Calibration guidance for power transformer and reactor LMS

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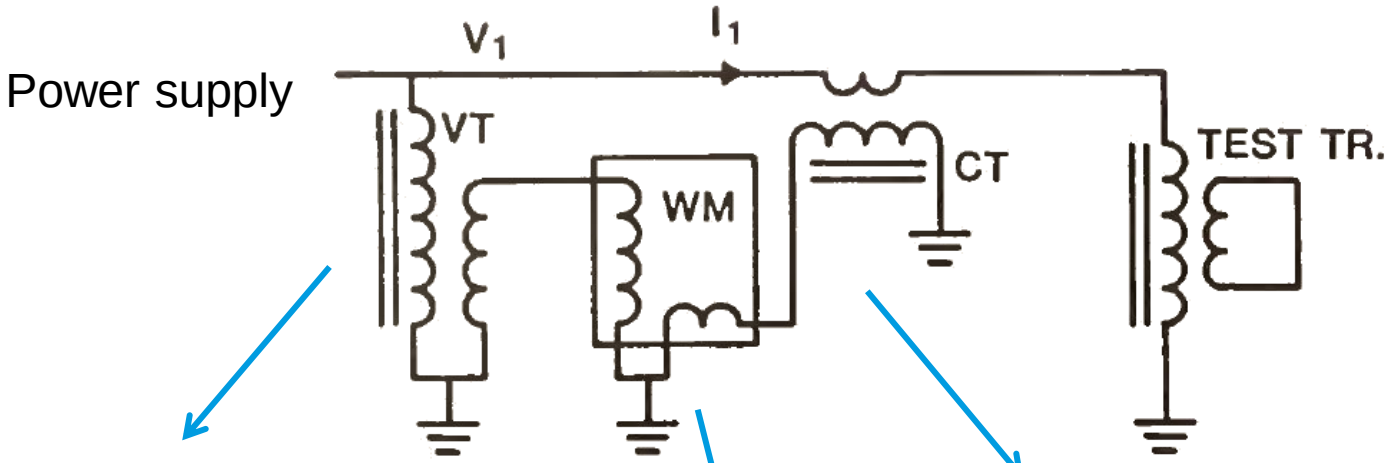
Calibration guidance for reliable power transformer loss tests

Reliable power transformer efficiency tests use transformer loss measurement systems (TLMS) that are

- Accurate
- Calibrated with sufficient accuracy
- … traceable to national standards
- … regularly
- … and not adjusted

Special reference setup for calibration of the TLMS as a whole (‘system calibration’)

Power Transformer Loss Measurement System (TLMS)



$$P = V \cdot I \cdot \cos \varphi$$

Challenge: *phase* accuracy
< 300 μrad / 1 min

↕

3 % at PF=0.01

TLMS typical measurement range: 0 – 100 kV, 0 – 2000 (4000) A

TLMS accuracy requirements

- IEEE C57.12.00-2010, par. 9.4: 3 % accuracy down to PF = 0.01
- IEEE C57.123-2010 “Transformer Loss Measurement”

  Ch. 7: “The maximum value of correction to the measured load losses due to the test system phase-angle error is limited to 5% of the measured losses. If more than 5% correction is required, the test method and test apparatus should be improved for an adequate determination of losses.”

- IEC 60076-8, par. 10.5

  “The resulting phase angle error for the complete system may be of the order of 100 µrad to 200 µrad (0,3 min to 0,6 min). With such systems, an overall maximum error of ±3 % may be achieved for the loss determination down to a power factor of 0,02 or even lower.”

- Ecodesign Directive, Annex III, market surveillance: 5 % accuracy

Table 20—Test system accuracy requirements

Quantity measured	Test system accuracy
Losses	±3.0%

Table

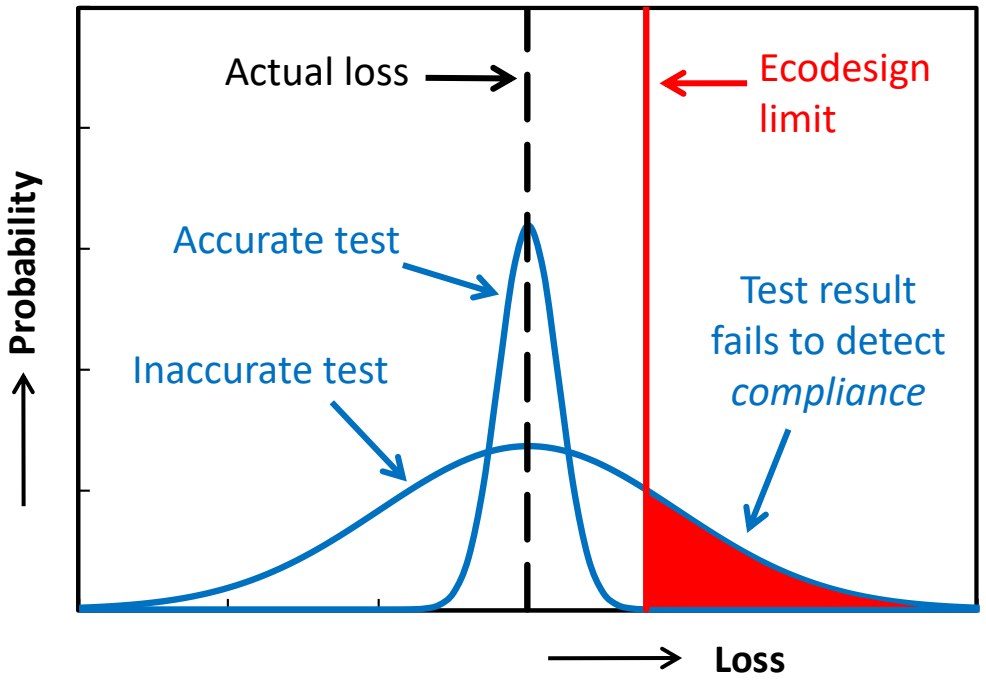
Measured parameter	Verification tolerances
Load losses	The measured value shall not be greater than the declared value by more than 5 %.
No load losses	The measured value shall not be greater than the declared value by more than 5 %.
The electrical power required by the cooling system for no load operation	The measured value shall not be greater than the declared value by more than 5 %.

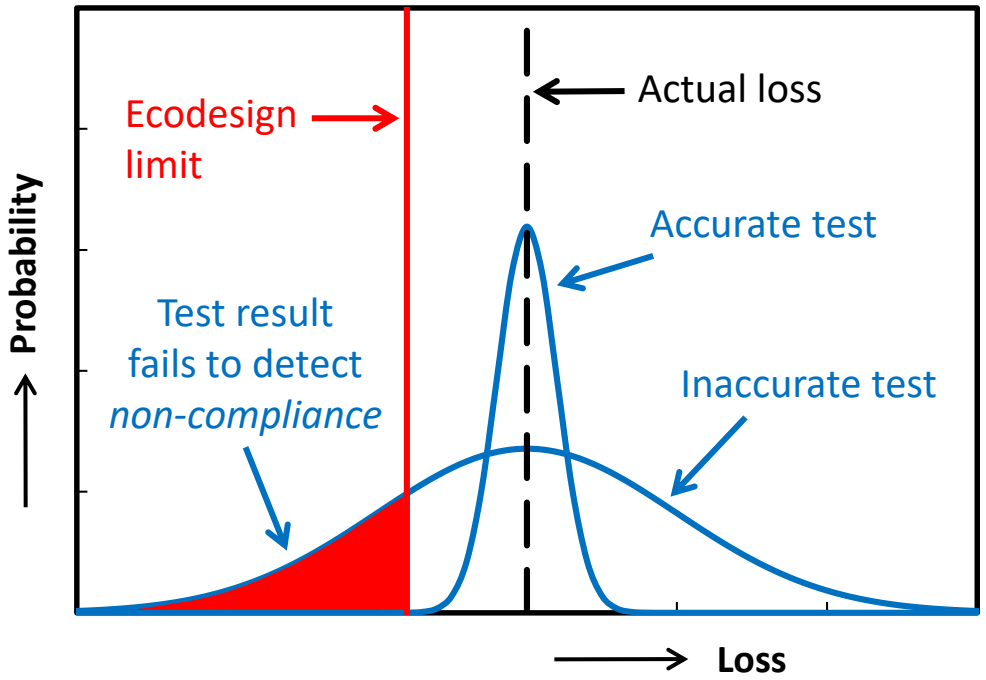
Reliable = accurate

3-5 % accuracy at PF = 0.01

TLMS 1-3 % accurate

Tests: influence of test / calibration uncertainty





Low accuracy = high risk of incorrect decisions

High accuracy = opportunity to save cost

- Loss < (limit + uncertainty)
- Loss < (limit – uncertainty)

TLMS calibration methods & requirements

TLMS accuracy is confirmed via calibration, two approaches:

- Component calibration (CT, VT, power meter individually)
  - Easier to perform, larger overall system uncertainty, not all effects covered
- System calibration (complete system as a whole)
  - Difficult to perform, low overall system uncertainty, all effects included

Accuracy confirmed by calibration
Reference < 0.5 %
at PF = 0.01

Calibration uncertainties for confirming 1 % TLMS accuracy at PF = 0.01, with TUR = 3:

- Component: each component < 0.2 %; at PF=0.01 → 0.06 min (1 m° / 20 µrad)
- System: overall system < 0.3 %; at PF=0.01 → 0.1 min (1.5 m° / 30 µrad)

Increased measurement challenge: TUR = 5, or reactor loss measurements (PF = 0.001)
⇒ Reference measurement accurate to 0.2 % at PF = 0.01 → 0.06 min (1 m° / 20 µrad)
⇒ can only be achieved with system calibration

Reliable, accurate TLMS? Calibration!

TLMS accuracy can only be achieved via calibration!

Specifications are “just” manufacturer claims that must be independently verified

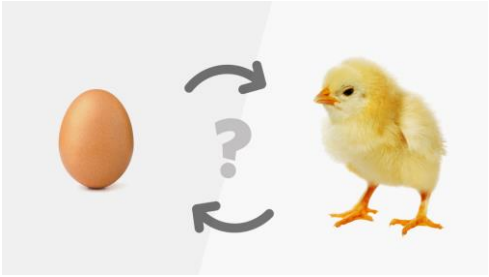
Two calibration approaches:

- Component calibration (CT, VT, power meter individually)
  - Easier to perform
  - Larger overall system uncertainty, not all effects covered
- System calibration (complete system as a whole)
  - Difficult to perform
  - Low overall system uncertainty, all effects included

Accuracy achieved by calibration

System calibration is most accurate

TLMS calibration uncertainties



General rule: the reference system used in the calibration must be 3 – 5 times more accurate than the system that is calibrated!

⇒ Prevent the 'chicken – egg' problem where the reference system is of comparable accuracy as the system checked ("who is checking who?")

Calibration uncertainties for confirming 3 % TLMS accuracy at PF = 0.01, with TUR = 6:

- Component: each component < 0.3 %; at PF=0.01 → 0.1 min – 0.003 % in phase
- System: overall system < 0.5 %; at PF=0.01 → 0.2 min – 0.005 % in phase

Increased measurement challenge: TUR = 10, or reactor loss measurements (PF = 0.001)

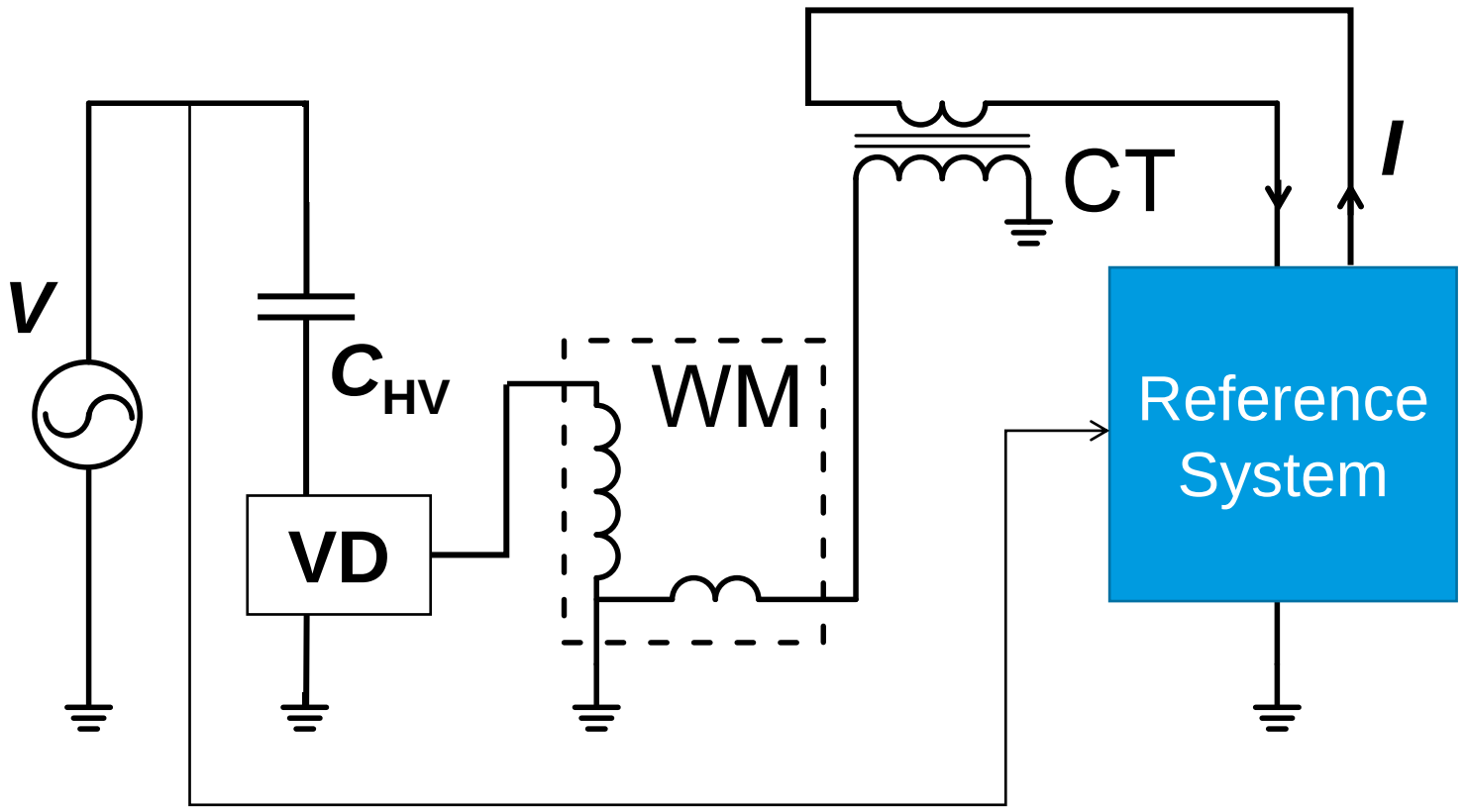
⇒ Reference measurement accurate to 0.2 % at PF = 0.01 → 0.06 min – 0.002 % in phase

⇒ *can only be achieved with system calibration*

TLMS 1-2 %, < 3 %?

Reference < 0.5 % at PF = 0.01!

TLMS system calibration



Reference system simulates adjustable losses to TLM

- Phantom power
- Calibration includes all systematic effects
- Calibration under actual PF values

⇒ More complex to perform, but smaller overall system uncertainty

Traceable to national standards, accredited

- IEEE C57.123-2010 “Transformer Loss Measurement”, ch. 7

  “Having traceability is a prerequisite to being able to achieve this specification. It provides a means to have **documented evidence** of the magnitude and phase errors of the various components of the measurement system and their associated uncertainties.” (mentions “system calibration” to achieve this)

Certified calibration to national standards ISO 9001 → ISO 17025

- IEC 60076-1, par. 11.1.1: “All measuring systems used for the tests shall have certified, traceable accuracy and be subjected to periodic calibration, according to the rules given in ISO 9001.”

- IEC 60076-2, par. 4.1: Any calibration shall be traceable to national and/or international standards

Only a calibrated TMS system, traceable to national standards, gives reliable tests results

⇒ ISO 17025 accreditation assures this

Traceability: “unbroken chain of calibrations, each contributing to the measurement uncertainty”

Calibration intervals

Best practice for calibration intervals:

- 1 yr: electronic equipment (power meter)
- 1 – 3 yr: stable equipment, equipment with history
- 3 – 5 yr: reference transformers (magnetic cores)

IEC 60060-2, par. 4.2/4.3: "*It is recommended that the performance test should be repeated **annually**, but the maximum interval shall not be longer than five years.*"

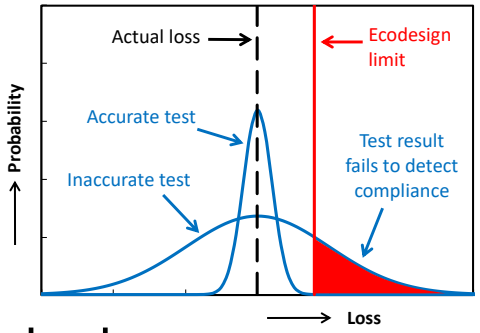
Key: user decides, evaluates confidence/risk ⇔ calibration costs

IEC 60060-2, par. 4.2/4.3: "*NOTE Long intervals between performance tests can increase the risk of an undetected change in the measurement system.*"

- Extend calibration intervals when a history is built up and cross-checks are performed (**IEC 60076-8**, par. 10.2, e)
- *NO adjustments* allowed! (or cal before & after adjustment)

Regular calibration
(1–3 year) & cross checks
No adjustments!

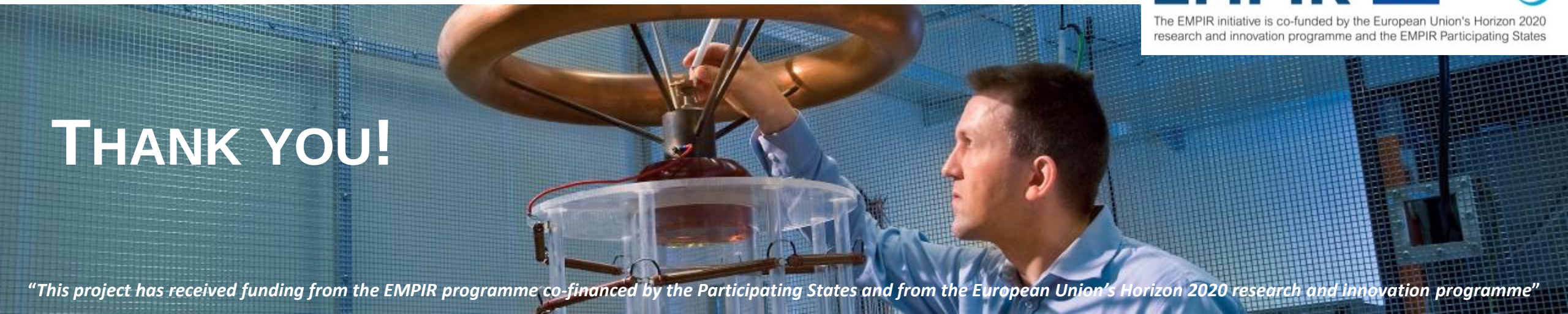
Summary



Reliable power transformer loss tests are achieved via TLMS that are

- Accurate: 1 – 3 % at PF = 0.01, with the trend: < 0.5 % at PF = 0.01
- Regularly calibrated (1–3 year period, accuracy 0.2 – 0.5 %) and cross-checked
- Not adjusted; or if so, have a ‘before & after’ calibration
- Traceable to national standards, accredited (preferably ISO 17025)

System calibration achieves the highest reliability



THANK YOU!

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