# TEST VOLTAGES INFLUENCE ON TURN RATIO TESTING

## ndb Technologies model ART-3D

**Application**

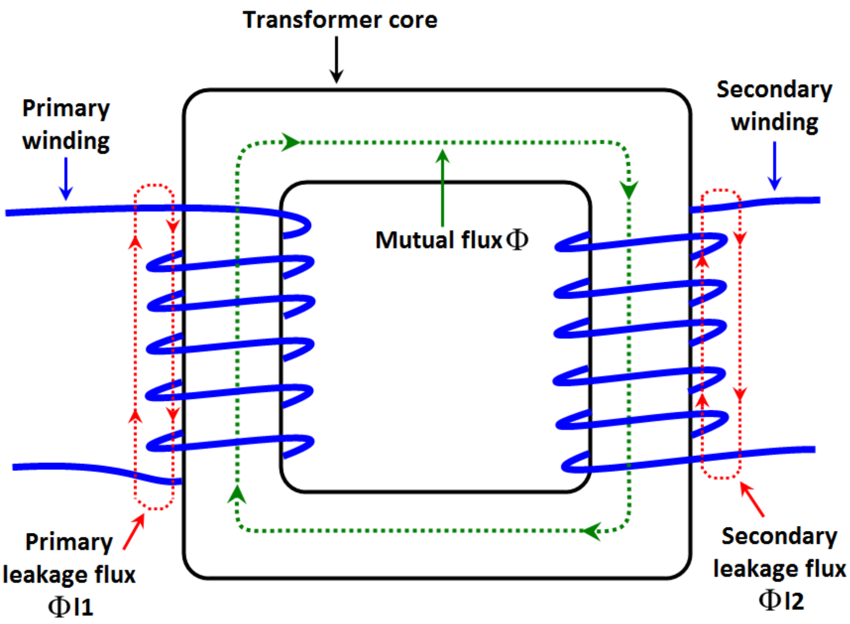
ndb Technologies has been working with several transformer maintenance crews and manufacturers over the years. One of the prevalent challenges was obtaining high accuracy ratio measurements to identify transformer coupling discrepancies. ABB Transformer Canada have been challenged with this higher ratio error problem as they strive to surpass the field maintenance standard acceptance tolerance of 0.5% (IEEE, ANSI and IEC). They target lower than 0.25% error. We have worked closely with them to define the technologies that would address this issue.

**Research**

Many testing solutions where trialed and one interesting element was increasing test voltages, which proved to increase the accuracy result. Several test voltages where tried. Higher voltages above 2kV, required additional potential transformers or coupling type capacitors devices to safely measure these higher voltages. Unfortunately, they add an extra later of measurement error often in the range of 0.3 to 0.5% error. This, in fact, defeated the purpose for achieving higher ratio accuracy readings.

To better understand the phenomenon of ratio accuracy error, we need to consider magnetic flux leakage theory. In an ideal (theoretical) transformer, all the flux would link with both primary and secondary windings, but in reality, this is not possible.

Although most of the flux will link with both windings through the core of the transformer, there will remain a small amount of flux which will link either winding to themselves but not to each other. This phenomenon is called leakage flux. Leakage flux will pass through the winding insulation and transformer insulating oil instead of passing through the transformer's core. This leakage flux in transformers, both primary and secondary windings, is also referred to leakage reactance. This phenomenon in transformer is also known as **Magnetic leakage.**

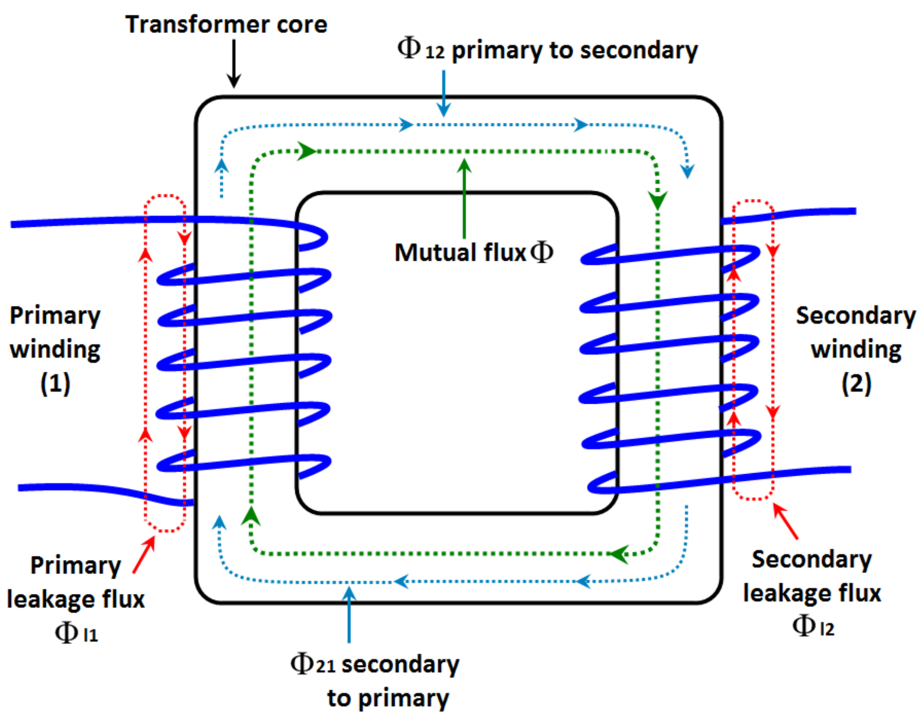


The mutual flux Φ, is confined mostly to the core and is **common to both** the primary and the secondary windings, transforms the power from primary to secondary. It is the resultant of mmf (magnetomotive force in Ampere-Turns) of the primary and secondary windings and the core flux in Weber (excitation current).

- *<u>$\Phi_{12}$ = mutual flux</u> in the transformer core from primary winding linking to the secondary winding.*
- *<u>$\Phi_{21}$ = mutual flux</u> in the transformer core from secondary winding linking to the primary winding.*

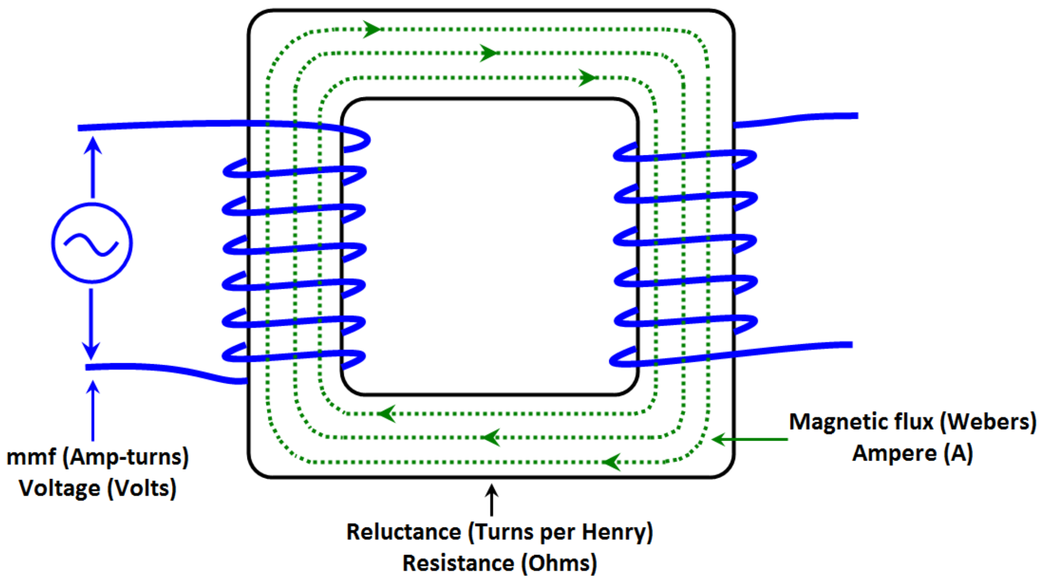
- The primary winding <u>leakage flux $\Phi_{l1}$</u>, is due to the mmf in the primary winding which links the primary only **without** linking the secondary.
- The secondary <u>leakage flux $\Phi_{l2}$</u>, due to the mmf in the secondary winding which links the secondary only **without** linking the primary winding.

- Resultant flux is described as follow:
  - <u>Total Average Primary flux **$\Phi_p$**</u> = leakage flux $\Phi_{l1}$ + (*$\Phi_{21}$ mutual flux* + $\Phi_{12}$ mutual flux)
  - <u>Total Average Secondary flux **$\Phi_s$**</u> = leakage flux $\Phi_{l2}$ + (*$\Phi_{12}$ mutual flux* + $\Phi_{21}$ mutual flux)



Analogy between Ohm's law and Magnetic reluctance:

**Magnetic Flux (Φ) phi** = similar to Amperes but expressed in Webers
**Reluctance (*R*)** = similar to Ohm's but expressed in Turns per Henry
**Magnetomotive Force (*F*) mmf** = similar to Volts, but expressed in Ampere-turns




For ratio measurement the voltage ratio results are used to calculate the turns ratio. If we consider that the voltage induced at the winding terminals is the result of the following:

Primary:

$V_{primary} = R_p \times I_p + N_p\,(d\Phi_p/d_t)$

- Where $\Phi_p = \Phi l_1 + (\Phi_{21} + \Phi_{12})$

Secondary:

$V_{secondary} = R_s \times I_s + N_s\,(d\Phi_s/d_t)$

- Where $\Phi_s = \Phi l_2 + (\Phi_{12} + \Phi_{21})$

Where:

V = Voltage at terminals
R = Winding resistance
I = Current in winding (with no load tests this value is near 0)
N = Number of turns in winding
*dΦ = Delta total average resultant flux (this is relative to the excitation current levels)*
*dt = Delta time*


**Advanced and innovative solutions**

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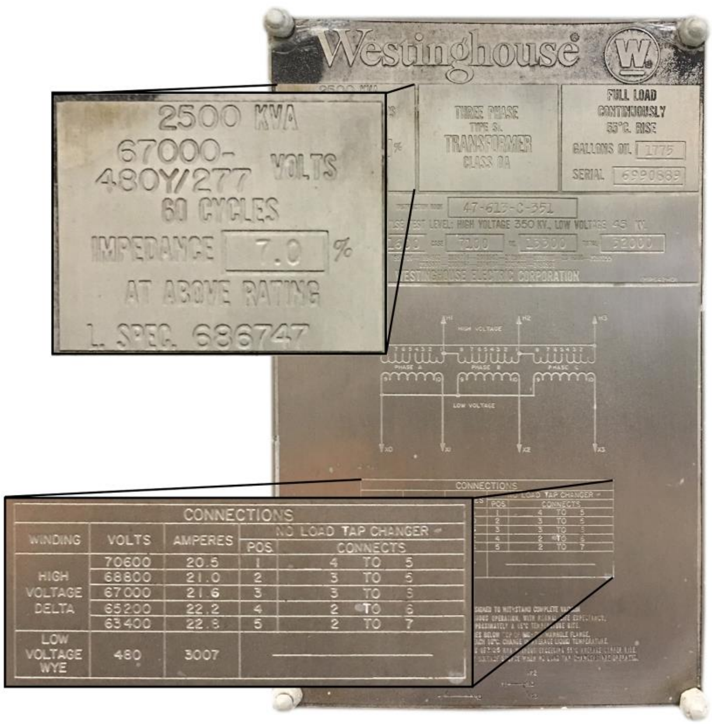
In essence, a higher voltage induced on the primary winding will result in increased primary excitation currents which will increase the links to core of leakage flux levels, sufficiently to reduce the proportion of leakage loss in the total mutual flux levels. This will directly increase the voltage ratio accuracy and therefore increase the turn ratio measurement accuracy.

This phenomenon can be observed in measurements in the field using the ART-3D:




Tap#2: 68800 V – 480 V

Step-up transformer

ART-3D ratio test results:

| | |
|---|---|
| Manufacturer | Westinghouse |
| Location | Quebec |
| Test Mode | Normal |
| Test Voltage | 8V |
| Threshold | 0.5% |
| Results | Pass |

| | |
|---|---|
| Type | Dyn1 |
| Primary Voltage | 68800V |
| Secondary Voltage | 480V |
| Secondary Phase | 30° |

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Primary - Secondary

**Test performed at 8V**

| Tap Name | Ref.Ratio | Phase | Meas.ratio | Rel. Error (%) | Phase Diff. (°) | Current (mA) |
|---|---|---|---|---|---|---|
| - | 248.26 | A | 248.94 | 0.27 | 0.0 | 0.17 |
| | | B | 249.07 | 0.32 | 0.0 | 0.34 |
| | | C | 249.13 | 0.35 | -0.0 | 0.27 |

Primary - Secondary

**Test performed at 40V**

| Tap Name | Ref.Ratio | Phase | Meas.ratio | Rel. Error (%) | Phase Diff. (°) | Current (mA) |
|---|---|---|---|---|---|---|
| - | 248.26 | A | 248.59 | 0.13 | 0.1 | 0.37 |
| | | B | 248.65 | 0.16 | 0.1 | 0.45 |
| | | C | 248.74 | 0.19 | 0.1 | 0.53 |

Primary - Secondary

**Test performed at 100V**

| Tap Name | Ref.Ratio | Phase | Meas.ratic | Rel. Error (%) | Phase Diff. (°) | Current (mA) |
|---|---|---|---|---|---|---|
| - | 248.26 | A | 248.51 | 0.10 | 0.1 | 0.45 |
| | | B | 248.54 | 0.11 | 0.1 | 0.61 |
| | | C | 248.52 | 0.10 | 0.1 | 0.71 |

Primary - Secondary

**Test performed at 275V**

| Tap Name | Ref.Ratio | Phase | Meas.ratio | Rel. Error (%) | Phase Diff. (°) | Current (mA) |
|---|---|---|---|---|---|---|
| - | 248.26 | A | 248.37 | 0.04 | 0.1 | 0.80 |
| | | B | 248.42 | 0.06 | 0.1 | 1.12 |
| | | C | 248.39 | 0.05 | 0.1 | 1.24 |