

Unit 67: Further Electrical Principles

NQF Level 3: BTEC National

Guided learning hours: 60

Unit abstract

Electrical technicians need to be able 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.

This unit will enable learners to develop advanced skills in electrical principles and will provide a firm foundation for the range of tasks expected of an electrical technician.

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.

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 Understand the behaviour of single-phase alternating current (AC) circuits
- 4 Understand 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: Thevenin's theorem eg application of theorem to a parallel circuit having two sources of electromotive force (EMF) and three resistors; Norton's theorem eg application of theorem to a parallel circuit having two sources of EMF and three resistors; maximum power transfer theorem eg 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 Thevenin needs to be applied first

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

Direct current (DC) generator: type eg separately-excited, shunt, series compound; construction eg main frame or yolk, commutator, brushes, pole pieces, armature, field windings; characteristics eg 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 eg integrator and differentiator circuits; calculations eg 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 eg time constant, growth of current, decay of induced voltage, current decay

3 Understand the behaviour of single-phase alternating current (AC) circuits

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 ($\cos \Phi$) and power triangle eg apparent power ($S = VI$), true or active power ($P = VI \cos \Phi$) and reactive power ($Q = VI \sin \Phi$); conditions for series resonance eg inductive reactance equals capacitive reactance ($X_L = X_C$); Q factor (voltage magnification) eg

$$Q = \frac{V_L}{V}, Q = \frac{1}{R} \sqrt{\frac{L}{C}}, \text{ and its importance in high and low frequency circuits}$$

Parallel: evaluation of the voltage, current and phase angle in parallel combinations of resistance, inductance and capacitance eg RL, RC, LC and RLC; construction of phasor diagrams for impedance and phase angle; conditions for parallel resonance in an RLC circuit eg supply current and voltage in phase;

impedance at resonance eg dynamic resistance $R_D = \frac{L}{CR}$; Q factor (current

magnification) eg $Q = \frac{I_C}{I}$; filter circuits eg high pass, low pass, band pass, band stop

4 Understand three-phase alternating current (AC) theory

Three-phase AC theory: principles of single-phase and three-phase supplies eg 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 eg $P = \sqrt{3} V_L I_L \cos \theta$, $P = 3 I_p^2 R_p$

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

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

Grading grid

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

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:
<p>P1 use DC circuit theorems to solve one circuit problem using Thevenin's theorem, one using Norton's theorem and one using the maximum power transfer theorem for DC networks</p> <p>P2 explain and compare the construction and characteristics of a DC motor and a DC generator</p> <p>P3 explain the transient behaviour of current and voltage in an RC circuit and verify through calculation</p> <p>P4 explain the transient behaviour of current and voltage in an RL circuit and verify through calculation</p> <p>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</p>	<p>M1 analyse the effects of resonance and Q factor in both a series RLC and a parallel RLC circuit</p> <p>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</p> <p>M3 compare two different methods of power measurement in a three-phase system for both balanced and unbalanced loads.</p>	<p>D1 review the need for a DC motor starter and discuss its operation</p> <p>D2 evaluate the performance of a three-phase induction motor by reference to electrical theory.</p>

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:
<p>P6 investigate the performance of two filter circuits experimentally</p> <p>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</p> <p>P8 use three-phase theory to explain the advantages of three-phase systems and star and delta methods of connection</p> <p>P9 carry out a practical power measurement on a three-phase system</p> <p>P10 describe the construction, principle of operation and concept of a rotating magnetic field of a three-phase AC inductor motor.</p>		

Essential guidance for tutors

Delivery

The four learning outcomes of this unit are linked and working through them in order would be the preferred method of delivery. A combination of theory lessons and demonstrations, backed up with practical work in an electrical science laboratory/workshop will help to reinforce the new concepts and theorems. Following on from other electrical units, learners will be able to appreciate the combinations of the different components within more complex circuits/networks.

Tutors should make effective use of both paper-based and computer software-based exercises (eg calculate the required value of load resistance in a parallel circuit to obtain maximum power transfer). It is important that learners are encouraged to lay out circuits practically using either computer simulation or bread boarding techniques. Effective use of both of these methods will help to corroborate theory with practice.

Tutors may need to consider learners' level of computer skills and provide further support to enable them to use computer-based software for circuit simulation.

During delivery, learners should be given the opportunity to practise all the formulae identified in the content, but do not need to memorise them. They should, however, be encouraged to select the most appropriate and correct formula for the calculation of specific values (eg the line voltage for a star connected three-phase system $V_L = \sqrt{3}V_p$).

The ability to transpose complex equations is a requirement of this unit and, overall, the mathematical skills required are clearly of a high level. Therefore the provision of additional learning support for mathematics may need to be considered.

To study this unit, it is essential that learners have sufficient background knowledge of electrical and electronic principles. If this is not the case then they will have difficulty with the advanced concepts covered.

Centres are encouraged to relate theory to real engineering applications wherever possible. Industrial visits or work experience, where appropriate, would be of value and can give learners an appreciation of the industrial applications of further electrical and electronic principles.

Note that the use of 'eg' 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 'eg' needs to be taught or assessed.

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 Thevenin'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 Thevenin and Norton and then on to the use of Thevenin, 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 breadboarding 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 (eg 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 1, 2 and 3 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 (eg synchronous speed, pairs of poles) and point to one specific type of three-phase induction motor (eg squirrel-cage rotor).

The analysis of the effects of resonance and Q factor in both a series RLC and a parallel RLC circuit (M1) builds on and could be linked to P5 and P7. Evidence for M1 could also be provided by considering the difference in resonance frequency, for example when the value of the resistance is varied.

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.

All except the smallest of motors require some type of starter to prevent heavy currents being drawn from the supply on starting. D1 is intended to review this requirement in detail and consider the need for a DC motor starter (eg DC faceplate starter) and to discuss its operation. It is expected that learners will draw from the work done at pass and merit and produce a referenced technical report, supported by a suitably labelled diagram to aid their discussion of the operation.

D2 requires learners to evaluate the performance of a three phase induction motor by reference to electrical theory, eg 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.

Links to National Occupational Standards, other BTEC units, other BTEC qualifications and other relevant units and qualifications

The unit content is designed to extend the knowledge gained in *Unit 5: Electrical and Electronic Principles*.

The unit relies heavily on strong mathematical skills involving handling formulae, problem solving and producing graphical data/result. As such it is essential that *Unit 4: Mathematics for Technicians* has been completed.

It would also be beneficial if *Unit 28: Further Mathematics for Technicians* was studied concurrently or that an equivalent level of mathematical study knowledge has been previously achieved. If not, tutors need to ensure that a suitable level of support for mathematics is provided as part of the delivery of this unit.

The unit also covers some of the knowledge and understanding associated with the SEMTA Level 3 National Occupational Standards in Electrical and Electronic Engineering, particularly:

- Unit 15: Checking the Compliance of Electronic Components Against the Specification
- Unit 17: Assembling and Wiring Electronic Equipment and Systems
- Unit 18: Testing Post-Production Electronic Components and Circuits
- Unit 21: Writing Specifications for Testing Electronic Components or Circuits
- Unit 24: Assembling Transformers and Inductors
- Unit 25: Fitting Small Transformer and Inductor Cores
- Unit 26: Assembling Rotor and Armature Windings

- Unit 27: Assembling Stator Windings
- Unit 28: Assembling and Fitting Commutators
- Unit 30: Assembling and Fitting Electrical Rotating Equipment
- Unit 31: Mounting Electrical Components in Enclosures
- Unit 32: Wiring Electrical Components and Equipment in Enclosures
- Unit 33: Selecting and Preparing Materials and Components for Electrical Assembly
- Unit 34: Carrying Out Functional Tests on Electrical Equipment.

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

Bird J O – *Electrical and Electronic Principles and Technology* (Newnes, 2004)
ISBN 0750665505

Bird J O – *Electrical Circuit Theory and Technology* (Newnes, 2003)
ISBN 0750657847

Robertson C R – *Further Electrical and Electronic Principles* (Newnes, 2001)
ISBN 0750651466

Key skills

Achievement of key skills is not a requirement of this qualification but it is encouraged. Suggestions of opportunities for the generation of Level 3 key skill evidence are given here. Tutors should check that learners have produced all the evidence required by part B of the key skills specifications when assessing this evidence. Learners may need to develop additional evidence elsewhere to fully meet the requirements of the key skills specifications.

Application of number Level 3	
When learners are:	They should be able to develop the following key skills evidence:
<ul style="list-style-type: none"> • solving problems and interpreting results in any of the four outcome areas using conventional methods and/or computer-based software packages. 	<p>N3.2 Use this information to carry out multi-stage calculations to do with:</p> <ul style="list-style-type: none"> a amounts or sizes b scales or proportion c handling statistics d using formulae. <p>N3.3 Interpret the results of your calculations, present your findings and justify your methods.</p>
Information and communication technology Level 3	
When learners are:	They should be able to develop the following key skills evidence:
<ul style="list-style-type: none"> • researching and using a variety of different sources for product/component information • developing and presenting information on electrical and electronic principles. 	<p>ICT3.1 Search for information, using different sources, and multiple search criteria in at least one case.</p> <p>ICT3.2 Enter and develop the information and derive new information.</p> <p>ICT3.3 Present combined information such as text with image, text with number, image with number.</p>

Problem solving Level 3	
When learners are:	They should be able to develop the following key skills evidence:
<ul style="list-style-type: none"> • solving problems using different DC theorems • using conventional methods and computer-based software analysis and simulation packages to explore AC circuits. 	<p>PS3.1 Explore a problem and identify different ways of tackling it.</p> <p>PS3.2 Plan and implement at least one way of solving the problem.</p> <p>PS3.3 Check if the problem has been solved and review your approach to problem solving.</p>