Unit 16: Three-Phase Electrical Systems

Delivery guidance

Approaching the unit

Three-phase is, by its nature, a hazardous system involving higher voltages than those normally experienced by learners (eg 230V, 50V, 24V). It can also be a difficult concept for learners to grasp - why there are three line conductors supplying a load but only one (or no) neutral. This unit explores the principles behind the generation of three-phase and its uses. Transmission and distribution of electricity is in the three-phase format, and at varying voltages, from the 25kV at the power station up to 275kV or 400kV for transmission and 33kV or 11kV for distribution. Describe the local distribution transformer to learners, particularly in terms of its delta primary and star secondary winding configurations and how single-phase domestic installations are fed from the three-phase supply.

This unit examines the relationships between voltage, current and power within a three-phase system. It looks at line and phase voltages and currents, and the relationships between them. Much of this is theoretical and can be explored through a mix of classroom lectures and personal research by the learner.

Measurement of three-phase systems, both balanced and unbalanced, as well as line and phase voltage and current will require a live test rig of some description. Safety during these experiments and measurement activities is of the utmost importance due to the higher voltages present.

The effects of reactive load, for example in an industrial installation, are to be explored and the components of the reactive circuit, X_L, Xc, R and Z require calculation. Power factor and its correction form part of the assessment for this unit, in terms of power consumption and costs. Learners will need access to tariffs and charges levied by supply companies.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Learning aim A deals with the generation of electrical supply and the basic construction of a transmission grid or network. Examine the components of the three-phase synchronous generator. If there is an example available, this will of course be advantageous. Diagrams and technical data sheets will also be useful support. Carry out calculations of synchronous speed and frequency. The transmission and distribution, and the voltages in each part of this network, can form the basis of a learner-led research exercise. Include a diagram showing the grid and its component parts.

Explain the conversion of three-phase to single-phase for domestic installations in terms of the delta primary and star secondary of the local distribution transformer. These transformers are not generally accessible to the public, but an awareness of the location of the local distribution transformer would be useful for the learners to establish. It is worth contacting your local supply company to see if they would arrange access to a transformer compound. The supply company can certainly supply other useful information relevant to the unit.

The actual three-phase system and its features and values are examined in learning aim B. Calculations will include the relationships between line and phase voltages and currents in both star and delta systems, as well as reactive and capacitive inductance, resistance and impedance. Explore the effect of balanced and unbalanced loads in terms of current and power. A test rig would give a means of measuring these effects. The rig should feature a set of balanced, but individually switchable, loads. Supplying highly inductive discharge lighting from the rig, and introducing switchable capacitors into their circuits, makes possible the demonstration of the effects of power factor on power consumption and cost (as required in learning aim C).

Learning aim C is broken down into research, design and problem-solving. Your learners can carry out research to establish the tariffs and costs levied by two different supply companies. It may be a good idea to contact a number of these companies ahead of the learning delivery to establish that they are willing to give the information needed by the learner. Your learners can analyse various quotes from supply companies, and compare and prepare breakdowns of the costs. A 'real-life' installation would give structure to the assessment of the learning aim. Calculation of maximum demand is another learning aim requirement. The said 'real-life' installation would be an ideal subject for this calculation, and subsequent diversity decisions.

Power factor correction is an essential part of cost effective electrical supply within an industrial installation, which will consist of highly inducting loads such as discharge lighting and electrical machines. The learning aim B test rig can give the means for measuring and proving the effect of power factor.

Learning aim	Key content areas	Recommended assessment approach
A Examine the construction and operation of a national grid, which safely connects power stations and substations to supply electricity	**A1** Construction and operation of synchronous generators **A2** Transmission and distribution networks **A3** Safety considerations on high-voltage transmission systems	A written report examining the infrastructure of the national grid (or similar), to include generation transmission, distribution and protection.
B Explore the operation of three-phase power circuits which form the majority of electrical infrastructures globally	**B1** Connection methods for three-phase power circuits **B2** Electrical calculations for three-phase power circuits **B3** Electrical measurements for three-phase power circuits	An experimental report based on physical measurements and theoretical calculations, exploring the relationship between currents voltages and powers in three-phase power circuits.
C Investigate the cost of using three-phase electrical power systems in typical industrial applications	**C1** Supply considerations **C2** The cost of using electricity	A written report investigating the cost of using electricity, including tariff structures and power factor correction.

Assessment guidance

The recommended assessment method for learning aim A is a report that examines the national grid infrastructure. This report needs to show how power is generated and the voltages present in various parts of the network. The generator and its components should be described. Calculation showing synchronous speed and frequency should be present. Research tools such as textbooks and internet availability will be needed. Contact with a generating company may well prove a useful source of information.

An experimental report based on physical measurements and theoretical calculation is the suggested assessment approach for learning aim B. The values in a three-phase system are to be explored and calculated. A test rig should be available for the learner to carry out experiments and measurements. The rig will be a means to prove the theoretical assumptions, particularly in the realms of load balancing, and line and phase voltage and current.

A subject installation would be invaluable for completion of learning aim C. This could be part of the training centre or college, or it could be a workplace attended by the learners during the rest of their week, or an installation created as a subject for the research. Tariff and costs for electricity consumption need to be calculated and analysed. Learners should explain power factor and its correction, and the effects of uncorrected and corrected circuits on power consumption and cost. It may be helpful to visit an industrial installation to research the supply and power factor correction system installed.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 16: Three-Phase Electrical Systems

Introduction

Structured differently from the traditional circuit, the three-phase supply can be a confusing concept for your learners to grasp. In the three-phase system, there are three line conductors, which not only carry voltage and current separately but are also linked to one another in a relationship created at the generator and used to power three-phase machines. The absence of a neutral in the network side of electrical supply, as well in the supply to three-phase motors, is a further confusing aspect of this type of system. Even learners who may be working in the electrical industry may not have a full grasp of the principles behind three-phase supplies and systems. Three- phase needs to be fully explained and you need to be certain that your learners have grasped its principles before moving on.

Much of this subject is inevitably theoretical, so to prevent its delivery as a series of dry lectures give thought to exercises, both academic and practical, to add variety and to aid comprehension of the subject. Take great care with any practical tasks related to this unit because three-phase is extremely hazardous and therefore should be treated with respect.

Learning aim A – Examine the construction and operation of a national grid, which safely connects power stations and substations to supply electricity

- Start at the generator. Understanding the operation and principles of the three-phase generator will help make the relationship between the phases clear to your learners. Once the principles of its generation are established, move onto transmission and distribution of this electrical supply from the power station to the user. Emphasise that power is transmitted and distributed as a three-phasesupply. There is no neutral. Power distribution begins at the power station, is transmitted nationally via a transmission network then distributed to local transformers. This gives scope for a learner-led research project – the extent, make-up and components of the grid. The learners can research the various voltages and its hierarchy from the transmission grid to local supply. They can produce a block or family tree type diagram, which shows the elements, and voltages that make up the network. The learners will need to be able to describe individual components, such as HV switching, arc suppression and other safety devices.
- Your learners will research the safe operation and testing of HV systems. They will find information in the relevant regulatory documentation. Encourage the learners to contact supply company technical representatives. They will have knowledge of national and local HV procedures. The learners can also investigate the training necessary for those carrying out HV work.
- The key to distribution is the local transformer, which converts an incoming supply of 33kV or 11kV to 400V. The transformer has delta-wound primary and star-wound secondary windings. Neutral is created at the star point. A visit to a local transformer compound would be beneficial. Entry into the compound would be even better, however, access being granted is unlikely due to the stringent safety procedures surrounding high voltage systems. It is worth contacting the supply company, because it may result in information, a visit by a technical expert or access to the compound. Ask your learners to locate their own local transformer.

- This leads onto:
  - supply of single-phase to domestic installation from the three-phase mains
  - three-phase load balancing
  - calculation of line and phase voltage and current.
- The learner could gather these elements together into a report, written in a coherent and informative style. An accompanying presentation would act both as a summary and as reinforcement of the main principles of three-phase generation and distribution.

Learning aim B – Explore the operation of three-phase power circuits which form the majority of electrical infrastructures globally

- Three-phase is a form of AC supply, and as such, subject to reactance, capacitance, resistance, impedance and their subsequent effect on power. These effects can form the basis of the learner's experimental report for assessment. If your learners have already studied these effects as part of other units, then a minimum of teaching will be required. If they are not familiar with them, then basic grounding on the subject will be necessary. Calculations will reinforce the elements of this subject.
- Use an oscilloscope to:
  - show a 'live' representation of the three-phase sine wave
  - demonstrate the relationships between current and voltage in inductive, capacitive and resistive circuits.
- You must also ensure that learners can explain the following:
  - R, X and Z
  - kVa, kW and kVAr
  - power factor.
- Load balancing is vital where the circuits in an installation are supplied by both three and single-phase supplies. Your learners must be able to describe the need for load balancing, particularly in terms of third harmonics (neutral current). Encourage your learners to contact an electricity supply company. The technical department of a supply company will have information on the effects of an unbalanced supply.
- Make a test rig available to prove the effects of unbalanced loads in a three-phase system. This rig needs to give a safe means of taking voltage current and power readings. A set of separately switched lamps, evenly distributed across the phases will give a simple method of putting the system in and out of balance. The rig should also give a method for measuring line and phase voltage and currents.
- Your learners can then record and comment on the results of these measurements.

Learning aim C – Investigate the cost of using three-phase electrical power systems in typical industrial applications

- There are three main elements to this learning aim. These are:
  - maximum demand
  - power factor correction
  - costs of electrical supply.
- Define maximum demand – the absolute maximum amount of current used by an installation. Get your learners to calculate it for your department of your training

establishment (or their own workplace). Are the main fuses or other protective devices of a sufficient rating for the installation? Your learners can now calculate diversity, by referring to the diversity allowances such as those stated in the IET On-Site Guide.

- Your learners can also find out which supply company supplies power to their subject installation and the tariffs imposed by that company. What other tariffs are available? Your learners can obtain quotes. Draw up an analysis comparing the quotes and making recommendations. The analysis can also show the make-up of the quote. Which part of it is payment for actual power used and which is a standard charge? Are there cheaper rates at certain times of the day?
- Power factor has a significant effect on power consumption, particularly where an installation's loads are highly inductive (eg a factory or workshop full of electrical machines and illuminated by discharge lamps). Learning aim B includes the suggestion for a three-phase test rig. If the lamps supplied by the rig are a high- inductance, discharge type, installing switched capacitors in the circuits will give a means of proving the effect of capacitance on power.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC International Level 3 Qualifications in Engineering:

- *Unit 1: Mechanical Principles*
- *Unit 15: Electrical Machines*
- *Unit 18: Electrical Power Distribution and Transmission*
- *Unit 57: Electrical and Electronic Principles*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC International Level 3 Qualifications in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Grimwood T and Jeffery A – *Level 2 and 3 Diploma in Electrical Installations (Buildings and Structures)* (Pearson Education, 2013) ISBN 9781447940258.
  Gives a thorough grounding in all electrical principles and processes, with a comprehensive chapter on electrical science.
- *IET On-Site Guide (BS 7671:2008+A3:2015): Incorporating Amendment No. 3 (Electrical Regulations)*, Institution of Engineering and Technology, ISBN 9781849198875.
  A practical application of the IET Wiring Regulations. Includes an appendix showing diversity allowances for various installation types.