

Unit 62: Principles and Operation of Three-phase Systems

Unit code:	H/600/7116
QCF Level 3:	BTEC Nationals
Credit value:	10
Guided learning hours:	60

● Aim and purpose

This unit provides learners with knowledge and an understanding of electrical quantities in three-phase circuits, three-phase supply systems, three-phase balanced and unbalanced loads and three-phase power.

● Unit introduction

Three-phase systems are used to deliver the great amounts of power required to supply industrial, commercial and domestic demand. These systems can be divided into three main categories – generation, transmission and distribution.

This unit will cover the principles of the basic circuit configurations which are common to all parts of the electricity supply system. Circuits are connected in either star or delta using three wire circuits wherever possible, as four wire circuits are normally only used where division into single-phase distribution is required. The unit also covers the equipment required to protect systems against faults and the procedures used to operate systems safely and legally.

On completion of this unit, learners will have a broad understanding of the design and operation of three-phase circuits. This will include being able to read and produce simple circuit diagrams, make simple measurements and understand the principles of system operation and maintenance.

This unit provides a foundation for anyone interested in taking up a career in the electricity supply, manufacturing or processing industries. In large factories and processing plants three-phase systems are used for internal distribution.

● Learning outcomes

On completion of this unit a learner should:

- 1 Be able to use electrical relationships and determine current, voltage and power quantities for three-phase circuits
- 2 Know about the operation of three-phase supply systems
- 3 Be able to calculate parameters and carry out measurements in three-phase balanced and unbalanced loads
- 4 Know how three-phase power is protected and monitored and the safety requirements for working on high voltage equipment.

Unit content

1 Be able to use electrical relationships and determine current, voltage and power quantities for three-phase circuits

Three-phase circuit relationships: systems of connection eg 3-wire star, 4-wire star, delta; phasor diagrams

Current and voltage: star connection; delta connection; line and phase voltages; line and phase currents

Power in balanced loads: the power triangle eg real, reactive and apparent power values, relationships; real power eg single-phase equation, phase angle, power factor (PF); three-phase power eg total power relationships from phase and line currents and voltages, calculations involving phase and total power, kW, kVA and kVA values

2 Know about the operation of three-phase supply systems

Three-phase supplies: diagrammatic representation; system generation, transmission and distribution eg National Grid, schematic diagrams, operating voltages (such as 400kV, 275 kV, 132 kV, 33 kV, 11 kV, 400 V, 110 V), transformer connections (such as star-delta, star-star, delta-star)

Principle of operation of synchronous generators (alternators): calculations eg emf, voltage, leading/lagging power factor, power, efficiency; production of three-phase emfs eg distributed winding, salient pole, frequency, pole pairs, synchronous speed, phase sequence, effect of excitation; characteristics eg open circuit, v-curves

Construction of alternators: rotor eg cylindrical, salient pole; stator eg distributed windings, single layer, double layer; excitation methods eg DC exciter, AC exciter, brushless; parallel operation of generators eg conditions for synchronising onto supply system, voltage control

3 Be able to calculate parameters and carry out measurements in three-phase balanced and unbalanced loads

Circuits: calculations eg parameters (such as line and phase voltages, line and phase currents, real power, apparent power, reactive power, power factor, phase angles, 3 and 4-wire circuit currents, line, phase and neutral currents), phasor diagrams (such as sketches, scaled diagrams, determination of values); circuits eg balanced star and delta, unbalanced star and delta

Measurement of three-phase power: parameters from practical measurements eg voltage, current, real power, line and phase voltages, line, phase and neutral currents; measurement methods eg single wattmeter for 4-wire balanced circuits, three wattmeter and two wattmeter methods for unbalanced loads; equipment for practical measurements eg voltmeter, ammeter, wattmeter

4 Know how three-phase power is protected and monitored and the safety requirements for working on high voltage equipment

Faults and protection: protection equipment eg current transformers, voltage transformers, relays; protection of three-phase generators and transformers; common faults eg excess current, overvoltage, phase to phase, phase to earth; monitoring equipment eg voltmeter, ammeter, wattmeter, frequency meter, PF meter, kVAR meter, kVA meter

Supply considerations: availability of supply eg single-phase, three-phase, voltage; tariff structures eg commercial, industrial, maximum demand, metering and recording arrangements, methods and connection of power factor improvement equipment (such as capacity banks, capacitors on individual machines, synchronous motors operating on leading PF)

Safety: safety precautions when working eg warning notices, labelling, working space, earthing arrangements, interlocking arrangements, personal protective equipment, rubber mats, barriers, insulated tools, test equipment; documentation eg limitation of access, permit to work, sanction for test

Equipment, machines and systems: equipment eg switchgear, protection apparatus, monitoring apparatus; machines eg generators, transformers; systems eg transmission networks, distribution networks

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 three-phase circuit relationships to demonstrate current and voltage quantities for star and delta connections	M1 using practical examples and/or characteristics, explain how the variation of excitation of an alternator can be used to control power factor	D1 explain, using numerical examples, the need for different voltages for different parts of the generation, transmission and distribution systems
P2 determine real power and three-phase power for both star and delta connections, including the use of the power triangle	M2 explain why it is important to use the correct equipment when measuring three-phase power and the impact this would have on circuit calculations when using any of these measurements	D2 evaluate the benefits to commercial consumers and suppliers of installing power factor improvement equipment on consumers' equipment.
P3 using diagrams, describe the system of three-phase generation, transmission and distribution	M3 explain the operation of the protection system on a three-phase transmission line in the event of a given common fault.	
P4 describe the principle of operation of a synchronous generator with the aid of calculations		
P5 describe the construction of an alternator		
P6 carry out calculations relating to line and phase voltages and currents, in circuits with balanced and unbalanced three-phase loads [IE1]		
P7 measure voltages, currents and real power in circuits with balanced and unbalanced three-phase loads [IE1, SM3]		

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:
P8 describe the equipment required to protect three-phase generators and transformers against common faults and the equipment required to monitor supplies		
P9 describe the equipment and documentation required for safe working on high voltage equipment, machines and systems.		

PLTS: This summary references where applicable, in the square brackets, the elements of the personal, learning and thinking skills applicable in the pass criteria. It identifies opportunities for learners to demonstrate effective application of the referenced elements of the skills.

Key	IE – independent enquirers CT – creative thinkers	RL – reflective learners TW – team workers	SM – self-managers EP – effective participators
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Essential guidance for tutors

Delivery

This unit may be delivered as a stand-alone unit or linked with others in the qualification.

This unit should be delivered through a programme of lectures, demonstrations and practical work. Safety procedures associated with three-phase systems should be emphasised and applied throughout.

Because centres may have limited resources for the delivery of this unit, industrial visits could be used so that learners can see a wide range of three-phase circuits and equipment.

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.

Outline learning plan

The outline learning plan has been included in this unit as guidance and can be used in conjunction with the programme of suggested assignments.

The outline learning plan demonstrates one way in planning the delivery and assessment of this unit.

Topic and suggested assignments/activities and/assessment

Whole-class teaching:

- introduction to unit content, scheme of work and methods of assessment
- explain the use of three-phase circuit relationships
- explain line and phase voltages and currents
- explain power in balanced loads and demonstrate how to determine real and three-phase power for star and delta connections.

Individual learner activities:

- investigate and research numerical and phase relationships.

Whole-class teaching:

- explain three-phase generation, transmission and distribution and demonstrate diagrammatical representation
- explain principles of operation and characteristics of synchronous generators and production of three-phase emfs
- explain the construction of alternators and the parallel operation of generators.

Individual learner activities:

- investigate operation of three-phase supply systems.

Prepare for and carry out **Assignment 1: Three-phase Circuits** (P1, P2, P3, D1)

Whole class teaching:

- explain and demonstrate use of calculations to determine circuit parameters including line and phase voltages and currents
- demonstrate measurement of three-phase power using different measurement methods
- explain and demonstrate use of equipment for practical measurements on circuits.

Practical workshop activities:

- determine circuit parameters using a range of measurement methods and equipment.

Topic and suggested assignments/activities and/assessment

Prepare for and carry out **Assignment 2: Power Generation and Control** (P4, P5, P6, M1).

Whole class teaching:

- explain the use of equipment for the monitoring and protection of three-phase generators and transformers
- describe common faults that can occur in three-phase power systems
- explain the availability of power supply and different tariff structures
- explain safety precautions that should be followed when working with high-voltage equipment and correct use of relevant documentation.

Industrial visit:

- learners to view a range of high-voltage equipment and the relevant protection/monitoring equipment in an industrial setting.

Prepare for and carry out **Assignment 3: Protection and Safety Requirements for Three-phase Power** (P7, P8, P9, M2, M3, D2).

Feedback on assessment and unit evaluation.

Assessment

To achieve a pass grade, learners must demonstrate an understanding of the relationship between phase and line quantities in both star and delta connected three-phase systems. They need to carry out simple calculations and solve problems relating to star and delta connected three-phase systems.

Learners must have an understanding of three-phase generation and carry out simple calculations relating to phase and line values of voltage, current, power and power factor in star and delta connected balanced three-phase loads. They also need to demonstrate an understanding of the measurement of power in balanced three-phase loads and the safety requirements when working on high voltage equipment utilising three-phase power.

To achieve a merit grade, learners must demonstrate an understanding of the relationship between excitation of an alternator and controlling power factors. They need to understand the importance of accurate measurements and the impact this has on other calculations when some measurements are used. Learners must understand three-phase generation, transmission and distribution and explain the operation of a protection system when given a certain fault.

For a distinction grade, learners must demonstrate an understanding of three-phase generation, transmission and distribution by explaining the need for different voltages. They will also need to understand the commercial aspects of using three-phase power including tariffs and metering arrangements that impinge on the benefits to the consumer and supplier.

The unit could be assessed using three assignments.

The first assignment could be based on circuits throughout the supply system and the reasons for the choice of voltages. This could cover criteria P1, P2, P3 and D1. Exercises on numerical and phase relationships could be used to achieve P1 and P2. It is important that both line and phase voltages and currents are covered.

To achieve D1, diagrams of parts of the supply system for P3 could be coupled with explanations of the reasons for choosing different voltages. At distinction level such an exercise would require numerical evidence to be analysed to support the principles applied in selecting a voltage. Realistic or measured values should be used at all times.

To ensure authenticity of evidence, data would need to be varied for each learner. Alternatively the tasks for P1 and P2 could be carried out first in a time-controlled environment and then the rest of the assignment carried out in learners' own time.

The second assignment could cover the major aspects of power in three-phase systems and enable achievement of criteria P4, P5, P6 and M1.

The generation of power and the control of all types of power and power factor throughout the system are the main features of this assignment. Results from practical tests could be used for part or all of the work, although in this assignment the practical element is not being assessed. Simulation packages and low voltage equipment could be used for the measurements if other methods are not available.

As with the first assignment, data could be varied for each learner or these tasks could be carried out first in a time-controlled environment to ensure authenticity. As well as the requirement for carrying out calculations, the task to achieve P4 should consider the production of three-phase emfs and characteristics. A written task could then be given asking learners to describe the construction of an alternator and in doing so should include rotor, stator and excitation aspects as well as parallel operation of generators.

A further task could be given to achieve M1. The tasks for P4 and P6 could be done under controlled conditions and P5 and M1 by the learner in their own time.

The third assignment could focus on the protection of the system and the techniques of making work on high voltage systems safe. This would cover criteria P7, P8, P9, M2, M3 and D2.

To demonstrate an appreciation of the whole system learners would need to explain how and why it is important to operate at an economical power factor (D2). The consumer's equipment would be that found at the user end of the transmission and distribution networks. For this assignment a visit to a power station, sub-station or large industrial plant could provide the required background information.

A practical task needs to be set to measure voltages, current and real power (P7) and within the task there should be scope to cover measurement methods and equipment requirements. The evidence for this criterion is likely to be in the form of a witness statement/observation record supplemented by a table of results and annotated photographs.

A written task is required for P8 and P9 and further written tasks for M2 and M3. In the task for M3 a different fault could be given to each learner.

The task for P9 should ensure that equipment and documentation requirements are considered when working on all three aspects of high voltage. These should include a type of equipment, a type of machine and a type of system as listed in the content section of learning outcome 4.

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 Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, D1	Three-phase Circuits	A technician has been asked to look at a range of circuits in the supply system and determine current, voltage and power quantities.	A controlled test to determine current, voltage and power quantities plus a written explanation/ diagrams of three-phase generation, transmission and distribution including reasons for choice of different voltages.
P4, P5, P6, M1	Power Generation and Control	A technician needs to determine the operation of three-phase supply systems and line and phase voltages and currents.	A controlled test to determine operation of a synchronous generator line and phase voltages and currents, plus a written description of an alternator.
P7, P8, P9, M2, M3, D2	Protection and Safety Requirements for Three-phase Power	A technician must show a new apprentice how to measure voltages, current and real power and explain the use of relevant protection and safety equipment.	Results from practical measurement tasks supported by observation records, plus a written report.

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

This unit forms part of the BTEC Engineering sector suite. This unit has particular links with:

Level 1	Level 2	Level 3
		Electrical and Electronic Principles
		Electrical Technology

The unit can contribute skills, knowledge and understanding towards the evidence requirements of several units within the SEMTA Level 3 NVQ in Electrical and Electronic Engineering, particularly:

- Unit 1: Complying with Statutory Regulations and Organisational Safety Requirements
- Unit 34: Carrying Out Functional Tests on Electrical Equipment.

Essential resources

Centres delivering this unit must have access to industrial standard three-phase equipment and systems. Appropriate and adequate testing instruments and measurement equipment should also be provided.

A range of relevant international and British Standards and health and safety publications should be available.

Employer engagement and vocational contexts

Much of the work for this unit can be set in the context of learners' work placements or be based on case studies of local employers. Further information on employer engagement is available from the organisations listed below:

- Work Experience/Workplace learning frameworks – Centre for Education and Industry (CEI -University of Warwick) – www.warwick.ac.uk/wie/cei/
- Learning and Skills Network – www.vocationallearning.org.uk
- Network for Science, Technology, Engineering and Maths Network Ambassadors Scheme – www.stemnet.org.uk
- National Education and Business Partnership Network – www.nebpn.org
- Local, regional Business links – www.businesslink.gov.uk
- Work-based learning guidance – www.aimhighersw.ac.uk/wbl.htm

Indicative reading for learners

Textbooks

Bayliss C and Hardy B – *Transmission and Distribution Electrical Engineering* (Newnes 2006)
ISBN 0750666730

Bird J – *Electrical Circuit Theory and Technology* (Newnes, 2007) ISBN 9780750681391

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

Delivery of personal, learning and thinking skills

The table below identifies the opportunities for personal, learning and thinking skills (PLTS) that have been included within the pass assessment criteria of this unit.

Skill	When learners are ...
Independent enquirers	identifying questions to answer and problems to resolve when measuring and carrying out calculations relating to line and phase voltages and currents
Self-managers	organising time and resources and prioritising actions when carrying out circuit measurements.

Although PLTS are identified within this unit as an inherent part of the assessment criteria, there are further opportunities to develop a range of PLTS through various approaches to teaching and learning.

Skill	When learners are ...
Independent enquirers	analysing and evaluating information, judging its relevance and value when researching and investigating three-phase power systems
Reflective learners	setting goals with success criteria for their development and work.

● Functional Skills – Level 2

Skill	When learners are ...
Mathematics	
Select and apply a range of skills to find solutions	describing the principle of operation of a synchronous generator with the aid of diagrams carrying out calculations relating to line and phase voltages and currents
Draw conclusions and provide mathematical justifications	describing the principle of operation of a synchronous generator with the aid of diagrams carrying out calculations relating to line and phase voltages and currents
English	
Reading – compare, select, read and understand texts and use them to gather information, ideas, arguments and opinions	researching and investigating three-phase electrical systems
Writing – write documents, including extended writing pieces, communicating information, ideas and opinions, effectively and persuasively	describing the equipment required to protect three-phase generators and transformers against common faults describing the equipment and documentation required for safe working on high voltage equipment, machines and systems.