SQA Advanced Unit Specification

General information for centres

Unit title: Transformers

Unit code: HV4X 48

Unit purpose: This unit is designed to enable candidates to develop knowledge and the required level of understanding of the principles of transformers used in the power industry. The unit provides the study paths through the transformer subject area ranging from ideal transformers together with practical or less-than-ideal transformers operation, three-phase transformers and protection. This unit also gives candidates the opportunity to develop the necessary knowledge and mathematical skills in solving transformer equivalent circuits.

On completion of the unit the candidate should be able to:

1. explain the construction characteristics of transformers
2. analyse the operation of single-phase transformers on load
3. analyse the operation of three-phase transformers
4. explain transformer protection

Credit points and level: 1 SQA Advanced Credit at SCQF level 8: (8 SCQF credit points at SCQF level 8*)

**SCQF credit points are used to allocate credit to qualifications in the Scottish Credit and Qualifications Framework (SCQF). Each qualification in the Framework is allocated a number of SCQF credit points at an SCQF level. There are 12 SCQF levels, ranging from National 1 to Doctorates.*

Recommended prior knowledge and skills: Candidates should possess a broad knowledge and understanding of electrical principles, electromagnetic theory, power supply systems and complex number notation. This may be evidenced by possession of the following SQA Advanced Units: HP46 47 DC and AC Principles, HT7K 47 Three Phase systems, HT83 47 Electrical Machine Principles, HV3L 47 Electricity Power Systems, and HP48 46 Engineering Mathematics 1. However, entry requirements are at the discretion of the centre.

Core skills: there may be opportunities to gather evidence towards the following core skills or core skills components in this unit, although there is no automatic certification of core skills or core skills components:

- Written Communication (reading) at SCQF level 6
- Numeracy at SCQF level 6
- Critical Thinking at SCQF level 6

Context for delivery: This unit has been developed for the SQA Advanced Diploma in Electrical Engineering. If this unit is used in another group award it is recommended that it should be taught and assessed within the subject area of the group award to which it contributes.

Assessment: Assessment for this unit should comprise:

- a laboratory exercise or case study; and
- a written assessment paper

Knowledge and or skills item 3 in Outcome 2 should be assessed by means of a laboratory exercise or case study in which candidates are required to calculate transformer equivalent circuit parameters from open and short-circuit test results. This assessment should be conducted under controlled, supervised conditions. Candidates should be allowed access to relevant course notes. The time that should be allocated for this assessment task is one hour. This assessment should be carried out at a suitable time during the delivery of the unit.

The assessment for the remaining knowledge/skills items in Outcome 2, and all of Outcomes 1, 3 and 4 should be combined together into one written assessment paper. This paper should be taken by candidates at one single assessment event that should last two hours. The assessment paper should be composed of a suitable balance of short answer, restricted response and structured questions. This assessment should be carried out at the end of the delivery of the unit and be conducted under closed-book, controlled, supervised conditions.

SQA Advanced Unit Specification: statement of standards

Unit title: Transformers

The sections of the unit stating the outcomes, knowledge and/or skills, and evidence requirements are mandatory.

Where evidence for outcomes is assessed on a sample basis, the whole of the content listed in the knowledge and/or skills section must be taught and available for assessment. Candidates should not know in advance the items on which they will be assessed and different items should be sampled on each assessment occasion.

Outcome 1

Explain the construction characteristics of transformers

Knowledge and/or skills

- Transformer core type construction
- B/H curves
- Eddy current losses within the core
- Applied voltage and induced voltage
- Production of harmonics

Outcome 2

Analyse the operation of single-phase transformers on load

Knowledge and/or skills

- Full transformer equivalent circuit and simplified equivalent circuit
- Calculation of equivalent resistance and reactance
- Open and short-circuit tests
- Calculation of the transformer efficiency for full load, half load and different power factors
- Voltage regulation
- Parallel operation of single-phase transformers

Outcome 3

Analyse the operation of three-phase transformers

Knowledge and/or skills

- Transformer winding connections, vector diagrams, vector symbols and phase displacements
- Conditions for parallel operation of three phase transformers
- Tap changing
- Transformer cooling classifications
- Winding temperature indication and control

Outcome 4

Explain transformer protection

Knowledge and/or skills

- Effects of short-circuit faults
- Gas-oil actuated (Buchholz) relay
- Circuit breakers
- Surge protection

Evidence requirements

Evidence for the knowledge and /or skills in Outcomes 1 to 4 will be provided on a sample basis. The evidence may be presented in responses to specific questions. Each candidate will need to demonstrate that she/he can answer correctly questions based on a sample of the items shown under the knowledge and skills items in the outcomes.

In any assessment of the outcomes **three out of five** knowledge and/or skills items should be sampled from Outcome 1, **four out of six** knowledge and/or skills items from Outcome 2 (one of which must be knowledge/skills item 3 which is assessed separately by means of a laboratory exercise or case study.), **three out of five** knowledge and/or skills items from Outcome 3 and **two out of four** knowledge and/or skills items from Outcome 4.

In order to ensure that candidates will not be able to foresee what items they will be questioned on, a different sample of three out of five knowledge and/or skills items from Outcome 1, four out of six knowledge and/or skills items from Outcome 2 (one of which must be knowledge/skills item 3 which is assessed separately by means of a laboratory exercise or case study), three out of five knowledge and/or skills items from Outcome 3 and two out of four knowledge and/or skills items from Outcome 4 is required each time the unit is assessed. Candidates must provide a satisfactory response to all items.

Where sampling takes place, a candidate's response can be judged to be satisfactory where evidence provided is sufficient to meet the requirements for each item by showing that the candidate is able to:

Outcome 1: Explain the construction characteristics of transformers

- describe, with the aid of sketches, transformer core type construction for both single and three-phase units
- draw and explain the b/h curves for two types of magnetic core materials, and conclude the magnetising characteristics, hard and soft, from the data provided
- explain the production of eddy current losses within the core, and the constructional features that reduce them
- calculate applied voltage and induced voltage
- explain how harmonics components are generated in a transformer

Outcome 2: Analyse the operation of single-phase transformers on load

- draw and label both the full equivalent circuit and the simplified equivalent transformer circuit
- calculate equivalent resistance and reactance
- calculate equivalent circuit parameters from open and short-circuit test results
- calculate transformer efficiency for full load and half load, each with different power factors
- explain and calculate the percentage voltage regulation of a transformer
- describe how two single-phase transformers can be connected in parallel, and calculate percentage loading on each unit

Outcome 3: Analyse the operation of three-phase transformers

- complete a table showing winding connections, vector diagrams, vector symbols and phase displacements for transformers in each of the four connection groups
- state the essential and desirable conditions for connecting three-phase transformers in parallel, and the possible consequences of not complying with these conditions
- describe off-load and on-load tap changing methods
- describe two of the following transformer cooling classifications: ONAN, ONAF, OFAF, OFAN, and OFWF
- explain the operation of a winding temperature control system

Outcome 4: Explain transformer protection

- explain the effects of short-circuit currents on mechanical stresses in the transformer
- explain the operation of the gas-oil actuated (Buchholz) relay and state examples of three faults that this relay could detect
- escribe the operation of one of the following types of circuit breaker: sulphur hexafluoride (SF_6), vacuum, air or oil
- explain the operation and application of surge protection used for transformers connected to overhead lines

Evidence for knowledge and/or skills item 3 in Outcome 2 should be generated in response to a laboratory exercise or case study. This should be undertaken in controlled, supervised conditions, and candidates should be allowed access to relevant course notes.

Evidence for the remaining knowledge/skills items in Outcome 2, and all of Outcomes 1, 3 and 4 should be generated through a written assessment paper undertaken in controlled, supervised conditions. This assessment should be conducted under closed-book conditions and as such candidates must not be allowed to bring any textbooks, handouts, or notes to the assessment.

Candidates will be permitted to use scientific calculators during both assessments.

Assessment guidelines

Assessment for this unit should comprise:

- a laboratory exercise or case study; and
- a written assessment paper

Knowledge and/or skills item 3 in Outcome 2 should be assessed by means of a laboratory exercise or case study in which candidates are required to calculate transformer equivalent circuit parameters from open and short-circuit test results. This assessment should be conducted under controlled, supervised conditions. Candidates should be allowed access to relevant course notes. The time that should be allocated for this assessment task is one hour and it should be carried out at a suitable time during the delivery of the unit.

Each candidate can be issued with the same set of test results or a different set of test results. Where facilities and apparatus are available, candidates should carry out the tests or witness a demonstration of the tests being carried out.

The assessment for the remaining knowledge/skills items in Outcome 2, and all of Outcomes 1, 3 and 4 should be combined together to form one assessment paper. This single assessment paper should be taken at a single assessment event lasting two hours and be carried out under closed-book, supervised, controlled conditions. Such a paper should be composed of an appropriate balance of short answer, restricted response and structured questions. This assessment should be undertaken at the end of the delivery of the unit.

Administrative information

Unit code: HV4X 48

Unit title: Transformers

Superclass category: XK

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SQA Advanced Unit Specification: support notes

Unit title: Transformers

This part of the unit specification is offered as guidance. The support notes are not mandatory.

While the exact time allocated to this unit is at the discretion of the centre, the notional design length is 40 hours.

Guidance on the content and context for this unit

This unit has been written in order to allow candidates to develop knowledge, understanding and skills in the following areas:

1. construction characteristics of transformers
2. operation of single-phase transformers on load
3. operation of three-phase transformers
4. transformer protection

This unit is at SCQF Level 8 and has been devised as a unit within the mandatory section of the SQA Advanced Diploma in Electrical Engineering. However this does not preclude the use of this unit in other awards were award designers feel this to be appropriate.

In designing this unit, the writer has identified the range of topics expected to be covered by lecturers. The writer has also given recommendations as to how much time should be allocated to each outcome. This has been done to help lecturers decide what depth of treatment should be given to the topics attached to each of the outcomes. While it is not mandatory for centres to use this list of topics, it is recommended that they do so since the assessment exemplar pack for this unit is based on the knowledge and/or skills identified in each of the learning outcomes.

A list of topics for each outcome is provided below. Lecturers are advised to study this list in conjunction with the assessment exemplar pack so that they can get a clear indication of the standard of achievement expected of the candidates in this unit.

1 Explain the construction characteristics of transformers (8 hours)

Transformer construction: shell type and core type, concentric and sandwich windings
Core materials: hard and soft magnetic materials; relative permeability
Insulation materials, graded insulation

B/H curves: sketch B/H curves from given data; relationship between B/H area and hysteresis loss: effect of frequency of applied voltage on hysteresis loss
Methods to reduce hysteresis loss: choice of steel; maximum operating flux density; and operating frequency

Production of eddy currents and their associated losses
Measures to reduce eddy current losses: material selection, flux density, supply frequency and core laminations

Applied voltage and induced voltage
Revision of equations:

$$E = 4.44 f N \Phi$$

$$\frac{V1}{V2} = \frac{N1}{N2} = \frac{I2}{I1}$$

Harmonics: transformers operate under varying conditions of saturation and produce harmonics= Transformer magnetising current (I_{mag}) contains the 3rd, 5th and 7th harmonic components

2. Analyse the operation of transformers on load (10 hours)

Full equivalent circuit of transformer
Phasor diagrams for practical transformers
Concept of impedance transformation
Simplified equivalent circuit (neglecting losses) with resistances and reactances referred to one side

R_e and X_e referred to primary,

$$R_e = R_1 + R_2\left(\frac{N_1}{N_2}\right)^2$$

and

$$X_e = X_1 + X_2\left(\frac{N_1}{N_2}\right)^2$$

$$Z_e = \sqrt{\left(R_e^{\,2} + X_e^{\,2}\right)}$$

Similar equations for referring all circuit parameters (including core R and X) should also be covered

Practical laboratory exercise to carry out open and short-circuit tests
Calculation of equivalent circuit parameters from open and short-circuit test results

Transformer efficiency for full load and half load, and for both leading and lagging power factors

Explanation of voltage regulation
Calculation of voltage regulation and secondary terminal voltage for various loads with leading and lagging power factors

Description of how single-phase transformers can be connected in parallel
Essential and desirable conditions for connecting in parallel (same voltage ratios, same polarity, same P.U. impedances, same R/X ratio)
Consequences of not complying with essential and desirable conditions

Effect of connecting transformers with non-identical voltage ratios in parallel (concept of circulating current)

Calculation of percentage loading on each of two transformers connected in parallel (transformers having identical voltage ratios)

3. Analyse the operation of three-phase transformers (10 hours)

Winding connections: star, delta and zigzag

Refer to current British Standard for Power Transformers for all possible phase displacements between primary and secondary voltages

Table from current British Standard for Power Transformers showing Phase Displacement, vector symbols, vector diagrams, and winding connections for transformers in each of the four main groups. In an assessment this table could be presented to the candidate partially complete, and the candidate could insert missing data, diagrams etc.

Essential and desirable conditions for connecting three-phase transformers in parallel (same conditions as given in Outcome 2 support notes for single phase transformers, but with the addition of the essential conditions of same phase sequence and phasor grouping)

Consequences of not complying with the above essential and desirable conditions

Requirement for tapped windings and tap changers: to compensate for regulation within the transformer and maintain the output voltage within specified statutory limits; to compensate for slight variations in load; o compensate for changes in the applied voltage on bulk supply transformers

Off-load tap changing as employed in 11kV/400V transformers
On-load tap changing as employed on larger e.g. 33/11 kV transformers (explanation of basic operation of high-speed resistor tap changer)
Essential conditions to be maintained during an on-load tap change (i.e. load current must not be interrupted, and tapped sections of the winding must not be shorted)

Transformer cooling classification codes from current British Standard for Power Transformers

Descriptions of cooling systems e.g:
AN and AF
ONAN, ONAF, OFAN, OFAF and OFWF

Explanation of the operation and application of a winding temperature indicator and control system (indication of winding temperature, control of forced cooling fans and pumps, initiation of alarm signal, and initiation of circuit breaker trip signal to disconnect load from the transformer)

4. Explain transformer protection: (9 hours)

Explanation of how the mechanical stresses produced by transformer short-circuit currents are proportional to the square of these currents.

Operation and application of Buchholz relay

Operation and application of high-voltage circuit breakers to protect transformers from damage during fault conditions. At least one of the following types should be studied: sulphur hexafluoride (SF_6), vacuum, air or oil.

Consequences of high-voltage surges entering transformers and causing flashover and insulation breakdown
Operation and application of surge protection devices used on transformers that are connected to overhead lines (arcing horns and surge arrestors)

Unit assessment

Laboratory exercise or case study	**1 hour**
Written paper	**2 hours**

Guidance on the delivery and assessment of this unit

It is recommended that this unit be delivered after the candidate has gained experience in electrical principles, electromagnetic theory, power supply systems and complex number notation. In the SQA Advanced Certificate and SQA Advanced Diploma in Electrical Engineering these topics are covered in the following units: HP46 47 DC and AC Principles, HT7K 47 Three Phase systems, HT83 47 Electrical Machine Principles, HV3L 47 Electricity Power Systems, and HP48 46 Engineering Mathematics 1. It is recommended that, if possible, the delivery of these other units be carried out in advance of this unit.

During the delivery of this unit students should be given the opportunity to participate in tutorial sessions to enable them to practice and apply the theorems and laws that are crucial to this unit.

This unit has been developed as part of the SQA Advanced Diploma in Electrical Engineering. Where this unit is incorporated into other group awards it is recommended that it be delivered in the context of the specific occupational area(s) that the award is designed to cover.

Details on approaches to assessment are given under Evidence requirements and Assessment guidelines in the SQA Advanced Unit Specification: statement of standards section. It is recommended that this section be read carefully before proceeding with assessment of candidates.

Open learning

This unit could be delivered by distance learning, which may incorporate some degree of on-line support. However, with regard to assessment, planning would be required by the centre concerned to ensure the sufficiency and authenticity of candidate evidence. Arrangements would be required to be put in place to ensure that the assessment was conducted under controlled, supervised conditions.

For information on open learning arrangements, please refer to the SQA guide *Assessment and Quality Assurance of Open and Distance learning (SQA 2000).*

Equality and inclusion

This unit specification has been designed to ensure that there are no unnecessary barriers to learning or assessment. The individual needs of learners should be taken into account when planning learning experiences, selecting assessment methods or considering alternative evidence.

Further advice can be found on our website www.sqa.org.uk/assessmentarrangements.

General information for candidates

Unit title: Transformers

A transformer is a device used for transforming an AC voltage of one level into a voltage of another level with minimum power loss. Worldwide, transformers are used extensively in electricity supply systems, and many industrial consumers have voltage distribution networks running at high voltages that incorporate transformers. This unit has been designed to enable you to develop the knowledge and skills that will allow you to understand the theory and principles of these transformers.

You will begin by learning about the materials and designs used in the construction of transformers. You will then progress to study the operation of transformers. You will learn how to calculate quantities such as efficiency and voltage regulation. Both single-phase and three-phase transformers will be covered in this unit. You will learn about the different winding configurations used in transformers, and the conditions required to be satisfied before individual transformers can safely be paralleled together. The operation and application of transformer fittings such as cooling systems and tap changers will be investigated, and the methods of protecting transformers against fault damage will be explained.

In summary, by the end of this unit you should be able to: explain the construction characteristics of transformers; analyse the operation of single-phase transformers on load; analyse the operation of three phase transformers; and explain transformer protection.

The formal assessment for the unit will take two forms: a laboratory exercise (or case study) and a written, two-hour assessment paper. The laboratory exercise or case study will take place during the delivery of the unit. The written assessment paper will be carried out at the end of the delivery of the unit, and it will be conducted under closed-book conditions. This means that you will not be allowed to take notes, textbooks etc. into the assessment. You will be allowed to use a scientific calculator.