# Reference setup for calibration of power transformer loss measurement systems

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Abstract A reference system is developed for the on-site calibration of power transformer loss measurement systems (TLMs). A crucial element in such calibrations is the availability of voltage and current signals with adjustable phase close to 90°, that is power factor near to zero, in order to apply a known and stable loss or reference power to the TLM. In the new VSL reference system, digital signal processing is used to maintain the phase relation between the voltage (up to 100 kV) and the generated current (up to 2000 A) applied to the TLM. Initial results indicate that phase uncertainties of better than 20 μrad can be obtained.

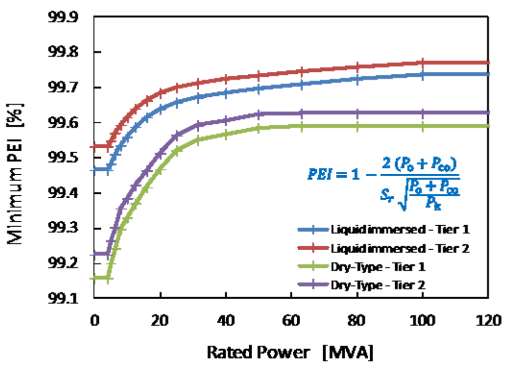
## Introduction

Power transformers significantly contribute to grid losses and their losses in turn are a major part of the total cost of ownership.

⇒ EU Ecodesign Directive requirements per 1 July 2015 on efficiency

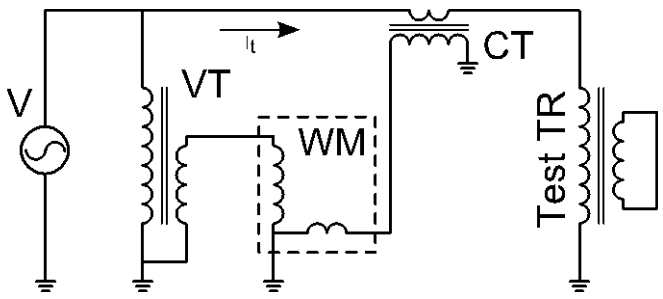
⇒ Similar requirements in IEC 60076-20 and IEEE C57.123-2010

⇒ Customers: fines for excess loss 10 k€/kW




## Transformer Loss Measurement Systems

Power transformer manufacturers use commercial TLMs to measure the no-load (NLL) and load losses (LL) of their transformers




Three main TLM components:

- CTs (4 kA)
- VTs (100 kV)
- Watt meter

Loss power:

$P = V \cdot I \cdot \cos(\varphi)$, with $\varphi \approx 90°$ (PF ≈ 0)

Key challenge is phase accuracy: 3 % at PF=0.01 ⇒ 300 μrad.

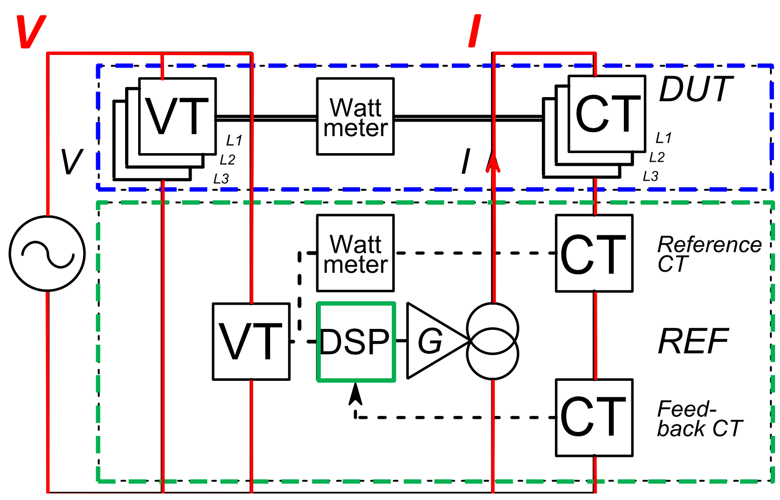
## TLM system calibration

System calibration covers all (in-situ!) aspects of the TLM.

Approach: generate a reference loss power to the TLM, via a current source *I* with stable, adjustable phase w.r.t. applied voltage *V*

⇒ DSP is the key element of the VSL reference system, to ensure tracking of the voltage under the non-ideal on-site conditions.

Reference watt meter (with CT, VT) is used as verification.




## Phase shifting

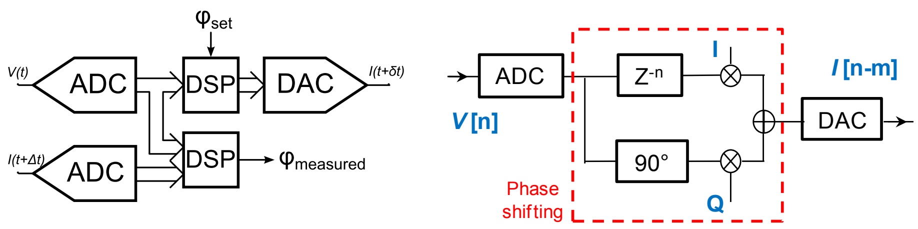
Variable load for calibrating a TLM at different losses is realised via a phantom technique is used to effectively mimic such a load.

⇒ Separated voltage and current measurement circuits

⇒ Inject generated current which is amplitude and phase related to the applied voltage (any impedance can be mimicked; L needed)

The digital realisation is in two steps / DSPs:

1. A fast, inaccurate first step resulting in a current drive signal with a minimum delay with respect to the input voltage.
2. A slower, accurate second step to accurately measure the actual current magnitude and phase and subsequently adjust the control signal via $\varphi_{set}$, consisting of I and Q.




## Performance

**Laboratory evaluation:**

- Different mathematical routines for realizing 90° digital copy of *V*
- Test setup resembling actual TLM system calibration configuration, using 1000 V test voltage and typical 800 A test current

⇒ DSP phase measurements (1 s avg) showed noise of better than 10 μrad; value agrees at same level with verification watt meter.

**First on-site experience:**

- Complete system transportable and fully automated
- TLM calibration on-site in power transformer manufacturer test bay

⇒ Larger phase noise ~ 30 μrad (1 s avg) due to generation ⇒ DSP algorithms need improvement

⇒ Final uncertainty around 25 μrad

## Conclusions

A reference setup has been developed for the calibration of commercial TLM systems. A core element of the setup is a DSP that arranges a known and stable phase angle between the voltage and the current applied to the TLM system.

The setup has been extensively tested in the laboratory and used on-site as well, showing that uncertainties of 25 μrad can be achieved under on-site conditions.

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