Unit 63: Three-Phase Motors and Drives

Unit code: K/600/7117

QCF Level 3: BTEC Nationals

Credit value: 10

Guided learning hours: 60

Aim and purpose

This unit aims to give learners knowledge of three-phase electric motors that are used in modern industry and their associated drives.

Unit introduction

Three-phase motors are used where greater amounts of power are required and single-phase motors would not be effective. A good example of this is a large compressor where a constant speed is required. The two main advantages of three-phase types over single-phase types are the smoother torque they provide and a higher power to weight ratio, giving smaller frame sizes for comparable power outputs.

This unit will develop learners' knowledge of the design and operation of three-phase motors which use electrical and electronic control devices to make them work. This will include being able to read and produce simple circuit diagrams and understand the principles of installation, commissioning and maintenance. Learners will be made aware of the requirements of a drive and the need for the motor and drive to be matched to the characteristics of the application.

The unit will provide a good foundation for anyone interested in taking up a career in the manufacturing or processing industry, particularly where large motor drives are involved.

Learning outcomes

On completion of this unit a learner should:

1 Know how squirrel-cage and wound rotor three-phase induction motors operate

2 Know how three-phase synchronous and synchronous-induction motors operate

3 Know about the function and operation of motor starters and control gear

4 Know about a range of industrial applications for installing, commissioning and maintaining three-phase motors.

Unit content

1 Know how squirrel-cage and wound rotor three-phase induction motors operate

Principle of operation: production of rotating magnetic field eg distributed winding, salient pole, frequency, pole pairs, synchronous speed, rotor speed; induction motor types eg squirrel cage, wound rotor (slip ring)

Constructional features: cores eg stator, rotor, laminations, spiders, materials; frame eg cast, fabricated, end covers, materials; rotor eg squirrel cage, wound type; stator eg distributed windings, single layer, double layer; enclosure eg cooling/ventilation, open, totally enclosed, drip proof, flameproof; shaft and fittings eg bearings, slip rings, brushes, brush lifting gear enclosure ratings eg Ingress Protection, BS 490, BS 5345

Characteristics and calculations: characteristics eg frequency, poles, speed/load, torque/speed, torque/slip; calculations eg speed, slip, starting current, load, torque, power, efficiency

2 Know how three-phase synchronous and synchronous-induction motors operate

Principle of operation: production of rotating magnetic field eg distributed winding, salient pole, frequency, pole pairs, synchronous speed, effect of excitation; synchronous motor types eg pony motor, synchronous-induction motor, synchronising; characteristics eg open circuit, v-curves; reasons for calculations eg speed, torque, leading/lagging power factor, power, efficiency

Constructional features: rotor eg cylindrical, salient pole; stator eg distributed windings, single layer, double layer; excitation methods eg DC exciter, AC exciter, brushless

3 Know about the function and operation of motor starters and control gear

Starters: circuit diagrams and operation of induction motor types eg direct on line (DOL), star-delta, auto-transformer, soft start, rotor resistance; circuit diagrams and operation of synchronous motor types eg pony motor, synchronous-induction motor, synchronising; effects of reduced voltage starting eg current, starting torque; protection devices eg short circuit, earth leakage, overload, interlocks, trips

Control gear: speed control eg variable frequency, inverters, pulse width modulation (PWM); motor drives eg DC transistor/thyristor, inverter types, braking, soft starting; programmable logic controllers eg simple ladder logic

4 Know about a range of industrial applications for installing, commissioning and maintaining three-phase motors

Load characteristics: load characteristics and demands of machinery eg centrifugal fans and pumps, compressors, machine tools, mechanical handlers, plastic extruders, lifts, hoists, conveyors

Ratings and calculations: electrical parameters eg power, KVA, KVAr, power factor, voltage, current; mechanical parameters eg power, speed, slip, torque, efficiency, gear ratios, volume, pressure, flow

Installation, commissioning and maintaining: installation procedures eg foundations, mountings, insulation checks, rotation, couplings; commissioning procedures eg starting, running, load test, temperature monitoring; maintenance procedures eg rotor/bearing checks, lubrication, brushes, brushgear, control gear, insulation tests

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 describe the principle of operation and the constructional features of a three-phase squirrel cage and a three-phase wound rotor (slip ring) induction motor	**M1** explain the production of a rotating magnetic field from a three-phase supply suitable for three-phase induction motors	**D1** explain the selection of a three-phase motor and its drive for a given application using calculations involving electrical and mechanical parameters
P2 carry out calculations involving frequency, poles, speed, torque, power and efficiency for a three-phase induction motor from given data [IE1]	**M2** explain the variation of torque and slip for a three-phase induction motor using values from given data	**D2** evaluate the speed control methods used for three-phase induction motors and explain the effects of changing speed on torque/slip characteristics.
P3 describe the principle of operation, constructional features and excitation methods of a three-phase synchronous motor	**M3** explain the methods of starting a three-phase synchronous motor and the effects of variation of excitation with reference to the v-curve characteristics.	
P4 describe, with the aid of suitable circuit diagrams, the operation of two different reduced voltage starters for induction motors, one starting method for a synchronous motor, and a protection device for use with a three-phase induction motor		
P5 describe the control gear required for a three-phase induction motor and a three-phase synchronous motor		
P6 describe the characteristics of typical loads for four types of machinery driven by three-phase motors		

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:**
P7	select a suitable three-phase motor for a given application giving details of ratings, starter types and control gear requirements [IE1]		
P8	describe the installation, commissioning and maintenance procedures for a three-phase motor.		

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	RL – reflective learners	SM – self-managers
	CT – creative thinkers	TW – team workers	EP – effective participators

Essential guidance for tutors

Delivery

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

Learning outcomes 1 and 2 will give learners an understanding of the characteristics and features of induction and synchronous motors. Delivery of these learning outcomes could be through a programme of lectures, demonstrations and practical investigations. There are some common features which can be covered in general at the beginning of the unit, eg the distributed three-phase winding and the production of the rotating magnetic field.

The constructional features of different types of motor would ideally be demonstrated through inspection of stripped-down examples. The types of motor used throughout the unit should be normal production types in preference to specially manufactured demonstration types. The voltage rating of the supplies used should be 400V 50Hz, although it is appreciated that local requirements and availability of equipment may dictate the use of different values. Although simulation and computer packages can be used to demonstrate some features and characteristics, these methods should not be used to deliver the whole unit.

When delivering starters and control gear in learning outcome 3, learners should see practical examples of as many types as possible. They should have opportunities to connect them to the appropriate motor, helping them know about their function and appropriate selection. The starting and synchronising of three-phase synchronous motors may prove difficult to demonstrate. Where this and other features cannot be demonstrated in the centre, efforts should be made to arrange industrial visits so that learners can see the appropriate equipment.

Learning outcome 4 could also be partly delivered in local industry. The coverage of load characteristics, installation, commissioning, maintenance, ratings and calculations should be supported by manufacturers' and suppliers' literature wherever possible.

Manufacturers' manuals that relate to all aspects of the unit content will be of tremendous help and should be freely available to learners.

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 distributed three-phase winding and the production of the rotating magnetic field • describe the operating principles and construction of squirrel cage and wound rotor induction motors. *Practical demonstration/workshop investigation:* • tutor-led inspection of a range of stripped-down induction motors. *Whole class teaching:* • explain use of calculations to determine induction motor characteristics.
Prepare for and carry out **Assignment 1: Induction Motors** (P1, P2, M1, M2).

Topic and suggested assignments/activities and/assessment
Whole-class teaching: • describe the operating principles and construction of three-phase synchronous and synchronous-induction motors • explain use of calculations to determine synchronous motor characteristics. *Practical demonstration/workshop investigation:* • tutor-led inspection of a range of stripped-down synchronous motors.
Prepare for and carry out **Assignment 2: Synchronous Motors** (P3, M3).
Whole-class teaching: • using circuit diagrams, describe the function and operation of a range of motor starters and related protection devices • explain the function and operation of a speed control devices, motor drives and programmable logic controllers. *Practical demonstration/workshop investigation:* • tutor-led practical investigation of starters and control gear and their connection to relevant motors. *Industrial visit:* • learners to view motors and the related starters and control gear.
Prepare for and carry out **Assignment 3: Starters and Control Gear** (P4, P5).
Whole-class teaching: • explain the load characteristics and demands of a range of different machinery driven by three-phase motors • explain the ratings for a range of different three-phase motors • describe installation, commissioning and maintenance procedures for three-phase motors. *Industrial visits:* • a series of visits to view installation, commissioning and maintenance of three-phase motors in an industrial setting.
Prepare for and carry out **Assignment 4: Applications of Three-phase Motors** (P6, P7, P8, D1, D2).
Feedback on assessment and unit evaluation.

Assessment

This unit could be assessed through the use of four assignments.

The first assignment could be about induction motors and cover criteria P1, P2, M1 and M2. A written task should be given to cover P1. Learners will need to consider the production of the rotating magnetic field when describing the principle of operation. They will also need to consider cores, frame, rotor, stator, enclosure and shaft and fittings when describing the constructional features.

Learners should be given data to use when carrying out the calculations required by P2. This data could be varied for each learner to aid authenticity, or the task could be time-constrained. A further task should be set asking them to explain the production of a rotating magnetic field and the variation of torque and slip using given values to achieve criteria M1 and M2 respectively. Learners' evidence will be written and will include their calculations.

The second assignment could cover synchronous motors and cover criteria P3 and M3. A written task could cover the construction, operation and excitation of synchronous motors. A practical exercise or demonstration could be done for starting and variation of excitation. From this information, learners can formulate relevant descriptions and explanations. Starting voltage, current and torque are useful parameters to be measured.

A third assignment on starting and control could cover criteria P4 and P5. While a written task could be used to cover both criteria, it would be more interesting for learners if they could operate starters and drives and take appropriate measurements. Description of the control gear could be as a result of stripping down or opening up starters, drives and other control gear. In doing so it is important that learners also consider the effects of reduced voltage such as current and starting torque.

The fourth assignment on applications could cover criteria P6, P7, P8, D1 and D2. Tasks should require learners to refer to details of typical loads and machinery to be driven (P6). Learners must then consider the types of motor and control gear appropriate for driving different loads and select and describe the features (P7). For D1 choices need to be supported by detailed calculations, with relevant explanations of some depth using calculated parameters. The evaluation of speed control (D2) must be linked to the torque/slip characteristics and include details of more than one method, eg thyristor drives and inverter drives. A further written task could ask learners to describe the installation, commissioning and maintenance procedures for a three-phase motor (P8).

Manufacturers' literature and specifications are a useful source of practical information for the above tasks.

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, M1, M2	Induction Motors	A technician needs to strip-down, inspect and report on the operation of induction motors.	A report including a set of written descriptions, the results of calculations and an explanation of the production of a rotating magnetic field and the variation of torque and slip.
P3, M3	Synchronous Motors	A technician needs to strip-down, inspect and report on the operation of synchronous motors.	A written report, including descriptions based on practical demonstration of excitation methods.
P4, P5	Starters and Control Gear	A technician needs to show a new apprentice the operation of starters and control gear.	A written report.
P6, P7, P8, D1, D2	Applications of Three-phase Motors	A technician has been asked to produce a report on the three-phase motors used in an industrial application in their workplace.	A written report based on a practical investigation or case study of local industrial applications.

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
		Features and Applications of Electrical Machines

This unit can contribute to the knowledge requirements of some of the units within the Level 3 NVQ in Electrical and Electronic Engineering, particularly:

- Unit 26: Assembling Rotor and Armature Windings
- Unit 27: Assembling Stator Windings endeavours
- Unit 28: Assembling and Fitting Commutators
- Unit 29: Balancing Assembled Rotors or Armatures
- Unit 30: Assembling and Fitting Electrical Rotating Equipment.

Essential resources

Centres delivering this unit must have access to industrial standard three-phase electric motors, starting/control gear and associated drives. In addition, appropriate and adequate testing instruments and fault-finding assemblies should be provided. European and British Standards, health and safety and other publications should also 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

Hughes A – *Electric Motors and Drives: Fundamentals, Types and Applications* (Newnes, 2005) ISBN 0750647183

Petruzella, F – *Electric Motors and Control Systems* (McGraw-Hill Education, 2009) ISBN 9780073521824

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 carrying out calculations involving frequency, poles, speed, torque, power and efficiency.

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 ...
Reflective learners	setting goals with success criteria for their development and work.

Functional Skills – Level 2

Skill	When learners are ...
Mathematics	
Identify the situation or problem and the mathematical methods needed to tackle it	carry out calculations involving frequency, poles, speed, torque, power and efficiency
Select and apply a range of skills to find solutions	carry out calculations involving frequency, poles, speed, torque, power and efficiency
English	
Reading – compare, select, read and understand texts and use them to gather information, ideas, arguments and opinions	investigating and researching three-phase motors and drives
Writing – write documents, including extended writing pieces, communicating information, ideas and opinions, effectively and persuasively	describing the principle of operation and the constructional features of motors describing the principle of operation, constructional features and excitation methods of a motor describing the control gear required for a three-phase induction motor and a three-phase synchronous motor describing the installation, commissioning and maintenance procedures for a motor.