Module 1

Introduction

Lesson
1
Introducing the Course on Basic Electrical

Contents

Introduction

Welcome to this course on **Basic Electrical Technology**. Engineering students of almost all disciplines has to undergo this course (name may be slightly different in different course curriculum) as a core subject in the first semester. It is needless to mention that how much we are dependent on electricity in our day to day life. A reasonable understanding on the basics of applied electricity is therefore important for every engineer.

Apart from learning d.c and a.c circuit analysis both under steady state and transient conditions, you will learn basic working principles and analysis of transformer, d.c motors and induction motor. Finally working principles of some popular and useful indicating measuring instruments are presented.

The course can be broadly divided into 3 major parts, namely: Electrical circuits, Electrical Machines and Measuring instruments. The course is spread over 10 modules covering these 3-parts, each module having two or more lessons under it as detailed below.

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Module-1 Introduction

Following are the two lessons in this module.

1.1 Introducing the course

Currently we are in this lesson which deals with the organization of the course material in the form of modules and lessons.

1.2 Generation, transmission and distribution of electric power: an overview

This lesson highlights conventional methods of generating 3-phase, 50 Hz electrical power, its transmission and distribution with the help of transmission lines and substations. It will give you a feel of a modern power system with names and function of different major components which comprise it.

Module-2 DC circuits

This module consists of seven lessons (2.1-2.7) starting with the fundamental concepts of electric circuit (active and passive) elements, circuit laws and theorems that established the basic foundation to solve dc network problems or to analyze the voltage, current and power (delivered or absorbed) in different branches. At the end of each lesson a set of problem is provided to test the readers understanding. Answers to these problems are located therein. The contents of each lesson are described below.

2.1 Introduction to electrical circuits

This lesson provides some basic concepts on Kirchoff's law, difference between linear and nonlinear circuits, and understanding the difference between current and voltage sources. The mathematical models of voltage and current sources are explained and subsequently the basic principles of voltage and current dividers are discussed. Each topic of this lesson is clearly illustrated by solving some numerical problems.

2.2 Loop Analysis of resistive circuit in the context of dc voltages and currents

In this lesson, loop analysis method based on Ohms law and Kirchoffs voltage law is presented to obtain a solution of a resistive network. This technique is particularly effective when applied to circuits containing voltage sources exclusively; however, it may be applied to circuits containing both voltage and current sources. Several numerical problems including both voltage and current sources have been considered to illustrate the steps involved in loop analysis method.

2.3 Node-voltage analysis of resistive circuit in the context of dc voltages and currents

Node voltage analysis is the most general and powerful method based on Kirchhoff's current law is introduced in this lesson for the analysis of electric circuits. The choice of one the nodes as reference node for the analysis of dc circuit is discussed. The procedure for analyzing a dc network is demonstrated by solving some resistive circuit problems.

2.4 Wye (*Y*) – Delta (∆) or Delta (∆) – Wye (*Y*) transformations

The objective of this lesson is to introduce how to convert a three terminal Delta (∆) / Wye (*Y*) network into an equivalent Wye (Y) / Delta (∆) through transformations. These are all useful techniques for determining the voltage and current levels in a complex circuit. Some typical problems are solved to familiarize with these transformations.

2.5 Superposition Theorem in the context of dc voltage and current sources acting in a resistive network

This lesson discusses a concept that is frequently called upon in the analysis of linear circuits (See 2.3). The principle of superposition is primarily a conceptual aid that can be very useful tool in simplifying the solution of circuits containing multiple independent voltage and current sources. It is usually not an efficient method. Concept of superposition theorem is illustrated by solving few circuit problems.

2.6 Thevenin's and Norton's theorems in the context of dc voltage and current sources in a resistive network

In this lesson we consider a pair of equivalent circuits, called Thevenin's and Norton's forms, containing both resistors and sources at the heart of circuit analysis. These theorems are discussed at length and highlighted their great utility in simplifying many practical circuit problems.

Reduction of linear circuits to either equivalent form is explained through solution of some circuit problems. Subsequently, the maximum power transfer to the load from the rest of circuit is also considered in this lesson using the concept of these theorems.

2.7 Analysis of dc resistive network in presence of one non-linear element

Volt-ampere characteristic of many practical elements (Carbon lamp, Tungsten lamp, Semiconductor diode, Thermistor etc.) exhibits a nonlinear characteristic and it is presented in this lesson. A common graphical procedure in case of one nonlinear element or device in a circuit is also introduced in this lesson to analyze the circuit behavior. This technique is also referred to as load line analysis method that is intuitively appealing to analyze some complex circuits. Another method based on analytic technique is described to analyze an electric circuit that contains only one nonlinear element or device. These techniques are discussed through worked out problems.

Module-3 DC transient

The study of DC transients is taken up in module-3, consisting of two lessons (3.1 and 3.2). The transients in a circuit containing energy storage elements occur when a switch is turned on or off and the behavior of voltage or a current during the transition between two distinct steady state conditions are discussed in next two lessons. At the end of each lesson some problems are given to solve and answers of these problems are located therein. The contents of each lesson are described below.

3.1 Study of DC transients in R-L and R-C circuits

This lesson is concerned to explore the solution of first order circuit that contains resistances, only single energy storage element inductance or capacitance, dc voltage and current sources, and switches. A fundamental property of inductor currents and capacitor voltages is discussed. In this lesson, the transient and steady state behavior in a circuit are studied when a switch is turned on or off. The initial condition, the steady solution and the time constant of the first order system are also discussed that uniquely determine the system behavior. The solution of differential equation restricted to second order dynamic systems for different types of forcing function are included in Appendix of this, lesson. Some problems are solved and their dynamic responses are plotted.

3.2 Study of DC transients in R-L-C circuits

The solution of second order circuit that contains resistances, inductances and capacitances, dc voltage and current sources, and switches is studied in this lesson. In this lesson, the transient and steady state behavior of a second order circuit are studied under three special cases namely, (i) over damped system (ii) critically damped system (iii) under damped system that can arise depending upon the values of circuit parameters. Some examples are solved and their dynamic responses are shown.

Module-4 Single phase AC circuits

There are six lessons (4.1-4.6) in this module, where the various aspects related to ac circuits fed from single phase supply, are described.

4.1 Generation of single phase ac and fundamental aspects

The principle of generation of sinusoidal (ac) waveforms (single phase) in an ac generator is first presented. Then, the two aspects – average and root mean square (rms) values, of alternating or periodic waveforms, such as voltage/current, are described with typical examples (sinusoidal and triangular).

4.2 Representation of sinusoidal quantities in phasor with j operator

As the phasor relations are widely used for the study of single phasor ac circuits, the phasor representation of sinusoidal quantities (voltage/current) is described, in the lesson, along with the transformation from rectangular (Cartesian) to polar form, and vice versa. Then, the phasor algebra relating the mathematical operations, involving two or more phasors (as the case may be), from addition to division, is taken up, with examples in each case, involving both the forms of phasor representations as stated.

4.3 Steady state analysis of series circuits

The steady state analysis of series (R-L-C) circuits fed from single phase ac supply is presented. Staying with each of the elements (R, L & C), the current in steady state is obtained with application of single phase ac voltage, and the phasor diagrams are also drawn in each case. The use of phasor algebra is also taken up. Then, other cases of series circuits, like R-L, R-C and R-L-C, are described, wherein, in each case, all methods as given, are used.

4.4 Analysis of parallel and series-parallel circuits

The application of phasor algebra to solve for the branch and total currents and the complex impedance, of the parallel and the series-parallel circuits fed from single phase ac supply is presented in this lesson. The phasor diagram is drawn showing all currents, and voltage drops. The application of two Kirchoff's laws in the circuits, for the currents at a node, and the voltage drops across the elements, including voltage source(s), in a loop, is shown there (phasor diagram).

4.5 Resonance in electrical circuits

The problem of resonance in the circuits fed from a variable frequency (ac) supply is discussed in this lesson. Firstly, the case of series (R-L-C) circuit is taken up, and the condition of resonance, along with maximum current and minimum impedance in the circuit, with the variation in supply frequency is determined. Then, the problem of parallel circuits and other cases, such as, lossy coil (r-L), is taken up, where the condition of resonance is found. This results in minimum current and maximum impedance here.

4.6 Concept of apparent, active and reactive power

The formula for active (average) power in a circuit fed from single phase ac supply, in terms of input voltage and current, is derived in this lesson, followed by definition of the term, ‘power factor’ in this respect. The concept of apparent and reactive power (with its sign for lagging and leading load) is presented, along with formula.

Module-5 Three phase AC circuits

There are only three lessons (5.1-5.3) in this module. Only the balanced star-and delta-connected circuits fed from three-phase ac supply are presented here.

5.1 Generation of three-phase voltage, line and phase quantities in star- and delta-connection and their relations

The generation of three-phase balanced voltages is initially presented. The balanced windings as described can be connected in star- and delta-configuration. The relation between line and phase voltages for star-connected supply is presented. Also described is the relation between phase and line currents, when the windings are connected in delta. The phasor diagrams are drawn for all cases.

5.2 Solution of three-phase balanced circuits

The load (balanced) is connected in star to a balanced three-phase ac supply. The currents in all three phases are determined, with phasor diagram drawn showing all voltages and currents. Then, the relation between phase and line currents is derived for balanced delta-connected load. The power (active) consumed in the balanced load is derived in terms of the line voltage and currents for both cases.

5.3 Measurement of three-phase power

The total power (in all three phases) is measured using two wattmeters only. This is shown for both unbalanced and balanced cases. The phasor diagram with balanced three-phase load is drawn. Other cases are also described.

Module-6 Magnetic circuits & Core losses

In this module there are two Lessons 21 and 22 as enumerated below.

6.1 Simple magnetic circuits

It is often necessary to produce a desired magnetic flux, in a magnetic material (core) having a definite geometric shape with or without air gap, with the help of current passing through a coil wrapped around the core. This lesson discusses how the concept of circuit analogy can be introduced to tackle such problems. Both linear and non-linear magnetic circuit problems are discussed through worked out problems.

6.2 Eddy current & hysteresis losses

These two losses are produced in any magnetic material which is subjected to an alternating time varying fields. Generally in all types of A.C machines /equipments working on electromagnetic principle these losses occur. In D.C machine armature too these losses occur. In this lesson the origin of these losses are explained and formula for estimating them are derived. Finally methods adopted to minimize these losses discussed as losses bring down the efficiency of any machines.

Module-7 Transformer

Transformers are one of the most important components of the modern power system. In this module having 6 lessons, various aspects of a transformer are explained and discussed as per the break up given below.

7.1 Ideal single phase transformer

Clear concept of ideal transformer goes a long way to understand the equivalent circuit representation of a practical transformer discussed in the next lesson. In ideal transformer all kinds of losses are neglected and permeability of core is assumed to be infinitely large. To have a **rough** and quick estimate of primary current for a given secondary current of a practical transformer one need not consider detail equivalent circuit but rather pretend that the transformer is ideal and apply simple relation of ideal transformer.

Properties of ideal transformer and its principle of operation along with phasor diagram are discussed both under no load and load condition.

7.2 Practical single phase transformer

A practical transformer has various losses and leakage impedance. In this lesson, it has been shown how these can be taken into account in the equivalent circuit. Phasor diagrams under no load and load condition developed. Concept of approximate equivalent circuit discussed and meaning of equivalent circuit referred to primary and secondary side are explained.

7.3 Testing, efficiency and regulation of transformer

Two basic tests called *open circuit* and *short circuit* test are discussed and then it is explained how equivalent circuit parameters of a single phase transformer can be obtained from the test data. Importance of selecting a particular side for a particular test is highlighted.

Importance of efficiency and regulation are discussed and working formula for them derived. Concept of *all day* efficiency for distribution transformer is given. Regulation is essentially a measure of change of magnitude of the secondary voltage from no load to full load condition and its value should be low. From the expression of regulation it is easily identified the parameters on which it depends.

7.4 Three phase transformer

Generation, distribution and transmission of power are carried out with a 3-phase, 50 Hz system. Therefore, stepping up or down of 3-phase voltage is required. This of course can not be done using a single phase transformer. Three separate identical transformers can be connected appropriately to serve the purpose. A 3-phase transformer formed by connecting three separate transformers is called a *bank* of 3-phase transformer. Another way of having a three phase transformer, is to construct it as a single unit of three phase transformer. The relative advantages and disadvantages of the two are discussed.

Various important and popular connections of 3-phase transformer (such as star/star, star/delta, delta/star etc.) are discussed. The importance of dot convention while making such connections are pointed out. Simple problems involving a 3-phase transformer connection are worked out assuming the transformer to be ideal.

Vector grouping of various three phase transformer connection are generally not meant for a first year course and can be avoided. However, for completeness sake and for students who want to know more, it is included.

7.5 Autotransformer

There are transformers which work with a single winding. Such transformers are called auto-transformers. The lesson discusses its construction and bring out differences with *two winding* transformer. Here, ideal auto transformer is assumed to show how to find out current distribution in different parts of the winding when it is connected in a circuit. It is also pointed out how three single phase auto transformers can be connected to transform a 3-phase voltage.

7.6 Problem solving on transformers

Few typical problems on single phase, 3-phase and auto transformers are worked out, enumerating logical steps involved.

Module-8 Three phase induction motor

In this module consisting of six lessons (8.1-8.6), the various aspects of the three-phase induction motor are presented.

8.1 Concept of rotating magnetic field

Before taking up the three-phase induction motor (IM), the concept of rotating magnetic field is introduced in this lesson. The balanced three-phase winding of the stator in IM are fed from a balanced three-phase supply. It is shown that a constant magnitude of magnetic field (flux) is produced in the air gap, which rotates at 'synchronous speed' as defined in terms of No. of poles of the stator winding and supply frequency.

8.2 Brief construction and principle of operation

Firstly, the construction of a three-phase induction motor is briefly described, with two types of rotor – squirrel cage and wound (slip-ring) one. The principle of torque production in a three-phase IM is explained in detail, with the term, 'slip' defined here.

8.3 Per phase equivalent circuit and power flow diagram

The equivalent circuit of a three-phase IM is obtained, which is explained step by step. Also the power flow diagram and the various losses taking place are discussed.

8.4 Torque-slip (speed) characteristic

The torque speed (slip) equation is obtained from the equivalent circuit of the rotor. The characteristics are drawn, with typical examples, such as variation in input (stator) voltage, and also in rotor resistance (with external resistance inserted in each phase).

8.5 Types of starters

The need of starter in a three-phase IM to reduce the stating current drawn is first explained. Then, three types of starters – Direct-on-line (DOL), star-delta one for use in an IM with a nominally delta-connected stator, and auto-transformer, are described. Lastly, the rotor resistance starter for a wound rotor (slip ring) IM is briefly presented.

8.6 Single-phase induction motor and starting methods

It is first shown that starting torque is not produced in a single phase induction motor (IM). Then, the various types of starting methods used for single-phase IM with two stator windings (main and auxiliary), are explained in detail. Lastly, the shaded pole single-phase IM is described.

Module-9 DC Machines

9.1 Constructional features of DC machines

The lesson discusses the important construction features of DC machines. The induced voltage in a rotating coil in a stationary magnetic field is always alternating in nature. The functions of commutator segments and brushes, which convert the AC voltage to DC form, are explained.

The examples of lap and wave windings used for armature are presented. It has been shown that the number of parallel paths in the armature will be different in the two types of windings. For the first time reading and depending upon the syllabus, you may avoid this portion.

9.2 Principle of operation of D.C machines

The lesson begins with an example of *single* conductor linear D.C generator and motor. It helps to develop the concept of driving force, opposing force, generated and back emf.

Concept of Driving and opposing torques in rotating machines are given first and then the principle of operation of rotating D.C generator and motor are explained. Condition for production of steady electromagnetic torque are discussed.

9.3 EMF and torque equations

The derivation of the two basic and important equations, namely emf and torque equations, which are always needed to be written, if one wants to analyse the machine performance. Irrespective of the fact that whether the machine is operating as a generator or as a motor, the same two equations can be applied. This lesson also discusses armature reaction, its ill effects and methods to minimize them.

The topic of calculation of cross magnetizing and demagnetizing mmf’s can be avoided depending upon the syllabus requirement and interest.

9.4 DC Generators

The lesson introduces the types of DC generators and their characteristics. Particular emphasis has been given to DC shunt and separately excited generators. The open circuit characteristic (O.C.C) and the load characteristics of both kinds are discussed. It is explained that from O.C.C and the field resistance line, it is possible to get graphically the load characteristic.

9.5 DC motor starting and speed control

In this important lesson, problem of starting a DC motor with full voltage is discussed, and the necessity of starter is highlighted. The operation of a three-point starter is explained. Various methods of controlling speed of DC shunt and series motors are discussed. At the end, a brief account of various methods of electrical braking is presented.

9.6 Losses, efficiency and testing of D.C machines

To calculate efficiency of any machines, it is essential to know various losses that take place in the machine. Major losses in a DC machine are first enumerated, and Swinburne's test and Hopkinson's tests are explained to estimate them.

9.7 Problem solving in DC machines

In this lesson, some typical problems of DC motors and generators are worked out. This lesson should be consulted from other relevant lectures of the present module whenever you feel it to be necessary.

Module-10 Measuring instruments

The magnitude of various electric signals can be measured with help of measuring instruments. These instruments are classified according to the quantity measured and the principle of operation. The study of DC and AC instruments for measuring voltage, current signals and subsequently induction type energy meter, are described in this module consisting of three lessons (10.1 10.3). at the end of each lesson (10.1 10.3), a set of problem is provided to test the readers understanding.

10.1 Study of DC and AC measuring instruments

The general theory of permanent magnet moving coil (PMMC), moving-iron (MI) instruments and their constructions are briefly discussed in this lesson. PMMC instruments are used as a dc ammeter or dc voltmeter where as MI instruments are basically used for ac current or voltage measurements. Various torques involved in measuring instruments are classified and explained. Subsequently, the advantages, limitations and sources of errors of these instruments are studied therein. Idea behind the multi-range ammeters and voltmeters are introduced by employing several values of shunt resistors or several multiplier resistors along with the meter resistance. In this context some problems are solved to illustrate the meaning of multi-range meters.

10.2 Study of electrodynamics type instruments

Electrodynamics meters can measure both dc signals and ac signals up to a frequency of. The basic construction of electro-dynamometer instruments and their principles of operation are studied in this lesson. Torque expressions for such instruments (as an ammeter, voltmeter and a wattmeter) are derived and then mode of meter connections to the load as an ammeter, voltmeter and a wattmeter are presented. Shunts and multipliers can be used for extension of meters range. A compensation technique is introduced to eliminate the errors in wattmeter readings. In this lesson, the constructional features and principle of operation of electro dynamometer instruments (ammeter, voltmeter and wattmeter) have been discussed. The sources of error and their corrections are highlighted. Some problems have been worked out for better understanding.

10.3 Study of single-phase induction type energy meter or watt-hour meter

The basic construction with different components of a single-phase induction type energy meter is considered in this lesson. Development of torque expression and errors in energy meters are studied. Some adjustment techniques are discussed to compensate the errors in energy meter. Finally, the extension of meter range using instrument transformers is discussed.