

PSL20

Transformer Trainer

User Guide




© **TecQuipment Ltd 2017**

Do not reproduce or transmit this document in any form or by any means, electronic or mechanical, including photocopy, recording or any information storage and retrieval system without the express permission of TecQuipment Limited.

TecQuipment has taken care to make the contents of this manual accurate and up to date. However, if you find any errors, please let us know so we can rectify the problem.

TecQuipment supplies a Packing Contents List (PCL) with the equipment. Carefully check the contents of the package(s) against the list. If any items are missing or damaged, contact TecQuipment or the local agent.

Symbols used in this manual

NOTE		<i>Important information</i>
CAUTION		<i>Failure to carry out this instruction could cause damage to the apparatus, other equipment, personal property, or the environment.</i>
WARNING		<i>Failure to carry out this instruction could cause personal injury.</i>

Contents

The Transformer Trainer

Introduction	1
Description	2
Main Supply Switch	2
Variable Autotransformer	2
The Upper Panel	2
The Lower Panel	3
The Dy11 Transformer (TX2)	3
The Educational Transformers (TX3, TX4, TX5 and TX6)	3
TX3	3
TX4, TX5 and TX6	3
Multifunction Instruments, Transducers and Sockets on the Lower Panel	4
Current Transformers (CTs)	4
Loads	5
Sockets to the Back of the Trainer	7
The Protection Relay and Optional External Relays	7
The Power System Laboratory (PSL)	7
Connecting the PSL Together	9
Technical Details	10
General	10
Transformers	10
Installation and Assembly	12
Location	12
Weight and Lifting	12
Assembly	12
Electrical Supply	12
Phase Sequence	13
Voltage Adjustment	13
Recommended Transformer Connections and Theory	
Winding Connections in the Single-phase Transformers	15
High Voltage (Primary) Winding - Coils in Series	15
High Voltage (Primary) Winding - Coils In Parallel	16
Low Voltage (Secondary) Winding - Coils in Series	17
Low Voltage (Secondary) Winding - Coils in Parallel	18
Tertiary Winding	19
Connections for three-phase experiments with the Single Phase Transformers	20
Star-star connection Yy0 (HWS5 and LWS1)	20
Delta-delta connection Dd0 (HWS1 and LWS1)	21
Delta-Star, Dy1, Phasor Displacement - 30° (HWS1 and LWS5)	21
Delta-Star, Dy11, Phasor Displacement + 30° (HWS1 and LWS5)	22
Star-Delta, Yd1 (HWS4 and LWS1)	22

Star-interconnected Star connection, Yz1 (HWS4 and Interconnected)	23
Open Delta Three Phase to Three Phase	23
Open Delta Three Phase to Single Phase	24
The Scott Three to Two-phase Connections	24
Connection Diagram	25
Phasor Diagram	25
Winding Connections in the Three-Phase Transformer	26
High Voltage Winding. Coils In Series For Delta Connection	26
High Voltage Winding. Coils In Parallel For Star Connection	26
Low Voltage Winding. Coils In Series	27
Low Voltage Winding. Coils In Parallel	28
The Le Blanc Three to Two Phase Connection	29
The Three Phase Transformer	29
Three-phase transformer winding connections	29
Connection Diagrams and Symbols	31
Harmonics and Unbalanced Loads	32
Single-Phase Transformers	32
Three-Phase Transformers	32
Harmonics in Different Three-phase Connections	33
Star-star Connection - Three wire system (no neutral connection from supply)	33
Star-star Connection - Three-phase four-wire system	34
Delta-Delta Connection - Dd0 Phasor Displacement 0 Degrees Group 1	34
Delta-Star and Star-Delta Connections	35
Tertiary Windings and Star-Star Connection	36
Other Uses of the Tertiary	36
Rating of Tertiary Winding	36
Star-interconnected Star Connections	37
Unbalanced loads in star-interconnected star connection	38
Rating of star-interconnected star connection	38
Protection Relays and Systems	
The MiCOM Relays	39
Relay Classification	39
P143 System Overview	39
Relay Front Panel	42
Relay Serial Numbers and Addresses	43
User Interface	43
Menu Structure	44
Navigation of the Menu and Settings	44
Browsing the Settings Menu	44
Passwords	45
Relay Configuration	45
Essential Operating Procedures	46

Reading Fault Records from a Relay Front Panel	46
Changing Settings from the Front Panel.	46
Changing Settings by PC from the Front Port	46
The P127 Directional Overcurrent Relay	48
Tests on the Educational Transformers	
Safety During Experiments	51
Take Care - Even With Low Voltage	51
Insulated Connectors and Instruments	51
Disconnect Power	51
Important Notes	51
Before Each Use	51
Connection to Supplies	52
Parallel Winding Connections	52
Abnormal Voltages and Harmonics	52
Test 1 - Overcurrent Protection with the Relay, and Circuit Familiarisation	54
Aim	54
Procedure	54
Test 2 - Single Phase Transformers - No load Voltage and Ratio Checks	56
Aims	56
Procedure 1 - No Load Voltage and Ratio	56
Procedure 2 - Series and Parallel Windings	57
Procedure 3 - Phasing of Windings	57
Test 3 - Single Phase Transformers - On Load (Current) Ratio Checks	59
Aims	59
Procedure	59
Test 4 - Single Phase Transformers - Open and Short Circuit Tests	61
Aims	61
Procedure 1 - Open Circuit (no load) Test to find iron core losses	61
Results Analysis - Open Circuit Test	62
Procedure 2 - Short Circuit Test	64
Results Analysis - Short Circuit Test	64
Efficiency (needs results from both tests)	65
Percentage Impedances and Reactances	66
Test 5 - Single Phase Transformers - Connected as a Three Phase Transformer ..	68
Aim	68
Procedure 1 - Without Tertiary Windings	68
Procedure 2 - With Tertiary Windings	68
Test 6 - Single Phase Transformers - The Scott Connection	72
Aim	72
Procedure	72

Test 7 - Single Phase Transformers - Different Connections and Their Phasor Diagrams	73
Aims	73
Procedure 1 - Star- star Yy0 Connection	73
Results Analysis	74
Procedure 2 - Star star - Yy6 Connection	75
Results Analysis	75
Procedure 3 - Star- Interconnected Star Transformer Yz1	76
Results Analysis	77
Procedure 3a - Improved Yz1 Phasor Diagram	77
Procedure 4 - Delta delta - Dd0	78
Results Analysis	78
Procedure 5 - Delta delta - Dd6	79
Results Analysis	80
Procedure 6 - Delta star - Dy11	80
Results Analysis	81
Procedure 7 - Delta star - Dy1	81
Results Analysis	82
Procedure 8 - Delta star - Dy1 Phasor Diagram	82
Results Analysis	83
Procedure 9 - Delta star - Dy11 Phasor Diagram	83
Results Analysis	84
Procedure 10 - Star-Delta - Yd1 Connection	84
Results Analysis	85
Test 8 - Three Phase Educational Transformer - Le Blanc Connection	87
Aim	87
Procedure	87
Results Analysis	87
Test 9 - Temperatures in Transformers	88
Aim	88
Procedure	88
Results Analysis	89
Tests on the Fixed Ratio Dy11 Transformer (TX2)	
Fixed Ratio Dy11 Transformer Tests	93
Aims	93
Procedure 1 - No Loads	93
Procedure 2 - Balanced Loads	94
Procedure 3 - Unbalanced Loads	94
Procedure 4 - Line to Line loads	94
Results Analysis	94
Typical Results	
Test 1	97
Test 2	97

Procedure 1 - No Load Voltage and Ratio	97
Procedure 2 - Series and Parallel Windings	97
Primary windings in series	97
Primary windings in parallel	98
Secondary windings in series	98
Secondary windings in parallel	98
Test 3	99
Test 4	99
Procedure 1 - Open Circuit Tests	99
Procedure 2 - Short Circuit Tests	101
Test 5	103
Procedure 1 - Without Tertiary Windings	103
Procedure 2 - With Tertiary Windings	104
Test 6	105
Test 7	105
Procedure 1	106
Procedure 2	106
Procedure 3	106
Procedure 3a	107
Procedure 4	107
Procedure 5	107
Procedure 6	107
Procedure 7	108
Procedure 8	108
Procedure 9	108
Procedure 10	109
Test 8	109
Test 9	110
TX2 Tests	111
Maintenance, Customer Service and Spares	
Maintenance	113
General	113
Electrical	113
Transformers	113
Fuses and Circuit Breakers	113
To renew a broken fuse or reset a tripped circuit breaker	113
Fuse and Circuit Breaker Location	114
Spare Parts	114
Customer Care	114

APPENDIX A Phasor Diagrams for Three-phase Transformers

APPENDIX B Settings for the P127 Relay

Settings for the P127 Relay	117
-----------------------------------	-----

APPENDIX C Optional Relay (PSA15)

Introduction	119
Note - Artificially High Relay Values	120
Experiment 1 - Differential Protection (Phase to Phase)	122
Aim	122
Procedure B - Fault Applied	122
Results Analysis	124
Experiment 2 - Differential Protection (Earth Fault)	124
Aim	124
Procedure	124
Results Analysis	127

The Transformer Trainer

Introduction

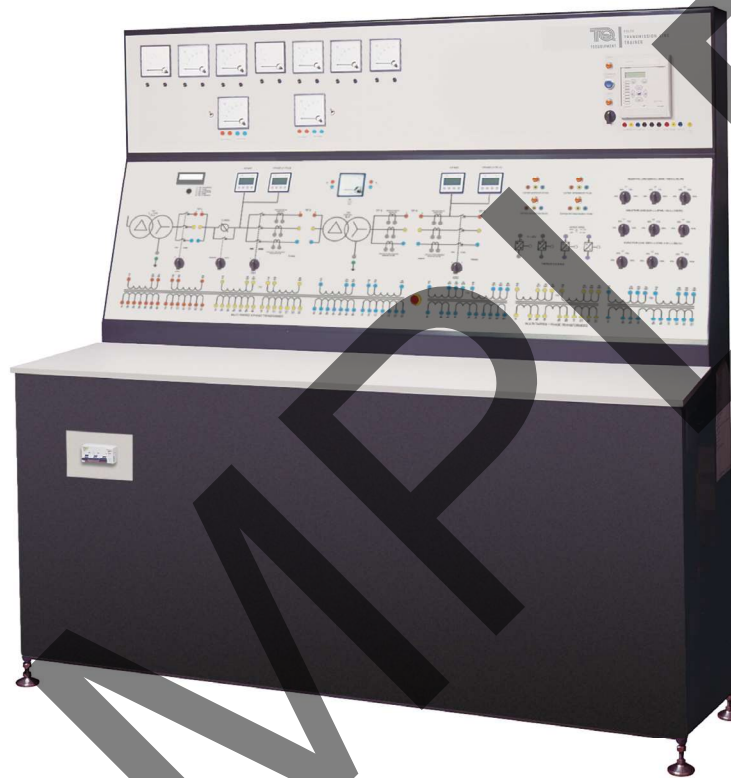


Figure 1 The Transformer Trainer (PSL20)

Transformers are key elements of any power system. They reduce transmission costs and efficiently distribute electrical power to consumers. Most are mechanically simple, with two or more windings coupled by a magnetic circuit, but their theory and variety of uses is complex. They work with powers of a few kilowatts up to several hundred megawatts.

The TecQuipment Transformer Trainer (PSL20) is part of TecQuipment's Power System Laboratory (PSL) range. You can install and use it stand-alone for transformer based experiments, but you may also connect it to other parts of the range for even more experiments.

The Trainer includes different transformers, power supplies, instruments and loads. It allows students to do a full range of experiments that show the characteristics and performance of power transformers.

Tests on the Educational Transformers

Safety During Experiments

Any laboratory equipment operating at high voltages is dangerous and must be maintained and operated with care by responsible personnel including students. There are many safety features in this equipment but you must obey these rules:

- REMEMBER - If you are using other modules, the supply from the other module may be connected to some of the circuits in this unit.
- NEVER remove connecting leads when there is a voltage on the circuit.
- NEVER use water or a damp cloth to clean the front panels.
- ALWAYS work in pairs.
- BE AWARE of resuscitation techniques.
- NEVER use damaged leads. Inspect all leads before use.

Take Care - Even With Low Voltage

Always take care. Remember that transformers increase and decrease (step up and step down) voltages. So, even when you connect a low voltage to the transformer, all its connections will be live, and some may have high voltages. This is especially important with the three-phase transformer because it has a shared core.

Insulated Connectors and Instruments

For safety, always use shrouded connectors to the transformers and any instruments you use. Never use connectors with bare or exposed metal.

Disconnect Power

Always switch off the supply before you change your circuit.

Important Notes

Before Each Use

Ask a qualified person to:

- Inspect all connecting leads, and replace any that show signs of damage or wear.
- Ensure the locks on the rear doors are effective and in place.
- Check the fronts of all the instruments for damage.

- Check that all the indicator lamps operate.

Connection to Supplies

Always use the variable supply (link TP1 and use TP2a as your supply) on all phases and set the autotransformer to minimum before beginning an experiment. This is good practice because:

- 1) You find connection errors in the circuit before you damage it.
- 2) The fuses in the autotransformer circuit give added protection. The educational transformers do not have fuses. You can use them in so many different ways that fuses on each tapping are not practical.
- 3) You can set the correct voltage you need for your test and make small adjustments if necessary.

Parallel Winding Connections

For good reasons, the transformers have no special construction to equalise the reactance between pairs of coils intended for operation in parallel. Therefore the winding sections will not divide the load current equally and one section will take a current corresponding to more than half the load.

The insulation of the transformers has a temperature limit of 155°C, which allows overloading for short periods, when the transformers are used in ambient temperatures below 30°C.

When using the transformers continuously with any windings connected in parallel, reduce the ratings to 0.8 of their nominal values to avoid local overheating.

Abnormal Voltages and Harmonics

You can exceed the nominal working voltages by up to 16% provided you reduce the output currents similarly, so you do not exceed the transformer ratings.

This is useful to show harmonics. For example, when the transformers are on light load, you can see harmonic distortion of the current and voltage waveforms in a three-phase transformer bank connecting the primaries in star arrangement. Use the 120 V connections instead of the 138 V connections. This will give a 15% increase in applied voltage and therefore also in flux density, showing a significant increase in harmonics.

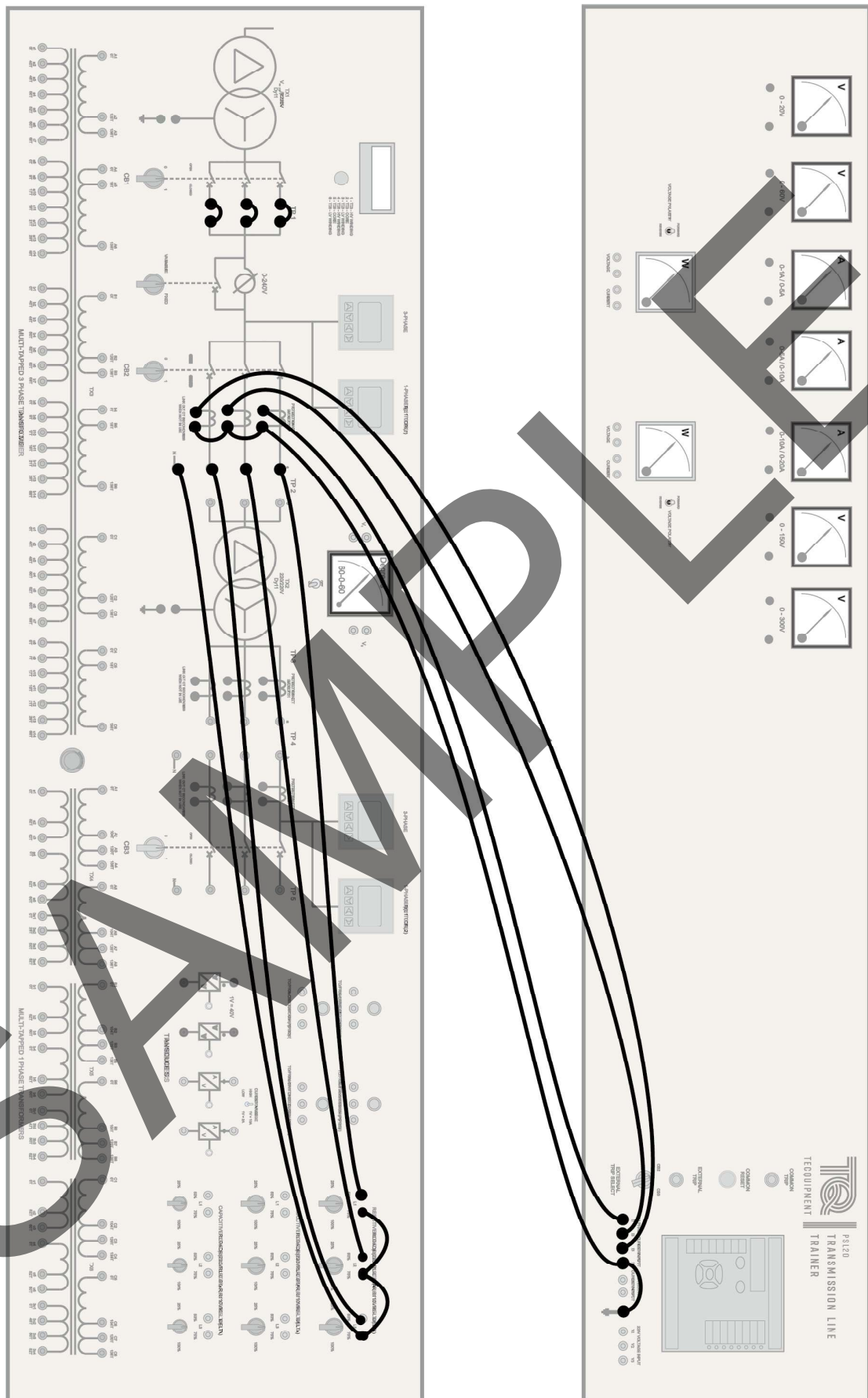


Figure 40 Supply Connections with Protection

Test 1 - Overcurrent Protection with the Relay, and Circuit Familiarisation

Aim

To show how to use a protection relay for overcurrent protection and help students to understand the supply and resistive loads of the three-phase circuit.

Procedure

- 1) Connect the three-phase circuit to the relay and resistive loads as shown in Figure 40. Note that you have connected the loads in star.
- 2) Set the relay for overcurrent protection of 4.55 A and set the loads to 25%. To set the overcurrent protection of 4.55 A, you set I_n to 0.65. The relay multiplies this by its own maximum rating (1 A) and the CT ratio that you connect to (7/1), so $0.65 \times 1 \times 7 = 4.55$ A.
- 3) Set the VARIABLE/FIXED switch (between CB1 and CB2) to the VARIABLE position and adjust the autotransformer (on the lowest panel) to its minimum position, fully anticlockwise.
- 4) Switch on the supply and shut CB1 and CB2. Use the multifunction meters to measure the voltages and currents, which should be low. Slowly turn the autotransformer to increase the line to line (L-L) voltage to 230 V and note the increase in current and power.
- 5) Change the settings of each of the loads and note the voltage and current readings. Try all loads at the same values (for example - 50%) and try unbalanced loads at different settings (for example 25%, 50% and 75%).
- 6) Reduce the supply to minimum. Set the loads to full (100%) and use the autotransformer to slowly increase the voltage, while using the multifunction meters to measure the line voltage and current. The relay should trip before you reach full voltage, protecting the circuit from currents greater than 4.55 A. It should open CB1 and CB2.
- 7) Reset the relay, turn the autotransformer down and shut CB1 and CB2.
- 8) Set just one of the loads to 100%, and the others to 25%. Increase the voltage again until the relay trips. Use the relay to find which phase caused the overcurrent trip (it should be the one with the 100% load).

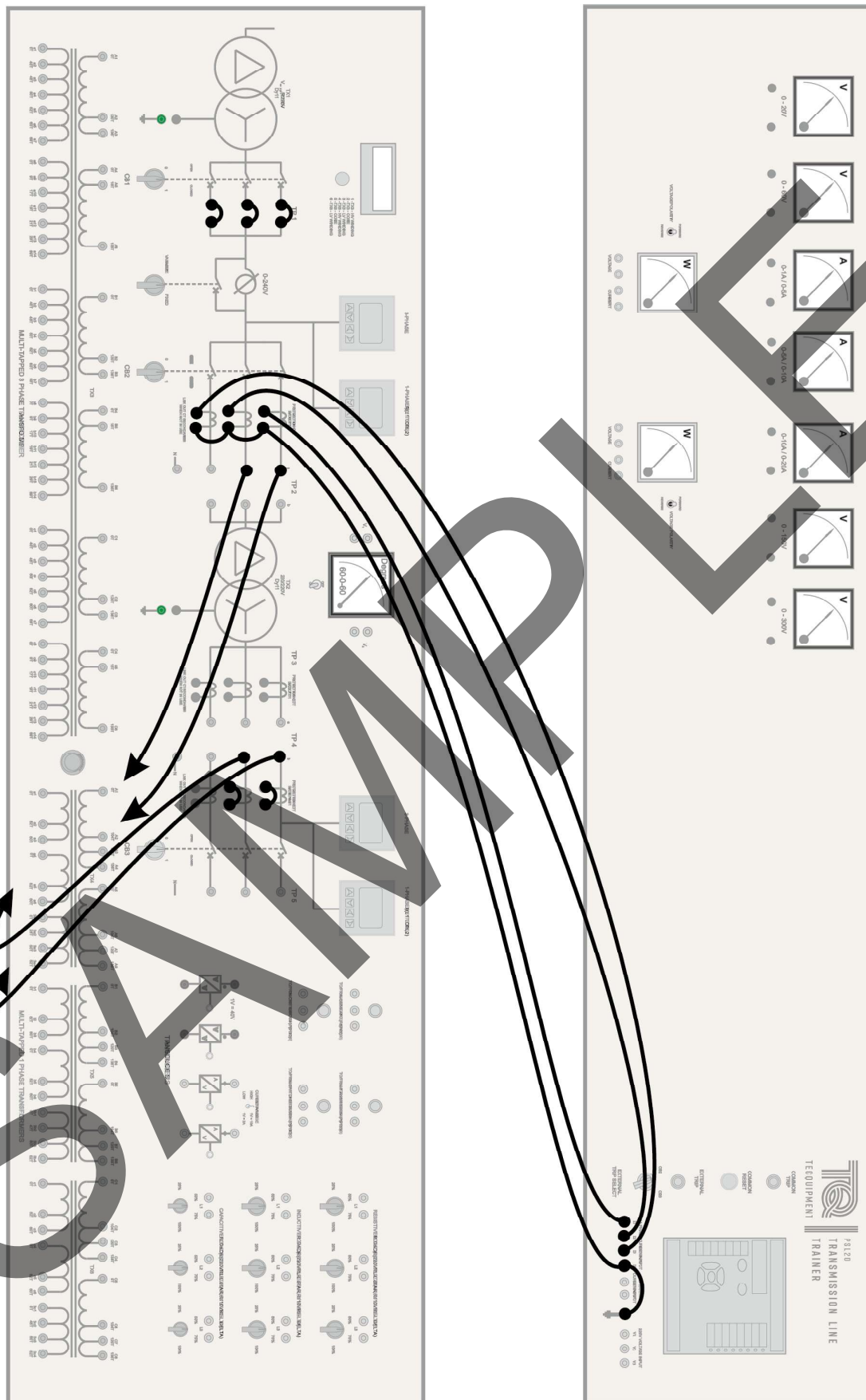


Figure 41 Connection for Experiment 2 Procedure 1 - Single Phase Tests

Test 2 - Single Phase Transformers - No load Voltage and Ratio Checks

Aims

To show students how the one turn per volt educational transformers work.

Procedure 1 - No Load Voltage and Ratio

- 1) Connect the circuit as in Figure 41. This circuit includes the protection relay in the supply for extra protection during your experiment. The relay does not need its voltage connections of Experiment 1.
- 2) You use the two flying leads of the supply to energise the primary windings of the transformers. The first (left-hand) 1 phase meter will show the supply voltage. You use the other two flying leads with the second 1 phase meter to measure the voltages on the secondary windings of the transformers.
- 3) Create a blank results table, similar to Table 14.
- 4) Use the red transformer (TX4). Connect the supply leads to tappings A1 and A3 of its primary windings and connect the other two flying leads to the secondary tappings a1 and a3 of the transformer. Shut CB1 and CB2 and carefully adjust the primary supply voltage to match the tappings that you connect. For example, if the primary windings has tappings of 0 and 120 turns, apply 120 volts across this winding. **Use the autotransformer to reduce the supply voltage, then open CB1 before you change any connections.**
- 5) Measure the voltages on the secondary and tertiary windings as you apply primary voltages and check that they match the number of turns and confirm the one-volt-per turn specification.
- 6) Now reconnect the supply to the A1 and A2 primary terminals. Set the supply to 104 V and measure the secondary voltage on a1 and a2.
- 7) As in Table 14, use the primary and secondary voltages of a complete winding to calculate the no load voltage ratio of each transformer.
- 8) Reduce the supply to 60 V and 52 V (half the normal voltages) and redo each test.
- 9) Note the ratio between the primary and secondary voltages and see that it approximately matches the turns ratio.

Primary Connections Used	Primary Voltage	Secondary Connections Used	Secondary Voltage	No Load Voltage Ratio (primary/secondary)	Turns ratio
A1 and A3	120 V	a1 and a3			
A1 and A2	104 V	a1 and a2			
A1 and A3	60 V	a1 and a3			
A1 and A2	52 V	a1 and a2			

Table 14 Blank Results Table

Procedure 2 - Series and Parallel Windings

Try the series and parallel primary and secondary connections suggested in Table 4 on page 15, Table 5 on page 16, Table 6 on page 17 and Table 7 on page 18.

Set the primary voltages as shown and measure the secondary voltages. **Never exceed the recommended voltages.** Again, calculate the voltage ratio to see that it matches the turns ratio.

Procedure 3 - Phasing of Windings

- 1) Connect the primary windings in series for a 240 V supply as in HWS1 of Table 4 on page 15.
- 2) Connect the secondary windings in series for a secondary voltage of 120 V as in LWS1 of Table 6 on page 17. This connects the 'end' of the second winding with the 'start' of the first.
- 3) Check that the secondary voltage is 120 V for a 240 V primary.
- 4) Reverse the phase of one secondary winding (swap a1 and a3). This connects the 'end' of one winding with the 'end' of the second winding.
- 5) Measure the secondary voltage. You should note that it is zero. One secondary winding has cancelled the other.

If you have the optional oscilloscope, connect each secondary winding across each of the two voltage transducers and connect your oscilloscope to the transducer outputs. Set the oscilloscope to see each voltage waveform and you should see that they are exactly 180 degrees out of phase.

- 6) Now set one the secondary windings to give 52 turns. You should note an output of 8 V (the difference between 60 V of one winding and 52 V of the other).

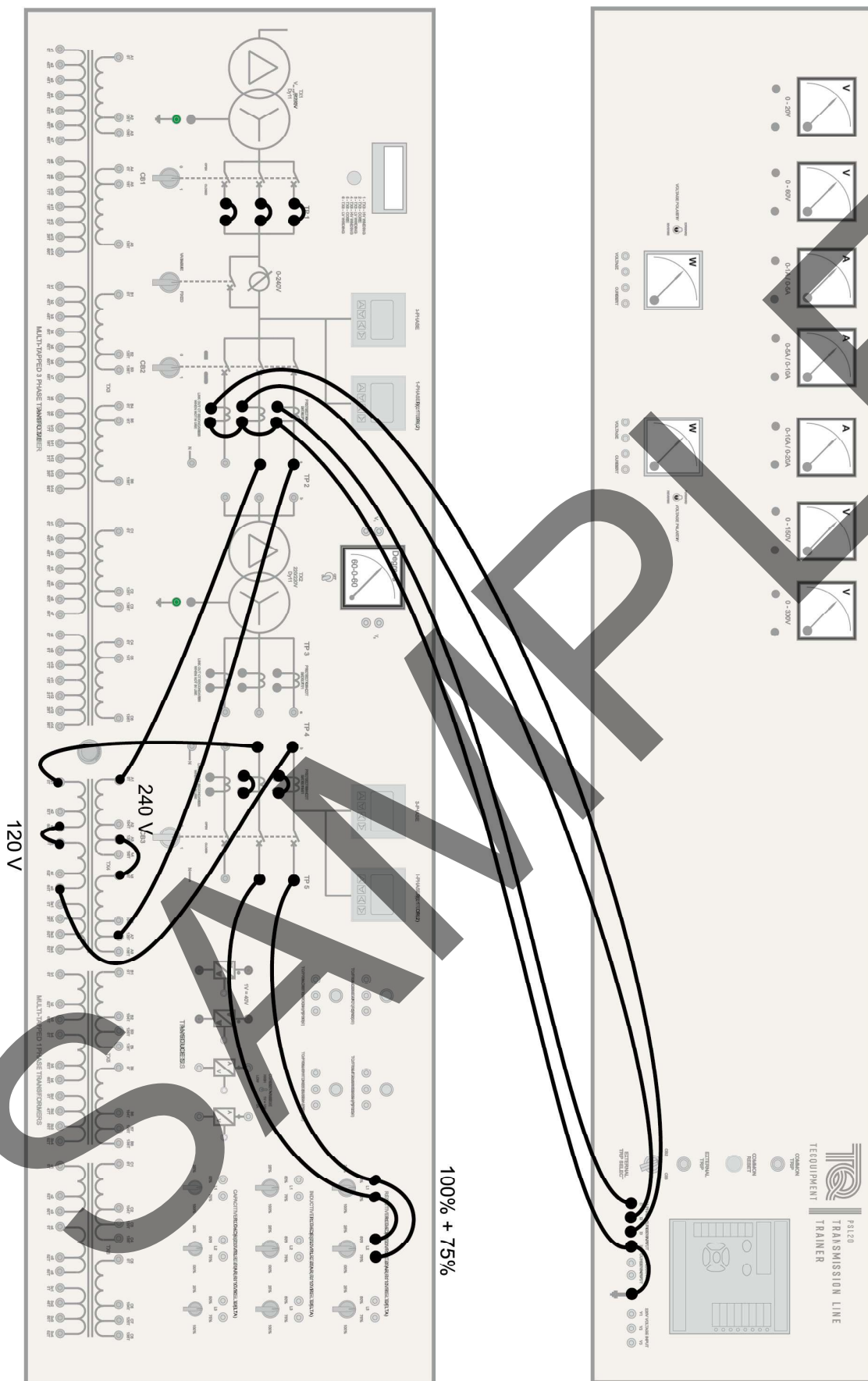


Figure 42 Connections for Test 3 - Single Phase Transformers - On Load (Current) Ratio Checks

Typical Results

NOTE



These results are typical only. Actual results may differ, determined by slight variations in transformer construction, loads and supplies.

Test 1

This is a simple test to allow the student to understand how to connect and use the relay and loads. The experiment procedure suggests typical results.

Test 2

Procedure 1 - No Load Voltage and Ratio

Primary Connections Used	Primary Voltage	Secondary Connections Used	Secondary Voltage	No Load Voltage Ratio (primary/secondary)	Turns ratio
A1 and A3	120 V	a1 and a3	60.04 V	120/60.04	~ 2:1
A1 and A2	104 V	a1 and a2	51.75 V	104/51.75	~ 2:1
A1 and A3	60 V	a1 and a3	29.92 V	60/29.92	~ 2:1
A1 and A2	52 V	a1 and a2	25.87 V	52/25.87	~ 2:1

Table 22 Typical Results

Procedure 2 - Series and Parallel Windings

Primary windings in series

Connections Used	Primary Voltage	Secondary Connections Used	Secondary Voltage	No Load Voltage Ratio (primary/secondary)	Turns ratio
HWS1 + LWS1	240 V	a1 and a6	120.3 V	240/120.3	~ 2:1
HWS2 + LWS2	224 V	a1 and a5	112.14 V	224/112.14	~ 2:1
HWS3 + LWS3	208 V	a1 and a5	103.66 V	208/103.66	~ 2:1

Table 23 Typical Results

Primary windings in parallel

Connections Used	Primary Voltage	Secondary Connections Used	Secondary Voltage	No Load Voltage Ratio (primary/secondary)	Turns ratio
HWS4 + LWS1	138 V	a1 and a6	120 V	138/120	~ 1.15:1
HWS5 + LWS2	120 V	a1 and a5	112 V	120/112	~ 1.07:1
HWS6 + LWS3	104 V	a1 and a5	104 V	104/104	~ 1:1

Table 24 Typical Results

Secondary windings in series

Connections Used	Primary Voltage	Secondary Connections Used	Secondary Voltage	No Load Voltage Ratio (primary/secondary)	Turns ratio
HWS1 + LWS1	240 V	a1 and a6	119.5 V	240/119.5	~ 2:1
HWS2 + LWS2	224 V	a1 and a5	111.75 V	224/111.75	~ 2:1
HWS3 + LWS3	208 V	a1 and a5	103.5 V	208/103.5	~ 2:1
HWS3 + LWS4	208 V	a2 and a6	15.9 V	208/15.9	~ 13:1

Table 25 Typical Results

Secondary windings in parallel

Connections Used	Primary Voltage	Secondary Connections Used	Secondary Voltage	No Load Voltage Ratio (primary/secondary)	Turns ratio
HWS1 + LWS5	240 V	a1 and a4 a3 and a6	59.8 V	240/59.8	~ 4:1
HWS2 + LWS6	224 V	a1 and a4 a2 and a5	51.9 V	224/51.9	~ 4.3:1
HWS3 + LWS7	208 V	a2 and a5 a3 and a6	7.95 V	208/7.95	~ 26:1

Table 26 Typical Results

Procedure 3 - Phasing of Windings

This is a simple procedure to show the relative phasing of each transformer, using an optional oscilloscope and connecting the 'ends' and 'starts' of the windings. The procedure gives suggested results.