Unit UEENEEG102A
SOLVE PROBLEMS IN LOW VOLTAGE A.C. CIRCUITS

KS01-EG102A
BOOK 2 of 2
Class Orientation

Introduction:
- Introduce yourself.
- Welcome to Electrical Trades Miller TAFE.
- Miller is part of SWSI Institute.
- Check enrolment forms.
- Discuss the requirement to carry TAFE Card

General Induction:
- Discuss location of:
  - Toilets
  - Building exits
  - Evacuation area
  - Fire extinguishers
  - First aid
  - Emergency Stop buttons (class room induction)
- Refer to the STUDENT CALENDAR (in front of book) and discuss the following:
  - Use for important dates, exams, holidays etc.
  - Schedule exam make-up dates etc. (only in consultation with the class teacher)
- Refer to the STUDENT CONTACTS page (in front of book) and discuss the following:
  - Head Teachers phone number and office number
  - Teachers phone number and office number
  - College support unit contacts and phone number
  - Other college phone numbers
- Refer to the EVACUATION PLAN and discuss the following:
  - Fire and Bomb threat procedures
  - The evacuation procedure
  - The requirement to check the roll at the evacuation area
- Refer to the COLLEGE MAP and discuss the following:
  - Car parking
  - Canteen & operating hours
  - Phone (in canteen – free for local calls only)
  - Student Association (in canteen area)
  - Library & operating hours
  - Main Office
- Refer to the MINIMUM STUDENT REQUIREMENTS page and discuss the following:
  - Each item listed in the document
  - Break times and punctuality
  - Emphasise employer correspondence for non-adherence
  - Always have required PPE. ie: clear safety glasses, correct footwear etc.
  - Always carry required resources eg: pens, calculators, drawing instruments & standards
Class Orientation

• Refer to the USEFUL LINKS page and discuss the following:
  - Available websites and services
  - Login procedures for varying services and sites
  - Recording of students DEC User ID and Password
  - Procedure for downloading Australian Standards
  - Accessing Moodle courses

• Refer to the EQUATION SHEET and discuss the following:
  - Every new student workbook has an equation sheet
  - Only new / clean equation sheets will be permitted in exams
  - Not all exams require the use of an equation sheet

• Refer to the WORK PERFORMANCE EVIDENCE page and discuss the following:
  - A broad overview of workplace training
  - The need to collect evidence whilst at work
  - Skills Tracker recording – Login details etc.
  - Skills Tracker orientation will be done during the year
  - You cannot course complete without adequate work performance evidence

• Refer to the COURSE OUTLINE and discuss the following:
  - Four year apprenticeship (in general)
  - Three years at TAFE, fourth year in the workplace
  - The IMPORTANCE of evidence collection for Workplace Performance (Skills-tracker)
  - Options for failed units and repeat classes
  - Failing a unit twice

• Refer to the UNIT GUIDE and discuss the following:
  - Prerequisites, and the possible need to repeat a unit or part thereof before advancing
  - Student Assessment Guidelines and signing of guidelines for each unit
  - Consequences for Cheating
  - Contacting the class teacher for missed exams
  - Explain the SAGs assessment table and the timing / weighting of exams
  - Successful completion of a unit is only achieved when a student shows sufficient Essential Knowledge & Associated Skills (EKAS) contained within the unit, whereby;
    ➢ Essential Knowledge is determined by the KS associated with the unit, and
    ➢ Skills are demonstrated by consistent performance across a representative range of contexts.

  NOTE: Evidence of skills may be collected in a number of ways. Examples include:
  - Skills-tracker portfolios
  - Workbook UNIT portfolios
  - In class simulated workplace activities, documented in the class roll by the teacher
  - A combination of all of the above.

  **Tour of Campus:** - For new classes, visit required locations listed above
## Minimum Student Requirements

### Electrical Trades Section - Miller

1. **SHOES / PPE**
   - Fully enclosed leather-top shoes must be worn at all times in all parts of the building. *Definitely no thongs or sandals.*

2. **ATTIRE**
   - Clean tidy clothing is required. Tops are required to have sleeves. *No singlet-style tops.*

3. **EYES / PPE**
   - *Clear, non-tinted safety glasses* must be provided by the student and worn where required e.g. workshop classes.

4. **BOOKS**
   - Each student must have his/her own text, tutorial and workbooks as well as any required accessories e.g. pens, drawing instruments, calculator, AS3000 rule book.

5. **ATTENDANCE**
   - Students are expected to be punctual and attend classes for the entire duration. In the event of not being able to attend a class or classes, the student should inform the class teacher and their employer.
   
   Non-attendances will result in employers being notified.

6. **ASSESSMENTS**
   - Students that miss exams for ANY reason must where possible contact their class teacher beforehand. Acceptable supporting evidence as to why the exam was missed MUST be provided. e.g. doctor certificate for illness. Refer to the ‘student assessment guidelines’ for further important information.
   
   - ‘SCHOOLIES’ is not an acceptable reason to miss exams.
   - Cheating and Plagiarism will not be tolerated

7. **SMOKING**
   - Smoking is not permitted on the College grounds at any time. Please make your way to the College entrance on Banks Road.

8. **EATING**
   - The consumption of food or drink is not permitted in any part of any building within the College (with the exception of the College Canteen).

9. **MOBILE PHONES**
   - *Mobile phones are to be turned off* prior to entering any classroom, workshop or wiring room. Mobile phones are not to be accessed during class.

10. **DISCIPLINE**
    - Students must be familiar with, and adhere to, the Code of Conduct which is printed in the Student Handbook that is available from the main office.
**Useful Links**

<table>
<thead>
<tr>
<th>Website</th>
<th>Description</th>
</tr>
</thead>
</table>
| **Skills-Tracker**<br>www.skills-tracker.com | An online resource used by individuals to gather and record their work performance evidence. Miller student access information:  
**LOGIN:** your student number.  
**PASSWORD:** your surname (in lower case letters). |
| **Miller Electrical WIKI space**<br>http://electricaltrades-miller.swsi.wikispaces.net | Find information about enrolments, calendars, contacts, help with maths, work performance evidence databases and lots more. |
| **Moodle**<br>http://swsi.moodle.tafensw.edu.au | Access unit information for some classes (see your teacher). You may also need a specific ‘enrolment key’ to access your teachers class work on Moodle.  
**LOGIN:** your DEC Username  
**PASSWORD:** your DEC password |
| **South Western Sydney Institute of TAFE**<br>www.swsi.tafensw.edu.au | Find information about enrolments, college contacts and locations, courses, additional services and much more. |
| **TAFE NSW Website**<br>https://www.tafensw.edu.au | Find information about courses, colleges, assessment, a range of student services, career advice, and much more.  
**NOTE:** Log onto student ‘eServices’ to find results etc. Click on the ‘student login’ link.  
**LOGIN:** your DEC Username  
**PASSWORD:** your DEC password |
| **State Training Services**<br>http://www.training.nsw.gov.au/index.html | For information regarding Skills Recognition, Craft Certificates, Certificates of Proficiency (COP), check apprenticeship registrations, access to Australian apprenticeship support services etc. |
| **Vocational Training Tribunal (VTT)** – 02 9266 8450 | | |
| **NSW Fair Trading**<br>www.fairtrading.nsw.gov.au | Find electrical licensing information. Go to the ‘Tradespeople’ link from the homepage. |
| **NSW Industrial Relations**<br>www.industrialrelations.nsw.gov.au | Find information for pay rates, long service and general award conditions. |

**USE THIS SPACE TO RECORD LOGIN DETAILS FOR SPECIFIC SITES**

<table>
<thead>
<tr>
<th>Password to log on to the TAFE computers</th>
<th>Password to log on to the Internet at TAFE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>User name:</strong> MIFG15-11 (e.g. ONLY)</td>
<td><strong>User name:</strong> Your DEC User ID</td>
</tr>
<tr>
<td><strong>Password:</strong> tafestudent (all one word)</td>
<td><strong>Password:</strong> Your DEC password</td>
</tr>
<tr>
<td><strong>Log on to:</strong> SOUTH_WESTERN</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Password to log on for library resources</th>
<th>Changes yearly. See library staff</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>User ID:</strong></td>
<td><strong>Password:</strong></td>
</tr>
</tbody>
</table>
Useful Links

How to access Standards Online Premium
Access to SAI Global to download AS/NZS 3000 and other AS Standards.


2. Left click on Standards Online Indexes

3. Consult library staff for this years’ User ID and Password

4. Left click on Standards Online Indexes

5. Type in the Standard that you want to access
   Examples:
   AS/NZS 3008.1.1
   AS/NZS 3000:2007

6. From the search results, click on the required standard. You can open and view the file.

   Saved files expire after 2 days

** Library staff can also assist you to access Standards Online Premium on library computers **
Useful Links

How to access Moodle

The following is a guide to login to Moodle from an external computer (example: from home).

If you are accessing Moodle from a TAFE computer, you will need to login to the TAFE computer first. See the instructions on the first page of ‘Useful Links’.

1. Go to http://www.swsi.moodle.tafensw.edu.au

2. Login using your portal username and password.
   
   Note: This is your DEC Username and password.

3. New users – search for the course name (or part thereof) given to you by your class teacher.
   
   Example: ‘UEENE1EE101A’ or ‘OHS’

4. If multiple courses of the same name appear, be sure to select the course name ending in ‘-mi’ for Miller TAFE

   Left click to enter course

5. Enter the enrolment key as given to you by your class teacher.

   Left click on the ‘Enrol me’ icon and access your course material.

6. Existing or returning users – left click on the ‘My home’ tab to see your previously registered courses. Access your course as per step 4. No enrolment key required.
### Stage 1: This list does not contain all equations in the course and transposition may be required.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$Q = It$</td>
<td>$F = ma$</td>
<td>$W = Pt$</td>
<td>$W = Fs$</td>
<td>$W = mg\ h$</td>
</tr>
<tr>
<td>2</td>
<td>$V = IR$</td>
<td>$I = \frac{V}{R}$</td>
<td>$R = \frac{V}{I}$</td>
<td></td>
<td>$P = \frac{2\pi nT}{60}$</td>
</tr>
<tr>
<td>3</td>
<td>$P = VI$</td>
<td>$P = I^2R$</td>
<td></td>
<td>$P = \frac{V^2}{R}$</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$R = \frac{\rho l}{A}$</td>
<td>$R_2 = \frac{R_1A_1l_2}{A_2l_1}$</td>
<td>$R_n = R_c(1 + \alpha\Delta t)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$V_T = V_1 + V_2 + V_3$</td>
<td>$R_T = R_1 + R_2 + R_3$</td>
<td>$I_T = I_1 = I_2 = I_3$</td>
<td>$V_1 = V_T \frac{R_1}{R_1 + R_2}$</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>$V_T = V_1 = V_2 = V_3$</td>
<td>$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$</td>
<td>$I_T = I_1 + I_2 + I_3$</td>
<td>$I_2 = I_T \frac{R_1}{R_1 + R_2}$</td>
<td>$R_T = \frac{R_1R_2}{R_1 + R_2}$</td>
</tr>
<tr>
<td>7</td>
<td>$C = \frac{Q}{V}$</td>
<td>$C = \frac{A \varepsilon_s \varepsilon_r}{d}$</td>
<td>$\tau = RC$</td>
<td>$C_T = C_1 + C_2 + C_3$</td>
<td>$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$</td>
</tr>
<tr>
<td>8</td>
<td>$L = N \frac{\Delta \phi}{\Delta I}$</td>
<td>$L = \frac{N^2 S}{S}$</td>
<td>$\tau = \frac{L}{R}$</td>
<td>$V = N \frac{\Delta \phi}{\Delta t}$</td>
<td>$V = \frac{L \Delta I}{\Delta t}$</td>
</tr>
<tr>
<td>9</td>
<td>$e = Blv$</td>
<td>$F = Bil$</td>
<td>$F_m = IN$</td>
<td>$B = \frac{\phi}{A}$</td>
<td>$S = \frac{l}{\mu_0 \mu_r A}$</td>
</tr>
<tr>
<td>10</td>
<td>$E_g = k\phi n$</td>
<td>$T = k\phi I_a$</td>
<td>$T = Fr$</td>
<td>$H = \frac{F_m}{l}$</td>
<td>$\phi = \frac{F_m}{S}$</td>
</tr>
</tbody>
</table>
**Stage 2:** This list does not contain all equations in the course and transposition may be required.

**Stage 1:** equations are also used during stage 2

<table>
<thead>
<tr>
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<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>$V_{ave} = 0.637 V_{max}$</td>
<td>$V_{RMS} = 0.707 V_{max}$</td>
<td>$v = V_{max} \sin \theta$</td>
<td>$V_L = \sqrt{3} V_p$</td>
<td>$f = \frac{nP}{120}$</td>
</tr>
<tr>
<td>12</td>
<td>$I_{ave} = 0.637 I_{max}$</td>
<td>$I_{RMS} = 0.707 I_{max}$</td>
<td>$i = I_{max} \sin \theta$</td>
<td>$I_L = \sqrt{3} I_p$</td>
<td>$t = \frac{1}{f}$</td>
</tr>
<tr>
<td>13</td>
<td>$I = \frac{V}{Z}$</td>
<td>$V = IZ$</td>
<td>$Z = \frac{V}{I}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>$Z = \sqrt{R^2 + X^2}$</td>
<td>$Z = \sqrt{R^2 + (X_L - X_C)^2}$</td>
<td>$X_L = 2\pi f L$</td>
<td>$X_C = \frac{1}{2\pi f C}$</td>
<td>$\cos \theta = \frac{R}{Z}$</td>
</tr>
<tr>
<td>15</td>
<td>$P = VI \cos \theta$</td>
<td>$S = VI$</td>
<td>$Q = VI \sin \theta$</td>
<td>$P = \sqrt{S^2 - Q^2}$</td>
<td>$\cos \theta = \frac{P}{S}$</td>
</tr>
<tr>
<td>16</td>
<td>$P = \sqrt{3}V_L I_L \cos \theta$</td>
<td>$S = \sqrt{3}V_L I_L$</td>
<td>$Q = \sqrt{3}V_L I_L \sin \theta$</td>
<td>$\tan \theta = \sqrt{3} \frac{(W_1 - W_2)}{(W_1 + W_2)}$</td>
<td>$\theta = \cos^{-1} \lambda$</td>
</tr>
<tr>
<td>17</td>
<td>$V' = 4.44\phi f N$</td>
<td>$\frac{V_1}{V_2} = \frac{N_1}{N_2}$</td>
<td>$\frac{l_2}{l_1} = \frac{N_1}{N_2}$</td>
<td>$V_{reg%} = \frac{(V_{NL} - V_{FL})}{V_{FL}} \times 100$</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>$N_{syn} = \frac{120 f}{P}$</td>
<td>$f_r = \frac{S% \times f}{100}$</td>
<td>$S% = \frac{(n_{syn} - n)}{n_{syn}} \times 100 \frac{1}{1}$</td>
<td>$V_{reg%} = \frac{(V_{NL} - V_{FL})}{V_{NL}} \times 100 \frac{1}{1}$</td>
<td>$T = k\phi I_a$</td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td>$P = \frac{2\pi nT}{60}$</td>
<td>$\eta% = \frac{output}{input} \times 100 \frac{1}{1}$</td>
</tr>
</tbody>
</table>
**Stage 2a:** This list does not contain all equations in the course and transposition may be required.

**Stage 1:** equations are also used during stage 2

<table>
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<tr>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>( V_T = E_G - (I R_i) )</td>
<td>( E = \frac{F}{A} )</td>
<td>( E = \frac{I}{d^2} )</td>
<td>( E = \frac{I}{d^2} \times \cos \theta )</td>
<td>( \eta = \frac{F}{P} )</td>
</tr>
<tr>
<td>23</td>
<td></td>
<td></td>
<td>( Q_c = P(\tan \theta_1 - \tan \theta_2) )</td>
<td>( X_c = R(\tan \theta_1 - \tan \theta_2) )</td>
<td></td>
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<tr>
<td>24</td>
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**Stage 3:** This list does not contain all equations in the course and transposition may be required.

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<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>( V_pY = 57.7% V_p \Delta )</td>
<td>( I_pY = 57.7% I_p \Delta )</td>
<td>( I_{motor \text{ st}} = \left( \frac{% TAP}{100} \right) \times I_{DOL} )</td>
<td>( I_{line \text{ st}} = \left( \frac{% TAP}{100} \right)^2 \times I_{DOL} )</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>( I_{ST} = \frac{1}{3} \times I_{DOL} )</td>
<td>( T_{ST} = \frac{1}{3} \times T_{DOL} )</td>
<td>( V_{st} = \left( \frac{% TAP}{100} \right) \times V_{DOL} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>( I_{ST} = \left( \frac{V_{st}}{V} \right) \times I_{DOL} )</td>
<td>( T_{ST} = \left( \frac{V_{st}}{V} \right)^2 \times T_{DOL} )</td>
<td>( \text{Constant} = \frac{V}{f} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Work Performance Evidence (WPE)

IMPORTANT:
Students should bring this to the attention of their employers as soon as possible.

Work Performance Evidence is required to be collected for each unit of study. This evidence is used to help measure the effectiveness of your learning and to demonstrate that the required work related practical skills have been obtained and used to consolidate the academic component of your study. That is, you possess both the theory knowledge AND practical ability to complete a task to a competent level.

For some units of study, your class teacher will collect this evidence on your behalf by setting tasks that realistically ‘simulate’ the workplace environment. The college will record and store this information. You should confirm with your class teacher at the commencement of each new unit of study whether he or she is going to collect work performance evidence on your behalf.

However, for the most part, YOU will be required to collect the evidence that demonstrates your progress in the workplace and that the required electro-technology skills are being achieved.

The electrical trades section of Miller TAFE has set-up on your behalf a ‘Skills-Tracker’ online portfolio account for you to collect and record all of your workplace learning. In due time, you will be given instruction and tuition on the use of the Skills-Tracker portfolio system.

In the meantime, log onto www.skills-tracker.com and have a look at the ‘learner guides’ and ‘supervisor guides’ found in the ‘downloads’ tab of the navigation bar.

Skills-Tracker
www.skills-tracker.com
Email: info@skills-tracker.com
Phone: +612 9543 1100

Miller student access information:
LOGIN: your student number.
PASSWORD: your surname (in lower case letters).

Note: Units that require you to collect WPE by the Skills-tracker portfolio will show a NC (Not Yet Competent) result on your transcript until your portfolio is complete and verified by the college. This will be the case even if you have passed all of your in class assessments. In most cases, the NC result will not be updated to a unit pass result of AC (Achieved Competence) until your work evidence portfolio is checked and verified toward the end of your course / apprenticeship.

***** REMEMBER *****
YOU are responsible for collecting your own workplace evidence
Unit Guide – Summary

FULL unit guides can be accessed online at www.training.gov.au
The following information is summarised and is intended to provide a broad overview only.

**Unit:**

UEENEEG102A Solve problems in low voltage a.c. circuits

**Unit Descriptor**

This unit covers ascertaining correct operation of single and three phase a.c. circuits and solving circuit problems as they apply to servicing, fault finding, installation and compliance work functions. It encompasses safe working practices, multiphase circuit arrangements, issues related to protection, power factor and MEN systems and solutions to circuit problems derived from calculated and measured parameters.

**Pre-Requisites**

Pre-requisites are units of study that must be completed prior to commencing a new unit of study. That is, you must pass subject ‘X’ before you are allowed to commence subject ‘Y’. In some instances, pre-requisite units may be studied concurrently with new units of study.

Pre-requisites for this unit of study are:

- UEEENEE101A Apply Occupational Health and Safety regulations, codes and practices in the workplace
- UEEENEE104A Solve problems in d.c circuits
- UEEENEEG101A Solve problems in electromagnetic devices and related circuits
Unit Guide – Summary continued

**Literacy and numeracy skills indicators for this unit – NRS Level 4:**

Participants are best equipped to achieve competency in this unit if they have reading, writing and numeracy skills at a level indicated by the following NRS levels.

The National Reporting System (NRS) is a nationally recognised mechanism for determining adult English language, literacy and numeracy levels.

In context for this unit of study these Indicators of Competence (IoC) are not an assessment system, but merely a guide to the specific reading writing and numeracy levels for this unit.


<table>
<thead>
<tr>
<th>Skill</th>
<th>IoC</th>
<th>Indicator of Competence</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reading: Level 4</strong></td>
<td>4.1</td>
<td>Reads and interprets structurally intricate texts in chosen fields of knowledge which require integration of several pieces of information for generating meaning.</td>
</tr>
<tr>
<td></td>
<td>4.2</td>
<td>Interprets texts, which include ambiguity, and inexplicitness where reader needs to distinguish fact from opinion and infer purpose.</td>
</tr>
<tr>
<td></td>
<td>4.3</td>
<td>Interprets and extrapolates from texts containing data which includes some abstraction, symbolism, and technicality presented in graphic, diagrammatic, formatted or visual form.</td>
</tr>
<tr>
<td><strong>Writing: Level 4</strong></td>
<td>4.4</td>
<td>Communicates complex relationships between ideas by matching style of writing to purpose and audience.</td>
</tr>
<tr>
<td></td>
<td>4.5</td>
<td>Generates written texts reflecting a range of genres and using appropriate structure and layout.</td>
</tr>
<tr>
<td><strong>Numeracy: Level 4</strong></td>
<td>4.10</td>
<td>Selects and investigates appropriate mathematical information and relationships embedded in an activity, item or text.</td>
</tr>
<tr>
<td></td>
<td>4.11</td>
<td>Selects and applies an expanding range of mathematical strategies flexibly to solve problems in a variety of contexts.</td>
</tr>
<tr>
<td></td>
<td>4.12</td>
<td>Examines and questions the appropriateness, possible interpretations and implications of aspects of a mathematical activity.</td>
</tr>
<tr>
<td></td>
<td>4.13</td>
<td>Uses a range of oral and written informal and formal language and representation including symbols, diagrams and charts to communicate mathematically.</td>
</tr>
</tbody>
</table>
Student Assessment Guidelines – (SAG’s)

Assessment is an important part of learning at TAFE NSW.

TAFE NSW provides comprehensive information for students regarding assessment. A copy of ‘Every Student’s Guide to Assessment in TAFE NSW’ can be obtained by visiting:


The following information provided in this workbook is to assist you in your understanding of the assessment process, by providing an overview of assessment for this unit. Any questions regarding assessment can be addressed by your class teacher.

Course: National Course Code: UEE30811

Qualification and name: Certificate III in Electrotechnology Electrician

TAFE NSW course number: 20222. Version: 1

Requirements to receive the qualification:

To achieve UEE30811 Certificate III in Electrotechnology, learners are required to complete all units from the core and elective units to a weight of 140 points. Core and elective units are shown in the ‘Course Outline’ contained in the preceding pages of this workbook.

Recognition: If you have completed other relevant training you may be eligible to have units of competency from previous training counted towards completion for this course. Talk to your teacher or head teacher if you think you may be eligible for recognition for units previously completed.

Learner Support: Students who require support to meet their learning goals should discuss their options by talking to their teacher or Teacher/Consultant for students with a disability.

Assessment Results: Results will be made available to you by your class teacher after each assessment event. Results may also be viewed online (final unit results only) by visiting TAFE ‘eServices’. See the ‘Useful Links’ on the ‘student contacts’ page in the front of this workbook for further information on TAFE eServices. Concerns you may have about your assessment results should be addressed to your class teacher within 3 weeks of receiving a result.
Meeting Competency Requirements:

In order to be deemed ‘competent’ in a unit of study, you will be required to achieve a minimum Knowledge and Skills (KS) percentile mark AND satisfactorily complete the Work Performance Evidence (WPE) requirements (ie: Skills-tracker or in-class evidence collected by your teacher). In all other cases participants will be deemed as ‘not yet competent’ (NC).

Units in this course are ungraded. Your TAFE transcript will record your result as follows:

- **AC** - A Unit result code of AC (achieve competency) will be issued if all associated KS specification(s) and work performance evidence have been passed and/or completed.
- **NC** - A Unit result code of NC (not yet competent) will be issued if either the KS specification or work performance evidence has not been passed and/or completed.

Note: Units that require you to collect WPE by the Skills-tracker portfolio will show a NC result on your transcript until your portfolio is complete and verified by the college. In most cases this will not be done until you approach the end of your course / apprenticeship.

Assessment Events:

Assessment events are varying methods of assessment used to collect information and measure an individual’s level of learning. Below is a table listing typical event methods.

<table>
<thead>
<tr>
<th>Assessment Event</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quizzes:</td>
<td>May consist of multiple choice questions, short answer questions, descriptive questions, calculations and diagram completion questions</td>
</tr>
<tr>
<td>Tutorial:</td>
<td>May consist of section review questions, projects, class assignments, research etc.</td>
</tr>
<tr>
<td>Skills Practice:</td>
<td>May consist of diagram completion questions, circuit and component connections, motor connections, cabling connections, safe isolation procedures, meter and test equipment connections and measurements and the like</td>
</tr>
<tr>
<td>Practical Exam:</td>
<td>May consist of diagram completion questions, circuit and component connections, motor connections, cabling connections, safe isolation procedures, meter and test equipment connections and measurements and the like</td>
</tr>
<tr>
<td>Theory Exam:</td>
<td>May consist of multiple choice questions, short answer questions, descriptive questions, calculations and diagram completion questions</td>
</tr>
<tr>
<td>Work Performance Evidence:</td>
<td>May consist of actual workplace evidence collected and recorded by profiling (eg: skill-tracker) or simulated workplace evidence collected in the classroom by your teacher or a combination of both</td>
</tr>
</tbody>
</table>

Assessment events used in this particular unit of study are ‘weighted’ and shown on the following page.
Unit Guide – Assessment

**Required skills and knowledge**

This describes the essential skills and knowledge and their level, required for this unit.

Evidence shall show that knowledge has been acquired of safe working practices, rationale and solving problems in the relevant unit. The knowledge and skills shall be contextualised to current industry standards, technologies and practices.

*View the section title page in your class workbook or the complete unit guide for a full list of the fundamentals covered by each topic within this unit.*

Below is a list indicating the content areas to be covered by the required skills and knowledge specification for this unit:

**Note:** Topics may not be delivered in the order indicated by the full unit guide.

Additional information pertinent to your learning may also be included during unit delivery.

**KS01-EG102A – Alternating current power circuits**

<table>
<thead>
<tr>
<th>WORKBOOK SECTION NUMBER</th>
<th>CONTENT</th>
<th>TOPIC NUMBER AS LISTED IN THE FULL UNIT GUIDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 1 Book 1</td>
<td>Alternating Current Quantities</td>
<td>T1</td>
</tr>
<tr>
<td>Section 2 Book 1</td>
<td>Sinusoidal Waveforms</td>
<td>T2, T3</td>
</tr>
<tr>
<td>Section 3 Book 1</td>
<td>Phasor Quantities</td>
<td>T3</td>
</tr>
<tr>
<td>Section 4 Book 1</td>
<td>Resistance and Capacitance in AC Circuits</td>
<td>T3, T4, T6</td>
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<tr>
<td>Section 5 Book 1</td>
<td>Purely Inductive AC Circuits</td>
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<td>R-L and R-C Series Circuits</td>
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<td>Series R-L-C Circuits</td>
<td>T5</td>
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<tr>
<td>Section 8 Book 1</td>
<td>Parallel AC Circuits</td>
<td>T6</td>
</tr>
<tr>
<td>Section 1 Book 2</td>
<td>Power in AC Circuits</td>
<td>T7</td>
</tr>
<tr>
<td>Section 2 Book 2</td>
<td>Power Factor Improvement</td>
<td>T8</td>
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<tr>
<td>Section 3 Book 2</td>
<td>Three Phase Generation</td>
<td>T10</td>
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<tr>
<td>Section 4 Book 2</td>
<td>Three Phase Star Connected Systems</td>
<td>T11, T12</td>
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<tr>
<td>Section 5 Book 2</td>
<td>Three Phase Delta Connected Systems</td>
<td>T13</td>
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<tr>
<td>Section 6 Book 2</td>
<td>Three Phase Power &amp; Power Factor</td>
<td>T14</td>
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<td>Section 7 Book 2</td>
<td>Three Phase Power measurement &amp; Harmonics</td>
<td>T9, T14</td>
</tr>
<tr>
<td>Section 8 Book 2</td>
<td>Star-Delta Interconnected Systems</td>
<td>T12, T13, T14</td>
</tr>
</tbody>
</table>

**Appendix A**

Fault Loop Impedance

*T15

**Note:** Fault Loop Impedance also covered in *UEENE prep107A: Electrical Apparatus & Circuits* Section 7 (T7) KS01 – EG107A
Student Assessment Guide for this unit:

Evidence for competence in this unit shall be considered holistically. The required skills and knowledge relating to this unit will be assessed in following manner:

<table>
<thead>
<tr>
<th>Event #</th>
<th>Event Name / Timing / Duration</th>
<th>Evidence Method</th>
<th>Wgt.</th>
<th>Out Of %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Quiz - Weekly</td>
<td>Formative Assessment</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>Skills Practice - Weekly</td>
<td>Formative Assessment</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>Practical exam 1 - After Section 8 - 1 Hr</td>
<td>Formative Assessment</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>4</td>
<td>Theory Exam 1 - After Section 8 - 2 Hrs - MUST PASS 60%</td>
<td>Summative Assessment</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>Work Performance Evidence (Pass / Fail)</td>
<td>Profiling / Skills Tracker</td>
<td>P/F</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Quiz - Weekly</td>
<td>Formative Assessment</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>7</td>
<td>Skills Practice - Weekly</td>
<td>Formative Assessment</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>8</td>
<td>Practical exam 1 - After Section 16 - 1 Hr</td>
<td>Formative Assessment</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>9</td>
<td>Theory Exam 1 - After Section 16 - 2 Hrs - MUST PASS 60%</td>
<td>Summative Assessment</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>Work Performance Evidence (Pass / Fail)</td>
<td>Profiling / Skills Tracker</td>
<td>P/F</td>
<td></td>
</tr>
</tbody>
</table>

* All 'MUST PASS' events must be passed AND Total Cumulative KS mark must be 60% or greater

* Work Performance Evidence (WPE) has been reviewed and satisfies requirements (Pass / Fail)

* Final Competency Result (AC) Achieved competency OR (NC) Not Yet Competent. See note below.

**Note:** Only award AC if ALL "MUST PASS' events are passed, KS mark 60% or greater AND WPE is Passed
Absence from a class assessment:

All students are expected to sit class assessments at the normal scheduled time.

If due to ill health or other unforeseen and acceptable circumstances you are not able to attend a scheduled class test, it is your responsibility to make contact with your class teacher or the section head teacher and inform them of your reason for missing the assessment.

NOTE: This contact must be made, prior to, but certainly no later than 24 hours after the scheduled assessment.

Failure to contact the class teacher or section head teacher within the specified time will be taken as your withdrawal from the assessment and a zero mark will be recorded.

‘Schoolies’ is not an acceptable reason to miss an assessment. Zero marks will be recorded.

Your Class Teachers Name: ____________________________________________
Your Class Teachers Phone No: _________________________________________
Or Head Teachers No: 9825-7398 or 9825-7389 Fax No: 9825-7470

Workplace Health and Safety (WHS):

The laws protecting the Health and Safety of people at work apply to students who attend TAFE Colleges, either part time or full time. These laws emphasise the need to take reasonable steps to eliminate or control risk at work (this includes a TAFE College). TAFE NSW has the responsibility for the control, and where possible, the elimination of health and safety risk at the college. This includes bullying and harassment. You are encouraged to help in eliminating hazards by reporting to your teacher or other College staff, anything that you think may be a risk to you or other people.

Your teacher will encourage you to assist in hazard identification and elimination, and to devise control measures for any risks to yourself and other people that may arise during practical exercises. The WHS Act 2011 requires that teachers and students take reasonable steps to control and monitor risk in the classroom, workshop or workplace.

Individuals failing to observe and follow ALL Workplace Health and Safety requirements in any part of the college, not limited to but including, hall-ways, class rooms, laboratories, wiring rooms and workshops will be promptly removed for their own safety and for the safety of others. Breaches will be recorded on your TAFE record.
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<td>Practical 8</td>
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<tr>
<td>Tutorial 8</td>
<td>167</td>
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</tbody>
</table>
POWER IN AC CIRCUITS

PURPOSE:

To develop an understanding of the methods of determining power consumed by an AC single phase AC circuit.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- Describe the meaning of the terms -
  - true power
  - reactive power
  - apparent power, and state their units of measurement.
- Draw the power triangle for a single phase load.
- Describe what is meant by the term power factor.
- Calculate the true power, reactive power and apparent power associated with a single phase AC load given voltage, current and phase angle or power factor.
- Calculate circuit current drawn from an AC supply given power consumption, voltage and power factor.
- Draw a circuit diagram showing how a wattmeter is connected to measure true power and how a voltmeter and ammeter are connected to measure apparent power.

REFERENCES:

1. CIRCUIT COMPONENTS AND POWER CONSUMPTION

As described in the module Applied Electricity 4, the three basic circuit components to be found in AC circuits are the -

- resistor
- inductor
- capacitor.

The operation of each of these components was studied in detail and in relation to power consumption it was found -

- the only component to consume power is the __________________________.

- the inductor consumes __________ power because all of the energy taken from the supply to set up the __________________________ is returned to the supply when the __________ collapses.

- the capacitor consumes __________ power because all of the energy taken from the supply to __________ the capacitor is returned to the supply when the capacitor __________.

Figure 1 shows a summary of the characteristics of the three basic components when connected to an AC supply.

![Diagram of circuit components](image)

- Purely Resistive
  - Voltage and current are __________
  - Phase angle = ________
  - Power consumed = ________

- Purely Inductive
  - Current _____ voltage by ________
  - Phase angle = ________
  - Power consumed = ________

- Purely Capacitive
  - Current _____ voltage by ________
  - Phase angle = ________
  - Power consumed = ________

Figure 1
2. **TRUE POWER**

Consider the R-L series circuit shown in figure 2.

![Figure 2](image-url)

The phasor diagram for the circuit of figure 2 would be as shown in figure 3.

![Figure 3](image-url)

From the phasor diagram the circuit voltage triangle may be derived, as shown in figure 4.

![Figure 4](image-url)

Based on the work completed in Applied Electricity 4, it can be stated that all the power consumed by an AC circuit containing resistance and inductance is due to its resistance, therefore -

\[
\text{Power consumed} = \text{resistor voltage drop} \times \text{current}
\]

Power consumed = ____________________
By the application of basic trigonometry to the voltage triangle formed in figure 4 -

\[ \cos \phi = \]

\[ \therefore V_R = \quad \text{______________} \]

Substituting into the power equation -

Power consumed = \text{______________}.

Therefore, the true power consumed by a single phase AC circuit is given by the equation -

where: \( P = \) true power consumed in watts
\( V = \) supply voltage in volts
\( I = \) circuit current in amperes
\( \phi = \) circuit phase angle in degrees

**Example: 1**

A 240V, 50Hz supply is connected to an R-L circuit that consists of a resistance of 18Ω and inductive reactance of 24Ω. Determine the -

(a) circuit impedance
(b) circuit current
(c) phase angle
(d) power consumed.

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Example: 2
A single phase motor draws 6A from a 240V, 50Hz supply. If the motor operates with a phase angle of 25° lag, determine the true power supplied to the motor.

3. POWER TRIANGLE

Once again consider an R-L series circuit and its associated phasor diagram, as shown in figures 6 and 7.

![Figure 6](image)

![Figure 7](image)

Multiplying each side of the voltage triangle formed in figure 7 by the current I, gives the right angle triangle shown in figure 8.

![Figure 8](image)

The triangle formed is known as the __________________________.

The sides of the triangle represent the three components of power -
- $V_R \times I$ is called the __________________________
- $V_L \times I$ is called the _________________________ (Q), which does no useful work
- $V \times I$ is called the _________________________ (S), the power that appears to be taken when considering only the supply voltage and current.
Application of the basic trigonometric functions allows the sides of the triangle to be identified in a different manner. For example -

Taking the cosine of the phase angle - \( \cos \phi = \)

\[ \therefore V_R = \]

\[ \therefore P = \]

Taking the sine of the phase angle - \( \sin \phi = \)

\[ \therefore V_L = \]

\[ \therefore Q = \]

Figure 8

Therefore as stated there are three components of power -

- **true power** - represents the power that does useful work
  - represented by the letter \( P \)
  - measured in watts

- **reactive power** - is due to either inductive or capacitive elements and does no useful work
  - represented by the letter \( Q \)
  - measured in a unit called the volt-amp reactive \( V_A R \)

- **apparent power** - the power that appears to be taken when considering only supply voltage and current
  - represented by the letter \( S \)
  - measured in a unit called the volt-amp \( V_A \).
Any one of the three components of power may be determined provided the supply voltage, circuit current and circuit phase angle are known -

<table>
<thead>
<tr>
<th>True power</th>
<th>Reactive power</th>
<th>Apparent power</th>
</tr>
</thead>
</table>

where:  
- \( P \) = true power in watts  
- \( Q \) = reactive power in VA  
- \( S \) = apparent power in VA  
- \( V \) = supply voltage in volts  
- \( I \) = circuit current in amperes  
- \( \phi \) = phase angle in degrees

**Example: 3**
A single phase load draws 25A at a phase angle of 30º lag from a 240V, 50Hz supply. Determine -
(a) apparent power  
(b) true power  
(c) reactive power

**Example: 4**
A single phase circuit takes a true power of 2400W and a reactive power 750VA. Determine the apparent power associated with the circuit.
4. **POWER FACTOR**

The power factor of a circuit is defined as the ratio of the ___________ power to the ___________ power.

Note, as the power factor is the ratio of one component of power to another, it has no unit of measurement.

The symbol for power factor is the Greek letter lambda ___________.

Therefore, to calculate the power factor of a circuit -

\[ \lambda = \text{power factor} \]
\[ P = \text{true power in watts} \]
\[ S = \text{apparent power in VA} \]

When related to the power triangle it will also be found that the power factor is equal to the ___________ of the ___________.

As the phase angle for a circuit may vary between 0º and 90º, it follows that the power factor of a circuit can vary between ___________. A power factor of _____ is known as _______.

**Example: 5**

A single phase motor draws 7.5A from a 240V, 50Hz supply. If the motor operates at a power factor of 0.9 lag, determine the -

(a) true power supplied to the motor

(b) motor phase angle

(c) apparent power of the motor

(a)

(b)

(c)
5. MEASUREMENT OF TRUE POWER

The true or average power consumed by an AC circuit can be measured using a wattmeter.

As seen in earlier modules a wattmeter consists of two coils, the -
- potential coil
- current coil.

The connection of a wattmeter to measure the true power taken by a load is shown in figure 9.

![Figure 9](image)

6. MEASUREMENT OF APPARENT POWER

The apparent power associated with an AC circuit can be determined from the readings of an ammeter and voltmeter. The values obtained are then multiplied together to give the apparent power.

Figure 10 shows the connection of a voltmeter and ammeter to determine a circuits apparent power.

![Figure 10](image)
**Example: 6**

The following readings were obtained from a test on a single phase AC circuit -
- ammeter reading 50A
- voltmeter reading 240V
- wattmeter reading 10.2kW.

Determine the -

(a) apparent power
(b) power factor
(c) phase angle
(d) reactive power
POWER IN AC CIRCUITS

PURPOSE:

This practical assignment will be used to examine the components of power in basic AC circuits.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Connect a single phase wattmeter.
- Use a voltmeter and ammeter to determine the apparent power of a circuit.
- From measured values of true and apparent power determine the -
  - circuit power factor
  - circuit phase angle.
- Draw the power triangle for an AC circuit.

EQUIPMENT:

- 1 x variable, single phase AC supply
- 1 x R-L-C panel
- 2 x digital multimeters
- 1 x AC current clamp
- 1 x wattmeter (25V, 0.1A)
- 4mm connection leads

NOTE:

This practical segment is to be completed by students on an individual basis. The time given per student is to be no longer than 40 minutes at the bench.

- REMEMBER -
  - WORK SAFELY AT ALL TIMES -
  observe correct isolation procedures
PROCEDURE:

1. **R-L CIRCUIT**

   1. Connect the circuit shown in figure 1.

      ![R-L Circuit Diagram]

   Figure 1

   2. Switch on the supply and adjust the variac to give a supply voltage of 25V, as indicated by the digital multimeter.

   3. Using the AC current clamp measure the current flowing into the 390Ω resistor and record in table 1.

      | Supply Voltage | Circuit Current | Circuit Power |
      |----------------|-----------------|---------------|
      | volts          | mA              | watts         |
      | 25V            |                 |               |

   4. Using the wattmeter, measure the power taken by the circuit and record in table 1.

      To determine the power indicated by the wattmeter - take the wattmeter reading directly from the scale and multiply by 0.208

      \[
      \text{Power} = \text{Wattmeter reading} \times 0.208
      \]

      \[
      = \underline{\phantom{0}} \text{watts}
      \]

   5. **Do not proceed** until the teacher checks your results and completes the progress table.

      | Progress Table 1 |
      |-------------------|
      | attempt 1 | attempt 2 | attempt 3 |
      | 5         | 2         | 0          |

   6. Switch off the power supply.
2. **R-C CIRCUIT**

1. Connect the circuit shown in figure 2.

![Circuit Diagram](image)

2. Switch on the supply and adjust the variac to give a supply voltage of 25V, as indicated by the digital multimeter.

3. Using the AC current clamp measure the current flowing into the 390Ω resistor and record in table 2.

<table>
<thead>
<tr>
<th>Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
</tr>
<tr>
<td>volts</td>
</tr>
<tr>
<td>25V</td>
</tr>
</tbody>
</table>

4. Using the wattmeter, measure the power taken by the circuit and record in table 2.

   To determine the power indicated by the wattmeter - take the wattmeter reading directly from the scale and multiply by 0.208

\[
\text{Power} = \text{Wattmeter reading} \times 0.208 = \text{_______________ watts}
\]

5. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

6. Switch off the supply, then disconnect the circuit.

7. Please return all equipment to its proper place, safely and carefully.
3. **OBSERVATIONS:**

1. Calculate the apparent power of the R-L circuit of figure 1.
   $$ S = V \times I $$

2. Calculate the power factor of the circuit of figure 1.
   $$ \lambda = \frac{P}{S} $$

3. Determine the phase angle for the circuit of figure 1.
   $$ \phi = \cos^{-1} \lambda $$

4. Draw the power triangle for the circuit of figure 1. Use the line below as a reference.
   Scales: 1mm = 0.01W, 1mm = 0.01VA and 1mm = 0.01VAR

5. From the power triangle drawn, determine the true power and reactive power.
   
   True power = _________ watts
   Reactive power = _________ VA_r
6. Calculate the true power taken by the circuit of figure 1, using the power equation.

\[ P = V \times I \times \lambda. \]

7. Compare the calculated value of true power with that determined from the power triangle. Based on your results, is the power triangle a true representation of the components of power within the circuit?

8. Calculate the apparent power of the R-C circuit of figure 2.

\[ S = V \times I \]

9. Calculate the power factor of the circuit of figure 2.

\[ \lambda = \frac{P}{S} \]

10. Determine the phase angle for the circuit of figure 2.

\[ \phi = \cos^{-1} \lambda \]
11. Draw the power triangle for the circuit of figure 2. Use the line below as a reference.
   Scales: 1mm = 0.01W, 1mm = 0.01VA and 1mm = 0.01VA

12. From the power triangle drawn, determine the true power and reactive power.
    True power = ___________ watts
    Reactive power = ___________ VA

13. Calculate the true power taken by the circuit of figure 1, using the power equation.
    \[ P = V \times I \times \lambda. \]

14. Three components were used in the two circuits tested in this assignment - a resistor, an inductor and a capacitor. List in order, starting with the component that takes the greatest power, the three components.
Power in AC Circuits

Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question and part number with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter of your choice on your answer sheet.

1. True power is measured in ______ and is a measure of the ______.
   (a) volt-amps; power supplied
   (b) volt-amps; power consumed
   (c) watts; power consumed
   (d) watts; power supplied

2. In a purely resistive circuit there is no:
   (a) apparent power
   (b) true power
   (c) average power
   (d) reactive power

3. In a power triangle, apparent power is represented by the:
   (a) side adjacent the phase angle
   (b) hypotenuse
   (c) side opposite the phase angle
   (d) cosine of the phase angle

4. Power factor is a ratio of:
   (a) reactive power to apparent
   (b) true power to reactive power
   (c) apparent power to true power
   (d) true power to apparent power
5. The power consumed in a circuit is determined by:
   (a) apparent power times the power factor
   (b) apparent power divided by the power factor
   (c) reactive power times the power factor
   (d) true power plus the power factor

SECTION B

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

1. Neatly copy the diagram of figure 1 on your answer sheet. On the diagram of figure 1, label which sides represent the:
   (a) apparent power,
   (b) true power;
   (c) reactive power;
   (d) also show which angle represents the phase angle for the circuit.

2. The power factor for a circuit can be found by either using the ratio of ___(a)___ or by the ___(b)___ of the phase angle, and uses the symbol ___(c)___.

3. True power is measured in ___(a)___, and uses the circuit symbol ___(b)___.

4. Apparent power is measured in ___(a)___, and uses the circuit symbol ___(b)___.

5. Reactive power is measured in ___(a)___, and uses the circuit symbol ___(b)___.

6. Reactive power is the power ___(a)___ to the supply when either the magnetic field of an ___(b)___ collapses or a capacitor ___(c)___.

7. Power factor has a range of ___(a)___ to ___(b)___, and can be either ___(c)___ for an inductive circuit or ___(d)___ for a capacitive circuit.

8. In a purely resistive circuit, the power factor is equal to ___(a)___, or is said to be ___(b)___ power factor.

9. If you wished to determine the power factor of a circuit, you would need a ___(a)___ to measure true power, a ___(b)___ and an ___(c)___ to measure apparent power, and you would use the ratio of ___(d)___ to calculate the power factor.
SECTION C

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple.

1. A heating element connected to a 240V, 50Hz supply draws 10A. Determine the:
   (a) the circuit phase angle. (0°)
   (b) apparent power of the circuit; (2400VA)
   (c) true power consumed by the circuit. (2400W)

2. A capacitor connected to a 240V, 50Hz supply draws 12A. Determine the:
   (a) the circuit phase angle. (90° leading)
   (b) apparent power of the circuit; (2880VA)
   (c) true power consumed by the circuit. (0W)

3. A single phase 240V, 50Hz circuit draws 5A from the power supply, and operates at a lagging power factor of 0.8. Determine the:
   (a) the circuit impedance; (48Ω)
   (b) the circuit phase angle. (36.8°)
   (c) true power consumed by the circuit; (960W)

4. A single phase load draws 2.5A from a 32V, 50Hz supply. If the power consumed by the circuit is 60W, determine the:
   (a) the circuit impedance; (12.8Ω)
   (b) apparent power of the circuit; (80VA)
   (c) circuit power factor; (0.75)
   (d) circuit phase angle; (41.4°)
   (e) reactive power of the circuit; (52.9VAr)

5. A 240V, 50Hz, single phase circuit operates at a lagging phase angle of 30°. If the power consumed is 1.5kW, use a power triangle to determine the apparent and reactive power for the circuit. Use a scale of 1mm = 15VA/W/VAr (S = 1.732kVA; Q = 863VAr)
POWER FACTOR IMPROVEMENT

PURPOSE:

To develop an understanding of the effects of low power factor and methods used for power factor improvement.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- List the disadvantages operating a single phase circuit with a low power factor.
- Name the most common method used for power factor improvement.
- Determine the capacitance required to improve the power factor of a circuit to a specified value.
- Determine the reactive power required to improve the power factor of a circuit to a specified value.
- State the local supply authority and AS/NZS 3000 requirements concerning the installation of power factor improvement equipment.

REFERENCES:

Pages 184-189.
1. **POWER FACTOR**

As discussed in the previous section, the power factor of a circuit is defined as the ratio of the _____________ power to the ________________ power.

The symbol for power factor is the Greek letter lambda __________.

Therefore, to calculate the power factor of a circuit -

\[
\lambda = \frac{P}{S}
\]

where: \( \lambda = \) power factor  
\( P = \) true power in watts  
\( S = \) apparent power in VA

When related to the power triangle it will also be found that the power factor is equal to the ________________ of the ________________.

As the phase angle for a circuit may vary between 0° and 90°, it follows that the power factor of a circuit can vary between ________________.

A power factor of _____ is known as ________________.

Power factor varies with the type of load connected, for example -
- incandescent lamps
- fluorescent lamps
- heating elements
- electric motors.
The power factor of a single device may change, depending upon operating conditions, for example -
• an induction motor at no-load and full-load.

2. EFFECTS OF LOW POWER FACTOR

To determine the effect of varying the power factor of a circuit, consider the following example.

Example: 1
A single phase 240V, 50Hz load operates with a constant power input of 1440W. If the load power factor can vary between 0.1 lag and unity, determine the current taken by the load when the power factor is -
(a) unity
(b) 0.8 lag
(c) 0.2 lag.

From the results obtained in example 1 it can be seen the lower the power factor the _____________ the current required to supply the same power.
Because of the extra current required at a low power factor, or as it is called - a poor power factor, other circuit factors are effected -

- conductors with a larger csa are required
- larger supply transformers
- higher rated switchgear
- larger voltage drops along conductors
- increased copper losses
- larger generators are required
- decreased system efficiency.

3. POWER FACTOR IMPROVEMENT

The majority of loads with a poor power factor are inductive and as a result have a lagging power factor.

To improve the power factor of such loads, either of two methods may be used -

- ________________ connected in parallel with the load (most common)
- ________________ in parallel with the load.

What constitutes an appropriate or acceptable power factor is stipulated in the New South Wales Service and Installation Rules -

```
The customer must maintain the power factor of the consumers installation at a value **not less than 0.9 lagging**. This provision does not apply in any one residential installation with less than 10 separately metered customers.

The electricity distributor may require metering of the installation, at an appropriate tariff, if the power factor of the supply taken by a consumers installation is such that either:

- the distribution system is not, or would not be used efficiently, or
- the supply to another customer is, or would be adversely affected.

The installation of power factor correction equipment, or in the case of the variation of any inductive load, must not:

- cause the power factor of the installation to become leading at any time; and
- adversely affect the operation of the electricity distributor's frequency injection load control system.
```
4. PARALLEL CONNECTED CAPACITANCE

As stated, the most common method employed for power factor correction is the parallel connected capacitor. The following examples illustrate the effect the capacitor has on the supply current and power factor of a circuit.

Example: 2

A single phase 240V, 50Hz supply is connected to a small factory. If the total current drawn from the supply is 30A at a power factor of 0.7 lag, determine the -

(a) power consumed
(b) phase angle
(c) apparent power
(d) reactive power.
(e) also draw the power triangle for the installation.

Scale 1mm = 100W, 100VA & 100VAR

Figure 2
If a capacitor bank that takes a current of 8A is connected in parallel with the load, determine the new -

(a) total circuit current (scale: 1mm = 0.5A)
(b) phase angle
(c) power factor
(d) power consumed
(e) apparent power
(f) reactive power.

Figure 3
The effects of adding the capacitor in parallel with the original load are the -

- load current and power factor are ________________________
- supply current is ______________________
- overall installation power factor is ______________________
- overall installation true power supplied is ______________________
- overall installation apparent power is ______________________
- overall installation reactive power is ______________________.

**Example: 3**

A single phase 240V, 50Hz supply is connected to a motor which draws 8A at a power factor of 0.6 lag. Determine the capacitance and VAR rating of a capacitor bank connected in parallel with the motor to improve the power factor to -

(a) unity
(b) 0.9 lag.
Scale: 1mm = 0.1A
**Example: 4**

A single phase load draws 90A at a phase angle of 45° lag from a 240V, 50Hz supply. Determine the rating of a capacitor bank to be connected in parallel with the load to achieve an installation power factor of 0.9 lag. Scale: 1mm = 1A
**Example: 5**

The circuit shown in figure 4 is to have its power factor improved to 0.85 lag by connecting a capacitor in parallel with the motor. Determine the required -

(a) capacitor current (scale: 1mm = 0.5A)
(b) capacitance
(c) capacitor VA_R rating.

![Figure 4](image-url)
POWER FACTOR IMPROVEMENT

PURPOSE:

This practical assignment will be used to examine power factor improvement via parallel connected capacitance.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- State the effect on circuit current of improving the power factor.
- Using measured values determine the -
  - apparent power
  - circuit power factor
  - circuit phase angle.
- Draw the power triangle for an AC circuit
- Determine the capacitance required to improve the power factor of a circuit to unity.

EQUIPMENT:

- 1 x fixed, single phase AC supply
- 2 x capacitors: 80-110µF and 320-400µF
- 1 x split phase induction motor and bed
- 1 x wattmeter (25V and 5A)
- 2 x digital multimeters
- 1 x AC current clamp
- 4mm connection leads

NOTE:

This practical segment is to be completed by students on an individual basis. The time given per student is to be no longer than 40 minutes at the bench.

- REMEMBER -
  - WORK SAFELY AT ALL TIMES -
  observe correct isolation procedures
PROCEDURE:

1. **MOTOR CIRCUIT - NO PF IMPROVEMENT**

   1. Connect the circuit shown in figure 1.

   ![Figure 1](image)

   2. Make sure the switch S1 is in the open position.
   3. Switch on the supply, the motor should start.
   4. After the motor has reached full speed close switch S1.
   5. Measure, and record in table 1, each of the following values -
      - supply voltage - use digital multimeter
      - supply current - use AC current clamp
      - true power - use wattmeter - to determine the power indicated by the wattmeter, take the wattmeter reading directly from the scale and multiply by 5
      - motor current - use AC current clamp.

<table>
<thead>
<tr>
<th>Supply Voltage</th>
<th>Supply Current</th>
<th>True Power</th>
<th>Motor Current</th>
<th>Capacitor Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>volts</td>
<td>amperes</td>
<td>watts</td>
<td>amperes</td>
<td>amperes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   6. **Do not proceed** until the teacher checks your results and completes the progress table.

   ![Progress Table 1](image)

<table>
<thead>
<tr>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

   7. Switch of the power supply.
2. **MOTOR CIRCUIT - LOW VALUE PARALLEL CAPACITANCE**

1. Connect the circuit as shown in figure 2, by adding a 80-110µF capacitor in parallel with the motor.

![Motor Circuit Diagram](image)

2. Make sure the switch S1 is in the open position.
3. Switch on the supply, the motor should start.
4. After the motor has reached full speed close switch S1.
5. Measure, and record in table 2, each of the following values -
   - supply voltage - use digital multimeter
   - supply current - use AC current clamp
   - true power - use wattmeter - to determine the power indicated by the wattmeter, take the wattmeter reading directly from the scale and multiply by 5
   - motor current - use AC current clamp.
   - capacitor current - use AC current clamp

<table>
<thead>
<tr>
<th>Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supply Voltage volts</strong></td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

6. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

7. Switch off the supply.
3. **MOTOR CIRCUIT - HIGH VALUE PARALLEL CAPACITANCE**

1. Connect the circuit as shown in figure 3, by replacing the 80-110µF capacitor in parallel with the motor with a 320-400µF capacitor.

![Figure 3](image)

2. Make sure the switch S1 is in the open position.
3. Switch on the supply, the motor should start.
4. After the motor has reached full speed close switch S1.
5. Measure, and record in table 3, each of the following values -
   - supply voltage - use digital multimeter
   - supply current - use AC current clamp
   - true power - use wattmeter - to determine the power indicated by the wattmeter, take the wattmeter reading directly from the scale and multiply by 5
   - motor current - use AC current clamp.
   - capacitor current - use AC current clamp.

| Table 3 |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| Supply Voltage  | Supply Current  | True Power      | Motor Current   | Capacitor       |
| volts           | amperes         | watts           | amperes         | amperes         |
|                 |                 |                 |                 |                 |

6. **Do not proceed** until the teacher checks your results and completes the progress table.

| Progress Table 3 |
|-------------------|-----------------|-----------------|-----------------|
| attempt 1         | attempt 2       | attempt 3       |
| 5                 | 2               | 0               |

7. Switch off the power supply, then disconnect the circuit.
8. Please return all equipment to its proper place, safely and carefully.
4. **OBSERVATIONS:**

1. For the circuit of figure 1, calculate the -
   (a) apparent power - $S = V.I$
   (b) power factor - $\lambda = \frac{P}{S}$
   (c) phase angle - $\phi = \cos^{-1}\lambda$

2. Draw the power triangle for the circuit of figure 1.
   Scales: 1mm = 2W, 1mm = 2VA and 1mm = 2VA $R$

3. For the circuit of figure 2, calculate the -
   (a) apparent power
   (b) power factor
   (c) phase angle.

4. Draw the power triangle for the circuit of figure 2.
5. For the circuit of figure 3, calculate the -
   (a) apparent power
   (b) power factor
   (c) phase angle.

6. Draw the power triangle for the circuit of figure 3.
   Scales: 1mm = 2W, 1mm = 2VA and 1mm = 2VA_R

7. What was the effect on circuit power factor, of connecting capacitance in parallel with the motor?
8. What was the effect on circuit current, of improving the circuit power factor?

9. Did the connection of the power factor improvement capacitors have any effect on the operation of the motor?

10. Determine the capacitance required to improve the power factor of the motor circuit to unity.
POWER FACTOR IMPROVEMENT

Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question and part number with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter of your choice on your answer sheet.

1. Poor power factor is usually caused by:
   (a) inductive loads
   (b) resistive loads
   (c) low power consumption loads
   (d) high power consumption loads

2. In a purely resistive circuit the power factor is:
   (a) 0 - 1 leading
   (b) 0 - 1 lagging
   (c) unity
   (d) reactive power

3. Power factor correction is usually achieved by:
   (a) connecting a resistor in series with the load
   (b) connecting a capacitor in parallel with the load
   (c) connecting a special electronic correcting device to the load
   (d) any of the above methods.

4. When power factor correction is used, the:
   (a) circuit current decreases
   (b) true power decreases
   (c) reactive power power increases
   (d) apparent power remains constant
5. The value of power factor correction capacitor used is often given in:
   (a) VA  
   (b) W  
   (c) VAr  
   (d) Ω (Xc)

SECTION B

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

1. List five effects of having low or poor power factor.

2. Generally, the power factor in a customer's installation should not be less than ___(a)___.
   The publication this figure is given in is the ___(b)___.

3. When power factor is improved, the circuit ___(a)___ will decrease; the apparent power for
   the circuit will ___(b)___; the true power for the circuit will ___(c)___; and the reactive
   power for the circuit will ___(d)___.

4. For the following loads, state the power factor you would expect to find.
   (a) A 40W fluorescent lamp ballast.
   (b) A 2.4kW hot water heater.
   (c) A 1kW pool pump motor.
   (d) A 60W incandescent lamp.

5. Whilst operating at no load, the power factor of an induction is ___(a)___, but will ___(b)___
   as the motor is loaded.

SECTION C

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple.

1. A 240V, 50Hz single phase inductive load operates at a constant 2.4kW input power.
   Determine the circuit current when:
   (a) the power factor is at 0.2 lag; (50A)
   (b) the power factor has been improved to 0.9 lag. (11.1A)

2. Draw a power triangle for a 1500W load operating at 0.5 lagging power factor, using a scale
   of 1mm = 50W = 50VA = 50 VAr. Also show on your power triangle the new apparent and
   reactive power if the power factor is improved to 0.95 lagging. (1600VA, 500VAr)
3. For the circuit of figure 1, determine:
   (a) the supply current (scale: 1mm = 0.25A). (19.5A)
   (b) the phase angle (16.5° lag)
   (c) the power factor; (0.96 lag)
   (d) the apparent power; (4.68kVA)
   (e) the true power; (4.49kW)
   (f) the reactive power. (1.33kVAR)

4. For the circuit of figure 2, determine:
   (a) the kVAR rating of a capacitor required to improve the power factor to 0.9 lag. Use a scale of 1mm = 100W = 100VA = 100VAr. (10.1kVAR)
   (b) the new value of apparent power. (3.4kVA)
   (c) the new value of circuit current. (14.2A)

5. For the circuit of figure 2, determine the value of capacitance required to reduce the current to half of its original value. Use a scale of 1mm = 0.5A. (345μF)

6. A single phase 240V, 50Hz circuit draws 15A from the power supply, and operates at a lagging power factor of 0.8. Determine the kVAR rating and value of capacitance required to improve the power factor to unity. (2.16kVAR; 119μF)
THREE PHASE GENERATION

PURPOSE:

To develop an understanding of the basic principles of three phase generation.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- List the advantages of a three phase system.
- Make a comparison of the voltages generated by single and three phase generators.
- Describe how the voltages of the three phase supply are generated.
- Explain the term phase sequence.
- Draw the voltage phasors for both positive and negative phase sequence.
- Calculate the line voltage of a star connected generator, given the phase voltage.
- Calculate the line voltage of a delta connected generator, given the phase voltage.
- Identify the line and phase voltages of a star or delta connected three phase system.
- Draw the star or delta connection of three coils.

REFERENCES:

Pages 197-203.
1. SINGLE PHASE GENERATION

A single phase supply is produced when a conductor moves in a circular path within a magnetic field, producing a varying electromotive force (emf). This is illustrated in figure 1.

Modern alternators are designed to generate an electromotive force (emf) having a sinusoidal waveform, that is, the emf generated obeys the sine wave law.

The ends of the windings are referred to as the start and finish. The start and finish of a winding are identified by the following labels -

- "1" represents the start of the winding, eg. A₁
- "2" represents the finish of the winding, eg. A₂.

The main advantages of a sinusoidal waveform are -

- it is the only waveform that can be transformed in a transformer and retain the same shape
- some measuring instruments only operate satisfactorily with sine waves of emf or current.

The relationship between the instantaneous value of the emf and the angle at which the conductor cuts the magnetic field is represented by the equation -

where:  

\[ v = \text{the instantaneous value of the induced emf, in volts} \] 
\[ V_M = \text{the maximum value of voltage induced, in volts} \] 
\[ \theta = \text{the angular displacement from the reference point, in degrees} \]
2. TWO-PHASE GENERATION

A polyphase system is a system which employs two or more phases.

Each winding of a polyphase machine develops the same emf but there are definite fixed phase angles between them.

A two-phase supply is obtained from an alternator which has two windings displaced 90° from one another around the circumference of the armature. Figure 2 shows a simple two-phase generator - note the separation of the starts of the two phase windings, A₁ and B₁.

The emf's of this two-phase system are represented by the sinusoidal voltage waves in figure 2 and by the phasor diagram of figure 3.

The instantaneous phase voltages for the alternator of figure 2 are described by the following equations -

• ____________________________________________
• ____________________________________________

![Figure 2](image-url)

![Figure 3](image-url)
3. THREE-PHASE GENERATION

Consider three coils, or phase windings, spaced 120° apart as shown in the simple alternator of figure 4.

![Figure 4](image)

It can be seen from figure 4 that whatever happens at a certain instant in phase A will occur 120° later in phase B, and 240° later in phase C. Thus each of the three emf's produced in this alternator has a phase difference of 120° between it and the other two, and their combination is said to produce a three-phase system.

The voltage induced in each phase winding is called the __________________________.

The instantaneous phase voltages for the alternator of figure 4 are described by the following equations -

- __________________________
- __________________________
- __________________________

The emf's produced by the elementary three-phase alternator are represented by the sinusoidal voltage waves at figure 4 and by the phasor diagram of figure 5.

![Figure 5](image)
4. **PHASE SEQUENCE**

It has already been pointed out that the emfs induced in the three phases of a three-phase system have a phase difference of 120 degrees.

The order in which the emfs in each phase reach their maximum value is called the ____________________________.

For anti-clockwise rotation of the alternator armature of figure 4, the phase sequence is _____ That is, the emf in phase B lags behind the emf in phase A by 120° and the emf in phase C lags behind the emf in phase B by 120°.

This is known as _____________________ phase sequence.

If the direction of rotation of the alternator armature is reversed, then the phase sequence becomes ________, and is known as _____________________ phase sequence.

![Figure 6](image)

Instruments called “Phase Rotation or Phase Sequence Indicators” are used frequently to determine the phase sequence of a three-phase system. See figure 7.

![Figure 7](image)
The connection of a typical Phase Rotation Indicator to a three-phase circuit, is shown in figure 8.

When the instrument is connected to the lines as shown, and the arrow rotates in a clockwise direction, the phase sequence of the currents supplied to the instrument terminals is R-W-B and therefore the mains connected to them may be coloured Red-White-Blue, respectively, or labelled Line A, Line B, Line C in the same order. Rotation of the pointer in an anticlockwise direction means that any two of the colours or letters on the mains must be interchanged.

The Rotary Phase Sequence Indicator works on the same principle of operation as the three-phase induction motor. It should be noted that manufacturers stipulate that these indicators must not be left in circuit for a period of more than one minute, as they are not designed for continuous operation.
5. **STAR CONNECTION**

In the star-connected system, the three starts or the three finishes of the phase windings are connected together to form what is known as the star or neutral point (N) as shown in figure 9.

![Figure 9](image)

The name of this system is derived from the diagram of the windings which has the form of a star. The star point is sometimes referred to as the neutral point (N) because this point is at neutral or zero potential and can be (and usually is) connected to earth. See figure 10.

![Figure 10](image)

The neutral wire has two functions -

- allow the connection of single-phase apparatus between it and one of the active conductors or lines.
- to carry any out-of-balance current.
The current in the neutral wire is the phasor sum of the currents in the phases. This current is zero in a balanced system, but even in an unbalanced system the out-of-balance current carried by the neutral is generally much less than the current in the line wires. Consequently, the neutral wire usually has only about half the cross-section of the line wires.

In a three-phase system the voltage between -

- one line and neutral is called the _________________________________ \( (V_p) \)
- any two of the line wires is called the _________________________________ \( (V_l) \).

Considering the instantaneous values of phase voltage, \( V_A, V_B \) and \( V_C \) respectively, as being positive when acting outwards from the star point, as shown in figure 11, then the instantaneous voltages between lines can be represented by the expressions -

\[
\begin{align*}
V_{AB} &= \text{____________________} \text{ (in the direction A to B).} \\
V_{BC} &= \text{____________________} \text{ (in the direction B to C).} \\
V_{CA} &= \text{____________________} \text{ (in the direction C to A).}
\end{align*}
\]

It can be seen from figure 11 that the line voltage between phases A and B of a star-connected system is equal to the phasor difference of phase voltages \( V_A \) and \( V_B \) because corresponding ends of the phase windings are joined together.
Figure 12 shows the phasor diagram for the circuit of figure 11.

Thus in a star-connected system the line voltage $= \sqrt{3}$ times the voltage per phase and there is a phase difference of $30^\circ$ between them.

The complete phasor diagram of phase and line voltages for a three-phase star-connected system is shown in figure 13.
Example: 1
A star connected three-phase generator has a phase voltage of 6350 volts. Determine the generator line voltage.

6. DELTA CONNECTION

In the delta or mesh system of connections the phase windings of a three-phase machine are connected end to end, the finish of one phase being connected to the start of the next to form a closed local circuit, as shown in figure 14.

![Figure 14](image1)

A more common representation of a delta connection is that shown in figure 15.

![Figure 10](image2)
In the delta system the line voltage is equal to the phase voltage since there is always one phase connected directly across any two lines.

The phasor diagram of voltages in a delta connected system are shown in figure 15.

Figure 15

At first sight it appears that there is a short-circuit formed by the three phases of figure 14, since the phases are all connected in series with one another and the circuit is closed.

However, since the phasor sum of any two of the phase voltages in a delta system is equal and apposite to the remaining phase voltage, as shown in figure 16, then the resultant voltage acting around the delta is zero. This condition therefore does not produce any internal circulating currents in the machine.

Figure 16

**Example: 2**

A delta connected three-phase generator is required to supply a load with a line voltage of 32V. Determine the generator phase voltage.
Example: 3
A three-phase star connected supply has a phase voltage of 240V, determine the line voltage.

Example: 4
A delta connected supply has a line voltage of 415V, determine the phase voltage.

7. ADVANTAGES OF THREE-PHASE SYSTEMS

The three-phase system has many advantages over the single-phase system; the chief of these are -

- the phase voltage generated in a three-phase alternator can be increased \( \sqrt{3} \) times by merely using the star system of connection. This results in smaller and cheaper alternators as well as less copper required for transmission.

- for a given size of machine, a three-phase alternator or motor has a greater output and a higher efficiency than a single-phase machine.

- a rotating magnetic field is obtainable from stationary coils in polyphase systems.

- three-phase motors produce a constant torque, whereas most single-phase motors have a pulsating torque.

- most single-phase motors have to be fitted with a special starting winding. Three-phase motors do not require this.

- power is constant at every instant in balanced polyphase systems.

- from a three-phase system 2, 6, 9 and 12-phase systems may be obtained readily by using transformers.

***********************
THREE PHASE SUPPLY

PURPOSE:

This practical assignment will be used to examine phase sequence and the relationship between phase and line voltages of a three phase supply.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Use a phase sequence indicator to determine the phase sequence of a three phase supply.
- Measure line and phase voltages for a three phase star connected system.
- Determine the ratio of line voltage to phase voltage for a three phase star connected supply.
- Use an oscilloscope to measure the phase angle between the phase voltages of a three phase supply.
- Draw the phasor diagram of the phase and line voltages of a three phase supply.

EQUIPMENT:

- 1 x fixed, three phase AC supply
- 1 x CRO + 2 probes
- 1 x phase sequencer indicator
- 1 x digital multimeter
- 4mm connection leads

NOTE:

This practical segment is to be completed by students on an individual basis. The time given per student is to be no longer than 40 minutes at the bench.

- REMEMBER -
  - WORK SAFELY AT ALL TIMES -
  observe correct isolation procedures
PROCEDURE:

1. **PHASE SEQUENCE INDICATOR**

1. Connect the phase sequence indicator to the three phase supply as shown in figure 1.

![Figure 1](image)

2. Switch on the supply and check the phase rotation.

   The phase rotation is (normal or reverse) _____________________.

   The phase sequence is (A-B-C or A-C-B) _______________.

3. Reverse the connections of phases B and C on the phase rotation indicator and note the effect on the indicator.

   The phase rotation indicator ______________________________________________.

4. **Do not proceed** until the teacher checks your results and completes the progress table.

   

<table>
<thead>
<tr>
<th>Progress Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

5. Switch off the power supply, then disconnect the phase sequence indicator.
2. THREE PHASE WAVEFORMS

1. Connect channel 1 of the CRO to A phase of the three phase supply, as shown in figure 2.

   ![CRO Connection Diagram]

   Figure 2

2. Adjust the channel 1 trace to be vertically centred on the screen.
3. Switch on the supply.
4. Sketch the voltage waveform for A phase on the grid shown in figure 3.

   ![Grid for Sketching Waveform]

   Figure 3

5. Measure the periodic time for the waveform displayed.

   Periodic time = ________________

6. Adjust the channel 2 trace to be vertically centred on the screen.
7. Connect channel 2 of the CRO to B phase of the three phase supply as shown in figure 4.

![Figure 4](image)

CRO Settings
Channel 1 = 10V/div
Channel 2 = 10V/div
Sweep Time = 5mS/div

8. Determine the phase angle between A phase and B phase.

\[
\text{Phase angle} = \frac{\text{Time Displacement}}{\text{Periodic Time}} \times 360
\]

9. Sketch the voltage waveform for B phase on the grid shown in figure 3. Be sure to draw the waveform for B phase with the correct phase relationship to A phase.

10. Connect channel 2 of the CRO to C phase of the three phase supply as shown in figure 5.

![Figure 5](image)

CRO Settings
Channel 1 = 10V/div
Channel 2 = 10V/div
Sweep Time = 5mS/div

11. Determine the phase angle between A phase and C phase.

\[
\text{Phase angle} = \frac{\text{Time Displacement}}{\text{Periodic Time}} \times 360
\]

12. Sketch the voltage waveform for C phase on the grid shown in figure 3. Be sure to draw the waveform for C phase with the correct phase relationship to A phase.

13. **Do not proceed** until the teacher checks your results and completes the progress table.

![Progress Table 2](image)

<table>
<thead>
<tr>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

14. Switch off the supply and disconnect the CRO.
3. LINE AND PHASE VOLTAGES

1. Using an appropriate multimeter measure the three line voltages of the three phase supply. Record the values in table 1.

<table>
<thead>
<tr>
<th></th>
<th>V&lt;sub&gt;AB&lt;/sub&gt;</th>
<th>V&lt;sub&gt;BC&lt;/sub&gt;</th>
<th>V&lt;sub&gt;CA&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>volts</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1

2. Measure the three phase voltages of the three phase supply. Record the values in table 2.

<table>
<thead>
<tr>
<th></th>
<th>V&lt;sub&gt;AN&lt;/sub&gt;</th>
<th>V&lt;sub&gt;BN&lt;/sub&gt;</th>
<th>V&lt;sub&gt;CN&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>volts</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2

3. Switch on the supply, the motor should start.

4. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th></th>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Progress Table 3

5. Switch off the power supply.

6. Please return all equipment to its proper place, safely and carefully.
4. **OBSERVATIONS:**

1. If a three phase supply was tested with a phase sequence indicator and found to have reversed phase sequence, what would have to be done to rectify the problem?

2. What is meant by the terms positive phase sequence and negative phase sequence?

3. Based on your results, what was the phase angle between the phases of the three phase supply used in this practical?

4. Draw the phasor diagram of the three phase supply tested. On your diagram show the three phase voltages and the three line voltages.
   Scale: 1mm = 1V
5. Make a comparison of the measured values of the three -
   (a) phase voltages
   (b) lines voltages.

6. Calculate the average value of the three phase voltages measured.
   \[ V_{AV} = \frac{V_a + V_b + V_c}{3} \]

7. Calculate the average value of the three line voltages measured.
   \[ V_{AV} = \frac{V_{AB} + V_{BC} + V_{CA}}{3} \]

8. Calculate the ratio of the line voltage to the phase voltage of the three phase supply and compare to the theoretical value of \( \sqrt{3} \) (1.732). Note use the average values determined in questions 6 and 7.
   \[ \text{Ratio} = \frac{\text{Line voltage}}{\text{Phase voltage}} \]

***************
NOTES:
Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question and part number with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter of your choice on your answer sheet.

1. One advantage of a three phase supply over a single phase supply is:
   (a) only three conductors are required for three phase systems
   (b) three phase voltages are lower than single phase voltages
   (c) three phase machines are larger for a given output power
   (d) three phase motors produce a constant torque

2. Positive phase sequence is represented by:
   (a) B-A-C
   (b) C-B-A
   (c) A-B-C
   (d) A-C-B

3. Single phase loads can be connected to a three phase distribution system that is:
   (a) delta connected with three wires
   (b) delta connected with four wires
   (c) star connected with three wires
   (d) star connected with four wires

4. When transmitting a given amount of power using a three phase system compared to a single phase system:
   (a) more conductor material is required
   (b) less conductor material is required
   (c) the same amount of conductor material is required
   (d) a different conductor material is required
5. In a three phase alternator, the angle between the windings is:
   (a) 120°
   (b) 180°
   (c) 90°
   (d) 60°

SECTION B

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

The order in which the phases of a three phase supply reach their maximum value is known as the ___(1)___

Two methods of connecting a three phase supply or load are ___(2)___ and ___(3)___

The colours used to identify the three phase conductors of a three phase system are ___(4)___, ___(5)___ and ___(6)___

If a three phase motor is used in preference to single phase motor of the same physical size, the three phase motor will have a ___(7)___ power output and a higher ___(8)___

A poly phase system uses ___(9)___ or more phases.

If connected in star, a three phase supply will have two voltages available, known as the ___(10)___ voltage (measured between an active conductor and the ___(11)___ conductor) and the ___(12)___ voltage (measured between any two ___(13)___ conductors).

14. List two functions of the neutral conductor in a star connected supply.

15. Figures 1 and 2 represent the windings of a three phase alternator. Show how you would connect figure 1 in star configuration, and how would connect figure 2 in delta configuration. Also show how would connect the neutral conductor in figure 1.

Both figures 1 and 2 are reproduced on page 66 for you to cut and paste to your submitted assignment sheets.
SECTION C

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple.

1. A three phase generator has a phase voltage of 19kV. Determine the generators line voltage if connected in:
   (a) star. (33kV)
   (b) delta. (19kV)

2. A three phase supply has a line voltage of 415V. Determine the supply phase voltage if connected in:
   (a) star. (240V)
   (b) delta. (415V)

3. A three phase generator has a maximum generated voltage of 340V. Determine the instantaneous value of voltage for all three phases when A phase is at an angle of 45°.
   (A phase: 240V; B phase: 88V; C phase: -328V)

*****************************************************************************
Figure 1

Figure 2
THREE PHASE STAR CONNECTED SYSTEMS

PURPOSE:

To develop an understanding of three phase star connected systems.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- Draw and also make a three-phase star connection.
- Describe the phase relationships between line and phase voltages and line and phase currents of a star connected system.
- For a three-phase star connection calculate the:
  - line and phase voltages
  - line and phase currents.
- Describe the meaning of the terms balanced load and unbalanced load and give examples of each.
- Describe the purpose of the neutral conductor and determine the value and phase relationship of the neutral current in three-phase star connected systems.
- Describe the effect of a broken neutral or high impedance in the neutral conductor of a three-phase four wire system suppling an unbalanced load where MEN earthing is employed.
- Apply the AS/NZS 3000:2000 requirements regarding neutral conductors.

REFERENCES:

Pages 203-206 and 211-215.
1. **STAR CONNECTED SOURCES**

The most commonly encountered star connected sources are the -
- three-phase AC generator
- secondary of a three-phase transformer.

Figure 1 shows the usual connection of a three-phase star connected source.

![Figure 1](image)

A source develops balanced voltages, that is, phase voltages that are equal in magnitude, but 120° out of phase with each other.

Normally the star point is connected to earth to maintain the neutral at a reference potential of zero volts.

Two voltages can be obtained -  
- \( V_L \) = line voltage in volts  
- \( V_p \) = phase voltage in volts

where:  
\( V_L = \) line voltage in volts  
\( V_p = \) phase voltage in volts

The voltage referred to in a three-phase supply is the _______________ voltage, that is, 415V is the line voltage of the distribution system.
2. LOADS CONNECTED TO A STAR SYSTEM

There are basically five types of load that may be connected to a three-phase four wire supply -

- three-phase delta connected load
- three-phase star connected load
- two-phase load (normally only found in older installations)
- single phase 415V load
- single phase 240V load.

Figure 2 illustrates the connection of the various types of load to a three-phase four wire supply.

Three phase loads may be divided into either of two categories -

- __________________________ load - the same value of impedance in each phase
- __________________________ load - different values of impedance in each phase.
Figure 3 shows the distinction between balanced and unbalanced three-phase loads.

![Figure 3](image)

3. CURRENTS IN A STAR CONNECTED SYSTEM

In a three-phase star connection there are two currents which may be referred to. These currents are known as the -

- __________________ current
- __________________ current.

Figure 4 describes the location of the currents associated with a three-phase star connected system.

![Figure 4](image)

From the diagram shown in figure 4 it can be seen that the line current is equal to the phase current in a star connected system.
For a balanced three-phase star load or a load connected to a three-phase four wire supply, the phase current may be determined provided the phase voltage and phase impedance are known -

\[ I_p = \frac{V_p}{Z_p} \]

where: \( I_p \) = phase current in amperes  
\( V_p \) = phase voltage in volts  
\( Z_p \) = phase impedance in ohms

**Example: 1**

Three heating elements, each having an impedance of 24\( \Omega \), are connected in star to a 415V three-phase supply. Determine the -

(a) phase voltage  
(b) phase current  
(c) line current.

**Example: 2**

Three 42\( \Omega \) resistors are connected in star to a three-phase supply. If the voltage measured across each resistor is 250V, determine the -

(a) phase current drawn by each resistor  
(b) each line current  
(c) line voltage.
4. **NEUTRAL CURRENT**

The neutral wire has two functions -

- allow the connection of single-phase apparatus between it and one of the active conductors or lines.
- to carry any out-of-balance current - known as the neutral current. See figure 5.

![Figure 5](image)

The current in the neutral wire is the phasor sum of the currents in the individual phases.

![Box](image)

As a result, Clause 3.5.3 of AS/NZS 3000:2000 specifies the following in relation to the size of neutral conductors -

- single phase circuits - shall have the same current carrying capacity as the associated active conductor/s
- three phase - shall have a current carrying capacity of not less than the maximum out-of-balance current of the circuit.

For a balanced three-phase star connected load the neutral current is zero.

![Figure 6](image)
Example: 3
A 415V, three-phase, 4 wire supply is connected to an unbalanced star connected load. If each phase of the load is resistive, determine the neutral current if the phase currents are -
\[ I_A = 25\text{A}, \ I_B = 10\text{A}, \ I_C = 15\text{A}. \] (Scale: 1mm = 0.5A)

Example: 4
Three single phase loads are connected between each line and neutral of a 4 wire, 415V, three-phase supply. The loads are as follows -
- A phase - a single phase motor which draws 8A at a power factor of 0.866 lag
- B phase - a capacitor run motor drawing a current of 6A at a power factor of 0.906 lead
- C phase - a resistive heating element drawing 4A.
Determine the neutral current. Scale: 1mm = 0.1A
5. EFFECTS OF A BROKEN/HIGH IMPEDANCE NEUTRAL

The neutral conductor provides a path for the out-of-balance phase currents - so maintaining the load phase voltages equal in magnitude and displaced from one another by 120°.

Figure 7 shows the phasor diagram for a star connected system with the neutral correctly connected.

With the neutral disconnected or broken the -
- system line voltages remain equal and displaced 120° from one another
- load phase voltages are not equal, may not be 120° displaced from one another
- star point is no longer at zero potential.

Figure 8 illustrates the effect of an open circuit neutral conductor.
The adverse effects of a broken/disconnected or high impedance neutral on an unbalanced three-phase star load are -

- excessive voltage across one or two phases - which could damage the load
- a dangerous voltage can be developed between the star point of the load and zero or earth potential - producing a potential danger to personal safety.

It is for the reasons outlined above that AS/NZS 3000:2000 places limitations on the use of isolation devices in neutral conductors -

- Clause 1.7.12 states - An isolation device shall interrupt all active conductors but **shall not operate in a neutral conductor**, unless permitted by Clause 2.8.2.2, or an earthing conductor.

- Clause 2.8.2.2 states - A switch or circuit breaker **shall not operate in a neutral conductor** of -
  
  (a) an earth sheath return system; or
  (b) consumers mains; or
  (c) a submain where the neutral is used for earthing of an electrical installation in an out building; or
  (d) a submain or final subcircuit in which the neutral conductor is solidly earthed. The requirements of item (d) need not apply to -
    (i) a multipole switch which includes a contact intended for connection in the neutral; or
    (ii) a switch which is linked with corresponding switches so that the neutral contact cannot remain open when the active contacts are closed; or
    (iii) a switch is employed in a fire-pump control circuit in accordance with Clause 7.10.9.4; or
    (iv) a multipole switch which is installed for the purpose of connecting an alternative supply arrangement.
THREE PHASE STAR CONNECTED LOADS

PURPOSE:

This practical assignment will be used to the characteristics of three-phase star connected, balanced and unbalanced loads, with and without a neutral connected.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Connect a three-phase load using a star connection.
- For a star connected load measure the -
  - line and phase voltages
  - line and phase currents
  - neutral current.
- Draw phasor diagrams to represent circuit conditions for three-phase star, balanced and unbalanced loads .
- Determine, using a phasor diagram, the value of the neutral current for an unbalanced load and compare it with the measured value.

EQUIPMENT:

- 1 x fixed, three-phase AC supply
- 1 x lamp panel
- 1 x AC current clamp
- 2 x digital multimeters
- 4mm connection leads

NOTE:

This practical segment is to be completed by students on an individual basis.

The time given per student is to be no longer than 40 minutes at the bench.

- REMEMBER -
- WORK SAFELY AT ALL TIMES -
observe correct isolation procedures
PROCEDURE:

1. **BALANCED LOAD**

   1. Connect the three 24V lamps in star as shown in figure 1.

   ![Figure 1](image)

   2. Close switch S₁, connecting the neutral, then switch on the three-phase supply.

   3. Using a digital multimeter set to an appropriate AC voltage range measure the three line voltages and record their values in table 1.

   The line voltages are measured across the supply terminals.

<table>
<thead>
<tr>
<th>Line Voltages</th>
<th>Phase Voltages</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{AB}</td>
<td>V_{BC}</td>
</tr>
<tr>
<td>V_{CA}</td>
<td>V_{A}</td>
</tr>
<tr>
<td></td>
<td>V_{B}</td>
</tr>
<tr>
<td></td>
<td>V_{C}</td>
</tr>
</tbody>
</table>

   4. Using a digital multimeter set to an appropriate AC voltage range measure the three phase voltages and record their values in table 1. The phase voltages are measured across each lamp.

   5. Using a digital multimeter in conjunction with the AC current clamp measure the three line currents and record their values in table 2.

   The line currents are measured where current flows out of the supply terminals.

<table>
<thead>
<tr>
<th>Line Currents</th>
<th>Phase Currents</th>
<th>Neutral Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>I_{L1}</td>
<td>I_{A}</td>
<td>I_{N}</td>
</tr>
<tr>
<td>I_{L2}</td>
<td>I_{B}</td>
<td></td>
</tr>
<tr>
<td>I_{L3}</td>
<td>I_{C}</td>
<td></td>
</tr>
</tbody>
</table>
6. Measure the three phase currents and record their values in table 2.
   The phase currents are measured where current flows into the lamps.

7. Measure the current flowing in the neutral conductor and record in table 2.

8. Open switch S₁ and observe the effect on lamp brilliance. Is there any noticeable difference?

9. Do not proceed until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

10. Switch off the power supply.

2. UNBALANCED LOAD WITH NEUTRAL

1. Connect the circuit as shown in figure 2.
   Note, C phase has two lamps connected, hence an unbalanced load.

   ![Figure 2](image)

2. Close switch S₁, connecting the neutral, then switch on the three-phase supply.

3. Using a digital multimeter set to an appropriate AC voltage range measure the three line voltages and record their values in table 3.
   The line voltages are measured across the supply terminals.
4. Using a digital multimeter set to an appropriate AC voltage range measure the three phase voltages and record their values in table 3. The phase voltages are measured across each lamp.

5. Using a digital multimeter in conjunction with the AC current clamp measure the three line currents and record their values in table 4. The line currents are measured where current flows out of the supply terminals.

6. Measure the three phase currents and record their values in table 4. The phase currents are measured where current flows into the lamps.

7. Measure the current flowing in the neutral conductor and record in table 4.

8. Observe the lamp brilliance. Is there any noticeable difference from one lamp to another?

9. **Do not proceed** until the teacher checks your results and completes the progress table.

10. Switch off the power supply.
3. **UNBALANCED LOAD WITHOUT NEUTRAL**

1. Using the circuit of figure 2, open switch $S_1$ - disconnecting the neutral, then switch on the three-phase supply.

2. Using a digital multimeter set to an appropriate AC voltage range measure the three line voltages and record their values in table 5.

<table>
<thead>
<tr>
<th>Line Voltages volts</th>
<th>Phase Voltages volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{AB}$</td>
<td>$V_A$</td>
</tr>
<tr>
<td>$V_{BC}$</td>
<td>$V_B$</td>
</tr>
<tr>
<td>$V_{CA}$</td>
<td>$V_C$</td>
</tr>
</tbody>
</table>

3. Using a digital multimeter set to an appropriate AC voltage range measure the three phase voltages and record their values in table 5.

4. Using a digital multimeter in conjunction with the AC current clamp measure the three line currents and record their values in table 6.

<table>
<thead>
<tr>
<th>Line Currents mA</th>
<th>Phase Currents mA</th>
<th>Neutral Current mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{L1}$</td>
<td>$I_A$</td>
<td>$I_C$</td>
</tr>
<tr>
<td>$I_{L2}$</td>
<td>$I_B$</td>
<td></td>
</tr>
<tr>
<td>$I_{L3}$</td>
<td>$I_C$</td>
<td></td>
</tr>
</tbody>
</table>

5. Measure the three phase currents and record their values in table 6.

6. Observe the lamp brilliance. Is there any noticeable difference from one lamp to another? If so, which lamps are brighter?

7. Using a digital multimeter measure the voltage between the star point of the load and the star point of the supply.

   Voltage between star points = ____________
8. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

9. Switch off the power supply, then disconnect the circuit.

10. Please return all equipment to its proper place, safely and carefully.

4. **OBSERVATIONS:**

1. Do the line voltages of a three-phase star connected load vary, depending on whether the load is balanced or unbalanced, or a neutral is connected?

2. What is the relationship between line and phase currents in a star connected load?

3. What is the purpose of a neutral conductor when supplying a balanced load?

4. State, in terms of phase voltages and phase currents, what will happen if the neutral conductor is disconnected from an unbalanced load?
5. Draw the phasor diagram for the balanced three-phase load. On your diagram show the three phase voltages, the three line voltages and the three phase currents. Scales: 1mm = 0.5V and 1mm = 5mA

6. Using the phase currents recorded in table 4, draw a phasor diagram to determine the value of the neutral current. Scale: 1mm = 4mA
7. Compare the measured value of neutral current determined from the phasor diagram with that measured and recorded in table 4. Do your results verify that the neutral current is equal to the phasor sum of the phase currents?

8. Using values taken from table 5, draw a phasor diagram showing the three line voltages. Scale: 1mm = 0.5V
   On the same diagram draw the three phase voltages using the following procedure -
   (a) set your compass, to scale, to a radius equal to A phase voltage, then set the point of the compass at the intersection of the line voltages $V_{AB}$ and $V_{CA}$ and scribe an arc
   (b) repeat for B phase voltage, setting the point of the compass at the intersection of the line voltages $V_{BC}$ and $V_{AB}$
   (c) repeat for C phase voltage, setting the point of the compass at the intersection of the line voltages $V_{CA}$ and $V_{BC}$.
   The point where the three arcs intersect, represents the star point of the load. Note, this will not be in the centre of the triangle formed by the three line voltages.
9. Determine from the phasor diagram the voltage between the star point of the load and the star point of the supply.

Voltage between star points = ____________

10. Compare the voltage between star points as determined from the phasor diagram with the measured value.

11. If the neutral conductor supplying an unbalanced, three-phase star connected load became open circuit, what would be the effect on the -
(a) line voltages
(b) phase voltages
(c) neutral current
(d) potential at the star point of the load.
THREE PHASE STAR CONNECTED SYSTEMS

Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question and part number with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter of your choice on your answer sheet.

1. The line voltage of a star connected system is:
   (a) $\sqrt[3]{3} \ Vp$
   (b) $\sqrt{2} \ Vp$
   (c) 0.5Vp
   (d) equal to Vp

2. The purpose of the neutral conductor in an unbalanced star connected system is to:
   (a) provide an earth point
   (b) provide a protective circuit
   (c) carry out of balance currents
   (d) reduce the supply voltage

3. In a star connected system, the phase angle between the line current and phase current is:
   (a) 120°
   (b) 90°
   (c) 30°
   (d) 0°

4. The neutral current in an unbalanced star connected load is the:
   (a) algebraic sum of the phase currents
   (b) phasor sum of the line currents
   (c) algebraic sum of the line currents
   (d) numerical difference of the phase currents
5. In a star connected system, the phase angle between the line voltage and phase voltage is:
   (a) 120°
   (b) 90°
   (c) 30°
   (d) 0°

6. If a star connected system uses 16mm² active conductors and is used to supply single phase loads, the correct size of the neutral conductor would be:
   (a) 35mm²
   (b) 25mm²
   (c) 16mm²
   (d) 10mm²

7. In a star connected supply, the neutral is connected to:
   (a) the star point
   (b) any one of the line terminals
   (c) any one of the phase terminals
   (d) where ever you like

8. The line current of a star connected system is:
   (a) \( \sqrt{3} \) Ip
   (b) \( \sqrt{2} \) Ip
   (c) 0.5Ip
   (d) equal to Ip

SECTION B

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

In a star connected supply, the neutral is normally connected to ___(1)__. This connection maintains the neutral at a reference voltage of ___(2)__.

There are two voltages available in a star connected system. The ___(3)___ voltage is measured between any ___(4)___ conductor and the neutral conductor, whilst the ___(5)___ voltage is measured between any two active conductors.

6. List the five basic types of loads that can be connected to a three phase, four wire system.
   A ___(7)___ load will have impedances of equal value, whilst an ___(8)___ load has impedances which are unequal.
   The ___(9)___ currents of a star connected load are equal to line currents.

10. List two adverse effects of a disconnected or high impedance neutral on a three phase, four wire system.
SECTION C

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple.

1. Three 57Ω resistors are connected in star to a three phase supply. If the voltage across each resistor is 240V, determine the:
   (a) phase current drawn by each resistor; (I_p = 4.21A)
   (b) current in each supply line; (I_L = 4.21A)
   (c) line voltage. (V_L = 415V)

2. Three heating elements of 36Ω are connected in star to a 415V, three phase supply. Determine the:
   (a) phase voltage across each element; (V_p = 240V)
   (b) phase current in each element; (I_p = 6.67A)
   (c) current in each supply line; (I_L = 6.67A)
   (d) power in kW dissipated by each element. (P = 1.6kW)

3. Three heating elements each of 15Ω are connected in star to a 415V, 50Hz three phase, four wire supply. Using a scale of 1mm = 0.5A, determine the value of neutral current. (I_N = 0 A)

4. A three phase, four wire system has the following single phase resistive loads connected to it:
   (a) A phase: 3A;
   (b) B phase: 2A;
   (c) C phase: 4A.
   Using a scale of 1mm = 0.1A, determine the current flowing in the neutral conductor. (I_N = 1.7A)

5. A three phase, four wire system has the following single phase loads connected to it:
   (a) A phase: a single phase motor drawing 10A at 0.9 lag
   (b) B phase: a single phase motor drawing 15A at 0.65 lag
   (c) C phase: a 2.4kW radiator
   Using a scale of 1mm = 0.25A, determine the current flowing in the neutral conductor. (I_N = 10.5A)

6. Cut and paste the diagram of figure 1 on your answer sheet. On the diagram of figure1 correctly connect the loads as shown to the three phase, four wire supply.

******************************************************************************
### Figure 1

- **3φ Delta Load**
- **3φ Star Load**
- **2φ Load**
- **Single Phase 415V Load**
- **Single Phase 240V Load**
THREE PHASE DELTA CONNECTED SYSTEMS

PURPOSE:

To develop an understanding of three phase delta connected systems.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- Draw and also make a three-phase delta connection.
- Describe the phase relationships between line and phase voltages and line and phase currents of a delta connected system.
- For a three-phase delta connection calculate the -
  - line and phase voltages
  - line and phase currents.
- Describe the effect on line current of connecting a star connected load in delta.
- List examples of delta connected loads that are found in typical power systems.

REFERENCES:

1. THE DELTA CONNECTION

In the delta or mesh system of connections the phase components are connected end to end, the finish of one phase being connected to the start of the next to form a closed local circuit, as shown in figure 1.

![Figure 1](image1)

The most commonly encountered delta connected devices are the -

- three-phase induction motor
- primary of a three-phase distribution transformer
- elements of a three phase industrial oven.

Figure 2 shows the usual representation of a three-phase delta connection.

![Figure 2](image2)

A delta connected source develops balanced voltages, that is, phase voltages that are equal in magnitude, but 120° out of phase with each other.
2. LINE and PHASE VOLTAGES

Two voltages are referred to in a delta connected load or source -

• ____________________________
• ____________________________.

Figure 3 shows the two voltages.

Examination of the circuit of figure 3 reveals that the line voltage of a three-phase delta connected system is equal to the phase voltage.

where: \( V_L \) = line voltage in volts  
\( V_p \) = phase voltage in volts

The phasor diagram for the line and phase voltages of a delta connected system are shown in figure 4.
3. **LINE and PHASE CURRENTS**

In a three-phase delta connection there are two currents that may be referred to. These currents are known as the -

- ________________ current
- ________________ current.

Figure 5 describes the location of the currents associated with a three-phase delta connected system.

![Figure 5](image-url)

From the diagram of figure 5 it can be seen the line current is equal to the phasor difference of the phase currents.

The current in line A, $I_A =$ ________________

The current in line B, $I_B =$ ________________

The current in line C, $I_C =$ ________________.

The phasor diagram representing both line and phase currents for a delta connection are shown in figure 6.

![Figure 6](image-url)
From the phasor diagram of figure 6 it can be determined that the line current of a delta connected system is equal to $\sqrt{3}$ times the phase current.

where: $I_L =$ line current in amperes  
$I_P =$ phase current in amperes

Also, there is a 30º phase angle between the line current and the associated phase current within a delta connection. The phasor diagram of figure 7 shows the phase relationship between line and phase currents.

![Figure 7](image)

To determine the phase current flowing in a delta connected load, the phase voltage and phase impedance must be known -

where: $I_P =$ phase current in amperes  
$V_P =$ phase voltage in volts  
$Z_P =$ phase impedance in ohms
Example: 1
A three-phase 415V supply is connected to a three-phase delta connected motor. If the motor phase impedance is 50Ω determine the motor -

(a) phase voltage
(b) phase current
(c) line current.

Example: 2
A three-phase delta connected furnace draws 32A from a 415V three-phase supply. Determine the furnace -

(a) phase current
(b) phase voltage
(c) phase impedance.
4. COMPARISON OF STAR and DELTA LOADS

Example: 3

Determine the line current taken from a 415V three-phase supply, if three 24Ω heating elements are connected in -

(a) star
(b) delta.

A load connected in delta will take _____ times the line current, compared to the same load connected in star.
THREE PHASE DELTA CONNECTED LOADS

PURPOSE:

This practical assignment will be used to the characteristics of three-phase star connected, balanced and unbalanced loads, with and without a neutral connected.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Connect a three-phase load using a delta connection.
- For a delta connected load measure the:
  - line and phase voltages
  - line and phase currents.
- Determine the ratio of line to phase voltage and line to phase current for a delta connected load.
- Draw the complete phasor diagram for a delta connected load, showing line and phase voltages and line and phase currents.

EQUIPMENT:

- 1 x fixed, 41.5/24V, three-phase AC supply
- 1 x 100Ω, 20W resistor panel
- 1 x AC current clamp
- 2 x digital multimeters
- 4mm connection leads

NOTE:

This practical segment is to be completed by students on an individual basis.
The time given per student is to be no longer than 40 minutes at the bench.

- REMEMBER -
  - WORK SAFELY AT ALL TIMES -
  observe correct isolation procedures
PROCEDURE:

1. **BALANCED LOAD**

   1. Connect the three 100Ω resistors in delta as shown in figure 1.

   ![Figure 1](image)

   2. Using a digital multimeter set to an appropriate AC voltage range measure the three line voltages and record their values in table 1. The line voltages are measured across the supply terminals.

   **Table 1**
   
<table>
<thead>
<tr>
<th>Line Voltages</th>
<th>Phase Voltages</th>
</tr>
</thead>
<tbody>
<tr>
<td>volts</td>
<td>volts</td>
</tr>
<tr>
<td>$V_{AB}$</td>
<td>$V_A$</td>
</tr>
<tr>
<td>$V_{BC}$</td>
<td>$V_B$</td>
</tr>
<tr>
<td>$V_{CA}$</td>
<td>$V_C$</td>
</tr>
</tbody>
</table>

   3. Using a digital multimeter set to an appropriate AC voltage range measure the three phase voltages and record their values in table 1. The phase voltages are measured across each resistor.

   4. Using a digital multimeter in conjunction with the AC current clamp measure the three line currents and record their values in table 2. The line currents are measured where current flows out of the supply terminals.

   **Table 2**
   
<table>
<thead>
<tr>
<th>Line Currents</th>
<th>Phase Currents</th>
</tr>
</thead>
<tbody>
<tr>
<td>mA</td>
<td>mA</td>
</tr>
<tr>
<td>$I_{L1}$</td>
<td>$I_A$</td>
</tr>
<tr>
<td>$I_{L2}$</td>
<td>$I_B$</td>
</tr>
<tr>
<td>$I_{L3}$</td>
<td>$I_C$</td>
</tr>
</tbody>
</table>

   5. Measure the three phase currents and record their values in table 2. The phase currents are measured where current flows out of the resistors.
6. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

7. Switch off the power supply, then disconnect the circuit.

8. Please return all equipment to its proper place, safely and carefully.

2. **OBSERVATIONS:**

1. Using the results of this practical, determine the ratio of the line voltage to the phase voltage for a delta connected load.

   \[
   \text{Ratio} = \frac{V_L}{V_p}
   \]

   Theoretically, \( \frac{V_L}{V_p} = 1 \)

2. Using the results of this practical, determine the ratio of the line current to the phase current for a balanced delta connected load.

   \[
   \text{Ratio} = \frac{I_L}{I_p}
   \]

   Theoretically, \( \frac{I_L}{I_p} = \sqrt{3} = 1.732 \)

3. Does the equation \( I_L = \sqrt{3} \times I_p \) apply to an unbalanced delta connected load? If not, why not?
4. Draw to scale, the complete phasor diagram for the balanced, delta connected load connected in this assignment. On your diagram show the -
   - line and phase voltages
   - line and phase currents.

Scales: 1mm = 0.5V and 1mm = 0.01A

Note: Assume the load phase angle to be 0°.
**THREE PHASE DELTA CONNECTED SYSTEMS**

Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question and part number with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

**SECTION A**

In the following statements one of the suggested answers is best. Place the identifying letter of your choice on your answer sheet.

1. To correctly connect three windings labelled A1 - A2, B1 - B2 and C1 - C2 in delta, the wiring connections would be:
   () A2 to B1, B2 to C1 and C2 to A1
   () A1 to B1 to C1
   () A1 to B2, B1 to C2 and C1 to A2
   () B2 to C2 to A2

2. In a delta connected system, the phase angle between the line current and phase current is:
   () 120°
   () 90°
   () 30°
   () 0°

3. The line voltage of a delta connected system is:
   () $\sqrt{3} V_p$
   () $\frac{V_p}{\sqrt{3}}$
   () 0.5Vp
   () equal to $V_p$

4. When connecting a delta system, a neutral conductor is not used as:
   () there are no out of balance currents in delta
   () a neutral connection would create a short of one active to neutral
   () two voltages can be obtained without a neutral
   () there would be no return path for the phase currents
5. In a star connected system, the phase angle between the line voltage and phase voltage is:
   (0) 120°
   (0) 90°
   (0) 30°
   (0) 0°

6. The line current of a star connected system is:
   (0) \( \sqrt{3} \) Ip
   (0) Ip / \( \sqrt{3} \)
   (0) 0.5Ip
   (0) equal to Ip

SECTION B

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

The ratio of line currents to phase currents in a delta connected system is ___(1)___

2. List three commonly connected delta loads.

If a delta connected load is unbalanced the line currents will be ___(3)___

If a star connected load is reconnected in delta configuration, the line currents in delta will be ___(4)___ the line currents in star.

A delta connected system will always be a ___(5)___ wire system, whilst a star connected system can be a ___(6)___ wire or a ___(7)___ wire system.

The ratio of line voltages to phase voltages in a delta connected system is ___(8)___

SECTION C

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple.

1. Three 47Ω heating elements are connected in delta to a 415 volt three phase supply. Determine the:
   (0) phase current drawn by each resistor; \( I_p = 8.83A \)
   (0) current in each supply line; \( I_L = 15.3A \)
   (0) line voltage. \( V_L = 415V \)
2. Three heating elements of 36Ω are connected in delta to a 415V, three phase supply. Determine the:
   () phase voltage across each element; \( V_p = 415V \)
   () phase current in each element; \( I_p = 11.5A \)
   () current in each supply line; \( I_L = 20A \)
   () power in kW dissipated by each element. \( P = 8.3kW \)

3. A 415V, delta connected three phase transformer has 20A flowing in each of its windings. If connected to a delta connected three phase load, determine:
   () the current in each line; \( I_L = 34.6A \)
   () the impedance in each phase of the load. \( Z = 20.75\Omega \)

4. **Cut and paste** the diagram of figure 1 on your answer sheet.
   () On the diagram of figure 1 correctly connect the supply transformer in delta and the load in delta, then connect the load to the supply;
   () For the circuit of figure 1, determine the current flowing in the windings of the supply transformer. \( I_p = 2.39A \)
Figure 1
THREE-PHASE POWER & POWER FACTOR

PURPOSE:

To develop an understanding of true, reactive and apparent power in balanced and unbalanced three-phase systems. Also, the power factor of three-phase balanced loads will be dealt with.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- Calculate the true, reactive and apparent power in three-phase balanced loads.
- Calculate the true power taken by a three-phase unbalanced load.
- Calculate the power factor of a three-phase balanced load.
- Determine the capacitance and $\text{VAR}$ rating of a capacitor bank to improve the power factor of a three-phase balanced load to a specified value.

REFERENCES:

Pages 215-216, 219-220.
1. SINGLE PHASE POWER

As discussed in previous sections of this module, the true power dissipated by a single phase load is dependent upon three factors -

- supply voltage
- circuit current
- circuit phase angle or power factor.

\[ \lambda = \cos \phi \]

Figure 1

To calculate the power taken by a single phase load, the following equations may be used -

2. THREE PHASE LOAD - TRUE POWER

(i) Balanced, star connected load

Consider a three-phase star connected, balanced load, as shown in figure 2.

Figure 2

The power consumed by one phase of the load can be determined using phase values and the single phase power equation -
Therefore, the power consumed by the three phases of the load would be -

Applying the voltage and current relationships for a star connection -

Phase voltage, $V_p =$  
Phase current, $I_p =$

By substitution -

The total power consumed by a three-phase, balanced, star connected load can be determined using the equation -

where:  
$P =$ total power consumed in watts  
$V_L =$ line voltage in volts  
$I_L =$ line current in amperes  
$\lambda =$ load power factor.

(ii) Balanced, delta connected load:

Consider a three-phase delta connected, balanced load, as shown in figure 3.

![Figure 3](image)

The power consumed by one phase of the load can be determined using phase values and the single phase power equation -

Therefore, the power consumed by the three phases of the load would be -
Applying the voltage and current relationships for a delta connection -

\[ V_p = \text{Phase voltage}, \quad I_p = \text{Phase current} \]

By substitution -

The total power consumed by a three-phase, balanced, delta connected load can be determined using the equation -

\[ P = \frac{V_L \times I_L \times \lambda}{\sqrt{3}} \]

where:
- \( P \) = total power consumed in watts
- \( V_L \) = line voltage in volts
- \( I_L \) = line current in amperes
- \( \lambda \) = load power factor.

Thus in any balanced three-phase system, the total power is given by -

\[ P = V_L 	imes I_L \times \lambda \sqrt{3} \quad \text{or} \quad P = V_L 	imes I_L \times \lambda \]

**Example: 1**

A three-phase induction motor draws a line current of 13A from a 415V, three-phase supply. If the power factor of the motor at this load is 0.9 lag, determine the power consumed by the motor.

\[ P = 415 \times 13 \times 0.9 \times \sqrt{3} \]

**Example: 2**

A 415-volt, three-phase, star-connected alternator supplies a current of 200 amperes at a power factor of 0.86 lag. Determine the power supplied.

\[ P = 415 \times 200 \times 0.86 \times \sqrt{3} \]
Example: 3
An 11kV star connected AC generator supplies a 250kW, three-phase balanced load. If the load power factor is 0.85 lag, determine the -
(a) line current
(b) generator phase current.

(ii) Unbalanced, star or delta connected load:
For unbalanced star and delta connected loads, the total power consumed is equal to the sum of the powers consumed by each phase -

where: \( P_T \) = total power consumed by the load in watts
\( P_A \) = power consumed by A phase in watts
\( P_B \) = power consumed by B phase in watts
\( P_C \) = power consumed by C phase in watts

Example: 4
Determine the total power consumed by the star connected load shown in figure 5.
3. THREE-PHASE LOAD - APPARENT & REACTIVE POWER

For single phase circuits -

apparent power, _______________________
reactive power, _______________________

In the case of balanced three-phase circuits, the determination of the total apparent and reactive powers is usually achieved using line values -

<table>
<thead>
<tr>
<th>Apparent power</th>
<th>Reactive power</th>
</tr>
</thead>
</table>

As was the case with single phase circuits, the three components of power associated with three-phase circuits may be represented by the power triangle.

![Power Triangle](image)

**Example: 5**

A balanced, three-phase, 415V load takes a line current of 32A at a phase angle of 32° lag. Determine the -

(a) total true power
(b) total apparent power
(c) total reactive power
(d) true, apparent and reactive power taken by one phase.
4. POWER FACTOR OF A POLYPHASE CIRCUIT

The power factor of a circuit is the ratio of the ______________ power to the ______________ power.

For a three-phase circuit -

\[
\text{Power factor, } \lambda = \frac{\text{True power}}{\text{Apparent power}} = \quad \text{______________________}
\]

Therefore, the power factor of a three-phase system may be calculated from a knowledge of the true power and values of line voltage and line current.

Considering balanced circuits only, \( \phi \) is the angle of phase difference between the voltage and current in all the phases of the load, regardless of how the windings are connected at the supply.

The term “power factor” where applied to an unbalanced polyphase system has no real meaning. Balanced circuits only will be considered in this course.

The power factor of a three-phase system can also be read from the scale of an instrument called a power factor meter.

**Example: 6**

A 415 volt, three-phase, delta-connected, induction motor takes 43.88 kW and a current of 69.4 amperes. Determine the power factor and phase angle at which the motor operates.
Example: 7
A three-phase balanced load is supplied from an 11kV, 50Hz supply and takes 3MW of power when operating at a power factor of 0.5 lag. Determine the -
(a) line current taken by the load
(b) overall rating of a capacitor bank to improve the power factor to 0.9 lag
   Scales: 1mm = 50kW, 1mm = 50kVA and 1mm = 50kVAR
(c) capacitance per phase of a star connected capacitor bank
(d) line current of the load after power factor improvement is applied.
THREE PHASE POWER

PURPOSE:

This practical assignment will be used to compare the power taken by star and delta connected loads.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Calculate the power taken from a three-phase supply by a three-phase balanced load, when connected in -
  - star
  - delta.
- Using one wattmeter, determine the total power dissipated by a three-phase balanced load.
- Compare calculated and measured values of total power.
- Compare star and delta connected loads in terms of line current and total power.

EQUIPMENT:

☐ 1 x fixed, 41.5/24V, three-phase AC supply
☐ 1 x 100Ω, 20W resistor panel
☐ 1 x AC current clamp
☐ 2 x digital multimeters
☐ 1 x wattmeter (25V and 50V, 0.5A)
☐ 4mm connection leads

NOTE:

This practical segment is to be completed by students on an individual basis. The time given per student is to be no longer than 40 minutes at the bench.

- REMEMBER -
- WORK SAFELY AT ALL TIMES -
  observe correct isolation procedures
PROCEEDURE:

1. **STAR CONNECTED LOAD**

   1. Connect the three 100Ω resistors in star as shown in figure 1. Include a wattmeter in your circuit to measure the power taken by C phase.

   ![Figure 1](image)

   2. Switch on the three-phase supply.

   3. Using a digital multimeter set to an appropriate AC voltage range measure the three line voltages and record their values in table 1. The line voltages are measured across the supply terminals.

<table>
<thead>
<tr>
<th>Line Voltages (volts)</th>
<th>Phase Voltages (volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{AB}$</td>
<td>$V_{BC}$</td>
</tr>
<tr>
<td>$V_{CA}$</td>
<td>$V_A$</td>
</tr>
<tr>
<td></td>
<td>$V_B$</td>
</tr>
<tr>
<td></td>
<td>$V_C$</td>
</tr>
</tbody>
</table>

   4. Using a digital multimeter set to an appropriate AC voltage range measure the three phase voltages and record their values in table 1. The phase voltages are measured across each resistor.

   5. Using a digital multimeter in conjunction with the AC current clamp measure the three line currents and record their values in table 2. The line currents are measured where current flows out of the supply terminals.

<table>
<thead>
<tr>
<th>Line Currents (mA)</th>
<th>Phase Currents (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{L1}$</td>
<td>$I_A$</td>
</tr>
<tr>
<td>$I_{L2}$</td>
<td>$I_B$</td>
</tr>
<tr>
<td>$I_{L3}$</td>
<td>$I_C$</td>
</tr>
</tbody>
</table>

   6. Measure the three phase currents and record their values in table 2. The phase currents are measured where current flows into the resistors.
7. Using measured phase values, calculate the power taken by C phase and record in table 3. Assume a power factor of unity (purely resistive circuit).

\[ P_C = V.I.\lambda \]

Table 3

<table>
<thead>
<tr>
<th>Calculated Values of Power</th>
<th>Measured Values of Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>C phase power watts</td>
<td>Total power watts</td>
</tr>
<tr>
<td></td>
<td>C phase power watts</td>
</tr>
<tr>
<td></td>
<td>Total power watts</td>
</tr>
</tbody>
</table>

8. Using measured line values, calculate the total power taken by the three-phase load and record in table 3.

\[ P_T = \sqrt{3}.V.I.\lambda \]

9. Using the wattmeter measure the power taken by C phase and record in table 3.

10. Based on the power taken by C phase, determine the total power taken by the load and record in table 3.

\[ P_T = P_C \times 3 \]

11. Do not proceed until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

12. Switch off the power supply.
2. DELTA CONNECTED LOAD

1. Connect the three 100Ω resistors in star as shown in figure 2. Include a wattmeter in your circuit to measure the power taken by C phase.

![Diagram of Delta Connected Load]

2. Switch on the three-phase supply.

3. Using a digital multimeter set to an appropriate AC voltage range measure the three line voltages and record their values in table 4.
   The line voltages are measured across the supply terminals.

   Table 4
<table>
<thead>
<tr>
<th>Line Voltages volts</th>
<th>Phase Voltages volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{AB}$</td>
<td>$V_{BC}$</td>
</tr>
</tbody>
</table>

4. Using a digital multimeter set to an appropriate AC voltage range measure the three phase voltages and record their values in table 4.
   The phase voltages are measured across each resistor.

5. Using a digital multimeter in conjunction with the AC current clamp measure the three line currents and record their values in table 5.
   The line currents are measured where current flows out of the supply terminals.

   Table 5
<table>
<thead>
<tr>
<th>Line Currents mA</th>
<th>Phase Currents mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{L1}$</td>
<td>$I_{L2}$</td>
</tr>
</tbody>
</table>

6. Measure the three phase currents and record their values in table 5.
   The phase currents are measured where current flows into the resistors.
7. Using measured phase values, calculate the power taken by C phase and record in table 6. Assume a power factor of unity (purely resistive circuit).

\[ P_C = V.I.\lambda \]

\[ \lambda = \frac{V.I.}{PC} \]

| Table 6 |
|---|---|
| Calculated Values of Power | Measured Values of Power |
| C phase power watts | Total power watts | C phase power watts | Total power watts |

8. Using measured line values, calculate the total power taken by the three-phase load and record in table 6.

\[ P_T = \sqrt{3} \cdot V.I.\lambda \]

9. Using the wattmeter measure the power taken by C phase and record in table 6.

10. Based on the power taken by C phase, determine the total power taken by the load and record in table 6.

\[ P_T = P_C \times 3 \]

11. **Do not proceed** until the teacher checks your results and completes the progress table.

| Progress Table 2 |
|---|---|---|
| attempt 1 | attempt 2 | attempt 3 |
| 5 | 2 | 0 |

12. Switch off the power supply, then disconnect the circuit.

13. Please return all equipment to its proper place, safely and carefully.
3. OBSERVATIONS:

1. Using the results of this practical, determine the ratio of the line current taken in delta to that taken in star.

\[ \text{Ratio} = \frac{I_{L\text{DELTA}}}{I_{L\text{STAR}}} \quad \text{Theoretically, } \frac{I_{L\text{DELTA}}}{I_{L\text{STAR}}} = 3 \]

2. Using the results of this practical, determine the ratio of the total power taken in delta to that taken in star.

\[ \text{Ratio} = \frac{P_{T\text{DELTA}}}{P_{T\text{STAR}}} \quad \text{Theoretically, } \frac{P_{T\text{DELTA}}}{P_{T\text{STAR}}} = 3 \]

3. In the case of a balanced load, does the total power taken from the supply equal three times the power taken by one phase? Use results from this assignment to verify your answer.

4. Based on your results, is it possible to measure the power taken by a three-phase load using a single wattmeter?
THREE PHASE POWER & POWER FACTOR

Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter of your choice on your answer sheet.

1. The minimum number of fixed wattmeters required to measure the power consumed by a three phase, four wire unbalanced system is:
   () one
   () two
   () three
   () four

2. If the phase currents and power factors are equal in a three phase system, then the system is said to be:
   () balanced
   () unbalanced
   () star connected
   () delta connected

3. The power factor for a balanced three phase system is the ratio of:
   () true power to reactive power
   () apparent power to reactive power
   () true power to apparent power
   () reactive power to true power
4. The total power in a three phase system can be measured using a single wattmeter provided the:
   () load is balanced
   () load is unbalanced
   () load is star connected
   () neutral is not connected

5. Power factor correction applied to a three phase system is applied to:
   () all three phases
   () the phase with the largest power factor
   () the phase with the smallest power factor
   () any one of the three phases

SECTION B

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

If a three phase load is unbalanced, then either the currents or the ___(1)___ in all three phases of the load will be ___(2)___

In a three phase system, the power consumed by one phase can be used to determine the total power if the system is ___(3)___

If a three phase load is ___(4)___, the power consumption of each phase must be determined separately then added together to determine the ___(5)___ power consumption of the system.

If a load is connected in star, the power consumed can be determined by P = ___(6)___, but if the load is connected in delta, the power consumed can be determined by P = ___(7)___

If a three phase system is balanced, then the power taken by one phase will be ___(8)___ the total power taken by the system.

When connecting capacitors for power factor correction, the capacitors are connected in either ___(9)___ or ___(10)___ configuration across the supply.
SECTION C

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple.

1. A three phase load draws 16A when connected to a 415 volt three phase supply with a 0.8 lagging power factor. Determine the power consumed by the load. (9.2kW)

2. A three phase induction motor consumes 12kW at 0.759 power factor when connected to a 415V, three phase supply. Determine the:
   () line current drawn by the load; (22A)
   () apparent power of the circuit; (15.8kVA)
   () reactive power of the circuit; (10.3kVAr)

3. For the circuit of figure 1, determine the:
   () total power consumed by the circuit. (4968W)
   () total reactive power for the circuit; (2130VAr)
   () total apparent power for the circuit; (5405VA)

4. A 6.6kV, three phase delta connected induction motor takes 500kW and draws a current of 50.5A. Determine the:
   () power factor of the motor; (0.866lag)
   () phase angle of the motor currents; (30°)
   () reactive power of the load. (288kVAr)

5. When supplied from a 132kV, three phase supply, an aluminium smelter takes 6MW when operating at a power factor of 0.437 lag. Determine the:
   () line current taken by the load; (60A)
   () MVAr rating of a capacitor bank required to improve the overall power factor to 0.94 lagging; (10MVAr) Scale: 1mm = 100kW = 100kVA = 100kVAr
   () capacitance per phase of a star connected capacitor bank; (1.8μF)
   () line current for the smelter when the power factor improvement is applied. (28A)
THREE-PHASE POWER MEASUREMENT & HARMONICS

PURPOSE:

To develop an understanding of the measurement of power in a three-phase system and the effects of harmonics within a power system.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- Draw the circuit diagram showing the connections required to measure power consumed by a three-phase load using one, two or three wattmeters.
- Determine the total power consumed by a three-phase load given the wattmeter readings, using one, two or three wattmeters.
- Determine the power factor of a three-phase balanced load using the two wattmeter method.
- Define the term harmonic in relation to the sinusoidal waveform of an AC power system.
- List sources that produce harmonics in AC systems.
- Describe problems that arise in AC systems as a result of harmonics and how these are overcome.

REFERENCES:

Pages 215-219.
1. INTRODUCTION

The power taken by a load may be measured using a wattmeter, provided the wattmeter is connected to measure two quantities, the -

- _____________ flowing to the load
- _____________ applied to the load.

The connection of the wattmeter for the measurement of the power taken by a single phase load is shown in figure 1.

![Figure 1](image)

The wattmeter measures the _____________ power taken by the load, and so in effect via its operation carries out the calculation -

\[
P = V \times I \times \lambda
\]

where:  
- \( P = \) true power in watts
- \( V = \) load voltage in volts
- \( I = \) load current in amperes
- \( \lambda = \) load power factor

The purpose of this section is to show the measurement of power in a three phase system is based on the same principles as that applied to a single phase system. A number of variations will be covered, these include three-phase power measurement using -

- a single wattmeter
- three wattmeters
- two wattmeters.
2. THREE-PHASE LOAD POWER

Irrespective of whether a three-phase load is star or delta connected, the total power taken by the load is equal to the \[ \text{sum} \] of the powers taken by each phase.

![Figure 2](image_url)

The power taken by each phase is given by -

\[
\begin{align*}
P_A &= \text{_____________ watts} \\
P_B &= \text{_____________ watts} \\
P_C &= \text{_____________ watts}
\end{align*}
\]

The total power consumed by the load is -

\[
\text{P}_T = \text{_____________ watts}
\]

where:

\[
\begin{align*}
P_T &= \text{total power consumed in watts} \\
P_A &= \text{power consumed by A phase in watts} \\
P_B &= \text{power consumed by B phase in watts} \\
P_C &= \text{power consumed by C phase in watts}
\end{align*}
\]

Example: 1
An unbalanced three-phase load takes 1450W from A phase, 2760W from B phase and 800W from C phase. Determine the total power supplied.

Example: 2
A balanced three-phase load consumes 3000W in each phase. Determine the total power consumed.
3. SINGLE WATTMETER METHOD OF MEASURING THREE-PHASE POWER

If the load is balanced, one wattmeter can be used -

- and its reading multiplied by three,
or
- the wattmeter may be calibrated to indicate three times the single-phase power.

Figure 3 shows the connection of a single wattmeter to measure the power taken by A phase. Note, the wattmeter is connected to measure phase values - that is, phase voltage and phase current.

If the fourth wire or neutral is not available and one wattmeter is used, then an artificial star point may be made by connecting two resistors in star with the voltage coil of the wattmeter as shown in figure 4.

Each of these resistors must have the same resistance as the voltage coil of the wattmeter. This arrangement ensures the artificial star point or neutral is at zero potential and the voltage across the meter coil is the phase voltage of the system.
Example: 3
A balanced, inductive, star connected load is supplied from a three-phase 415V supply. If the line current is 15A and a wattmeter connected to A phase indicates 2500W, determine -
(a) total power taken by the load
(b) the impedance of each phase
(c) the power factor and phase angle of the load.

4. THREE WATTMETER METHOD OF MEASURING THREE-PHASE POWER

In this method, three wattmeters are used, each having its current coil connected in series with one line as shown in figure 5.

The voltage (or potential) coils are connected between each line and the star point or neutral wire, if one is available.
Each wattmeter measures the power in its own phase so that the total power is the sum of the three readings.

If the neutral, or fourth wire is not available and three wattmeters are used, then the three potential coils can be joined together to form a star point as shown in figure 6.

It is immaterial whether the phase windings of the load are connected in star or delta; the total power is always the sum of the three wattmeter readings.

**Example: 4**
A three-phase, unbalanced star connected load is connected to a three-phase 415/240V supply. Each phase of the load is inductive. If
\[ I_A = 10A \text{ and } P_A = 2000W, \quad I_B = 15A \text{ and } P_B = 1600W, \quad I_C = 12A \text{ and } P_C = 2700W \]
determine the-

(a) total power dissipated by the load

(b) impedance of each phase

(c) power factor and phase angle of each phase.
5. TWO WATTMETER METHOD OF MEASURING THREE-PHASE POWER

When two wattmeters are used, each meter has its current coil in a different line. The voltage coils are connected at one end to their respective current coils, the other ends being connected to the third line which has no current coil in it, as shown in figure 7.

![Figure 7](image_url)

Note that, in figure 7, wattmeter $W_1$ is shown with its current coil in line C and wattmeter $W_2$ with its current coil in line A. This arrangement was chosen to suit an equation which allows the determination of the load power factor from the wattmeter readings.

For the method of connections shown, the algebraic sum of the two wattmeter readings will give the total power.

\[
PT = W_1 + W_2
\]

where:  
- \( P_T \) = total power in watts  
- \( W_1 \) = reading of wattmeter 1 in watts  
- \( W_2 \) = reading of wattmeter 2 in watts

The two-wattmeter method of three-phase power measurement gives correct results for star and delta -
- balanced or unbalanced loads

\[
\begin{cases} 
\text{at any power factor and for any waveform} \\
\end{cases}
\]

The only restriction is that there must not be a neutral conductor.
When power measurements are made with two wattmeters over a wide range of power factors with lagging and leading currents, on balanced loads, it is observed the meters behave in the following manner.

At unity power factor -
- at unity power factor (when $\phi = 0^\circ$) the readings are equal: $W_1 = W_2$.

For lagging power factors -
- between 0.5 and 1 - $W_2$ reads less than meter $W_1$
- equal to 0.5 (when $\phi = 60^\circ$) - $W_2$ reads zero and $W_1$ reads the whole power in the circuit.
- below 0.5 (when $\phi$ exceeds 60º) - wattmeter $W_2$ reads backwards (ie. negative).

For leading power factors -
- between 0.5 and 1 - $W_1$ reads less than meter $W_2$
- equal to 0.5 (when $\phi = 60^\circ$) - $W_1$ reads zero and $W_2$ reads the whole power in the circuit.
- below 0.5 (when $\phi$ exceeds 60º) - wattmeter $W_1$ reads backwards (ie. negative).

Under the conditions where one wattmeter reads a negative value (reads backward), either the current coil or the voltage coil circuit, usually the latter, must be reversed by a switch and the forward reading thus obtained subtracted from the other meter reading to obtain total power.

It is the necessity for obtaining the algebraic sum of the readings, that leads to the subtraction of reversed or negative readings.

Figure 8 illustrates the variation in wattmeter readings with changes in power factor.
Example: 5

The power input to an induction motor supplied from 415V mains is measured by the two wattmeter method. At full-load, one wattmeter indicates 10kW, and the other 7kW. At light load, one wattmeter indicates 2.5kW and the other indicates 800 watts (reversed). Determine the power input to the motor -

(a) at full-load
(b) at light load.

Note that, unless otherwise specified, we will consider the wattmeter with the greater reading as $W_1$.

6. POWER FACTOR FROM TWO WATT-METER METHOD OF MEASURING THREE-PHASE POWER

When the load is balanced the power factor of the circuit can be obtained from the two wattmeter readings, if the meters are connected to measure three-phase power with the connection previously described, that is, with the meters numbered in the same order as the phase sequence of currents in the lines containing the current coils. It can be proved for these conditions that -

$$\phi = \text{circuit phase angle in degrees}$$

$$W_1 = \text{reading of wattmeter 1 in watts}$$

$$W_2 = \text{reading of wattmeter 2 in watts}$$

Example: 6

If with lagging current, $W_1$ indicates 1,200 watts and $W_2$ indicates 800 watts, determine the circuit phase angle and power factor.
Example: 7
If with a leading current, $W_1$ indicates, -400 watts and $W_2$ indicates 1,200 watts, determine the circuit phase angle and power factor.

Example: 8.
The power input to a three-phase induction motor running light is measured by the two wattmeter method. The readings of the instruments are: $W_1 = 580$ watts, $W_2 = 220$ watts (reversed). Determine the power input and the power factor.

7. HARMONICS

As we connect more electronic devices to our power systems, the “quality” of the power becomes more important. “Quality” can be defined many ways. Two characteristics which are very desirable in power systems are -

- stable voltages
- undistorted waveforms.

You have probably heard the term ‘harmonics and from this term the following questions arise -

- What are harmonics?
- How do they affect single and three phase circuits?
- What are the symptoms of harmonics?
- How do I address these systems?
- How do I solve the problem?
The concept of harmonics is a method used to analyse and explain distorted waveforms found in -

- computers
- electronic ballasts
- variable frequency drives
- power systems
- other equipment which have modern “transformer-less” power supplies.

In the case of an AC circuit, the voltage applied is a sinewave which operates 50Hz. Generating authorities go to great lengths to control the generation of voltage. Producing a sinewave that has (relatively) constant amplitude and constant frequency, see figure 9.

If this voltage is applied to a linear device, such as a resistor, the magnitude of current may be determined by the application of Ohm’s Law. Expressed mathematically \( I = \frac{V}{R} \) amperes. Expressed graphically, the current also takes the form of a sinewave. Ohm’s Law dictates the frequency of the current wave will also be 50Hz, as shown in figure 10.

Since an applied voltage sinewave will cause a sinusoidal current to be drawn, systems which exhibit this behaviour are called linear systems. Examples include -

- incandescent lamps
- heaters
- motors.
Some modern equipment, however does not fit this category and gives rise to what are known of as non-linear systems -

- computers
- variable frequency drives (VFD)
- electronic ballasts
- uninterruptable power supply systems (UPS).

In these systems, the resistance is not a constant and in fact, varies during each cycle of the applied sinewave. This occurs because the resistance of the device is not a constant. The resistance in fact, changes during each sinewave.

The power supply of these systems contain solid state devices such as -

- power transistors
- thyristors - silicon controlled rectifiers (SCRs) or triacs.

These circuits in which these devices are connected draw current in pulses, as shown in figure 11.

![Figure 11](image)

When voltage is applied the current drawn is zero until a critical “firing voltage” is reached. At this firing voltage, the circuit allows current to be conducted. This current typically increases over time until the peak of the sinewave and decreases until the critical firing voltage is reached on the “downward side” of the sinewave. The device then shuts off and current goes to zero. The same thing occurs on the negative side of the sinewave with a second negative pulse of current being drawn.

The current drawn then is a series of positive and negative pulses, and not the sinewave drawn by linear systems.

Some systems have different shaped waveforms such as square waves. These types of systems are often called non-linear systems. Once these pulse currents are formed, it is difficult to analyse their effect.
In order to solve this problem we turn to harmonics. Simply stated, it can be proved -

*Any periodic waveform can be expressed as a series of sinewaves with varying frequencies and amplitudes.*

That is, we can create a series of sinewaves of varying frequencies and amplitudes to model the series of current pulses, in which -

- the frequencies used are multiples of the fundamental frequency, 50Hz
- these multiple frequencies are called harmonics
- the second harmonic is two times 50Hz = 100Hz
- the third harmonic is 150Hz and so on.

In three phase power systems, the “even” harmonics (second, fourth, sixth, etc.) cancel, so we only need deal with the “odd” harmonics. Figure 12 shows what these harmonics look like.

[Figure 12]

Figure 12 shows the fundamental and the third harmonic. As you can see, there are three cycles of the third harmonic for each single cycle of the fundamental. If we add these two waveforms, we get a non-sinusoidal waveform.

This resultant now starts to form the peaks that are indicative of the pulses drawn by switch mode power supplies. This resultant waveform is very similar to figure 11. If we add in other harmonics, we can model any distorted periodic waveform, such as the square waves generated by UPS of VFD systems.
It's important to remember these harmonics are simply a model. The pulses or square waves, or other distorted waveforms are what we actually see if we connect an oscilloscope to the circuit. Figure 12 shows a typical distorted current waveform.

![Figure 12](image)

These current pulses will also begin to distort the voltage waveforms in the supply system. This voltage distortion can cause premature failure of electronic devices. Figure 13 shows a typical distorted voltage waveform.

![Figure 13](image)

On three phase systems, the three phases of the power system are 120° out of phase, as a result -

- 50Hz (fundamental) currents actually cancel in the neutral
- for balanced 50Hz currents on the three phase conductors, the neutral current will be zero
- the neutral current (assuming only 50Hz is present) will never exceed the highest loaded phase conductor. Thus, our overcurrent protection on our phase conductors also protects the neutral conductor.
When harmonic currents are present, the situation is different -
- the third harmonic of each of the three phase conductors is exactly in phase
- when these harmonic currents come together in the neutral, rather than cancel, they actually add - therefore, more current in the neutral conductor than on phase conductors. The neutral conductor is no longer protected.

Harmonic currents create heat which over a period of time will -
- raise the temperature of the neutral conductor
- overheat the transformer that supplies the power system.

These are the most obvious symptoms of harmonics.

Other symptoms include:
- nuisance tripping of circuit breakers
- malfunction of UPS systems and generator systems
- metering problems
- computer malfunctions
- overvoltage problems.

Several remedies are available to address these symptoms:
- oversizing neutral conductors - in three phase circuits with shared neutrals, it is common to oversize the neutral conductor up to 200% when the load served consists of non-linear loads.
- using separate neutral conductors - on three phase branch circuits, another philosophy is to not combine neutrals, but to run separate neutral conductors for each phase conductor.
- oversizing transformers and generators - the oversizing of equipment for increased thermal capacity should also be used for transformers and generators which serve harmonics-producing loads.
- special transformers - there are several special types of transformer connections which can cancel harmonics. For example, the traditional delta-star transformer connection will trap all the triplen harmonics (third, ninth, fifteenth, twenty-first, etc.) in the delta. Additional special winding connections can be used to cancel other harmonics on balanced loads.
- filtering - while many filters do not work particularly well at this frequency range, special electronic tracking filters can work very well to eliminate harmonics. These filters are presently relatively expensive but should be considered for thorough harmonic elimination.
- special metering - standard clamp-on ammeters are only sensitive to 50 Hertz current, so they only tell part of the story. New “true RMS” meters will sense current up to the kHz range. These meters should be used to detect harmonic currents. The difference between a reading on an old style clamp-on ammeter and a true RMS ammeter will give an indication of the amount of harmonic current present.
The measures described above only solve the symptoms of the problem. To solve the problem we must specify low harmonic equipment. This is most easily done when specifying electronic ballasts. Several manufacturers make electronic ballasts which produce less than 15% harmonics. These ballasts should be considered for any ballast retrofit or any new project.

Until low harmonics computers are available, segregating these harmonic loads on different circuits, different switchboards or the use of transformers should be considered.

This segregation of “dirty” and “clean” loads is fundamental to electrical design today.

8. **CLASSIFICATION OF HARMONICS**

Each harmonic has a name, frequency and sequence. The sequence refers to phasor rotation with respect to the fundamental (F), that is, in an induction motor -

- a positive sequence harmonic would generate a magnetic field that rotated in the same direction as the fundamental
- a negative sequence harmonic would rotate in the reverse direction
- zero sequence harmonics are the odd multiples of the 3rd harmonic - called triplens.

The first nine harmonics along with their effects are listed below:

<table>
<thead>
<tr>
<th>Name</th>
<th>F</th>
<th>2nd*</th>
<th>3rd</th>
<th>4th*</th>
<th>5th</th>
<th>6th*</th>
<th>7th</th>
<th>8th*</th>
<th>9th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>50</td>
<td>100</td>
<td>150</td>
<td>200</td>
<td>250</td>
<td>300</td>
<td>350</td>
<td>400</td>
<td>450</td>
</tr>
<tr>
<td>Sequence</td>
<td>+ve</td>
<td>-ve</td>
<td>0</td>
<td>+ve</td>
<td>-ve</td>
<td>0</td>
<td>+ve</td>
<td>-ve</td>
<td>0</td>
</tr>
</tbody>
</table>

* Even harmonics disappear when waves are symmetrical

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Rotation</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>Forward</td>
<td>Heating of conductors, circuit breakers, etc</td>
</tr>
<tr>
<td>Negative</td>
<td>Reverse</td>
<td>Heating as above + motor problems</td>
</tr>
<tr>
<td>Zero</td>
<td>None</td>
<td>Heating, + they add in the neutral of a 3φ, 4-wire system</td>
</tr>
</tbody>
</table>

**************************************************
TWO-WATTMETER METHOD OF POWER MEASUREMENT

PURPOSE:

This practical assignment will be used to determine the power factor of a balanced three-phase load over a range from lagging to leading current values.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Connect two wattmeters to allow the determination of load power factor.
- Using two wattmeters, determine the total power dissipated by a three-phase balanced load.
- Identify the condition known as unity power factor from the readings taken from the two wattmeters.

EQUIPMENT:

☐ 1 x fixed, 41.5/24V, three-phase AC supply
☐ 1 x 41.5V, three-phase synchronous motor
☐ 1 x AC current clamp
☐ 2 x digital multimeters
☐ 2 x wattmeter (50V, 1A)
☐ 4mm connection leads

NOTE:

This practical segment is to be completed by students on an individual basis.

The time given per student is to be no longer than 40 minutes at the bench.

- REMEMBER -
- WORK SAFELY AT ALL TIMES -
observe correct isolation procedures
PROCEDURE:

1. CIRCUIT CONNECTION

1. Connect the circuit as shown in figure 1.
   Note: Wattmeter W₁ is connected in C phase.

![Circuit Diagram](image)

Figure 1

2. Do not proceed until the teacher checks your circuit and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

3. Open switches S₁ and S₂.
4. Switch on the DC supply and adjust to provide a field voltage of 20V.
5. Switch on the three-phase supply - the motor will start.
6. Close switches S₁ and S₂ - the wattmeters will indicate the power taken by the motor.
7. Slowly decrease the field voltage until W₂ indicates 0 watts. Under this condition W₁ indicates the total power taken by the motor. Complete each of the following steps -
   - record this voltage in table 1, under the heading Field Voltage
   - using a digital multimeter in conjunction with the AC current clamp measure the line current in B phase and record the value in table 1
   - record the power indicated by W₁ in the appropriate column of table 1

the power indicated by a wattmeter = the wattmeter reading x 2.

8. Increase the field voltage to the next whole volt above the value set in step 7. For example, if the field voltage in step 7 was 13.2 volts, increase the field voltage to 14V.
9. Record the following values in table 1 -
   - field voltage
   - W₁ and W₂
   - line current.
10. Repeat the procedure, increasing the field voltage in steps of 1V.
    As the field voltage is increased the wattmeter readings will change, with $W_1$ decreasing
    and $W_2$ increasing.

<table>
<thead>
<tr>
<th>Table 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Voltage volts</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

11. Continue with the procedure until the condition is reached where $W_1 = W_2$ - this
    corresponds to unity power factor. For this condition record the following values -
    - field voltage
    - $W_1$ and $W_2$
    - line current.

12. Increase the field voltage in steps of 1V until the condition is reached where $W_1 = 0W$
    and $W_2$ indicates the total power taken by the motor.

13. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

14. Switch off the power supply.

15. Switch off the power supply, then disconnect the circuit.

16. Please return all equipment to its proper place, safely and carefully.
2. **OBSERVATIONS:**

1. For each set of readings taken, calculate the total power taken by the motor.
   \[ P_t = W_1 + W_2 \]
   Record your values in the appropriate column of table 1.

2. For each set of readings taken, determine the circuit phase angle (\( \phi \)), using the equations:
   \[ \tan \phi = \frac{\sqrt{3} W_1 \cdot W_2}{W_1 + W_2} \]
   \[ \phi = \tan^{-1} \text{ of } \tan \phi \]
   Record your values in table 1.

3. For each set of readings taken, determine the power factor of the load.
   \[ \lambda = \cos \phi \]
   Record your values in table 1.

4. When the reading of \( W_2 \) is greater than that of \( W_1 \), the value of \( \tan \phi \) obtained has a negative value. What does the negative sign tell you about the power factor?

5. When the conditions exist such that one wattmeter indicates 0W and the other the total power, what is the circuit phase angle?

6. What is the power factor of the circuit when the readings of the two wattmeters are equal?

7. Can the two wattmeter method of power measurement be used to measure the power taken by a three-phase, 4-wire load? Explain why?
8. On the axis provided in figure 2 plot the power factor versus the ratio of the wattmeter readings.

![Figure 2](image_url)
Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question and part number with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

SECTION A

In the following statements one of the suggested answers is best. Place the identifying letter of your choice on your answer sheet.

1. The power factor of a three phase load can be determined using the two watt meter method provided:
   (a) the power factor is greater than 0.5
   (b) the neutral is not connected
   (c) the load is balanced
   (d) there is no current in the middle phase

2. An indication that harmonics are present in a three phase supply system would be:
   (a) erratic motor behaviour
   (b) low transformer currents
   (c) low neutral currents
   (d) lower power consumption

3. When measuring power using the two watt meter method, if W1 reads zero, and W2 reads 100W, the circuit power factor will be:
   (a) unity
   (b) zero
   (c) 0.5 leading
   (d) 0.5 lagging
4. When measuring a balanced three phase load using the two wattmeter method, if both wattmeter readings are equal, the power factor is equal to:
   (a) unity  
   (b) zero  
   (c) 0.5 leading  
   (d) 0.5 lagging

5. To measure the total power in any three phase unbalanced load, the minimum number of wattmeters required is:
   (a) 1  
   (b) 2  
   (c) 3  
   (d) 4

SECTION B

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

List the relative wattmeter readings (ie comparing W1 to W2 etc..) that will give the following power factor indications when using the two wattmeter method of measuring power:

1 Unity  
2 0.7 leading  
3 0.5 lagging  
4 0.25 leading  
5 0.1 lagging

6. Neatly reproduce the diagram of figure 1 on your answer sheet, then complete the circuit of figure 1 to show how you would connect the circuit to use one wattmeter to measure the total power for the circuit.

7. Neatly reproduce the diagram of figure 1 on your answer sheet, then complete the diagram to show how you would connect the circuit to use two wattmeters to measure the total power for the circuit.

The frequency of a fourth harmonic with a fundamental frequency of 50Hz is ____(8)___

9. List four symptoms that would indicate the presence of harmonics in a three phase supply system.

The term “triplens” is used to describe harmonics that are the ____(10)___
SECTION C

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple.

1. A single wattmeter is connected to A phase of a balanced 415V, three phase star connected heating load and is used to measure the total power consumption. If the wattmeter indication is 1500W, determine the:
   (a) total power consumed by the load (4.5kW)
   (b) impedance of each phase of the load. (38.3Ω)

2. A balanced, delta connected induction motor is supplied from a three phase 415V supply. If the line current to the motor is 30A, and a single wattmeter connected to C phase indicates 4.5kW, determine the:
   (a) apparent power of the supply; (21.56 kVA)
   (b) total power taken by the load; (13.5 kW)
   (c) power factor and phase angle of the load; (0.626 lag, 51.3° lag)
   (d) reactive power of the load; (16.8 kVAr)
   (e) impedance of each phase of the load. (23.9Ω)

3. A 415V, inductive three phase load has its total power consumption measured using the two wattmeter method. If W1 indicates 250W and W2 indicates 1000W, determine the:
   (a) total power taken by the load; (1250W)
   (b) phase angle for the load; (46.1° lag)
   (c) factor of the load; (0.693 lag)

4. A 415V uses the two wattmeter method to measure its total power consumption. If W1 indicates -750W and W2 indicates 2 kW, determine:
   (a) the Total power supplied to the load; (1250W)
   (b) the Power factor for the load; (0.254 lead)
   (c) the Line current for the load; (6.85A)
   (d) the Impedance of each phase of the load if the load is star connected. (35Ω)

Explain why the power factor is leading from these results.

*******************************************************************************
STAR-DELTA INTERCONNECTED SYSTEMS

PURPOSE:

To develop an understanding of three-phase star-delta interconnected systems. The effects of an open circuit in one line will also be covered.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this section the student will be able to:

- Identify interconnected star-delta systems.
- Determine values of -
  - phase and line voltage
  - phase and line current
  - power and power factor
  - phase impedance
  for three-phase interconnected star-delta systems.
- Determine current and voltage relationships of a star connected load if one line becomes open circuited.
- Determine current and voltage relationships of a delta connected load if one line becomes open circuited.
- State the effect of reversing a phase winding in a star or delta connected alternator or transformer.
- Connect star and delta systems.

REFERENCES:

Pages 203-219 and 222.
1. INTRODUCTION

Any combination of three-phase groupings may be connected together by three lines in three-phase systems. Table 1 shows the possible combinations of supply source and load circuits.

<table>
<thead>
<tr>
<th>Supply Source</th>
<th>Load Circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Star</td>
<td>Star</td>
</tr>
<tr>
<td>Star</td>
<td>Delta</td>
</tr>
<tr>
<td>Delta</td>
<td>Star</td>
</tr>
<tr>
<td>Delta</td>
<td>Delta</td>
</tr>
</tbody>
</table>

The determination of values associated with star-delta interconnected systems is based on the basic laws previously established for star and delta connections.

Figure 1

<table>
<thead>
<tr>
<th>Star Connection</th>
<th>Delta Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_p =$</td>
<td>$I_p =$</td>
</tr>
<tr>
<td>$I_L =$</td>
<td>$I_L =$</td>
</tr>
<tr>
<td>$V_L =$</td>
<td>$V_L =$</td>
</tr>
<tr>
<td>$P_T =$</td>
<td>$P_T =$</td>
</tr>
<tr>
<td>$P_T =$</td>
<td>$P_T =$</td>
</tr>
<tr>
<td>$I_N =$</td>
<td>$I_T =$</td>
</tr>
</tbody>
</table>
2. **STAR-DELTA SUPPLIES and LOADS**

The following examples illustrate the application of the basic laws related to star and delta connections to determine the values associated with a complete three-phase system.

**Example: 1**
A three-phase, 415V, delta connected AC generator supplies three 24Ω heating elements connected in delta. Determine the -

(a) load phase current  
(b) generator line current  
(c) total power delivered by the generator  
(d) power taken by each phase of the load.

![Diagram of star and delta connections](image.png)

Figure 2
Example: 2
A three-phase, 415V, delta connected AC generator supplies three 24Ω heating elements connected in star. Determine the -

(a) load phase current
(b) generator line current
(c) total power delivered by the generator
(d) power taken by each phase of the load.
**Example: 3**

A star connected AC generator with a line voltage of 415V supplies a three-phase delta connected load. If the impedance of each phase of the load is 20.5Ω, determine the:

(a) load phase current
(b) line current
(c) generator phase current
(d) total power taken by the load (assume λ = 0.5 lag per phase)
(e) total power delivered by the generator.

![Generator Load Diagram]

Figure 4
**Example: 4**

A three-phase transformer with a star connected secondary delivers a 415V supply to an unbalanced star connected load. The load consists of the following -
- A phase - an impedance of 24\(\Omega\) with a power factor of 0.5 lag
- B phase - an impedance of 48\(\Omega\) with a power factor of 0.866 lag
- C phase - an impedance of 80\(\Omega\) with unity power factor.

Determine the -
(a) current in each phase of the load
(b) neutral current (scale: 1mm = 0.15A)
(c) generator phase currents
(d) total power delivered by the generator.

![Diagram of a three-phase system with a star connected load](image)
3. EFFECTS OF SOURCE PHASE REVERSAL

A correctly connected three-phase source, either a transformer or generator, produces three phase voltages equal in magnitude, but displaced by 120ºE from one another. This is illustrated in the phasor diagram of figure 6.

![Figure 6](image)

The question then arises, what happens if one phase of a source is incorrectly connected? The following details the effects.

**Star Connection**

If the ends of one phase winding of a star connection are reversed, the starts of the three windings are no longer 120º apart. If the connections of C phase are reversed, the phase voltage of C phase has a phase shift of 180º. The phasor diagram of figure 7 illustrates the effect.

![Figure 7](image)

From figure 7 it should be seen that -

- the phase voltages are equal but not separated by 120º and the phase sequence has changed to A-C-B
- the line voltages are not equal, nor 120º apart.
Figure 8 shows the magnitude and displacement of the line voltages for a star connection with C phase reversed.

As shown, the line voltages are not equal and do not have symmetrical displacement. Therefore, if one phase winding is reversed, the system is unsatisfactory for a balanced three-phase supply.

To test for a reversed phase in a star connected source, use a multimeter to measure the -
- three phase voltages - should be equal
- three line voltages - should be equal and have a value $\sqrt{3}$ times the phase voltage.

**Delta Connection**

When a three-phase source is correctly delta connected, the resultant voltage acting in the delta loop is ________ volts. This can be proven by taking the phasor sum of the phase voltages, as in figure 9.
A simple test that can be carried out on a three-phase source to prove the correct connection of the delta arrangement is to leave one junction open and connect a voltmeter across the open winding ends, as in figure 10.

![Figure 10](image)

If the delta connection has been made correctly, the voltmeter will indicate ______ volts.

If the start and finish of one phase of a delta connected source are reversed, the voltage associated with that phase is given a phase reversal of 180°. As a result -

- the phases are no longer in their correct phase sequence
- the phase voltages no longer have the correct phase relationship to one another.

The phasor diagram to describe this condition, assuming C phase is reversed, is shown in figure 11.

![Figure 11](image)

When one phase of a delta connection is reversed and a voltmeter is connected across the open ends of the delta, as in figure 10, the voltmeter will indicate a voltage equal to -

__________________________________________________________________________

If a delta connection is formed with one phase reversed, the resulting voltage acting around the delta loop is no longer zero volts. Therefore, a high circulating current will flow in the windings and cause them to quickly burn out.
4. EFFECT OF THE LOSS OF ONE SUPPLY LINE

To examine the effects of the loss of one supply line to a three-phase load, consider the following examples.

**Example: 5**
Three 41.5Ω heating elements are connected in delta to a 415V three-phase supply. Determine the -

(a) phase current if the supply is maintained on all three supply lines
(b) phase voltages if a fuse in one supply line operates
(c) phase currents if a fuse in one supply line operates.
**Example: 6**

Three 24Ω heating elements are connected in star to a 415V three-phase supply. Determine the phase voltage across each element if -

(a) supply is maintained on all three supply lines

(b) one line fuse operates and the neutral is connected to the load star point

(c) one line fuse operates and the neutral is not connected to the load star point.
NOTES:
STAR-DELTA INTERCONNECTED SYSTEMS

PURPOSE:

This practical assignment will be used to determine the power factor of a balanced three-phase load over a range from lagging to leading current values.

TO ACHIEVE THE PURPOSE OF THIS SECTION:

At the end of this practical assignment the student will be able to:

- Identify star and delta connections within a three-phase system.
- Measure values of line and phase voltage, line and phase current and neutral current.
- Identify the effects of an open circuit line in a star connected system.
- Identify the effects of a reversed phase winding in a supply source.

EQUIPMENT:

- 1 x fixed, 41.5/24V, three-phase AC supply
- 1 x three-phase transformer bank
- 1 x lamp panel (24V, 5W lamps)
- 1 x AC current clamp
- 2 x digital multimeters
- 4mm connection leads

NOTE:

This practical segment is to be completed by students on an individual basis. The time given per student is to be no longer than 40 minutes at the bench.

- REMEMBER -
- WORK SAFELY AT ALL TIMES -
observe correct isolation procedures
PROCEDURE:

1. STAR-STAR SYSTEM - NORMAL OPERATION

1. Identify the type of three-phase connection, that is star or delta, used for the -
   - transformer primary
   - transformer secondary
   - load.
   in the circuit of figure 1.
   Write the type of connection in the spaces provided on the diagram.

2. Connect the circuit shown in figure 1.

   41.5V Three Phase Supply

   ![Diagram of a star-star system circuit]

   Figure 1

3. **Do not proceed** until the teacher checks your circuit and completes the progress table.

   Progress Table 1
<p>|</p>
<table>
<thead>
<tr>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

4. Using a digital multimeter set to an appropriate voltage range measure the load line voltages. Record the values in table 1.
5. Measure the load phase voltages. Record the values in table 1.

6. Using the AC current clamp in conjunction with a digital multimeter, measure the load line currents and record in table 2.

Table 1

<table>
<thead>
<tr>
<th>Line Voltages volts</th>
<th>Phase Voltages volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{AB}</td>
<td>V_{BC}</td>
</tr>
<tr>
<td>V_{CA}</td>
<td>V_{A}</td>
</tr>
<tr>
<td></td>
<td>V_{B}</td>
</tr>
<tr>
<td></td>
<td>V_{C}</td>
</tr>
</tbody>
</table>

7. Measure the load phase currents and record in table 2.

8. Measure the load neutral current.

Load neutral current I_N = ___________

9. **Do not proceed** until the teacher checks your results and completes the progress table.

Table 2

<table>
<thead>
<tr>
<th>Line Currents mA</th>
<th>Phase Currents mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>I_L1</td>
<td>I_A</td>
</tr>
<tr>
<td>I_L2</td>
<td>I_B</td>
</tr>
<tr>
<td>I_L3</td>
<td>I_C</td>
</tr>
</tbody>
</table>

Progress Table 2

<table>
<thead>
<tr>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

10. Switch off the power supply.
2. **STAR-STAR SYSTEM - C PHASE OPEN CIRCUIT**

1. Open circuit line C by removing the lead connecting C phase of the transformer to the load, as shown in figure 2.

![Figure 2](image_url)

2. Switch on the supply and measure the load line and phase voltages and record in table 3.

<table>
<thead>
<tr>
<th>Line Voltages</th>
<th>Phase Voltages</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{AB}$</td>
<td>$V_A$</td>
</tr>
<tr>
<td>$V_{BC}$</td>
<td>$V_B$</td>
</tr>
<tr>
<td>$V_{CA}$</td>
<td>$V_C$</td>
</tr>
</tbody>
</table>

3. Switch off the power supply.
4. Disconnect the neutral connecting the star point of the load to the star point of the transformers.
5. Switch on the supply and measure the load line and phase voltages, record in table 4.

<table>
<thead>
<tr>
<th>Line Voltages</th>
<th>Phase Voltages</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{AB}$</td>
<td>$V_A$</td>
</tr>
<tr>
<td>$V_{BC}$</td>
<td>$V_B$</td>
</tr>
<tr>
<td>$V_{CA}$</td>
<td>$V_C$</td>
</tr>
</tbody>
</table>
6. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

7. Switch off the power supply.

3. **STAR SYSTEM - REVERSED PHASE**

1. Connect the circuit as shown in figure 3, with C phase reversed.

![Figure 3](#)

2. Switch on the supply and measure the secondary line and phase voltages. Record in table 5.

<table>
<thead>
<tr>
<th>Table 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line Voltages</td>
</tr>
<tr>
<td>volts</td>
</tr>
<tr>
<td>$V_{AB}$</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

3. **Do not proceed** until the teacher checks your results and completes the progress table.

<table>
<thead>
<tr>
<th>Progress Table 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>attempt 1</td>
</tr>
<tr>
<td>5</td>
</tr>
</tbody>
</table>

4. Switch off the power supply.
4. DELTA SYSTEM - REVERSED PHASE

1. Reconnect the transformer secondaries in delta, as shown in figure 4.

![Diagram of Delta System - Reversing Phase](image)

2. Switch on the supply and measure the line and phase voltages of the transformer secondaries. Record in table 6.

<table>
<thead>
<tr>
<th>Line Voltages</th>
<th>Phase Voltages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volts</td>
<td>Volts</td>
</tr>
<tr>
<td>$V_{AB}$</td>
<td>$V_A$</td>
</tr>
<tr>
<td>$V_{BC}$</td>
<td>$V_B$</td>
</tr>
<tr>
<td>$V_{CA}$</td>
<td>$V_C$</td>
</tr>
</tbody>
</table>

3. Switch off the power supply.

4. Connect a digital multimeter to measure the resultant delta voltage as shown in figure 5.

![Diagram of Delta System - Reversing Phase with Multimeter](image)
5. Switch on the supply and measure the resultant delta voltage.

   Delta correctly connected - resultant voltage = ___________

6. Switch off the supply.

7. Reconnect the circuit as shown in figure 6 - with the connections to C phase reversed.

   41.5V Three Phase Supply

   ![Figure 6](image)

8. Switch on the supply and measure the resultant delta voltage.

   Delta incorrectly connected - resultant voltage = ___________

9. **Do not proceed** until the teacher checks your results and completes the progress table.

   **Progress Table 5**

<table>
<thead>
<tr>
<th>attempt 1</th>
<th>attempt 2</th>
<th>attempt 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

10. Switch off the power supply, then disconnect the circuit.

11. Please return all equipment to its proper place, safely and carefully.

5. **OBSERVATIONS:**

   1. Assuming the lamps connected in the circuit of figure 1 operate at unity power factor, calculate the total power delivered to the lamps.
2. If the transformer secondaries in the circuit of figure 1 were delta connected, what would have been the line voltage to the load? Explain why.

3. If one line feeding a star connected load open circuits, what are the effects on the load. Assume a neutral is connected between the supply and load.

4. If one line feeding a star connected load open circuits, what are the effects on the load. Assume there is no neutral connected to the load.

5. List the effects of a reversed phase winding in a star connected source.

6. List the effects of a reversed phase winding in a delta connected source.
STAR-DELTA INTERCONNECTED SYSTEMS

Please note the following requirements in relation to tutorial work -

- All tutorial work is to be completed on ruled A4 pad paper, with multiple pages stapled together. Write on one side only of the answer sheets, and all work is to be completed in ink.
- In the case of multiple choice type questions, the question number and corresponding answer letter are to be written on the answer sheet.
- In the case of short answer type questions, the question and part number with your word or phrase choice is to be written on the answer sheet.
- All relevant equations and working are to be shown in the case of calculation type questions.

SECTION A

For the following questions, complete the statements on your answer sheet with the word or phrase you think fits best.

1. Refer to questions 2 & 3 below when setting your answer to this question. Draw 2 circuit diagrams, one for a star connected load and one for a delta connected load. Fully label your diagrams to include:
   (a) line and phase currents;
   (b) line and phase voltages;
   (c) phase impedance's;
   (d) a single wattmeter to measure A phase power;
   (e) labelling of the line terminals supplying each load.

2. Below your circuit diagram for a star connected load, complete a table to show how you would determine the following:
   (a) phase current;
   (b) line current;
   (c) line voltage;
   (d) total power for a balanced load;
   (e) total power for an unbalanced load;
   (f) current in the neutral conductor.

3. Below your circuit diagram for a delta connected load, complete a table to show how you would determine the following:
   (a) phase current;
   (b) line current;
   (c) line voltage;
   (d) total power for a balanced load;
   (e) total power for an unbalanced load.
4. Describe the effect of a phase reversal in a:
   (a) star connected supply;
   (b) a delta connected supply.

5. Describe how you can test for a phase reversal in a delta connected load. Accompany your answer with a circuit diagram.

6. Describe the effect of the loss of one supply line in a:
   (a) star connected supply;
   (b) delta connected supply.

SECTION B

The following problems are to be solved with the aid of a calculator. Any working for a problem is to be fully shown. Where a problem involves calculating for circuit conditions, a neat and fully labelled circuit diagram (if not provided) is to accompany the question. Answers are to be expressed in the appropriate multiple or sub-multiple.

1. For the circuit of figure 1, if the load represents heating elements, determine the:
   (a) load phase current; (19.2A)
   (b) line current supplying the load; (15.9A)
   (c) total power consumed by the load. (11.48kW)

2. A star connected 415V emergency generator supplies a delta connected three phase induction motor. If the motor winding impedance's are 20Ω each and the motor operates at a lagging power factor of 0.773, determine the:
   (a) phase currents in the motor; (20.75A)
   (b) phase currents in the generator; (36A)
   (c) total power consumed by the load (20kW)

3. For the circuit of figure 2, determine the:
   (a) voltage across each phase of the load; (V_b=V_c=415V; V_a=V_c=207.5V)
   (b) current in each phase of the load; (I_a=I_b=2.5A; I_c=5A)
4. For the circuit of figure 3, determine the:
   (a) line voltage output of the transformer secondary; (200V)
   (b) phase voltage of the heating load; (115V)
   (c) line current from the transformer to the load; (5A)
   (d) power used by the load, assuming the power factor is unity (1.732kW)

5. A delta connected transformer secondary supplies a star connected inductive load. The power consumption of the load is measured at 15kW at a power factor of 0.695. If the phase current of the load is 30A, determine the:
   (a) line voltage output of the transformer; (415V)
   (b) phase voltage of the load; (240V)
   (c) phase angle for the load; (46° lag)
   (d) current in the transformer windings. (17.32A)
****NOTES****