MITTON
INSTRUMENTS

Operating Instructions

Earthing System Test Equipment

Off-Frequency Low Current Injector LCI2000C

Tuned Voltmeter TVM1100

Throughout this operating manual the terms; earth, earthing, earth potential rise, EPR and OHEW can also be read as ground, grounding, ground potential rise, GPR and OHGW.

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1 Safety Warnings

This equipment must only be used by qualified personnel. The operator must ensure that use of this device is in compliance with all local rules and regulations applicable to the situation.

High voltages can be exposed at the injector output terminals (up to 200 Vac). The injector output is isolated from the mains supply but hazards to personnel can still exist between terminals and if one terminal is connected to earth in any way.

Reliable and safe operation of this equipment requires that suitable transport and storage measures are taken. Under no circumstances should the device be exposed to extreme temperatures, forces, and/or moisture of any kind. If for any reason the equipment is thought to have been exposed to extreme conditions, the equipment should be taken out of operation.

High voltages can also be exposed on the remote current injection probe during set up and testing. The operator must ensure that correct measures are taken to prevent electric shock hazards to both workers and public at the remote injection site. This should include but not be limited to:

- The use of a competent supervisor and communication at the remote injection site. The use of barriers around the remote injection site.
- Regular maintenance of injection cables.
- Avoidance of bare hand contact with test cables.

The operator should ensure that connection and operation of this equipment will not interfere with any nearby equipment (eg frame leakage protection or relays sensitive to earth currents).

The test procedures require that cables are sometimes run long distances in potentially busy areas (urban, industrial, and residential areas). The operator must take care in selecting and securing the cable routes so that no hazards are created by the presence of the cables. In particular the operator should:

- Ensure the cable is visible when place across footpaths or other pedestrian areas.
- Avoid running cables across busy roads.
- Never run any cable across train tracks. Closely monitor injection cable and particularly the remote injection electrodes

Qualified Personnel:

Qualified personnel refers to workers that have undergone appropriate electrical and safety training relevant to operation of this device. This should include:

- A recognized first aid/life support training course.
- Electrical training pertaining to safety around mains voltage levels.

2 Introduction

The Low Current Injector (LCI2000C) and Tuned Voltmeter TVM1100) provide a reliable method for comprehensive testing of earthing systems, particularly those with very low impedance, complex geography or where high power line noise is present. Low current injection also facilitates the measurement of touch, step, transferred voltages and earth fault current distribution.

The low current injection method injects a known current into the earth grid. The test current frequency used is near the power system frequency. This provides a very unique test condition and the test signal can be easily identified during the tests. Combined with the use of a narrowband tuned voltmeter (TVM1100), the earth grid characteristics can be determined.

The LCI2000C provides a constant current output. This is necessary for reliable testing and overcomes the phenomena of current variation due to the time varying resistance of the remote test probes (due to localised soil heating). The LCI2000C is tuneable from 45 Hz to 65 Hz. Recommended injection test frequencies are 52 Hz for 60 Hz systems and 58 Hz for 50 Hz systems. The TVM1100 filter frequency is similarly selectable and must be set at the same frequency as the LCI2000C.

Auto shut-off is a safety feature that ensures the injected current ceases should the injection circuit be interrupted. The LCI2000C output is galvanically isolated from the input supply.

In some cases it is impractical to use the LCI2000C, for example, where the injection is carried out using an existing power line running parallel to another line. In such cases the induced current from the live circuit into the test circuit may be excessive (> 5 A is considered excessive). Instead, a diesel generator operated at 52 or 58 Hz can be used in conjunction with tuned voltmeters (TVM1100).

Injection testing enables comprehensive testing of earthing systems. Many important earthing system parameters can be measured, including impedance, touch, step, and transferred voltages, earth potential rise contours, current splits in overhead earth/fibre wires and cable sheaths.

Injection testing is also suited to specific situations such as power stations or mining installations. Many sites require specific earthing measures for safety reasons and injection testing can confirm such issues.

Injection testing also allows identification of any transferred voltages, for example, on to farm fences, water and gas pipelines, telecommunications and railway signalling circuits etc. Injection test methods can also be used to measure induced voltages into other services in a transmission line right-of-way.

3 Equipment Summary

The LCI2000C current injector is an integrated system. On-screen instructions lead the operator through the set up process.

As part of the start-up sequence the LCI2000C will display the injection circuit loop resistance and the maximum possible injection current.
The loop resistance must be at least 4 Ω for injection. The maximum resistance should ideally be as low as possible to ensure maximum current injection.

The output switch must be on to undertake this test.
This enables the operator to determine if the remote injection electrode resistance is adequate. It is preferable to inject at least 5A or more (max 10A). However, in some circumstances it may only be possible to inject less current.

Once the injection circuit is confirmed to be adequate the actual injection current is activated. Use the up or down arrows to set the injection current (in 0.25 A steps). Allow some time for the current to stabilise.

Peak currents exceeding 16A though the power electronics will cause the unit to shut down. Normal operation will resume 1 second later once the overcurrent condition is removed. The peak current is the total sum of external currents and current delivered by the LCI2000C.

It should be noted that the lower the injection circuit loop resistance then the lower the required test voltage will be. Minimising the test voltage wherever practical is prudent hazard management.

4 Operation

This section describes the basic operation of the injector unit. Refer to the test procedures in section 5 for detailed guidelines on selecting and setting up the injection circuit.

Setting up the Injector

1) Find a dry, level, indoor area to set-up the injector unit.
2) Ensure that the output switch is off.
3) Connect the mains supply cord but do not energise.

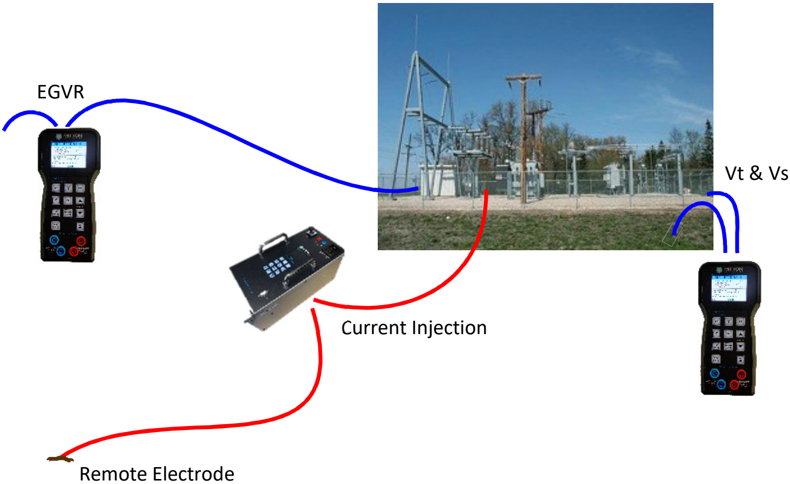
Establishing the Injection Current

1) When ready, advise the remote electrode supervisor that power is being applied to the injection circuit. (Establish a communication means between staff at the remote electrodes and the LCI2000C). Keep clear of the remote electrode (touch voltage hazard).
2) Turn the output switch to 'on'.'
3) Start the loop resistance test by pressing F1 key
4) Follow the instructions on the controller screen, to set the test current

To Stop the Current

1) Press the ON/OFF key to ramp the current back down to 0A.
2) Turn off the output isolating switch.

5 Earthing System Test Procedure



This section details the basic test procedure as it relates to electrical installation earthing systems. Examples include:

- Power stations, high voltage and medium voltage substations
- Large industrial, mining systems and urban substations
- Power system equipment earth grids

The basic test method begins by establishing a suitable current injection route and remote injection point. Once the injection current is flowing, a number of measurements can be made such as earthing system voltage rise, touch and step voltages and current splits between cable sheaths and other conductors.

The fundamental concept is to choose the injection circuit such that the remotely injected test current returns to the earthing system under test through the soil. It is this current that will create the earthing system voltage rise and associated touch and step voltages.

5.1 Current Injection Circuit

Minimum Remote Electrode Distances

The remote injection point must be far enough away from the earth grid under test so that the two are 'remote' from each other. The minimum required distance depends mainly on the size of the earthing system under test and will vary in each situation. The following table gives typical remote electrode location guidelines.

Type and Size of Earthing System (m)	Minimum Separation (m)
Large substation - greater than 100 x 100	700
Medium substation - 20 x 20 to 100 x 100	300 to 700
Small substation - less than 20 x 20	300

As a general rule the current injection point should be separated by at least 5 x the diagonal distance of the earthing system under test.

Earth grid modelling software can be used to calculate the minimum separation distance for large complicated sites. The earth potential rise is modelled to determine at what distance the EPR approaches zero, this is the minimum distance required for testing.

Injection Route

In most situations there are usually a number of possible current injection routes. However, in some urban areas it may not be feasible to run a dedicated test cable from a substation located in a busy urban area. In this case is may be necessary to use an out-of-service overhead line, earthed at a distant substation or at a convenient location en-route.

Note that induction from a nearby in-service circuit may be significant and can overload the injector. In such cases it may be preferable to use a suitably rated diesel genset operating at 52 or 58 Hz.

A standard 2.5 mm^2 or 4.0 mm^2 copper single core insulated conductor is suitable for the current injection cable. The following should be noted when selecting a cable:

- The cable should have a tough protective sheathing (TPS) for physical protection.
- The cable insulation should be in good condition to adequately insulate the conductor from the earth.

Care should also be taken when running cables in urban areas. Where possible, running cables across roads should be avoided unless proper traffic management procedures are in place (see safety warnings at beginning of manual).

Continuous monitoring of the injection cable and particularly the remote electrodes is required for safety unless the user is confident such risks do not exist.

Remote Injection Electrode

For sufficient test current, the total injection circuit loop impedance should be < 150 Ω and preferably < 30 Ω. The remote electrode resistance usually dominates the injection circuit loop impedance.

For remote electrodes, use 2 or more copper clad rods, spaced 2 m apart and driven approximately 1 m deep and bonded together. For safety, cover the electrodes with PVC pipe. Moist or swampy locations are most suitable. In some situations (stony, sandy or volcanic areas) this value may be difficult to achieve. Alternative remote electrodes could include:

- Transmission tower foundations. (There must be no overhead earth/earth wire connected to the tower).
- Water pipe or water well.
- A nearby substation earth grid.

It is important to obtain as the lowest electrode resistance as possible in order to maximise the test current. To further reduce the electrode resistance, water mixed with salt or washing soda (1 tsp/5 l) can be added at regular intervals, around the electrodes.

Care must be taken to ensure that the current injection circuit connection at the substation under test is not connected within any frame earth protection scheme (ie connect to the earth side of any earth leakage current transformer).

Establishing the Injection Current

Before starting the injector ensure that the injection cable and electrode have been set up correctly and that all safety checks have been completed (see warnings section at the beginning of this manual).

Follow the LCI2000C set-up instructions to measure the loop resistance (between the remote electrodes and the earth grid under test) of the injection circuit.

If using a section of overhead line for the injection that is parallel to another in-service line, first check for induced current in the injection circuit by temporarily connecting the current injection cable directly to the earth grid under test.

Measure the induced current using a standard clip-on meter. Even though the line section is earthed at the remote electrode location always treat the injection circuit (eg overhead line) as live where induction may exist.   Proper safety procedures must be used at all times (induced current levels can be hazardous). If the induced current exceeds 5 A then do not proceed using the LCI2000C.

To start the earth grid injection follow the instructions given in section 4.

Once established, the LCI2000C will maintain a constant current level by adjusting the applied voltage. The current should be set such that the applied voltage is not at maximum output. This will allow the injector to increase the voltage and maintain a constant test current if the injection circuit impedance increases (drying out of injection electrode etc).

5.2 Earth Potential Rise (EPR)

With the injection current flowing, the earthing system voltage rise can be measured. To achieve this, a voltage measurement traverse is carried out to a significant distance from the earthing system. The voltage on the earth is measured at regular intervals until the incremental change in voltage reduces to low a level (plateau). This is effectively the “remote” earth location.

Where possible, the voltage reference cable should be run at 90 degrees to the current injection cable route. This will minimize any induced voltage arising from the injection current. This is particularly important for earthing systems of very low impedance (eg < 0.5 Ω).

The voltage rise on the earth between the earth grid is repeated at a number of points along the traverse. These measurements can also be repeated in several directions to provide to enable plotting the EPR “contours” around the site.

It is more practical to take measurements starting at the earth grid. This means the EPR is being measured with respect to the earth grid. The measured voltage will start low and increase as the distance from the grid increases. In reality, during an earth fault, the voltage on the earth grid will be high and reduce as remote earth is reached. The results then need to be inverted to give the EPR with respect to remote earth (ie zero volts).

Connect the traverse cable (eg 500 m reel of 1 mm^2 insulated single core flexible conductor) to the earth grid and using the TVM1100 and a short probe, measure the voltage between the earth grid and the probe at specified locations. As the distance from the earth grid increases, the measured voltage will also increase.

5.3 EPR Traverse Measurements

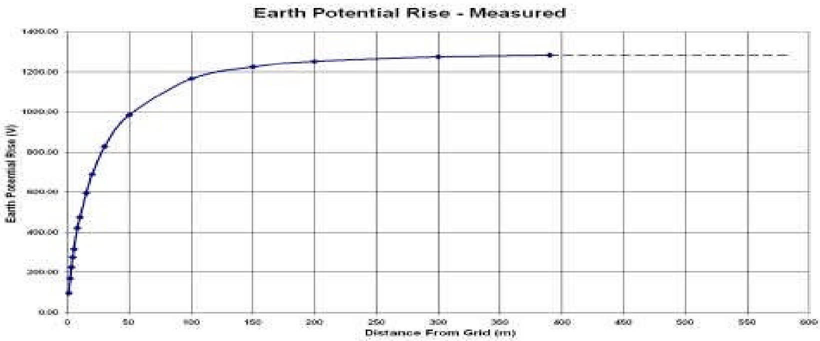
Close to the earth grid the measurements should be taken at small intervals, increasing to larger intervals further out. A suggested measurement points are (starting from the edge of the earthing system) 1m, 2m, 3m, 4m, 5m, 8m, 10m, 15m, 20m, 30m, 50m, 100m, 150m, 200m, 300m, 400m etc.

The measurements versus distance should be recorded and plotted in a spreadsheet.

For added safety (ie there is always a remote chance of a real power system earth fault occurring, causing hazardous EPR during testing) it is recommended that EPR measurements be taken for the first 10 m. The voltage traverse cable is then disconnected from the main earth grid and re-connected to an electrode driven 0.5 m deep at the 10 m location. The traverse is then continued from this location.

During the measurements, avoid handling the any bare voltage traverse cables or plugs.

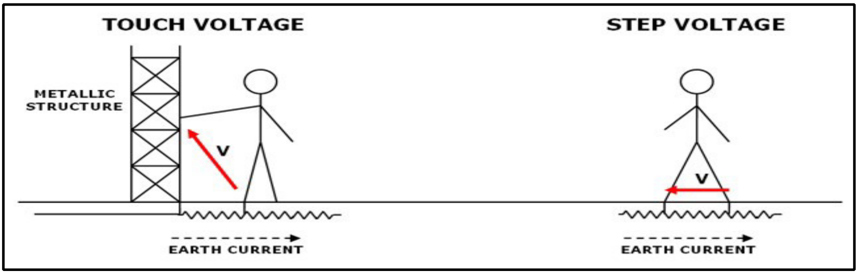
Record the actual measurements but on the spreadsheet. The voltage at the re-start location (eg 10 m) must to be added to all readings beyond that location.



The traverse measurements can then be inverted by plotting with respect to the remote earth voltage to give the EPR results.

5.4 Touch and Step Voltage Measurements

The LCI2000C and TVM1100 are ideal for enabling measurement of touch and step voltages on the earthing system. The injection current will cause voltages to arise around the site that represent, on a smaller scale, the actual touch and step voltages likely to be encountered during a real fault. When current flows through the earth, voltage differences will appear along the path of the current. Current flows out from an earthing system in all directions so touch and step voltages can appear all around the site. The basic touch and step voltage situations are shown below:



To measure these voltages a tuned voltmeter is required such as the TVM1100 (see section 8). This can be used in Touch Voltage conjunction with flat aluminium plates to simulate the electrical contact of a human foot (see below).

One large plate (402 cm^2) is used for touch voltage measurements to simulate the contact of two feet in parallel. Two smaller plates (each 201cm^2) are used for step voltages. Refer to section 7 of IEEE80:2000 for further details.

Some common touch voltage locations include substation primary plant, support stands, junction boxes, fences, water taps, metallic doors, disconnector handles, bonded items such as nearby domestic water pipes and any other metallic items that may be touched.

Step Voltage

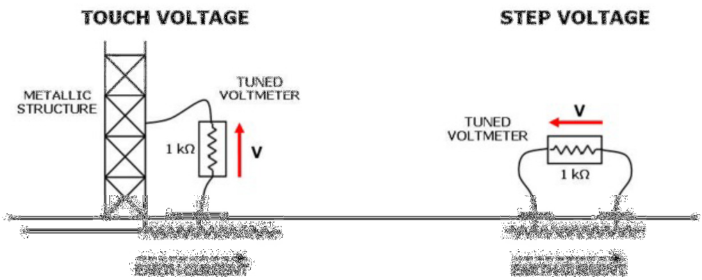
Touch voltage

The tolerable touch and step voltage limits are lower where there is a low resistivity surface material such as concrete or natural earth. On these surfaces the contact resistance of the foot is low and shock currents can be high. On high resistivity surfaces such as asphalt and crushed rock the contact resistance is high therefore larger voltages can be tolerated.

The measured touch and step voltages must be scaled up to represent a real fault situation. The scaled voltages can then be compared to the tolerable limits as calculated using guidelines given in the NZ EEA Guide to Power System Earthing or any specific company standards.

The touch and step voltages measured by the tuned voltmeter are prospective or open circuit values (these voltages are also calculated by earthing software packages). This means that the voltage will reduce when the touch or step voltage circuit is 'loaded'. How much the voltage drops depends on the contact resistance of the person's hands and feet. For high resistivity surfaces such as asphalt or crushed rock the loaded voltage will be much lower than the prospective value. This shows there will be less voltage across the person and subsequently less shock current.

The human body will ‘load’ the circuit with approximately 1 kΩ hand-to-hand or hand to foot (see IEC60479). To simulate this effect the TVM1100 tuned voltmeter has a ‘Low Z’ button that applies a 1 kΩ load to the measurement circuit as shown below. In this way both the prospective and loaded measurements can be taken without making any circuit adjustments.



The loaded value provides an indication of the voltage that is likely to appear across the human body. This should not be used to rule out voltage hazards as the contact resistance can vary greatly with weather conditions. On a wet day the loaded voltage could be much higher (and more hazardous) than on a dry day. The most consistent method is to use the prospective measurement as this provides an upper limit on the voltage across the human body.

The loaded value is only used to confirm voltage hazards identified by the prospective value. If the loaded value is high then the surface resistivity is low and therefore the hazard may be significant. It is important to first wet the earth underneath the footplate.

Current Split Measurements
The current injection method can be used to determine the effect of secondary earthing such as cables screens and overhead earth wires (OHEWs). The test current in these secondary paths can be detected using a tuned voltmeter in conjunction with a clip-on current transformer. A flexible Rogowski type CT (complete with amplifier) is most suited to this.

Measurement of 52 or 58 Hz current in 11 kV cable screen.

Only current at the test frequency will be detected because any power system frequency signals will be filtered out by the TWM 1100. This technique identifies the amount of current that is likely to flow through the secondary paths during a real earth fault (see section 6 for analysis details). This can be useful for earthing conductor sizing purposes. There may be phase angles present and a dual channel TVM can be used to record these if required.

6 Earthing System Analysis

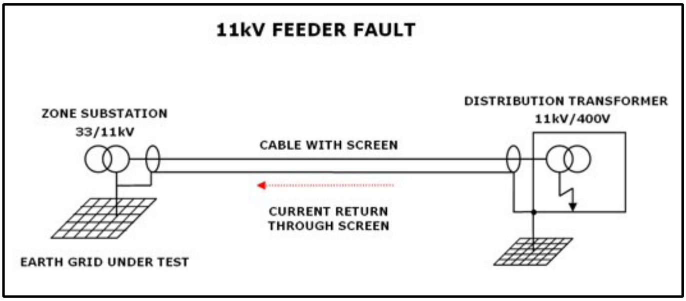
The earthing system impedance is calculated by:

$$Z_{System} = EGVR_{Test} / I_{Test}$$

$EGVR_{Test}$ (Earthing System Voltage Rise) is the measured earthing system voltage rise. The earthing system impedance may also include any external conductive connections to the grid such as OHEW and power cable screens.

The next step is to relate the voltage and current measurements to a real fault situation. First the worst case earth fault current must be calculated. In terms of EPR the worst case is the fault that results in the largest amount of current flowing into the earthing system under test.

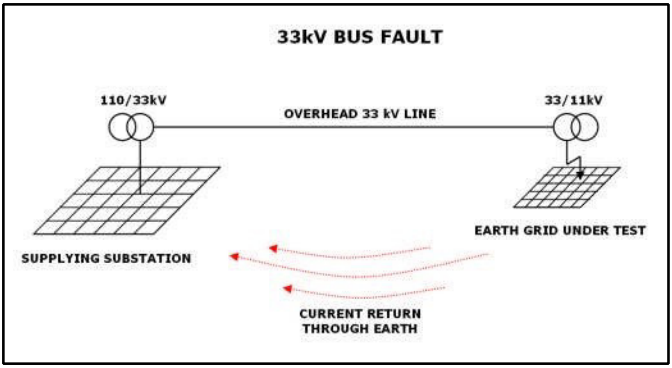
As an example an earth fault on an 11 kV feeder from a 33/11 kV zone substation may have a fault level of 12 kA. However if the feeder is an underground cable then most of the current will return to the zone substation transformer through the cable screen (if bonded to the earth grid). In this case there will be little or no earth potential rise around the zone substation (see below).



Alternatively, at the same zone substation a 33 kV bus earth fault may have a fault level of 6 kA. If the 33 kV bus is supplied by incoming overhead lines then all of the current will return to the supplying substation through the earth. This will result in the greatest earth potential rise around the zone substation even though the fault level is much less than the 11 kV feeder fault level.

More complex measurements and analysis of current splits in large earthing systems with OHEWs, power cables etc may allow determination of the actual earth grid impedance. However, the corresponding earth grid current itself requires careful calculation to ensure correct EPR values are obtained.

Once the worst case fault current is determined the scaling factor can be calculated. The current injection method accurately simulates a real fault situation therefore the



measurements can be directly scaled up. The scaling factor is simply the ratio of the test current to the worst case fault current:

$$\text{Scaling Factor SF} = I_{Fault}/I_{Test}$$

This factor can be used to scale up the measured earthing system voltage rise, EPR traverse voltages, touch and step voltages, and the cable screen currents.

Earthing System Voltage Rise

The EGVR during a worst case earth fault is given by:

$$EGVR = EGVR_{Test} \times SF$$

The scaled voltage rise indicates what voltage will exist on the earthing system for the duration of a real earth fault.

6.1 EPR Traverse Measurements

The measured EPR traverse values give the voltage difference between the earthing system and the earth at the test point. Traditionally, EPR values are given as the voltage rise of the earth above absolute zero volts. This means that the traverse measurements must be converted to the correct format.

First of all the traverse measurements must be scaled up to the real fault situation. This can be achieved by multiplying each measurement by the scaling factor SF:

For each traverse measurement:

$$V_{EPRscale}d = V_{EPRtest} \text{ x } SF$$

The next step is to calculate the maximum earthing system voltage rise as shown in the previous section. This value signifies the voltage rise of the earthing system above absolute zero volts and is used as a reference for the traverse calculations. The real earthing system voltage rise is:

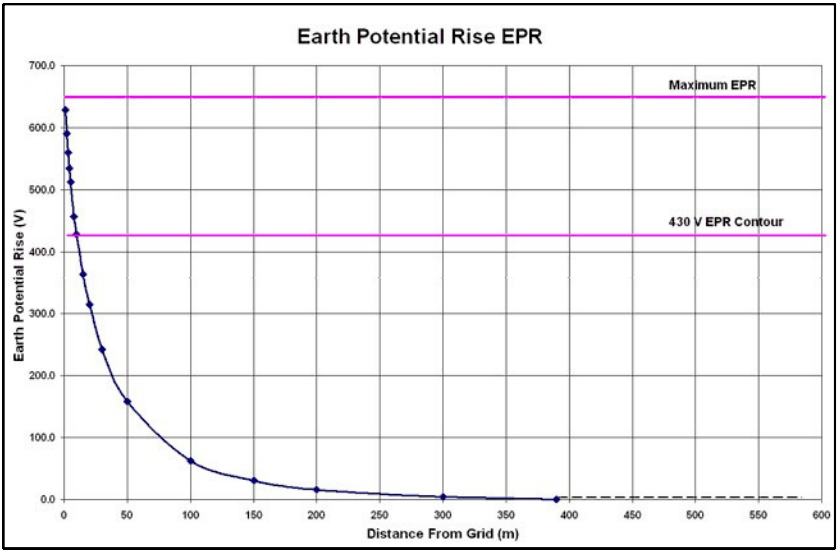
$$EGVR = EGVR_{test} \text{ x } SF$$

Finally the actual EPR values are given by subtracting the scaled measured EPR values from the maximum EPR value (ie the plateau value):

For each scaled traverse measurement:

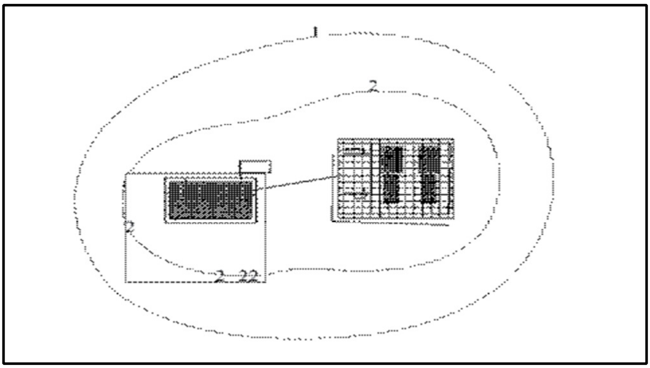
$$V_{EPR} = EGR - V_{EPRscaled}$$

These calculated values can then be plotted to give the actual EPR voltage traverse for a real earth fault (see diagram below). The location of EPR contours of interest (eg 430 V contour) can be determined from the plot. If more than one traverse was completed (useful if the earth grid is not symmetrical) then the process is can be repeated for each set of measurements.



The measured EPR values can be combined with earth grid modelling software to provide an overall picture of the earthing system EPR. The earthing software can be used to create an EPR contour plot based on the earthing system shape and soil characteristics. The EPR contours can be adjusted to match the EPR locations from the test results.

An example plot is shown below.



6.2 Touch and Step Voltage Measurements

The measured touch and step voltages are simply scaled up by the scaling factor (see beginning of section 6). The voltages can then be compared to the tolerable voltage limits as calculated according to relevant standards.

As an example, IEEE80:2000 calculates limits for touch and step voltages based on limiting body currents to safe levels defined by CF Dalziel ("Dangerous electric currents", 1946). For a 50 kg person (public areas) the safe body current limit is given by:

$$I_{50kg} = 0.116/\sqrt{t} \text{ Where } t$$

is the duration of the fault.

For a 70 kg person (i.e. restricted access areas) the safe body current limit is given by:

$$I_{70kg} = 0.157/\sqrt{t}$$

IEEE80 looks at the series impedance of the shock circuit and calculates a tolerable voltage limit corresponding to these currents. The shock circuit includes the contact resistance of the feet (and hands for touch voltages) and the body impedance (about 1 kΩ):

$$V_{Limit50kg} = I_{50kg} \times (R_{Feet} + R_{Body})$$
$$V_{Limit70kg} = I_{70kg} \times (R_{Feet} + R_{Body})$$

The contact resistance of a foot is found to be proportional to the earth surface resistivity and is given by:

$$R_{Foot} = 3\rho$$

Where ρ = resistivity of the earth surface (Ω-m)

For touch voltages there are two feet in parallel so the contact resistance is given by:

$$R_{Feet} = 1.5\rho$$

For step voltages there are two feet in series so the contact resistance is given by:

$$R_{Feet} = 6\rho$$

Therefore the following formulas are given for calculating the tolerable touch and step voltage limits:

50 kg person (public areas):

Touch:

$$V_{Limit50kg} = (0.116/ \surd t) \times (1.5\rho + 1{,}000)$$

Step:

$$V_{Limit50kg} = (0.116/ \surd t) \times (6\rho + 1{,}000)$$ 70 kg

person (restricted access areas):

Touch:

$$V_{Limit70kg} = (0.157/ \surd t) \times (1.5\rho + 1{,}000)$$

Step:

$$V_{Limit70kg} = (0.157/ \surd t) \times (6\rho + 1{,}000)$$

The 6ρ term in the formula for step voltages indicates why step voltage hazards are unlikely on high resistivity surfaces.

For loaded measurements the tolerable voltage limits are simply given by:

$$V_{Loaded50kg} = (0.116/ \surd t) \times 1{,}000$$

$$V_{Loaded70kg} = (0.157/ \surd t) \times 1{,}000$$

6.3 LCI2000C Technical Specifications

Supply voltage [1]: 95 Vac - 250 Vac
Output voltage (max): 220 Vac
Output current: 0.25 A - 10.00 A
Output power (max): 2.2 kW
Accuracy (output current): ± 0.5% FSD ± 1 count
Output frequency: 45 Hz - 65 Hz (in 1 Hz steps)
Load impedance: 4 Ω - 150 Ω
Dimensions: 370 mm L x 180 cm W x 180 mm D
Weight: 9 kg

[1] Output limited to 7 A on supply voltage < 150 Vac

7 TVM1100 Tuned Voltmeter

7.1 Introduction

The TVM1100 tuned voltmeter uses digital signal processing techniques and is specifically designed for use on 50 Hz or 60 Hz power systems with the LCI2000C to detect the injected signal under noisy conditions.

The TVM1100 can also be used with a diesel generator when it is impractical to use the LCI2000C because of injection circuit power frequency induction. However it should be noted that GPS phase mode should not be used in this condition.

In many instances, the residual 50 Hz/60 Hz or harmonic voltages on the grounding system or induced in the test cables may be many times the test signal level. The TVM1100 is able to filter out unwanted frequencies. This means very low levels of test voltage may be identified anywhere on the site under test, even where the background signal level is high.

The TVM1100 has a high input impedance to ensure accurate reading of prospective touch, step and transferred voltages. It also has a switchable low input impedance (1 kΩ) to simulate a person's body impedance.

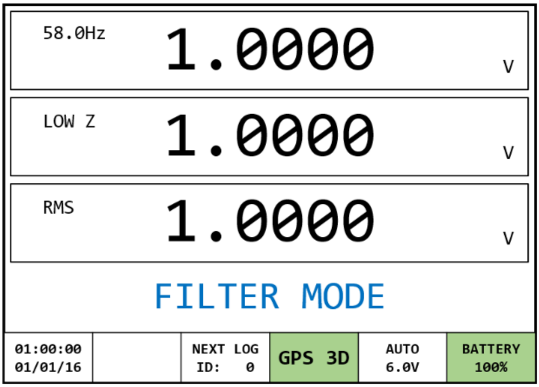
7.2 TVM1100 Setup

The TVM1100 filter can be adjusted between 45 Hz to 65 Hz.
When using the LCI2000C it is recommended to use 58 Hz for 50 Hz systems and 52 Hz for 60 Hz systems. Other frequencies can be used with. For example, a diesel genset or other current injection source. However, for optimum noise rejection it is recommended that these settings be used. The TVM1100 will track and display (lower left) the actual frequency within ± 1 Hz of the set frequency.

The instrument supports 3 different measurement modes.

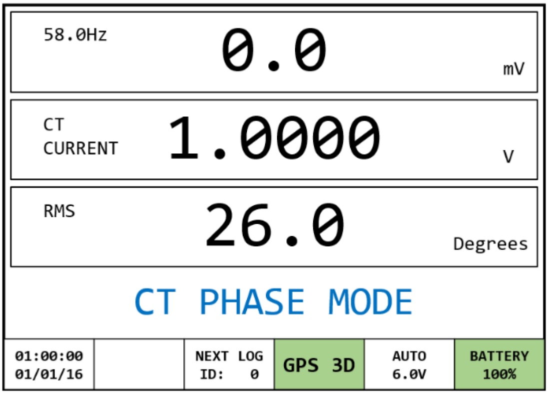
Pressing the MODE button cycles the display though three different modes, filter mode, CT phase mode and GPS phase mode.

Filter Mode



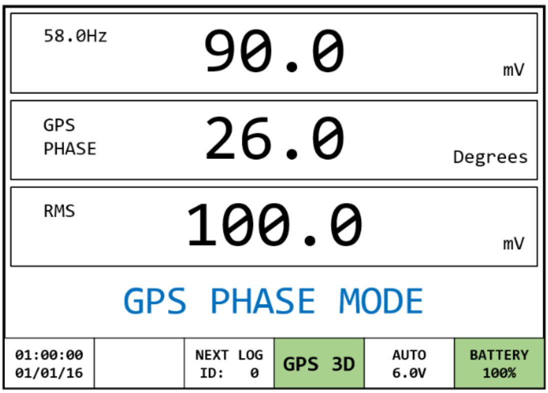
Filter mode screen

CT Phase mode



CT phase mode screen

GPS Mode



GPS mode screen

7.3 TVM1100 Filter mode

In filter mode the RMS at the selected frequency is displayed in the top line in addition to the voltage with low input impedance (middle value) and the total RMS voltage across the full instrument bandwidth (bottom line).

The Low Z value will only be displayed after the Z-LOW button has been pressed. If a valid reading is not obtainable the unit will display "----".

To protect the instrument against overheating of the internal load resistor the voltage should not exceed 20V peak when the LOW Z function is enabled. If the LOW Z function is selected with > 20V peak the display will show an overload message followed by a cooling period where the LOW Z function will be disabled.

7.4 TVM1100 CT phase mode

In CT Phase mode the RMS voltage at the selected frequency is displayed for red voltage input jacks top line. This is in addition to the voltage appearing at the CT input terminals and the relative phase between the CT and voltage terminals.

The CT inputs do not contain any burden load therefore it is the responsibility of the customer to provide a suitable external burden load for the selected CT or use a CT with built in burden or amplifier (eg a Rogowski coil CT).

The phase will only be displayed if both the voltage and CT inputs have a suitable signal at the selected centre frequency. If either the voltage or current is too small to reliably measure the phase will show "----"

The CT Phase mode is ideal for determining the overall impedance of (magnitude and phase) of an earth grid or earthing system. To do this, at the LCI2000C location, connect the TVM1100 to the remote EPR cable which is earthed at the remote end. Connect a CT around L1 connection to the remote injection, then measure the phase angle as described.

7.5 TVM1100 GPS phase mode

The instrument contains an internal GPS receiver which provides accurate time and phase information when used in conjunction with the LCI2000C with the externally connected GPS receiver.

Like all GPS receivers the instrument will require a reasonable signal from multiple GPS satellites. If the unit displays “NO GPS” try the following:

- Allow the unit a few minute to lock onto GPS signal.
- Move the unit outdoors if possible
- Move the unit away from strong electrical noise sources.

The GPS location is saved into battery backed up memory when the unit is powered down. If the battery is replaced or allowed to go completely flat these locations will be erased. The instrument will re-fix its position upon next power up however the instrument will take several minutes to relocate it position.

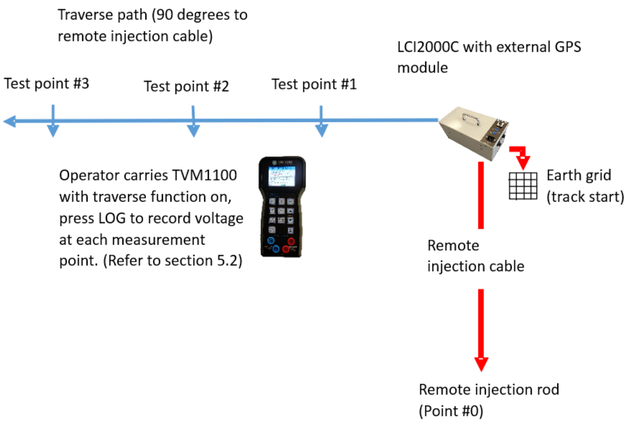
In GPS phase mode the instrument will wait for the 1 pps (1 pulse per second) signal to be received from the GPS satellite, it will then start measuring the time between zero crossing of the voltage waveform and the 1 pps signal then display the resulting phase at the selected frequency.

For the GPS phase information to be accurate the injection current must also be phase aligned with the 1PPS GPS signal. To achieve this the LCI2000C injector must be connected to an external GPS receiver and display “GPS 3D”. The phase alignment with the 1PPS signal will then automatically occur once current injection is started.

In GPS Phase mode the top display will display the voltage at the selected input frequency, the second the phase as described above and the third the RMS voltage across the instruments full bandwidth. Refer to section 8.7 for phase angle measurement.

7.6 GPS Guided Traverse

The guided GPS traverse function enables the operator to take measurements at repeatable measurement locations. This is achieved by using GPS navigation to measure distances relative to the fixed positions of the current injection point from the LCI2000C.



To use the GPS guided traverse function, the following must be configured

1. Valid GPS fix (3D GPS displayed on both LCI2000C injector and TVM1100)

2. The location of the remote injection electrode (point #0) refer to section 8.9.

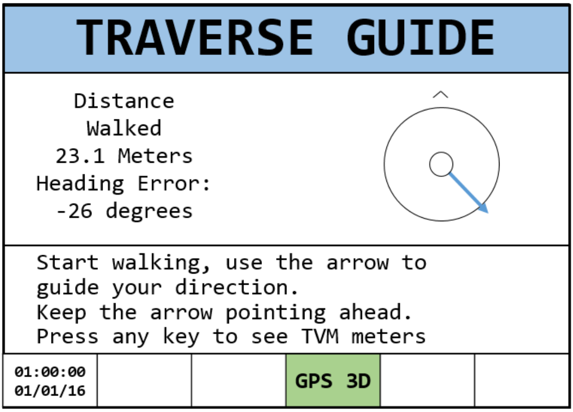
3. The traverse path direction (typically 90 degrees to remote injection cable) refer to section 8.9 (Earth grid, track start).

Traverse heading indicator

Push the TRAVERSE HEADING button to access the heading indicator.

Providing the Inject point location and the start location has been set, (refer to section 8.9) the GPS has a 3D fix and you are moving at greater that 2km/h, the heading indicator will be shown.

The line within the circle represents the required heading to follow providing the TVM is pointing in the direction of travel.



Traverse mode screen

The display also indicates the distance from the start of the traverse (earth grid) in metres, the required heading to follow to get back on track, in degrees, and the error as an angle taken from the start location to the desired traverse bearing. These functions enable the operator to ensure test points 2..3…4…n are taken in repeatable locations.

7.7 Phase Angle Measurements

TVM1100 + LCI2000C allows current splits in cable screens, OHEW/OPGW, metallic piping and larger items such gantries or poles (where any of these items extend beyond the earth grid) to be measured. The phase angle can be important where a detailed investigation of current splits is required, in order to properly summate the total outgoing split currents. A common example is the current in outgoing feeder cable sheaths.

There are three methods available. The first is to use the current channel on the TVM1100. The EPR voltage is used as a reference in the voltage input and an external CT (with voltage output) connected to the current input. Using CT phase mode, the current can be measured relative to the EPR voltage reference.

The second method is to use the injected current as the reference combined with GPS phase mode. This method is suitable for outdoor measurements and some indoor measurements as long as a GPS signal can be received (eg if the switchgear/cables etc are located near a window).

To ensure GPS function will operate refer to section 8.5. The CT being used must first be phase zeroed using the following procedure. This procedure must be repeated each time the TVM1100 is either turned off or the circuit configuration is altered.

Phase zeroing in GPS phase mode

1. Power up the TVM1100 and the LCI2000C with GPS attached.
2. Ensure both the LCI2000C and TVM1100 both display GPS 3D, indicating a valid GPS signal.
3. Connect a CT (with voltage output) around the injection cable connected to L1 at the injector. Connect the CT output to the TVM1100 voltage input (no connections are required to the TVM1100 current input). Start the current injection on the LCI2000C.
4. Enter GPS Phase mode on the TVM1100 by pressing MODE button repeatedly.
5. Press F1 key to zero the phase on the TVM1100 during this period it will display CAL.
6. CAL will disappear after a short period and the phase displayed will be close to 0 degrees. The TVM1100 will now internally store the relationship between the GPS 1PPS signal and the reference conductor.
7. Move the TVM1100 and CT to a new location and attach the CT to the new location (eg feeder cable). The phase of the reference conductor measured in step 5 will be displayed in the CT PHASE box.

The third method is a similar to the first except the measuring CT is connected to the current input on the TVM1100 and a second measuring CT is connected to the voltage input. The CT connected to the voltage input is placed around the injection conductor that is connected to the grid. With the TVM1100 in CT phase mode, the phase angle is measured then subtracted from the overall grid impedance phase angle. CT phase mode is covered in section 8.4.

7.8 TVM1100 Data Logging

Data logging to the internal SD card is possible in Filter mode, CT and GPS phase mode.

To undertake data logging ensure the reading has stabilised on all three values for the respective measurement mode and that the unit has a valid GPS signal.

Press the LOG Reading button, the instrument will store the value to the location indicated at NEXT LOG ID: XX where XX is the storage location.

To view the data connect the instrument to a PC via the mini USB port at the top of the instrument, power on the instrument and open the file DATA.csv located in root directory of the removable disk that appears once the instrument is connected.
The fields for the DATA.csv file are as follows;

Column Heading	Description
Name	The name of the data entry e.g. *Injection Location, Traverse Start Point* or *ID:#*
UTC Time	The time of a data entry – in Coordinated Universal Time = GMT in 24hrs.
UTC Date	The date of a data entry – in Coordinated Universal Time = GMT in 24hrs
GPS Fix	The GPS position fix; 1 = No Fix, 2 = 2D fix 3 = 3D fix. Note: The system will only traverse with a 3D fix.
Local Time	The time of a data entry in local time zone (based on UTC with offset set by user)
Local Date	The date of a data entry in local time zone (based on UTC with offset set by user)
Lat dec	The decimal latitude location of the data, as determined by the GPS when the LOG button was pushed
Long dec	The decimal longitude location of the data, as

	determined by the GPS when the LOG button was pushed
Elevation	The elevation determined by the GPS when the LOG button was pushed
Injector Distance from Start	Relevant only if the injector location has been set-up
Injector Bearing from Start	Relevant only if the injector location has been set-up
Traverse Bearing from Start	Relevant only if the injector location has been set-up
Traverse Heading from Start	Relevant only if the injector location has been set-up
Distance From Start	Relevant only if the start location has been set-up
Bearing Error	Relevant only if the start location has been set-up
TVM Measure Mode	The display mode when LOG was pushed e.g. *RMS*, *Filtered, Filtered with Load*, *loaded and un loaded* and *phase*.
RMS V	The RMS value (in volts) at the time when LOG was pushed.
Filtered V	The filtered value (in volts), Note: filter frequency is set in set-up
Loaded V	The filtered value (in volts) when the load button is set, Note: filter frequency is set in set-up
I	The current (in volts) as seen on channel 2
Frequency	The determined filter frequency (in Hertz)
Phase	The phase between Channel one and Channel 2 (units of degrees)

File Management

ID numbering is reset back to 1 every time a new injector location or track start location is stored, a new menu is also written to the CSV file at this point. Some CSV file management may be required using Excel to separate information for multiple switch yards.

If necessary you can delete the DATA.CSV file manually using windows file explorer.

7.9 Viewing GPS data on Google Maps

The DATA.CSV file can simply be converted in to a data.kml file that can be read by Google Earth using the application csv2kml.exe that is included on the TVM drive.

Once Google Earth and CSV2KML.exe have been installed open csv2kml and open the file DATA.CSV, press Convert.
Close CSV2KML.exe and open data.kml and all points will be loaded on to the map in Google Earth. Within Google Earth, click on a point to review the data stored at that location.

The CSV2KML.exe is installed inside the TVM it can also be downloaded from: https://docs.google.com/file/d/0B5R-yCvwhjTAam5ZQUtXODExZ3c/edit?pref=2&pli=1 if it has been deleted from the TVM.

7.10 TVM1100 Setup Menu

Date and Time setup:

The instruments date is determined from the internal GPS receiver inside the unit and can only be reprogrammed within a 24hr period. The time is determined by the GPS receivers reported UTC (Coordinated Universal Time) which then has a programmed time offset for the time zone from which the instrument is located in. In consideration of the above the time and date setting is only valid when a suitable GPS signal has been received.

To set the local time:

8. Ensure instrument is in FILTER MODE
9. Press SET UP for 1 second.
10. Use Up/Down Range buttons to set time/date
11. Press SETUP.
12. Press ON OFF

Reset LOG COUNTER:

Note resetting the log counter will result it data being overwritten by the TVM1100

1. Ensure instrument is in FILTER MODE
2. Press SET UP twice.
3. Press LOG READING to reset log counter.
4. Press ON OFF

Set Injection location:

The injector location relative to the TVM1100 is logged to the SD card into DATA.csv each time a measurement is logged. The injection location is assumed to remain fixed during each measurement logged. The location must therefore be reset each time the injection probe is moved.
To set injector location;

1. Ensure instrument is in FILTER MODE
2. Press SET UP three times.
3. Stand next to the injection probe.
4. Press LOG READING button once GPS 3D is displayed.
5. Press ON OFF

Set Track start:

During a typical logging session multiple measurement points maybe taken along a track. The start of the track can be saved to the SD card into DATA.csv for future reference.
To set track location;

1. Ensure instrument is in FILTER MODE
2. Press SET UP four times
3. Stand next to the injector point.
4. Use UP/DOWN button to set the direction of traverse for which track is travelling.
5. Press LOG READING button once GPS 3D is displayed.
6. Press SET UP

Set Filter frequency:

The filter frequency is used to fit the centre frequency of the programmable bandpass filter, the same frequency is used for both voltage and current inputs. The frequency is programmable between 45-65Hz, refer to chapter 1 for recommended test frequencies.

To set track location:

1. Ensure instrument is in FILTER MODE
2. Press SET UP five times
3. Press UP/DOWN to set centre frequency
4. Press SET UP

GPS Diagnostics:

GPS diagnostics can be used to determine the current location of the instrument.
To enter GPS diagnostics press the GPS STATUS button at the FILTER MODE screen.
LAT displays the current Latitude in degrees
LON displays the current Longitude in degrees
Error displays the measured error from the previous GPS position reading
TestDist is used for display the vector change in distance since the F1 button was last pressed.

The green bars indicate the relative signal strengths of up to 12 satellites, the taller the bar the better. A green bar indicates the satellite signal is being received and the instrument is using it to fix position, a white bar indicates a signal received however a fix is still in progress.

Note due to limitations in the accuracy of the GPS system it is not recommended to use the instrument for precision distance measurement < 3 m.

7.11 TVM1100 Technical Specifications

Batteries: 2 x 3.7V Li-Ion (NCR18650) cells
Charging: 12V dc 2A, centre positive
Ranges [1] (auto & manual ranging, voltage inputs):
0 – 6.0 Vrms, resolution 100µV
0 - 60 Vrms, resolution 1mV
0 - 300 Vrms, resolution 10mV
(Current inputs):
0 – 3.0V RMS, resolution 100µV
Accuracy [2]: ± 0.5% FSD ± 2 counts
Frequency Lock: XX Hz ± 1 Hz (where XX is the filter frequency)
Operating Temperature: 0 - 40°C
Input Impedance (voltage): 2 MΩ/1 kΩ (LOW Z mode)
Input Impedance (current) [3]: 94 kΩ
Noise Rejection: > 70 dB (> 3,000:1) @ 50 Hz/60 Hz
Display: Trans-reflective colour LCD
Battery Life: 8-16 hrs
Weight: 200 g
Dimensions: 210 mm H x 100 mm W x 32 mm D

[1] Voltages exceeding 300V RMS AC into voltage inputs or voltages exceed 3V RMS AC into current inputs may cause permanent damage to the instrument which is not covered by product warranty.

[2] Filter accuracy is dependent on input conditions. High level noise may cause the TVM1100 to select a higher range.

[3] output of CT device must be voltage. Use CT device with internal burden or add external burden if necessary.