EN 206 - Power Electronics and Machines

Transformers

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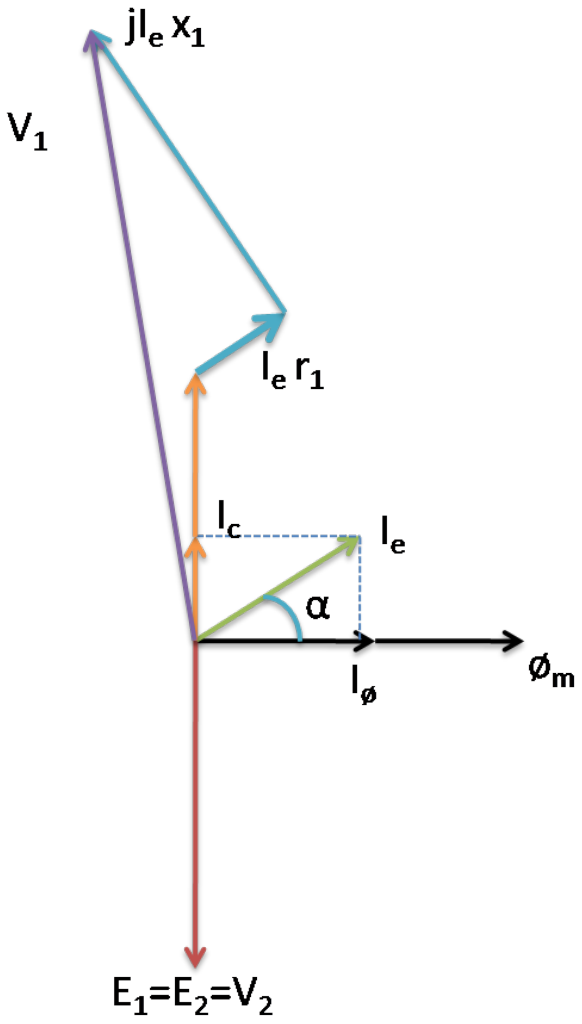
Lecture Organization - Modules

- Introduction and Power Semiconductor Switches
- Module 1: Transformers
- Module 2: AC/DC converter / Rectifier
- Module 3: DC machines and Drives
- Module 4: DC/DC converter
- Module 5: Induction Machine
- Module 6: DC/AC converter / Inverter
- Module 7: AC/AC converter / Cyclo converter
- Module 8: Synchronous Machine
- Module 9: Special Topics: Machines, HVDC, APF

Review of Last Class

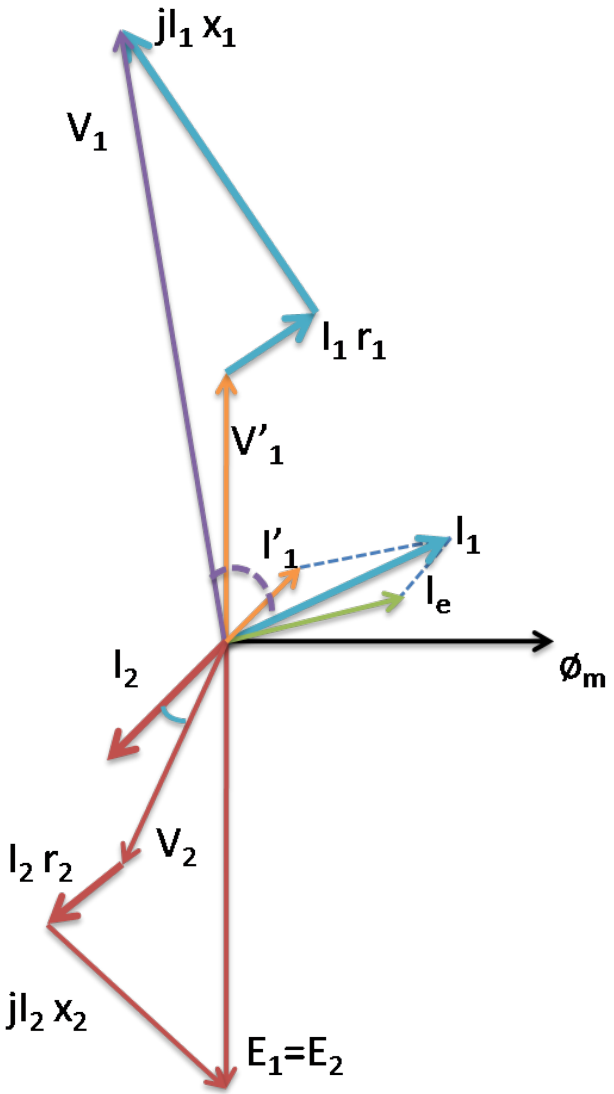
- Transformers
  - Types, applications, construction
  - Principle of operation, emf equation
  - Phasor diagram for ideal transformer and no load condition, impedance transformation

Phasor Diagram - No Load



- α: Hysteresis angle, I_e: exciting current, I_ϕ : Magnetizing current, I_c: Core loss component
- r_1: primary resistance
- x_1: fictituous quantity introduced to represent the leakage flux in primary
- Primary leakage impedance drop is about 2 to 5% even at full load.
- The magnetizing current is typically 1% of full load current and hence is neglected.

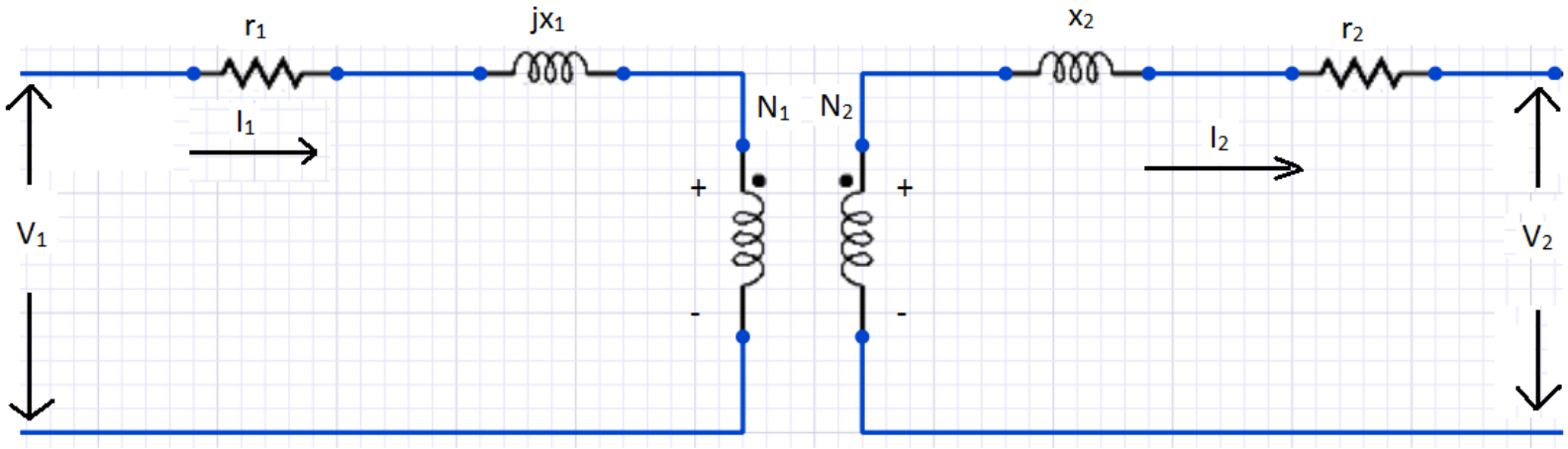
Phasor Diagram - Lagging Load



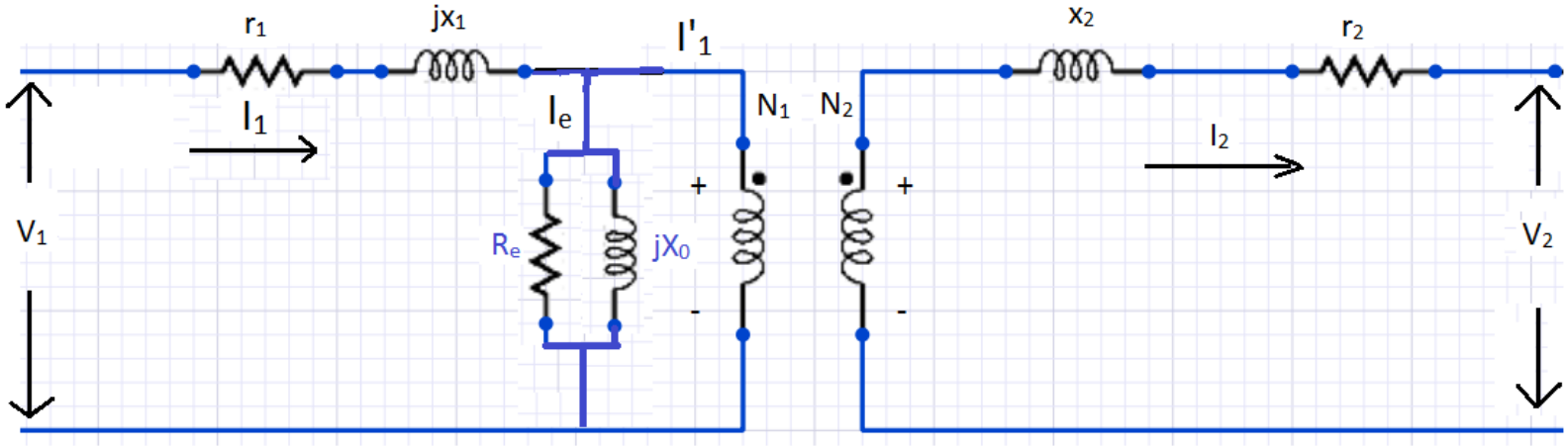
- θ_1 and θ_2 is the power factor of the load and source respectively.
- r_1: primary resistance
- x_1: fictituous quantity introduced to represent the leakage flux in primary
- Primary leakage impedance drop is about 2 to 5% even at full load.
- Phasor diagram is helpful only:
  - When a transformer is to be studied alone
  - When the internal behaviour of the transformer is to be understood

Equivalent Circuit

With Exciting current neglected:

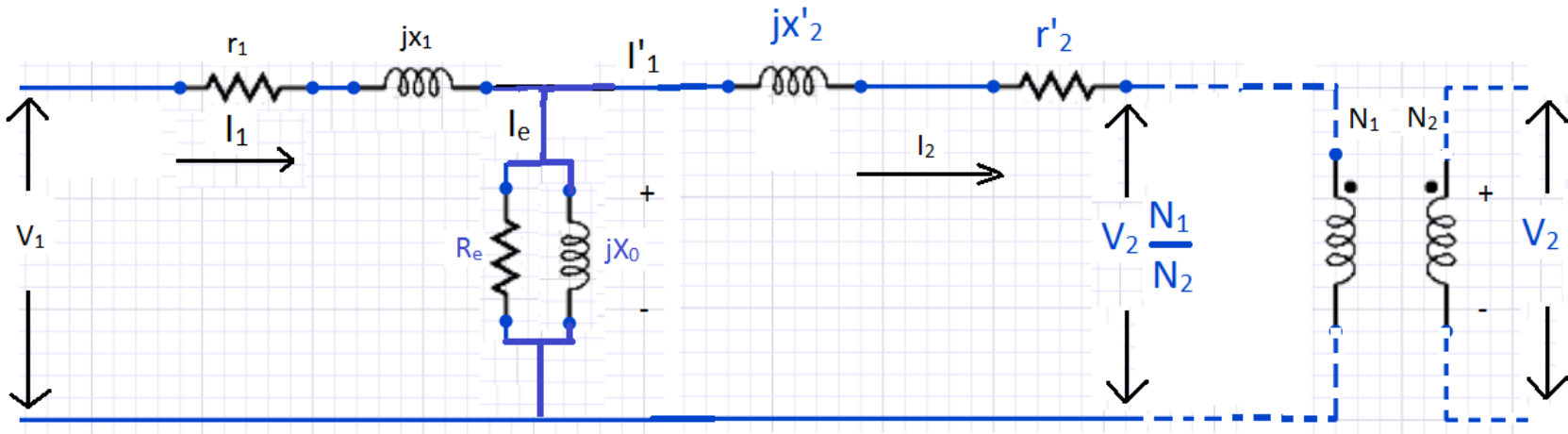


Exact equivalent circuit:



Equivalent Circuit

Equivalent circuit referred to primary:



Problem-1

A 33 kVA, 2200/220V, single phase transformer has resistances and leakage reactances as follows:

$$r_1 = 2.4\Omega,\ r_2 = 6.0\Omega,\ x_1 = 0.03\Omega,\ x_2 = 0.07\Omega$$

Subscripts 1 and 2 denote high voltage and low voltage windings respectively.

(a) Determine the total ohmic losses at full load.

(b) Calculate the voltage to be applied to the HV side in order to obtain a short circuit current of 160A in the LV side. Also find the input power for this condition.

Problem-2

A 10 kVA, 2500/250V, single phase transformer has resistances and leakage reactances as follows:

$$r_1 = 4.8\Omega,\ r_2 = 0.048\Omega,\ x_1 = 11.2\Omega,\ x_2 = 0.112\Omega$$

Subscripts 1 and 2 denote high voltage and low voltage windings respectively. With primary voltage held constant at 2500V, calculate the secodnary terminal voltage, when

(a) The low voltage winding is connected to a load of impedance of 5+j3.5 Ω.

(b) The transformer delivers its rated current at 0.8pf lagging on the low voltage side.

Open Circuit (OC) and Short Circuit (SC) Test

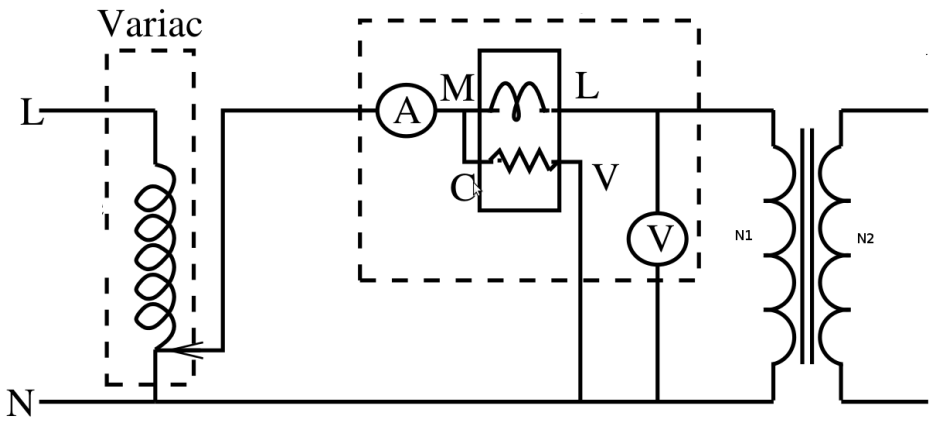
OC and SC test on a transformer are performed to find out:

- The parameters of equivalent circuit
- Voltage regulation
- Efficiency

All these tests are performed without loading the transformer.

Open Circuit Test

Circuit diagram for OC Test:



1. The meters are connected on low voltage side of the transformer
2. The high voltage side is kept open, and rated frequency voltage is applied to the primary using variac
3. At this condition, the rated flux flows into the core of the transformer.

Open Circuit Test

What do the meter(s) reading indicate?

- The ammeter indicate the excitation current of the transformer (no load current)
- As the value of I_e is small, the voltage drop across the leakage impedance can be negleced.
- The applied voltage can be assumed to be equal to emf induced (for all practical purpose)
- The reading of wattmeter gives core losses in the machine (neglecting copper losses).

OC Test - Analysis

Let V_1 be the voltage applied across the primary (LV) side of the transformer, I_e is the exciting current, P_c is core loss, then:

$$P_c = V_1 I_e \cos\theta, \therefore \text{ no load power factor is given by:}$$

$$cos\theta_o = \frac{P_c}{V_1 I_e}$$

From the phasor diagram, we can obtain that:

$$I_c = I_e cos\theta_o \text{ and } I_\phi = sin\theta_o$$

$$\therefore R_c = \frac{V_1}{I_e cos\theta_o}, X_\phi = \frac{V_1}{I_e sin\theta_o}$$

OC Test - Summary

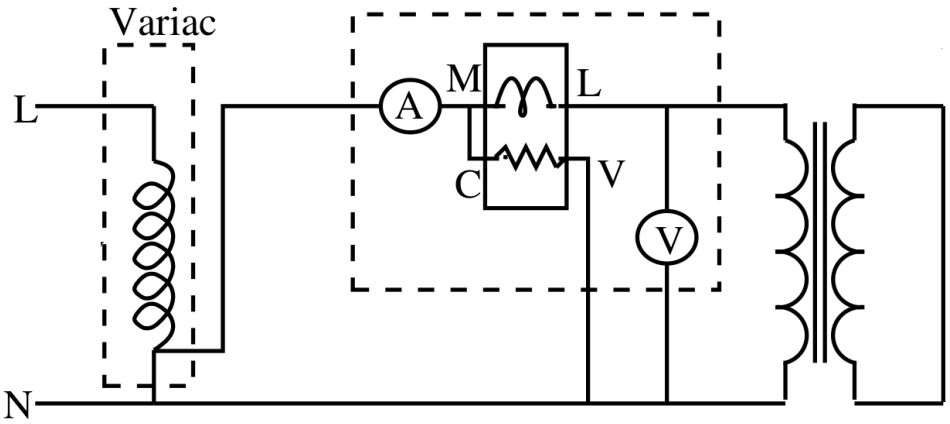
OC test on a transformer gives the following information

- Core losses at rated voltage and frequency
- The shunt branch parameters of the equivalent circuit (R_c and X_ϕ)
- Turns ratio of the transformer

Note: The values of R_c and X_ϕ determined are to be referred to the side in which instruments are placed.

Short Circuit Test

Circuit diagram for SC Test:



1. The low voltage side terminals are short circuted.
2. The meters are connected on high voltage side of the transformer.
3. Voltage is applied to the primary using variac (2 to 12% of V_{rated}).
4. At this condition, full load current will flow in both the windings.
5. Core flux is 1 to 6% of its rated value.

Short Circuit Test

What do the meter(s) reading indicate?

- The ammeter indicate full load current of HV side
- The reading of wattmeter gives copper losses in the machine at full load (neglecting core losses).
- The exciting current may be neglected to obtain a simplified equivalent circuit.

Short Circuit Test - Analysis

If $r_{e,hv}$, $x_{e,hv}$ and $z_{e,hv}$ represent equivalent resistance, leakage reactance and impedance referred to hv side:

- $z_{e,hv} = \frac{V_{sc}}{I_{sc}}$
- $r_{e,hv} = \frac{P_{sc}}{I_{sc}^2}$
- $x_{e,hv} = \sqrt{z_{e,hv}^2 - r_{e,hv}^2}$

Short Circuit Test - Summary

- SC test is generally performed on high voltage side
- The readings of SC test help in determining the resistance and leakage reactance of the windings.
- It is possible to determine the efficieny of the transformer using SC test data and core losses.

Summary

- Transformers
  - Phasor diagram of transformer (loaded)
  - Equivalent Circuit
  - Open Circuit and Short Circuit Test

  Next Class
  - Auto Transformer and Three phase Transformers
- Thank you!!

For Further Reading:

- Transformer Engineering: Design and Practice Authors: S.V. Kulkarni and S.A. Khaparde Publisher: Marcel Dekker (Taylor & Francis Group), New York, May 2004 ISBN: 0-8247-5653-3
- Electric Machinery: A. E. Fitzgerald, C. Kingsley, S. D. Umans. Publisher: TMH, New Delhi, India, 2009