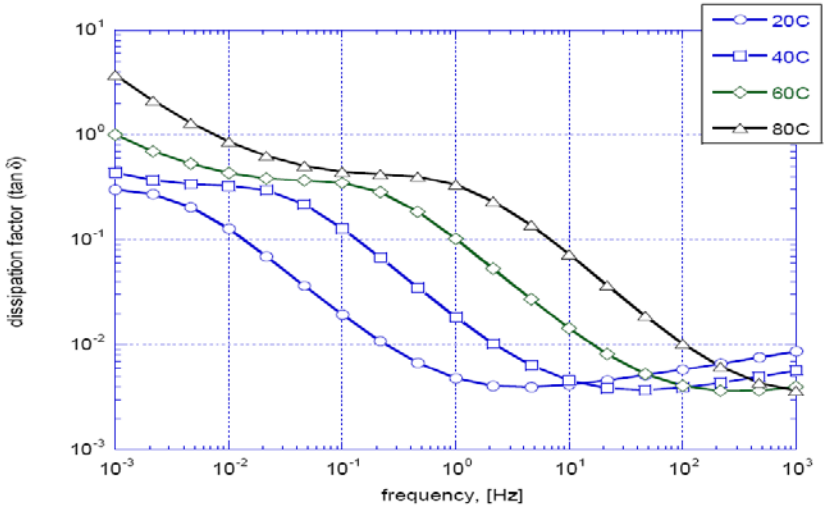
Narrowband Dielectric Frequency Response

- Standard power factor test sets with expanded test frequency capabilities can be used to do a shorter version of DFR at a lower voltage
- Power factor shows increased sensitivity to presence of moisture and contaminants at the lower frequencies
- Helpful in early detection of bushing deterioration before significant changes start to occur in the 60Hz power factor

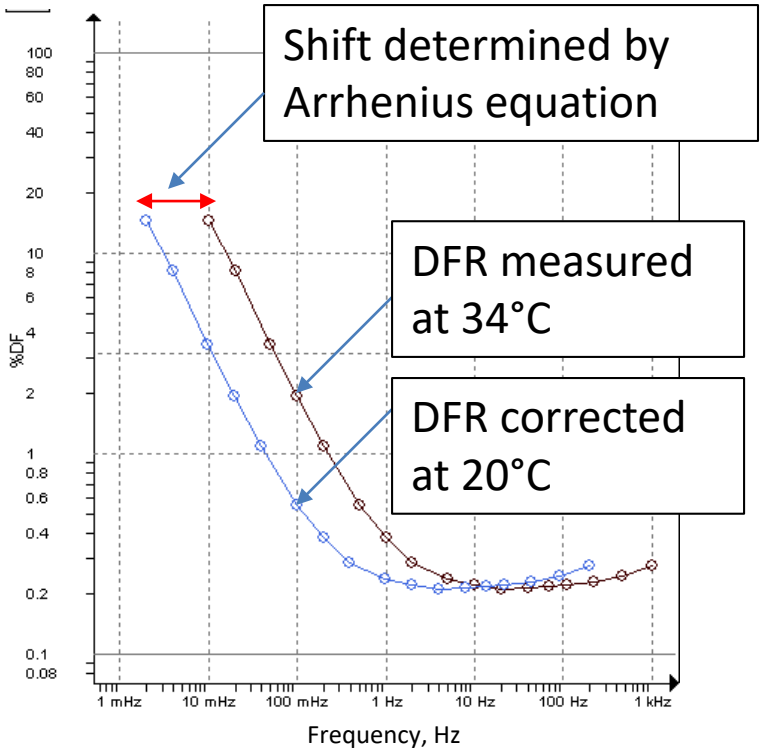


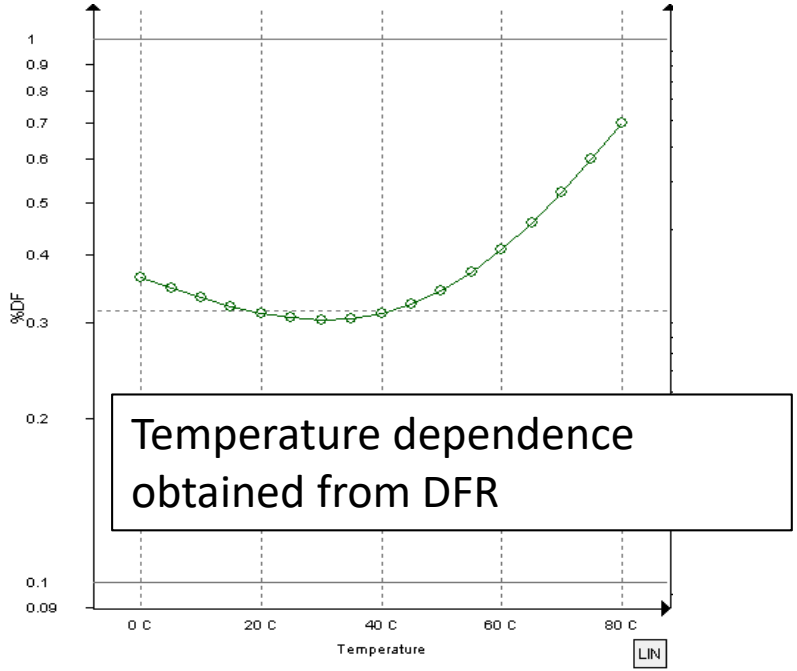
Effect of temperature on DFR

- DFR curve shifts horizontally with change in temperature
- Through Arrhenius equation, it is possible to determine the magnitude of the shift for a certain change in temperature
- This helps in **temperature correction** of power factor
- From x Hz power factor measured from DFR at y °C, it is possible to determine 60Hz power factor at 20°C



Temperature correction through DFR





How to analyze NBDFR results?

- Compare bushings on the same winding
- Increase in PF in the lower frequencies suggests bushing should be closely monitored
- Favorable to test at higher temperatures
- To compare NBDFR curves on the same bushing over time, test at the same temperature if temperature correction is not available for the curve

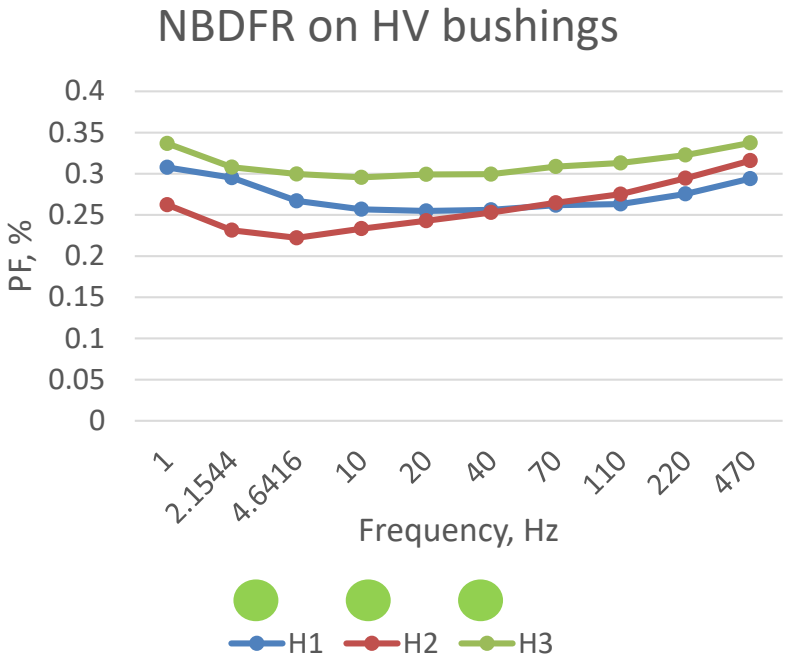
Field experience - Case 1

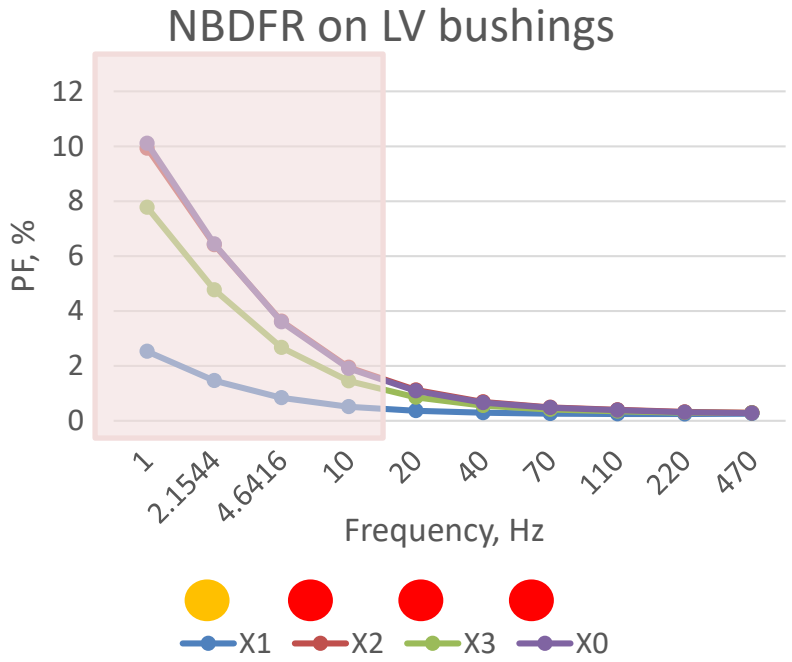
Bushing	Meas %PF at 28°C	Nameplate %PF	As per C57.152
H1	0.26	0.24	Good
H2	0.26	0.26	Good
H3	0.30	0.30	Good

Power factor tests done on the bushings of a 161/12.47kV 18MVA Dyn1 transformer

Bushing	Meas %PF at 28°C	Nameplate %PF	As per C57.152
X1	0.27	0.22	Good
X2	0.58	0.22	Bad
X3	0.51	0.21	Bad
X0	0.57	0.22	Bad

Field experience - Case 1





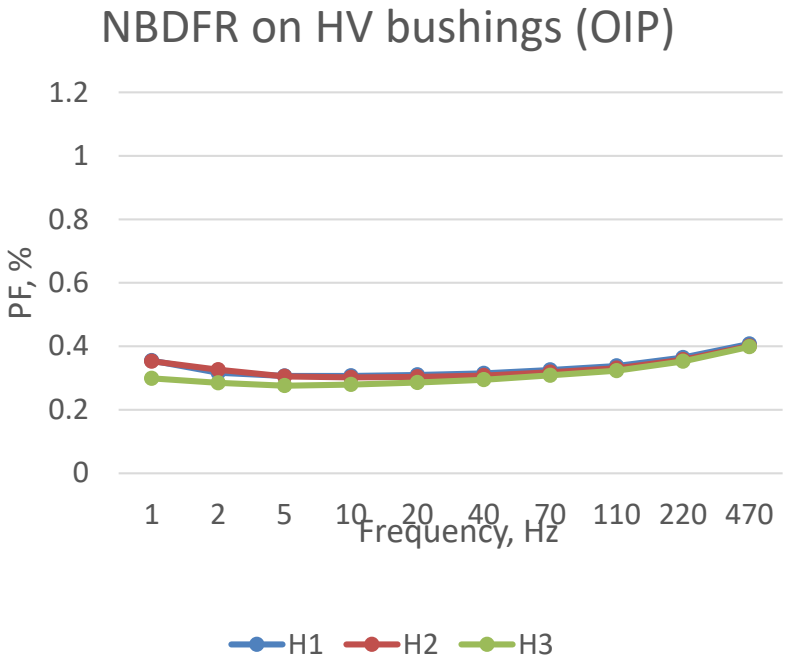
Field experience - Case 2

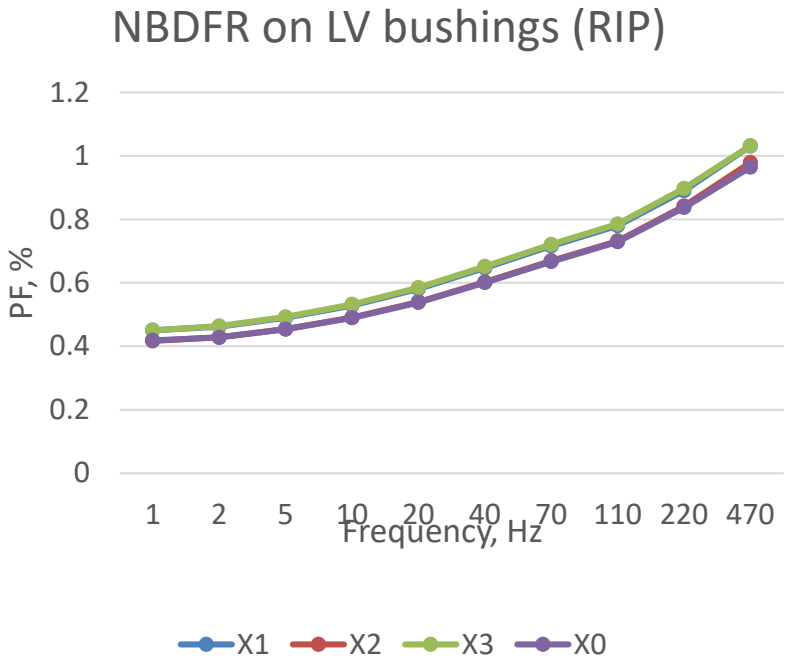
Bushing	Meas %PF at 11°C	Nameplate %PF	As per C57.152
H1	0.32	0.33	Good
H2	0.32	0.31	Good
H3	0.31	0.30	Good

Power factor tests done on the bushings of a 115/13.2kV 20MVA Dyn1 transformer

Bushing	Meas PF at 11°C	Nameplate PF	As per C57.152
X1	0.70	0.67	Good
X2	0.65	0.64	Good
X3	0.70	0.71	Good
X0	0.65	0.64	Good

Field experience - Case 2





Conclusion

- Line frequency power factor testing has been used to test bushings traditionally
- Need to have a reliable way of temperature correction for fair analysis of 60Hz PF
- NB DFR testing presents an advanced diagnostic tool that can be used for early detection of bushing insulation related problems
- Thus, providing the user with more time for corrective measures