AALBORG UNIVERSITET

HIGH VOLTAGE ENGINEERING

LABORATORY EXCERCISE INSTRUCTIONS FOR MINIPROJECT

Qian Wang, *PhD. Fellow*, Claus Leth Bak, *Professor*

Department of Energy Technology, Aalborg University, Pontoppidanstraede 111, 9220 Aalborg, Denmark

Email: qiw@et.aau.dk ,clb@et.aau.dk

Introduction

The High Voltage engineering laboratory exercises will be held after the lectures in order to apply the theoretical concepts given during the lecture. There is one mandatory demonstration of HV laboratory safety. The students should read the safety rules prior to the lecture, which can be found in the following:
http://www.et.aau.dk/digitalAssets/48/48085_rules_highvoltage_lab.pdfattend.

The student MUST sign the document and return it to Claus Leth Bak before any work in the HV lab is allowed.

It is mandatory to attend the laboratory demonstrations carried out by the lecturer and his assistant (duration ½ - 1 hour). After the demonstration, the students are free to work for each laboratory exercise on their own and supervised by the lecturer or his assistant. This is highly recommended, but not mandatory.

A miniproject must be handed out at the end of the semester. The student should include all the measurements carried out during the laboratory sessions following the instructions for each laboratory exercise.

The following skills will be gained:

- Fundamentals of High Voltage Engineering
- Measurements, according to IEC standards, of high AC, DC and impulse voltages for testing purposes in the HV laboratory.
- Sphere gap measurements
- Electrostatic field theory for simple insulation systems.
- Non-destructive tests methods in HV engineering.
- Dynamic properties of dielectrics in time and frequency domain
- Insulation ageing and lifetime assessment- test methods.
- Modelling of dielectric properties by means of electrical equivalent circuits.
- Dielectric loss and capacitance measurement – the Schering Bridge
- External partial discharges, origin and practical importance for HV power system components, corona, overhead line audible noise and measurements of corona phenomena.
- Internal partial discharges, origin and practical importance for HV power system components.

1. Inductive Voltage Transformer

SAFETY MEASURES: Interlocks are provided to prevent high voltage to be switched on while the gates/ doors are open. Despite these measures it is necessary to connect the safety earth stick to the HV parts before touching. (There could be some charge left on the capacitors). Special safety rules for the High Voltage laboratory must be read, understood, signed and always followed to every detail!

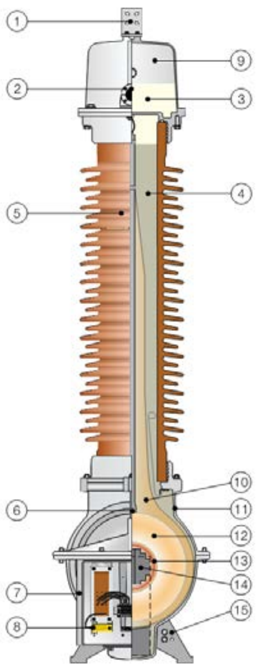
1.1 Objectives

The student must gain the following knowledge and comprehension in the following topics:

- General description and understanding of inductive voltage transformer.
- Dielectric design description.
- Nameplate parameters and specifications, understanding of all the data provided by the manufacturer.
- Theoretical calculation and experimental measurement of transformer transfer ratio.

1.2 General Description

The ABB Inductive Voltage Transformer EMF (EMF 52-170) is a voltage transformer which is used for voltage metering and protection in high voltage network systems. The purpose is to transform the high voltage into low voltage adequate to be processed in measuring and protecting instruments in the secondary side. Therefore, a voltage transformer isolates the measuring instruments from the high voltage side.



The standard design of the EMF 52-170, which is depicted in Figure 1, has a single high voltage terminal and three low voltage terminals (e.g., *1a-1n*, *2a-2n* and *da-dn*). The last one, *da-dn*, is normally used for measuring ground faults, but other configurations can be made available if required.

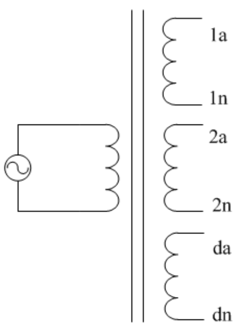


Figure 1. ABB EMF 72 kV inductive voltage transformer.

1.3 Dielectric Design

The dielectric characteristics of the inductive voltage transformer will be explained during the laboratory session. The student is expected to **take notes** and **pictures**.

There are two types of insulators; the student must point out the purpose of using them:

- Outer insulator: ceramic insulator.
- Inner insulator: oil, paper insulator, quartz filling, etc.

1.4 Nameplate

The nameplate contains information about the transformer, e.g., voltage, current, frequency, voltage factor, etc. The student is expected to take notes of the information provided by the manufacturer. The student must describe and understand the data given in the nameplate.

Table I. ABB inductive voltage transformer.

	Nameplate	Size	Unit
1	Type	EmFC72	
2	Number	8350834	
3	Isolation level	140 - 350	kW
4	Max. constant voltage	72,5	kV
5	Frequency	50	Hz
6	Norm	IEC186	
7	Voltage factor	1.9 / 8	H
8	Total mass	140	kg
9	Production year	1998	

Table II. Data described in the terminal. ,

	Terminal data	A-N	1a-1n	2a-2n	da-dn
10	Voltage (phase-neutral)	60000 / 3^(1/3)	110 / 3^(1/3)	110 / 3^(1/3)	110 / 3^(1/3)
11	Load	-	1 - 15	1 - 65	75
12	Class	-	0.2	0.2	3*P

1.5 Transfer Ratio

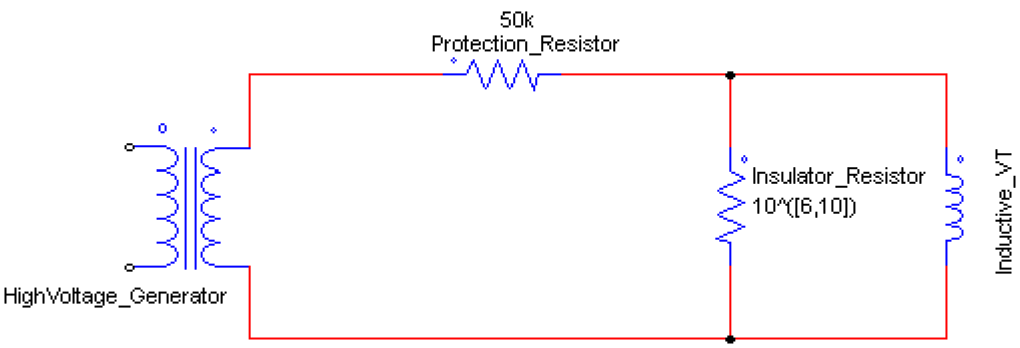
The number of turns on each winding determines the transfer ratio between the primary, which in this case is the high voltage side and the secondary, the low voltage side. The transfer ratio, *m*, is given by:

$$m = \frac{Vp}{Vs} = \frac{Np}{Ns}$$

The student has to calculate the rated transfer ratio with the information given on the transformer's nameplate and further on, verify the transfer ratio by means of experimental tests. Several measurements must be conducted (e.g., primary voltage range from 5 kV up to 30 kV) in order to demonstrate the good functionality and linearity of the inductive voltage transformer. The student must provide a comprehensive description of the experimental setup and explain the differences observed between the theory and experimental results:

- Why the maximum voltage applied at the high side should not exceed 35 kV?
- How the voltage is measured on HV side? Which equipment is used?
- How the voltage is measured on LV side? Which equipment is used?
- How many secondary windings on the LV side are tested? At least two of them must be tested.
- Asses the linearity of the voltage transformer ratio. Illustrate in a graph the relationship between the voltage measured on HV side and the voltage measured on LV side.
- Asses the measurement accuracy of the measured transfer ratio, both high voltage and low voltage measurement.

Please draw a schematic of the circuit with all the equipment that has been used:



Why the maximum voltage applied at the high side should not exceed 35 kV?

The nameplate of the transformer states that the maximum rated voltage is 60 kV / sqrt(3) = 34.6 kV which is roughly similar to 35 kV. That means that if this voltage is exceeded it could result in the damage or destruction of the components of the test setup, because the insulation fail.

How the voltage is measured on HV side? Which equipment is used?

The voltage in the HV side is measured using a capacitive voltage divider, which is better than a resistive voltage divider for HV measurements, as capacitors can withstand higher voltages than resistors without power consumption or heating.

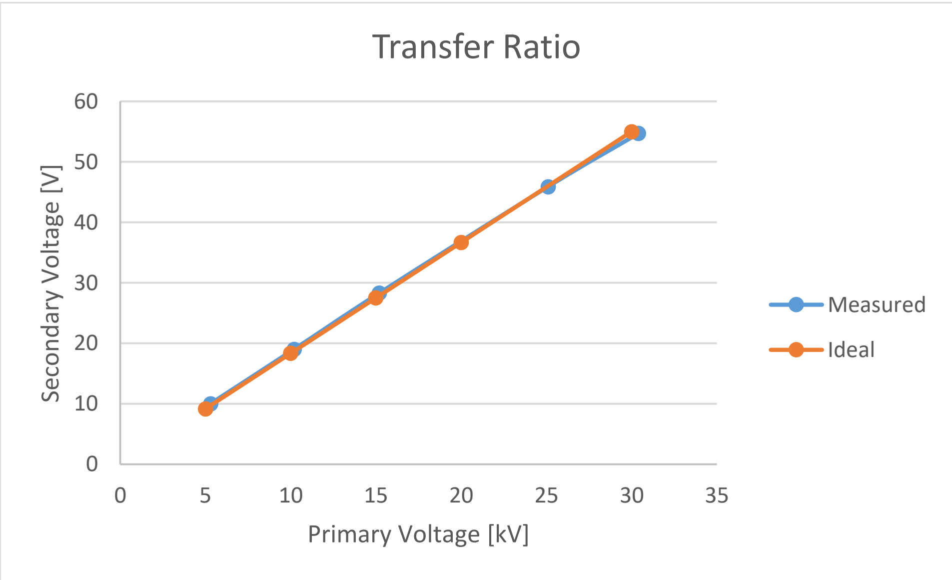
How the voltage is measured on LV side? Which equipment is used?

The voltage in the LV side is measured using a multimeter because the output is a DC low voltage signal.

How many secondary windings on the LV side are tested?

Two secondary windings on the LV side were tested, 1a-1n and 2a-2n, so it is possible to verify the functionality of the transformer by comparing the results obtained in both cases.

Asses the linearity of the voltage transformer ratio. Illustrate in a graph the relationship between the voltage measured on HV side and the voltage measured on LV side.



The response of the system shows a qualitatively linear behaviour. However, according to experimental tests, the relationship between input and output varies from 530 at Vin = 5.3 kV to 555 at Vin = 30 kV. There's a slight divergence between this data and the transfer ratio stated in the nameplate, 545.

Asses the measurement accuracy of the measured transfer ratio, both high voltage and low

Difference in Transfer Ratio	Difference[%]
-15,45	-2,83
-8,61	-1,58
-8,35	-1,53
1,39	0,25
10,30	1,89
Mean difference [%]	-0,76

Secondary winding tested: 1a - 1n

Primary side [kV]	Secondary side [V]	Transfer Ratio
5.3	10	530
10.2	19	536.8
15.2	28.3	537.1
25.1	45.9	546.8
30.4	54.7	555.7

Secondary winding tested: 2a - 2n

Primary side [kV]	Secondary side [V]	Transfer Ratio
5.4	10	540
10.2	19.1	534
15.1	28.3	533.6
25	45.8	545.9
30.2	54.5	554.1

2. DC Voltages Generation

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2.1 Objectives

The student must gain the following knowledge and comprehension in the following topics:

- General description of the half-wave rectifier circuit for DC voltage generation and become familiar with the experimental setup.
- Conduct DC voltage generation test and describe the procedure.
- Experimental measurement of ripple voltage and ripple factor.
- Voltage divider design.

2.2 General description

The rectification of alternating currents is the most efficient means of obtaining DC voltages. When a HV diode, a load capacitor C and a resistive load R are connected to the output of a simple HVAC transformer, a half-wave rectifier circuit is established and a DC voltage is generated. The diode opens for half-waves of one polarity and closes for the opposite polarity. It opens only as long as the AC voltage at the transformer output is higher than the voltage of the charged capacitor. As soon as the capacitor carries any charge, its discharging starts and becomes significant when the diode closes after the voltage has reached its maximum. The capacitor is discharged to a minimum voltage, until the diode opens again for a short time. This means the output voltage is not constant, and it shows a so-called ripple voltage.

A oscilloscope can be used to measure the generated DC voltage waveform along with the ripple voltage/factor. However, the maximum input voltage of the oscilloscope is much lower than the DC voltage, a voltage divider should be designed.

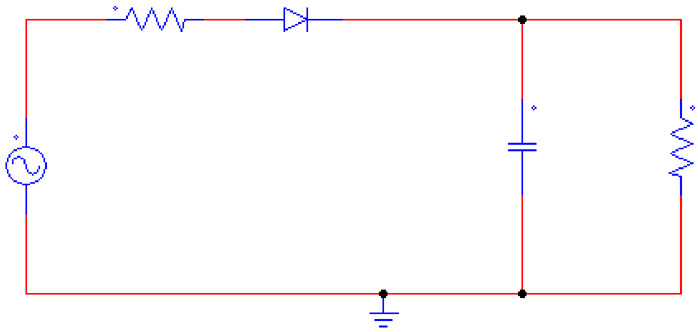
In order to generate and measure a DC voltage, a single-phase half-wave rectifier circuit is used. The student must carry out the following tasks:

- Draw as **detailed as possible** the schematic of the setup, equipment, etc., and draw the trend curve of voltage/current at the load R.
- Identify the maximum AC supplying voltage V_{max} in the circuit (hint:

consider the diode withstand voltage).

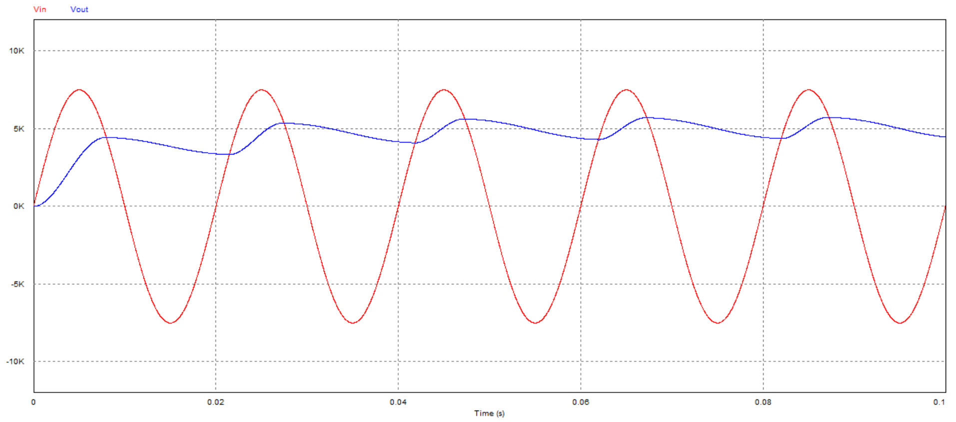
- Identify the resistance of the voltage divider and define the voltage division ratio.

Please draw a schematic of the setup with all the equipment that has been used:



· The diode used diode has a voltage rating of 140 kV. The capacitor maximum voltage will be Vmax then Vmax shouldn't eexceed V_diode_max/2 in order to ensure that the system won't damage the diode when Vin = -Vmax.

· Input voltage (red) and system response (blue) for an input peak voltage of 7.5 kV:



· The voltage divider has a total resistance of 24 MOhm.

2.3 DC voltage generation test

Once the student becomes familiar with the setup and understands the principle of the half-wave rectifier circuit, the next step is to conduct the DC voltage generation test.

The procedure will be explained during the laboratory session so the student is expected to take notes and include them in the mini-project.

The student has to give different AC supplying voltages and measure corresponding generated DC voltages. The ripple voltage δV and ripple factor S should be calculated based on the experimental waveforms captured in the tests.

AC supplying voltage [kV]	DC averaged voltage [kV]	Ripple voltage [kV]	Ripple factor [%]
5.3	4.6	2.89	62.8
19.9	22.5	5.64	25.1
29.9	34.6	7.68	22.2
34.6	40.4	8.53	21.1