Unit 65: Three-phase Systems

NQF Level 3: BTEC National

Guided learning hours: 60

Unit abstract

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 give learners an understanding of electrical quantities in three-phase circuits, three-phase supply systems, three-phase balanced and unbalanced loads and three-phase power.

The 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 industry, 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 Understand the utilisation of three-phase power and the safety requirements when 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, kVAr 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 **Understand the utilisation of three-phase power and the safety requirements when 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

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:**
P1 use three-phase circuit relationships to demonstrate current and voltage quantities for star and delta connections P2 determine real power and three-phase power for both star and delta connections, including the use of the power triangle P3 using diagrams, describe the system of three-phase generation, transmission and distribution P4 with the aid of calculations, describe the principle of operation of a synchronous generator P5 describe the construction of an alternator	M1 using practical examples and/or characteristics, explain how the variation of excitation of an alternator can be used to control power factor 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 M3 explain the operation of the protection system on a three-phase transmission line in the event of a given common fault.	D1 explain, using numerical examples, the need for different voltages for different parts of the generation, transmission and distribution systems D2 evaluate the benefits to commercial consumers and suppliers of installing power factor improvement equipment on consumers' equipment.

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:**
P6 carry out calculations relating to line and phase voltages and currents, in circuits with balanced and unbalanced three-phase loads P7 measure voltages, currents and real power in circuits with balanced and unbalanced three-phase loads 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.		

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.

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 will need to carry out simple calculations and solve problems relating to star and delta connected three-phase systems.

Learners will have an understanding of three-phase generation and be able to 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 will 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 will also understand the importance of accurate measurements and the impact this has on other calculations when some measurements are used. Learners will understand three-phase generation, transmission and distribution and will be able to 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.

Diagrams of parts of the supply system for P3 could be coupled with explanations of the reasons for choice of different voltages to achieve D1. 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.

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

This unit can be linked to *Unit 5*: *Electrical and Electronic Principles*, *Unit 52*: *Electrical Technology* and *Unit 64*: *Electrical Applications*.

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 IEC, European, British Standards, health and safety and other publications should be available.

Indicative reading for learners

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

Bird J — *Electrical Circuit Theory and Technology* (Newnes, 2004) ISBN 0750657847

Patrick D and Fardo S — *Electrical Machines Power Systems* (Newnes, 1996) ISBN 0750697229

Patrick D and Fardo S — *Electrical Motor Control Systems* (Goodheart-Wilcox, 2000) ISBN 156637703X

Robertson C R — *Electrical and Electronic Principles - Vol 2* (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.

Communication Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• describing the construction of an alternator • 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.	C3.3 Write **two** different types of documents each one giving different information about complex subjects. One document must be at least 1000 words long.