		Marks	OBE	
			CO	RBT
1	**List the different tests conducted on underground cables and briefly explain them.**	[10]	CO6	L1

Cables are very important electrical apparatus for transmission of electrical energy by underground means. They are also very important means for transmitting voltage signals at high voltages. Of the different electrical and other tests prescribed, the following are important to ensure that cables withstand the most severe conditions that are likely to arise in service.
Different tests on cables may be classified into

i. mechanical tests like bending test, dripping and drainage test, and fire resistance and corrosion tests,
ii. thermal duty tests,
iii. dielectric power factor tests,
iv. power frequency withstand voltage tests,
v. impulse withstand voltage tests, partial discharge tests, and
vi. Life expectancy tests.

Descriptions of some of the test are as follows:

Dielectric Power Factor Test

The dielectric power factor test is done using the high voltage Schering Bridge. The power factor or dissipation factor tan δ is measured at 0.5, 1.0, 1.66, and 2.0 times the rated voltage (phase to ground) of the cable. The maximum value of the power factor and the difference in power factor between the rated voltage and 1.66 times the rated voltage, as well as, between the rated voltage and two times the rated voltage are specified. Sometimes choke is used or a suitably rated transformer winding is used in series with the cable to form a resonant circuit. This improves the power factor and raises the test voltage between the cable core and the sheath to the required value, when a source of high voltage and high capacity is used. The Schering Bridge has to be given protection against over voltages, in case breakdown occurs in the cables.

High Voltage Tests on Cables

Cables are tested for withstand voltages using the power frequency a.c., d.c., and impulse voltages. At the time of manufacture, the entire cable is passed through a high voltage test at the rated voltage to check the continuity of the cable. As a routine test, the cable is tested applying an a.c. voltage of 2.5 limes the rated value for 10 min. No damage to the cable insulation should occur.
Type tests are done on cable samples using both high voltage d.c. and impulse voltages. The d.c. test consists of applying 1.8 times the rated d.c. voltage of negative polarity for 30 min., and the cable system is said to be fit, if it withstands the test. For impulse tests, impulse voltage of the prescribed magnitude as per specifications is applied, and the cable has to withstand five applications without any damage.

Partial Discharges

1. Discharge measurement:

The cable connection to the discharge detector through the coupling condenser is shown in Figure 1. If the detector is connected through a coupling capacitor to one end of the cable as in Figure 1a, it will receive the transient travelling wave directly from the cavity towards the nearer end, and after a short lime, a second travelling wave pulse reflected from the far end is observed. Thus, the detected response is the combination of the above two transient pulses. But, if the connections are made as in Figure 1b, no severe reflection is involved except as a second order effect of negligible magnitude.

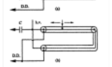


Figure 1 Discharge detector connection to long length of cable D.D.—Discharge detector

2. Location of discharge:

The voltage dip caused by a discharge at a fault or a void is propagated as a travelling wave along the cable. This wave is detected as a voltage pulse across the terminals of the cable ends. By measuring the time duration between the pulses, the distance at which the discharge is taking place from the cable end can be determined. The shapes of the voltage pulses depend on the nature of the discharges

2 **Describe the Testing of Transformers.** [10] CO6 L2

Transformers are very important and costly apparatus in power systems. Great care has to be exercised to see that the transformers are not damaged due to transient over voltages of either lightning or power frequency. Hence, overvoltage tests become very important in the testing of transformers.

Induced Overvoltage Test

Transformers are tested for over voltages by exciting the secondary of the transformer from a high frequency a.c. source (100 to 400 Hz) to about twice the rated voltage. This reduces the core saturation and also limits the charging current necessary in large power transformers. The insulation withstand strength can also be checked.

Partial Discharge Tests

The transformer is connected to the discharge circuit and the discharge measurements are made. The location of the fault or void is sometimes done by using the travelling wave technique. So far, no method has been standardized as to where the discharge is to be measured. Multi-terminal partial discharge measurements are recommended. Under the application of power frequency voltage, the discharge magnitudes greater than 10 pico coulomb are considered to be severe, and the transformer insulation should be such that the discharge magnitude will be far below this value.

Impulse Testing of Transformers

The purpose of the impulse tests is to determine the ability of the insulation of the transformers to withstand the transient voltages due to lightning, etc. Since the transients are impulses of short rise time, the voltage distribution along the transformer winding will not be uniform. The equivalent circuit of a transformer winding for impulses is shown in Figure 2. If an impulse wave is applied to such a network (shown in Figure 2) the voltage distribution along the element will be uneven, and oscillations will be set in producing voltages much higher than the applied voltage. Impulse testing of transformers is done using both the full wave and the chopped wave of the standard impulse, produced by a rod gap with a chopping time of 3 to 6 μs. To prevent large over voltages being induced in the windings not under test, they are short circuited and connected to ground.

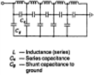


Figure 2 Equivalent circuit of transformer winding for impulses.

3 **Explain the two different schemes of cascading the transformers to generate HVAC.** [10] CO4 L4

Figure 3 shows the cascade transformer units in which the first transformer is at the ground potential along with its tank. The second transformer is kept on insulators and maintained at a potential of V_2, the output voltage of the first unit above the ground. The high voltage winding of the first unit is connected to the tank of the second unit. The low voltage winding of this unit is supplied from the excitation winding of the first transformer, which is in series with the high voltage winding of the first transformer at its high voltage end. The rating of the excitation winding is almost identical to that of the primary or the low voltage winding. The high voltage connection from the first transformer winding and the excitation winding terminal are taken through a bushing to the second transformer. In a similar manner, the third transformer is kept on insulators above the ground at a potential of $2V_2$ and is supplied likewise from the second transformer. The number of stages in this type of arrangement is usually two to four, but very often, three stages are adopted to facilitate a three-phase operation so that $\sqrt{(3V_2)}$ can be obtained between the lines. Supply to the units can be obtained from a motor-generator set. The rating of the primary or the low voltage winding is usually 230 or 400 V for small units up to 100 kVA. For larger outputs the rating of the low voltage winding may be 3.3kV, 6.6 kV or 11 kV.

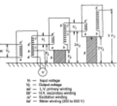


Figure 3 Cascade Transformer Connection (Schematic)

In Figure 4, a second scheme for providing the excitation to the second and the third stages is shown. Isolating transformers I_{s1}, I_{s2} and I_{s3} are 1:1 ratio transformers insulated to their respective tank potentials and are meant for supplying the excitation for the second and the third stages at their tank potentials. Power supply to the isolating transformers is also fed from the same a.c. input. This scheme is expensive and requires more space. The advantage of this scheme is that the natural cooling is sufficient and the transformers are light and compact. Transportation and assembly is easy. Also the construction is identical for isolating transformers and the high voltage cascade units. Three phase connection in delta or star is possible for three units. Testing transformers of ratings up to 10 MVA in cascade connection to give high voltages up to 2.25 MV are available for both indoor and outdoor applications.

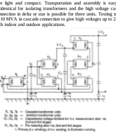


Figure 4 Cascade transformer unit with isolating transformers for excitation

4	**Describe the set up of Resonant Transformer. Mention the advantages and disadvantages.**	[10]	CO4	L1

The equivalent circuit of a high voltage testing transformer consists of the leakage reactances of the windings, the winding resistances, the magnetizing reactance, and the shunt capacitance across the output terminal due to the bushing of the high voltage terminal and also that of the test object. This is shown in Figure 5(a) with its equivalent circuit in Figure 5(b). It may be seen that it is possible to have series resonance at power frequency ω, if $(L_1 + L_2) = 1/\omega C$. With this condition, the current in the test object is very large and is limited only by the resistance of the circuit. The waveform of the voltage across the test object will be purely sinusoidal.

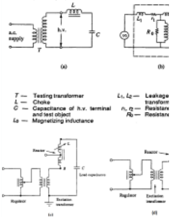


Figure 5 Resonant Transformer and Equivalent Circuit

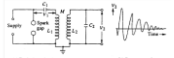
A transformer with 50 to 100 kV voltage rating and a relatively large current rating is connected together with an additional choke, if necessary. The test condition is set such that $\omega(L_e+L) = 1/\omega C$ where L_e is the total equivalent leakage inductance of the transformer including its regulating transformer.

The chief advantages of this principle are:

a) it gives an output of pure sine wave,
b) power requirements are less (5 to 10% of total kVA required),
c) no high-power arcing and heavy current surges occur if the test object fails,
d) as resonance ceases at the failure of the test object,
e) cascading is also possible for very high voltages,
f) simple and compact test arrangement, and
g) no repeated flashovers occur in case of partial failures of the test object and
h) insulation recovery. It can be shown that the supply source takes Q number of cycles at least to charge the test specimen to the full voltage.

The disadvantages are the requirements of additional variable chokes capable of withstanding the full test voltage and the full current rating. A simplified diagram of the series resonance test system is given in Figure 5c and that of the parallel resonant test system in Figure 5d.

5 (a) With the help of a neat diagram describe the Tesla Coil. [05] CO4 L2



(a) Equivalent circuit (b) Output waveform

Figure 6 Tesla coil equivalent circuit and its output waveform

The commonly used high frequency resonant transformer is the Tesla coil, which is a doubly tuned resonant circuit shown schematically in Figure 6a. The primary voltage rating is 10 kV and the secondary may be rated to as high as 500 to 1000 kV. The primary is fed from a d.c. or a.c. supply through the condenser C_1. A spark gap G connected across the primary is triggered at the desired voltage V_1 which induces a high self-excitation in the secondary. The primary and the secondary windings (L_1 and L_2) are wound on an insulated former with no core (air-cored) and are immersed in oil. The windings are tuned to a frequency of 10 to 100 kHz by means of the condensers C_1 and C_2. The output voltage V_2 is a function of the parameters L_1, L_2, C_1, C_2 and the mutual inductance M. usually, the winding resistances will be small and contribute only for damping of the oscillations

(b) Explain how Rogowski Coil is used for the measurement of high impulse current. [05] CO5 L4

If a coil is placed surrounding a current carrying conductor, the voltage signal induced in the coil is

$$v_i(t) = M\frac{dI(t)}{dx}$$

where M is the mutual inductance between the conductor and the coil, and I(t) is the current flowing in the conductor. Usually, the coil is wound on a nonmagnetic former of toroidal shape and is coaxially placed surrounding the current carrying conductor. The number of turns on the coil is chosen to be large, to get enough signal induced. The coil is wound cross-wise to reduce the leakage inductance. Usually an integrating circuit (see Figure 7) is employed to get the output signal voltage proportional to the current to be measured. The output voltage is given by

$$V_m(t) = \frac{1}{CR}\int_0^t V_i(t) = \frac{M}{CR}I(t)$$

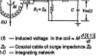


Figure 7 Rogowski Coil for high impulse current measurements

Rogowski coils with electronic or active integrator circuits have large bandwidths (about 100 MHz). At frequencies greater than 100 MHz the response is affected by the skin effect, the capacitance distributed per unit length along the coil, and due to the electromagnetic interferences. However, miniature probes having nanosecond response time are made using very few turns of copper strips for UHF measurements.

Interpret how HVDC is generated using Simple and cascaded Voltage doubler circuit. [10] CO4 L2

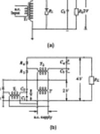


Figure 8 (a) Simple Voltage Doubler (b) Cascaded Voltage Doubler

When higher d.c. voltages are needed, a voltage doubler or cascaded rectifier doubler circuits are used. The schematic diagram of voltage doublers are given in Figure 8a and b. In voltage doubler circuit shown in Figure 8a, the condenser C_1 is charged through rectifier R to a voltage of $+V_{max}$ with polarity as shown in the figure during the negative half cycle. As the voltage of the transformer rises to positive $+V_{max}$ during the next half cycle, the potential of the other terminal of C_1 rises to a voltage of $+2V_{max}$. Thus, the condenser C_2 in turn is charged through R_2 to $2V_{max}$.

Cascaded voltage doublers are used when larger output voltages are needed without changing the input transformer voltage level. A typical voltage doubler is shown in Figure 8b. The rectifiers R_1 and R_2 with transformer T_1 and condensers C_1 and C_2 produce an output voltage of $2V$ in the same way as described above. This circuit is duplicated and connected in series or cascade to obtain a further voltage doubling to $4V$. T is an isolating transformer to give insulation for $2V_{max}$ since the transformer T_2 is at a potential of $2V_{max}$ above the ground. The arrangement may be extended to give $6V$, $8V$, and so on by repeating further stages with suitable isolating transformers. In all the voltage doubler circuits, if valves are used, the filament transformers have to be suitably designed and insulated, as all the cathodes will not be at the same potential from ground. The arrangement becomes cumbersome if more than $4V$ is needed with cascaded steps.

Write a note on two types of Voltage multiplier circuits with supporting figures. [10] CO4 L3

Cascaded voltage multiplier circuits for higher voltages are cumbersome and require too many supply and isolating transformers. It is possible to generate very high d.c. voltages from single supply transformers by extending the simple voltage doubler circuits. This is simple and compact when the load current requirement is less than one milliampere, such as for cathode ray tubes, etc. Valve type pulse generators may be used instead of conventional a.c. supply and the circuit becomes compact A typical circuit of this form is shown in Figure 9a. A d.c. power supply of about 500 V applied to the pulse generator, is sufficient to generate a high voltage d.c. of 50 to 100 kV with suitable number of stages. The pulse frequency is high (about 500 to 1000 Hz)

Voltage multiplier circuit using the Cockcroft-Walton principle is shown in Figure 9b. For higher output voltage of 4,6,... 2n of the input voltage V the circuit is repeated with cascade or series connection. Thus, the condenser C_4 is charged to $4V_{max}$ and C_{2n} to $2nV_{max}$ above the earth potential. But the volt across any individual condenser or rectifier is only $2V_{max}$.

Figure 9(a) Cascaded rectifier unit with pulse generator, (b) Cockcroft-Walton Voltage Multiplier circuit

Course Outcomes		PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1:	Summarize the need for generating High Voltages	1	1	2	2	1	1	1	2	2	2		3
CO2:	Quote the Industrial Applications of high Voltage	2	3	2	3	2	2	1	2	1	2		2
CO3:	Classify the Insulating media and understand the properties and breakdown strength	2	3	2	3	2	3	1	2	1	2	1	2
CO4:	Explain the principle and operation of HVAC and HVDC generating circuits.	3	3	3	3	3	3	1	3	1	2		3
CO5:	Interpret origins of over voltage and protection against them.	3	3	3	3	2	3	1	3	1	2		2
CO6:	Demonstrate the Testing of electrical apparatus by high voltage application	3	3	3	3	2	2	1	2	2	3	1	3

Cognitive level	KEYWORDS
L1	List, define, tell, describe, identify, show, label, collect, examine, tabulate, quote, name, who, when, where, etc.
L2	summarize, describe, interpret, contrast, predict, associate, distinguish, estimate, differentiate, discuss, extend
L3	Apply, demonstrate, calculate, complete, illustrate, show, solve, examine, modify, relate, change, classify, experiment, discover.
L4	Analyze, separate, order, explain, connect, classify, arrange, divide, compare, select, explain, infer.
L5	Assess, decide, rank, grade, test, measure, recommend, convince, select, judge, explain, discriminate, support, conclude, compare, summarize.