Unit 33: Further Electrical Principles

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Electrical technicians need to apply practical and theoretical principles of electrical engineering to the development, manufacture and servicing of complex electrical and electronic systems.

They can expect to perform technical functions involved in assembling, installing, repairing and maintaining electrical equipment. These could include the calibration, prototyping, modification and general maintenance of electrical equipment in accordance with manufacturers' instructions and company technical procedures.

Other tasks could include using electrical test equipment on various types of instruments, equipment and systems and replacing faulty components and parts using safe working practices and precision instruments.

The unit will extend learners' understanding of simple direct current (DC) circuits that can be solved by Ohm's law and Kirchhoff's laws. This will require learners to apply advanced circuit analysis theorems such as Thévenin's, Norton's and the maximum power transfer theorems for DC networks.

Learners will develop their understanding of DC transients and of series and parallel alternating current (AC) circuits. They will consider series and parallel circuits that include resistors (R), inductors (L) and capacitors (C) in AC circuits.

The unit will also introduce learners to the theory and advantages of three-phase AC systems. This will include power measurements in a three-phase AC system and the construction and principles of operation of a three-phase AC induction motor.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Be able to apply direct current (DC) circuit analysis methods and consider the types, construction and characteristics of a DC motor and generator
2. Understand the transient behaviour of resistor-capacitor (RC) and resistor-inductor (RL) DC circuits
3. Be able to apply single-phase alternating current (AC) theory
4. Be able to apply three-phase alternating current (AC) theory.

Unit content

- 1 **Be able to apply direct current (DC) circuit analysis methods and consider the types, construction and characteristics of a DC motor and generator**

  Direct current (DC) circuit theorems: Thévenin's theorem e.g. application of theorem to a parallel circuit having two sources of electromotive force (emf) and three resistors; Norton's theorem e.g. application of theorem to a parallel circuit having two sources of emf and three resistors; maximum power transfer theorem e.g. application of theorem to a series circuit with a source of EMF, internal resistance and a load resistor; application to a more complex circuit where Thévenin needs to be applied first

  Direct current (DC) motor: type e.g. shunt, series, compound; construction e.g. windings, motor starter circuits, speed control (series resistance in the armature circuit); characteristics e.g. EMF generated, torque, back emf, speed and power, efficiency

  Direct current (DC) generator: type e.g. separately-excited, shunt, series compound; construction e.g. main frame or yolk, commutator, brushes, pole pieces, armature, field windings; characteristics e.g. generated voltage/field current (open circuit characteristics), terminal voltage/load current (load characteristic), $V = E - I_a R_a$

- 2 **Understand the transient behaviour of resistor-capacitor (RC) and resistor-inductor (RL) DC circuits**

  Transient behaviour of RC circuit: variation of current and voltage with time when charging/discharging; time constant; graphical determination of growth and decay of voltage and current when charging/discharging; practical RC circuit to demonstrate transient behaviour; demonstrate the effect of the circuit time constant on a rectangular waveform e.g. integrator and differentiator circuits; calculations e.g. time constant, growth of capacitor voltage, initial and steady state values of current, decay of resistor voltage

  Transient behaviour of RL circuit: variation of current and voltage with time when connected/disconnected to a DC voltage source; time constant; graphical determination of growth and decay of current and voltage when connected/disconnected to a DC voltage source; practical RL circuit to demonstrate transient behaviour; calculations e.g. time constant, growth of current, decay of induced voltage, current decay

- 3 **Be able to apply single-phase alternating current (AC) theory**

  Series R, L and C alternating current (AC) circuits: current and phase angle in series combinations of RLC circuits (RL, RC, RLC); construction of phasor diagrams and relationship with voltage and impedance triangles for each of the three types of R, L and C combinations; power factor (cosΦ) and power triangle e.g. apparent power ($S = VI$), true or active power ($P = VI \cos\Phi$) and reactive power ($Q = VI \sin\Phi$); conditions for series resonance e.g. inductive reactance equals capacitive reactance ($X_L = X_C$); Q factor (voltage magnification) e.g.

  $$Q = V_L \qquad \square = \frac{1}{\square}\sqrt{(\frac{\square}{\square})}$$

  *a*nd its importance in high and low frequency circuits

Parallel: evaluation of the voltage, current and phase angle in parallel combinations of resistance, inductance and capacitance e.g. RL, RC, LC and RLC; construction of phasor diagrams for impedance and phase angle; conditions for parallel resonance in an RLC circuit e.g. supply current and voltage in phase; impedance at resonance e.g. dynamic resistance $R_D = \frac{□}{□□}$

Q factor (current magnification) e.g. $Q = I_C/I$; filter circuits e.g. high pass, low pass, band pass, band stop

- 4 **Be able to apply three-phase alternating current (AC) theory**

Three-phase AC theory: principles of single-phase and three-phase supplies e.g. rotation of a single coil in a magnetic field, rotation of three identical coils fixed 120° apart in a magnetic field; star and delta methods of connection for power distribution systems; three and four wire systems; voltage relationships for star and delta connections under balanced conditions of load; calculation of power in balanced and unbalanced three-phase loads, e.g. $P = \sqrt{3}.V_L I_L \cos\theta$, $P = 3I_p^2R_p$

Power measurements in a three-phase AC system: e.g. delta system – one wattmeter method, star system – two wattmeter method

Three-phase AC induction motor: construction e.g. stator, rotor, poles; principle of operation e.g. production of torque, synchronous speed, number of poles, starting methods, characteristics (speed/torque/efficiency versus current curves); concept of a rotating magnetic field e.g. application of a three-phase supply to the stator windings, flux generated by each phase of the stator winding

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 use DC circuit theorems to solve one circuit problem using Thévenin's theorem, one using Norton's theorem and one using the maximum power transfer theorem for DC networks	M1 explain the need for a DC motor starter and discuss its operation	
P2 explain the construction and characteristics of a DC motor and a DC generator		
P3 explain the transient behaviour of current and voltage in an RC circuit, verifying through calculation		
P4 explain the transient behaviour of current and voltage in an RL circuit, verifying through calculation		

P5 use single-phase AC theory to calculate the current, voltage, impedance, power and phase angle in one of each of the series combinations of R, L and C circuits		
P7 use single-phase AC theory to calculate the input current, voltage, impedance and phase angle for a parallel combination of R, L and C	M2 discuss the advantages of power factor correction in an RLC circuit for a commercial consumer, giving a practical example by reference to specific calculations	D1 analyse the effects of resonance and Q factor in both a series RLC and a parallel RLC circuit
P6 investigate the performance of two filter circuits experimentally		
P8 use three-phase theory to explain the advantages of three-phase systems and star and delta methods of connection	M3 compare two different methods of power measurement in a three-phase system for both balanced and unbalanced loads.	D2 evaluate the performance of a three-phase induction motor by reference to electrical theory.
P9 carry out a practical power measurement on a three-phase system		
P10 describe the construction, principle of operation and concept of a rotating magnetic field of a three-phase AC inductor motor.		

Essential guidance for tutors

Assessment

A good deal of the assessment evidence for this unit can be achieved by practical experimentation, with real components and circuits and/or computer-based software packages where appropriate.

Because of the nature of the learning outcomes and unit content, up to six assessment instruments may be required. If a structured programme of practical work and short tests is also used then the actual total number of pieces of assessed work could be even more than this. However, careful consideration should be given when designing the assessment not to place an unduly high assessment burden on learners or the tutor. Wherever possible, practical work should lead to a final product that can be assessed without further need for report writing.

Practical activities within the laboratory will need careful supervision. Tutors can capture this evidence by using appropriate records of observation and oral questioning for each learner.

For P1 learners will need to be able to solve circuits involving Thévenin's theorem, Norton's theorem and the maximum power transfer theorem. Before attempting this criterion, learners could be introduced to the idea of a constant voltage source and a constant current source by using a suitable practical demonstration. Further development of this could lead to the link between Thévenin and Norton and then on to the use of Thévenin, before applying the maximum power transfer theorem.

P2 involves the explanation and comparison of a motor and a generator. Learners could possibly be shown actual motors/generators and be issued with incomplete diagrams for completion and annotation.

P3 and P4 require learners to explain the transient behaviour of current and voltage in an RC and an RL circuit both practically and theoretically. Use of a simple bread-boarding technique for both criteria would be ideal here.

For both P5 and P7, an in-class assessment involving the evaluation of current, voltage, impedance and phase angle could be utilised. Learners could be given different circuit values and be encouraged to check their answers with a suitable software programme.

The investigation of the performance of two filter circuits (P6) could be achieved by using a signal generator with a low voltage output ($V_{IN} = IV$) connected to an RC network. Learners could then measure the output (V_{OUT}) as the frequency is raised from, for example, 100Hz to 10,000 Hz.

P8 requires learners to explain the advantages of three-phase systems (e.g. smaller conductors, two available voltages). The latter of these leads into the two forms of connection (star and delta). Assessment could take the form of an incomplete handout to be submitted at the end of a lecture or film about the advantages and forms of connection.

P9 requires learners to carry out practical power measurements in three-phase systems. A suitable three-phase resistance load bank together with a three-phase, four wire low voltage supply and three wattmeters could be used to enable learners to measure the power using one, two and three wattmeters for the different configurations.

Evidence for P10 is likely to be in the form of an investigative report. Again, it may be helpful to provide learners with an incomplete diagram for them to complete and annotate. For the principles of operation and concept of a rotating magnetic field of a three-phase induction motor it may be necessary to include a number of key words (e.g. synchronous speed, pairs of poles) and point to one specific type of three-phase induction motor (e.g. squirrel-cage rotor).

All except the smallest of motors require some type of starter to prevent heavy currents being drawn from the supply on starting. M1 is intended to evaluate this requirement in detail and consider the need for a DC motor starter (e.g. DC faceplate starter) and to discuss its operation. It is expected that learners will draw from the work done at pass and produce a referenced technical report, supported by a suitably labelled diagram to aid their discussion of the operation.

For M2, learners need to discuss the advantages of power factor correction in an RLC circuit for a commercial consumer, giving a practical example by reference to specific calculations. These could include reduced cost to the consumer with reference to a practical example. This could follow a practical demonstration of how the supply current reduces on the introduction of power factor correction, but can increase if over-corrected. M3 could be linked to the practical carried out for P9.

The analysis of the effects of resonance and Q factor in both a series RLC and a parallel RLC circuit (D1) builds on and could be linked to P5 and P7. Evidence for D1 could also be provided by considering the difference in resonance frequency, for example when the value of the resistance is varied.

D2 requires learners to evaluate the performance of a three-phase induction motor by reference to electrical theory, e.g. squirrel cage by reference to electrical theory. This could be achieved practically by using appropriate experimental rigs that allow the learner to compare their results with the known characteristics for specific machines.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	**Assignment title**	**Scenario**	**Assessment method**
P1, P2, M1	DC Circuit Analysis and Generators	An activity requiring learners to complete three tasks that together solve circuit problems, compare a DC motor and generator, and evaluate the performance of a three-phase induction motor.	A report containing solutions to circuit theorems and written responses about DC motor/generator and three-phase induction motor characteristics. Carried out under controlled conditions.
P3, P4	DC Transients	A written activity that requires learners to explain the transient behaviour of an RC and RL circuit with a numerical verification.	A report containing written responses about the transient behaviour of RC/RL circuits supported by numerical calculations carried out under controlled conditions.
P5, P7, M2, D1	AC Single-Phase Series And Parallel Circuits	A written activity requiring learners to carry out calculations relating to the behaviour of series and parallel R, L and C single phase AC circuits.	A report containing the results of calculations to determine specific parameters of series and parallel R, L and C single phase AC circuits carried out under controlled conditions.
P6	Filter Circuits	A practical investigation for learners to measure the response of two simple filter circuits.	A report containing written responses and graphical evidence regarding the response of simple filter circuits.

Criteria covered	Assignment title	Scenario	Assessment method
P8, P9, M3, D2	Three-phase AC Theory	A combined written and practical activity requiring learners to explain the advantages of three-phase systems, the star and delta method of connection followed by a practical power measurement with a comparison of two different methods for both balanced and unbalanced loads together with an evaluation of its performance.	A report containing written responses to the advantages of three-phase systems, an illustration of the methods of connection and measurements of the practical work carried out.
P10	Three-phase AC Induction Motor	A written activity describing the construction, operation and concept of a rotating magnetic field for a three-phase (AC) induction motor.	A report containing neat diagrams and descriptions relating to a three-phase (AC) induction motor.

Essential resources

Learners will need access to a well-equipped electrical/electronics laboratory with up to date instruments such as digital/analogue multimeters, function generators and oscilloscopes. Centres will also need to provide appropriate circuit components as identified in the unit content together with the means to physically construct circuits.

Centres are strongly advised to consider the provision of suitable hardware and software to enable the use of computer-based methods for circuit design and simulation.

Indicative reading for learners

Textbooks

Bird J O – *Electrical and Electronic Principles and Technology* (Routledge, 2013) ISBN 9780415662857

Bird J O – *Electrical Circuit Theory and Technology* (Routledge, 2013) ISBN 9780415662864

Robertson C R – *Further Electrical and Electronic Principles* (Routledge, 2008) ISBN 9780750687478