Endeavour Energy Earthing (3E) - Earthing Design Tool - Handbook

3E version 2.6

Earthing and Power Quality

May 2017

Comments and enquiries

To enable Endeavour Energy to continually improve its standards and practices, feedback is encouraged. Any comments or suggestions should be forwarded to:

earthingenquiry@endeavourenergy.com.au

To enable us to reply to your feedback, please clearly provide your contact details.

Amendment record

The following amendments to this standard have been made since its inception:

Date	Comments	Revision
Feb-12	Added help file and fixed confusing units	1
Feb-12	Fixed calculation method for h<0.5 to a per rod method	1.1
Oct-12	Added metallic return calculations to main page	1.2
Dec-13	Over hall of sheet to meet requirements of EDI100	2
Sep-14	• Added user SEF pick up • Clearer indication of pass or fail for common earthed designs • Update terminology • Change soil res to require minimum values • Changed soil res to drop down selections • Fixed LV rod issue • Show required LV/HV electrode separation (requires No. of connected MEN to be entered for Common or Separately earthed designs)	2.2a-b
Jan-15	• Ticks removed (side bar shows common earth status) • Side bar shows status of design and if the sheet has been filled • Locked soil res calculator to require valid input, otherwise sheet won't work • Update LV/HV separation to give minimum of 4m even if distance to MEN is 0m • Update to formatting so sheet can be printed • Design will show if it is separately or common earthed • Update to protection to cater for instantaneous protection settings	2.3
Jan-15	• Project field was locked (now unlocked) • Latitude/Longitude field formatting fixed • Issues with "DESIGN INCOMPLETE" rectified • Issues with blank protection values fixed • Notes field added	2.3a
Aug-15	• Updated LV/HV to accommodate HV & LV electrode length when customers > 4 • Issue with single rod resistance and insulated layer fixed	2.3b
Apr-16	• Update to protection calculations to allow for IEC 60255 trip time calculations • Enforcement of GPS location for soil resistivity location • Ability to store soil resistivity readings taken (currently internal staff only) • View location of soil test in google maps • Version check on main sheet (currently internal staff only) • Update to protection input to allow for advance input and additional relays • Update Backyard scenario to match EDI0001 and EG(0) • Update calculations using Max and Min fault current • ALARP Design sheet and check added	2.5 (2.4, not released)
May-17	• Enforcement of two soil resistivity test results with at least 20m spacings entered • Updated check CMEN warning • Addition of validating design with actual commissioning test results • Updated GPR to EPR to reflect Australian industry terminology • Removal of School limit as this should be assessed on a case by case scenario by the designer • Fix bug in DOF clearing time for 3A, 20A and 40A	2.6

Note: All changes in this revision will be highlighted in grey.

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1.0 EXECUTIVE SUMMARY

This report has been prepared to provide a brief introduction into the use of revision 2.5 of Endeavour Energy's earthing design tool "3E". This version of 3E uses empirical equations to model the performance of a distribution earthing system. This means the tool may not be accurate for all environments. It has been compared against analytic results for most typical environments, and has been shown to be conservative.

This document was prepared as a supplement to the design report, highlighting the key requirements of the design. This document should be read in conjunction with the design report.

2.0 BACKGROUND

Endeavour Energy moved to a risk based earthing design practice for distribution earthing in 2011 with the introduction of SDI100 amendment 9. In 2011, the first version of 3E was developed to be released along with the implementation of SDI100 amendment 10. The tool was only for use in separate earth designs, as a simplistic table was included in the standard for common earthed designs. A number of training seminars were conducted to familiarise both internal and external designers in the use of the tool. In October 2012, a revision was released to include the calculation of the soil voltage at conductive equipment associated with metallic pipelines in line with AS4853:2012.

With the release of the new earthing standard, a significant overhaul of the tool has been undertaken. The tool is able to assess the performance of both separate and common earthed systems, and includes the provision for a metallic return to the ZS. This revision is titled 3EV2.6

3.0 SOFTWARE REQUIREMENTS

3.1 Issues with opening in same instance

It is advised that 3E is not opened in the same instance of another 3E sheet. This can cause the sheets to malfunction, if you are going to open more than one copy of 3E please open in another instance or session of Microsoft Excel.

3.2 Add-ins

3E requires the following add-ins enabled in excel before it can be fully functional, they are as follows:

- Analysis ToolPak
- Analysis ToolPak - VBA
- Solver Add-in

To check you can navigate to in excel through, **File → Options → Add-ins.**
Please ensure these add-ins are enabled before sending any errors through to the earthing team.

3.3 Macros

3E requires macros to be enabled for the sheet to function.

4.0 INPUT PARAMETERS

The tables below detail all of the input parameters in the tool. There are only two input pages in the tool; the Main page and the Soil Model page.

4.1 Main Page:

Input	Location	Comments on input
Location	Work info	The location of the proposed earthing system
Project number	Work info	The project number the work will be done under
Designed by	Work info	The designer's name
Company	Work info	The designer's company
Proposed equipment	Work info	The proposed asset being design (select asset from the drop down menu or other)
Conductive pole	Work info	If a pole mounted asset is proposed, is it on a conductive pole?
Other	Work info	If "other" is selected as the proposed equipment, enter a description of the proposed asset
Location category	Work info	Normal/Special/Remote (see EDI100 for definitions)
Zone Substation	Supply	The zone substation that will normally the supply asset (drop down menu)
Zone substation - Other	Supply	If "Other" is selected as the zone substation, enter the supplying zone substation name
Feeder number	Supply	The feeder name that will normally supply the asset
Feeder nominal voltage	Supply	The nominal voltage of supply (11,22 kV)
SLG fault level	Protection Info	The single line to ground fault level at the location (or at the next upstream substation)
EF settings used	Protection Info	Drop down: - Default – use when actual settings are unknown - User defined – use (carefully) when actual settings are known[1] - Fuse – use where asset is protected by HV drop out fuses
Fuse Rating	Protection Info	When "fuse" is selected as EF setting – enter rating of fuse used
SEF available	Protection Info	Yes/No – whether sensitive earth fault protection is present on the feeder
SEF Pickup	Protection Info	Allows user to enter SEF pickup when user defined settings is selected
FL at substation number	Protection Info	The substation number at which the fault level was taken (from the fault level report)

[1] When protection settings are required, the protection team will fill out all the required information, ready to be inputted into 3E. Protection settings can be obtained from Protection.Enquiries@endeavourenergy.com.au.

Input	Location	Comments on input
EF pickup (A)[1]	Protection Info **When "User defined" is selected as EF setting:**	Earth fault protection pickup current in Amps
IEC Time lever[1]	Protection Info	Earth fault protection time lever setting
Hi-Set (Y/N) [1]	Protection Info	Select if Hi-set (sometimes referred to as instantaneous) is present. If yes is selected the related attributes will not be shown
Hi-Set (A) [1]	Protection Info	If Hi-Set is selected yes, this field is for the pick-up current
Hi-set Operate Time (s) [1]	Protection Info	If Hi-Set is selected yes, this field is for the operating time of the Hi-set element
Time Margin (Y/N) [1]	Protection Info	Select if there is an additional time margin present. If yes is selected the related attributes will be shown
Time Margin (s) [1]	Protection Info	This is any additional time required to additional protection elements to grade
Protection Curve[1]	Protection Info	The protection curve used: IEC SI, IEC VI, IEC EI, Areva SI, Areva VI, Areva EI, Basler SI, Basler VI, Basler EI, GE SI, GE VI, GE EI, NOJA SI, NOJA VI, NOJA EI, NOJA ANSI STI, NULEC SI, NULEC VI, NULEC EI, SEL SI, SEL VI, SEL EI, Basler CO-2, Basler CO-6, Basler CO-7, Basler CO-8, Basler CO-9, CDG33 1.55 sec, CDG31 3 sec
Common/Separate?	Earthing configuration	Is a common earth or separate earth design proposed?
Metallic return to source	Earthing configuration	Is there a continuous metallic return (through HV cable screens and LV neutral connections) to the supply ZS and is the supply ZS listed as CMEN/DBZS
Radius "r" of rod/s (mm)	HV Earth Grid – Earth grid details	The radius of the proposed electrodes (default is 7.5mm)
Length "L" of rod/s (m)	HV Earth Grid – Earth grid details	The length of the exposed electrodes in the HV earthing system (in metres)
Insulated to depth "h" (m)	HV Earth Grid – Earth grid details	The depth below ground level at which the exposed electrode begins (only available for non-conductive pole mounted assets)
Number of rods	HV Earth Grid – Earth grid details	The number of rods making up the main HV earthing system
Commissioning check	HV Earth Grid – Earth grid details	Checking the validity of the design using commissioning test results
Neutral bond to 1 other DS?	LV Earth Grid – Earth grid details	Yes/No – is there a continuous LV neutral connection to one other distribution sub?
Length "L" of rod/s (m)	LV Earth Grid – Earth grid details	The length of the exposed electrodes in the LV earthing system (in metres)
Number of rods	LV Earth Grid – Earth grid details	The number of rods making up the main LV earthing system

[1] Please note user defined settings can only be obtained from the Endeavour Energy Protection team. They can be contacted on: Protection.Enquiries@endeavourenergy.com.au

Input	Location	Comments on input
Number of connected customers	MEN details	The number of customers connected together via a well meshed MEN, this must be entered to separately earthed designs and common earthed designs
MEN Type	MEN details	Select from drop down menu “Dense Urban”, “Industrial” or “Rural”
Fences near location?	Constraints	Select “Yes” if there are, and enter the minimum horizontal distance along the surface between any part of the HV earth system and the fence
Metallic MEN connected infrastructure near location?	Constraints	Select “Yes” if there are, and enter the minimum horizontal distance along the surface between any part of the HV earth system and the infrastructure
Communications assets near location?	Constraints	Select “Yes” if there are, and enter the minimum horizontal distance along the surface between any part of the HV earth system and the pit
Metallic pipelines near location?	Constraints	Select “Yes” if there are, and enter the minimum horizontal distance along the surface between any part of the HV earth system and the closest contactable fitting
Single metallic object (touch voltage)	Constraints	Select “Yes” if there are, and enter the minimum horizontal distance along the surface between any part of the HV earth system and the closest contactable part to obtain touch voltage
Other Constraints	Constraints	Enter any other constraints in the design
User Defined Criteria (V)	Limits	If the designer has determined a touch voltage limit based on the principles of EG-0 and EDI001 then this can be entered here
User Defined Criteria note:	Limits	If the designer has determined a custom touch voltage limit this must be justified in this cell

4.2 Soil Model page:

Input	Comments on input
Address of test	The address or GPS location of the soil resistivity test
Latitude of the test	Latitude of test location (decimal degrees)
Longitude of the test	Longitude of test location (decimal degrees)
Date	The date the test was taken
Time	The time of day the test was taken
Temperature	The air temperature at the time of the test (use BOM temperature if unknown)
Soil type	Description of soil eg. Clay or sandy loam, etc.
Soil condition	Condition of soil eg. Damp, dry etc.

Input	Comments on input
Meter model	The model of the instrument used
Meter serial number	The serial number of the instrument used
Electrode spacing	The spacing “a” between test electrodes using the Wenner method
Test Applied 1-3	The resistance (Ω) measure for each spacing
Soil Model	The resistivity of layers 1 and 2 and the depth may be manually entered here if a model is determined using other software Otherwise, these values will be populated using the model builder macro

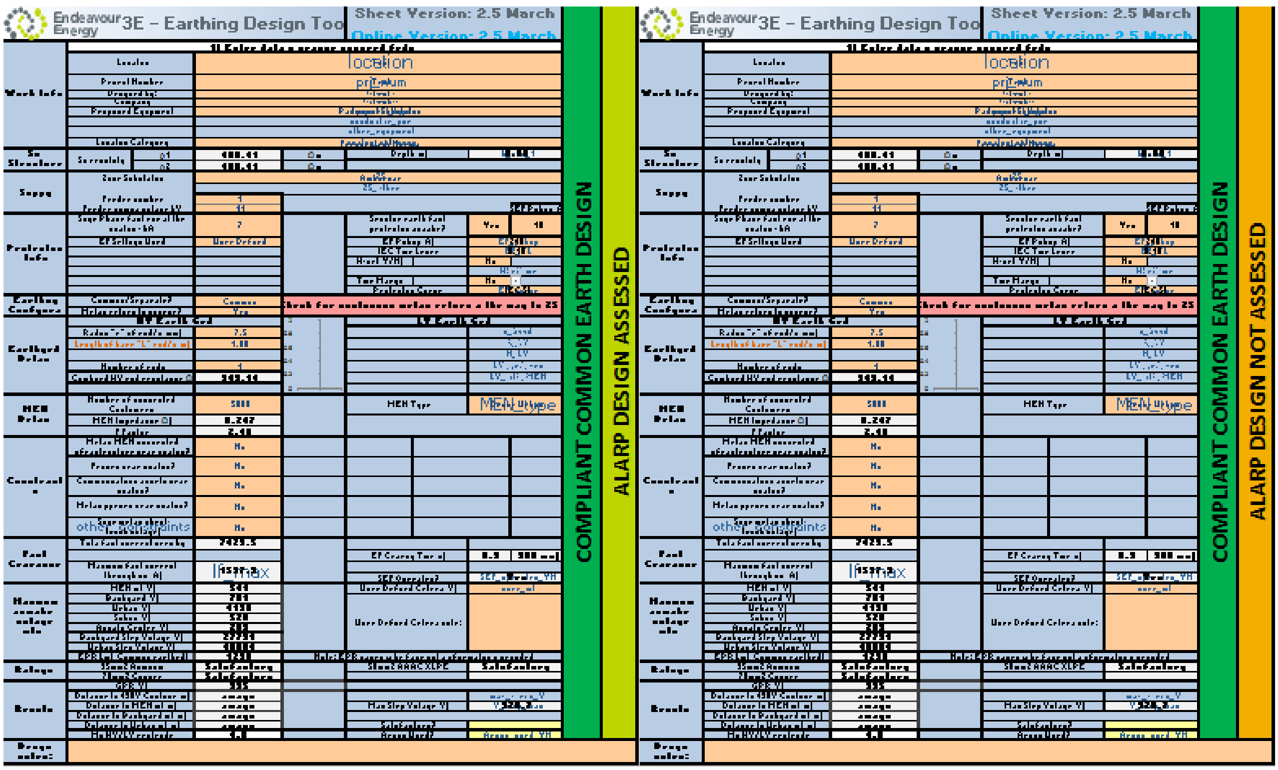
4.3 ALARP Design

Part of earthing design under NSW Workplace Health and Safety Legislation (2011) is producing a design that is As Low As Reasonably Practicable (ALARP).

Previous versions of 3E had no mechanism to record risk reduction techniques or additional options designers have considered as part of their design.

The current version has an added sheet, labelled “ALARP Design” which allows the designer to comment on the steps they have considered to reduce the risk to this required ALARP level.

Shown below is the updated sheet, as we can see when the “ALARP Design” sheet is completed the status will show in green “ALARP DESIGN ASSESSED”. When the “ALARP Design” sheet is not completed the status will show in orange “ALARP DESIGN NOT ASSESSED”.



The “ALARP Design” sheet being filled in is **NOT** a mandatory requirement; it is simply a mechanism to allow designers to record with the technical design why they believe it is ALARP.

5.0 OUTPUT PARAMETERS

5.1 Main page

Output	Location	Comments on input
Soil resistivity	Soil Structure	ρ1, ρ2 and the depth will be loaded from the soil model page
Combined resistance in (Ω)	HV Earth Grid – Earth grid details	The HV earth resistance value calculated – see Earth grid calcs page
LV resistance in (Ω)	LV Earth Grid – Earth grid details	The LV earth resistance calculated – see Earth grid calcs page
LV with MEN (Ω)	LV Earth Grid – Earth grid details	The combined resistance of the LV earth grid in parallel with the modelled MEN resistance – LV earth grid res in parallel with the MEN resistance
Satisfactory	LV Earth Grid – Earth grid details	True/False - Determines if the LV earthing system meets the requirements of EDI100 (min of 2x2.4m electrodes, and either a connection to one other DS or a combined resistance less than the designed HV)
MEN impedance	MEN details	The modelled resistance of the MEN network– see Earth grid calcs page
F Factor	MEN details	The ratio of the EPR to the maximum touch voltage on the MEN for a common earthed system – see Earth grid calcs page
Total fault current seen by protection (A)	Fault Clearance	Current seen by the protection relay assuming a reactive source impedance and a voltage factor of 1.1
Minimum current seen by SEF	Fault Clearance	Current seen by the protection relay assuming a purely resistive source and 0.9 voltage factor
Maximum fault current through soil (A)	Fault Clearance	Current entering the soil assuming a reactive source impedance and a voltage factor of 1.1
EF Clearing Time (s)	Fault Clearance	The protection clearing time determined for the Total fault current seen by protection
HV Fuse Trip Time?	Fault Clearance	The HV fuse trip time for maximum fault current (if fuse is selected as the EF protection)
SEF Operates?	Fault Clearance	Yes/No – Will SEF protection operate for minimum fault current
MEN limit	Limits	TDMEN limit from EG-0 and EDI001
Backyard	Limits	TDB limit from EG-0 and EDI001
Aquatic centre	Limits	AQ12 limit from EG-0 and EDI001
Urban Step Voltage	Limits	Step voltage limit in an urban location from Argon
Backyard Step Voltage	Limits	Step voltage limit in a backyard location from Argon
EPR at …	Constraints	The soil voltage calculated at the distance to the particular infrastructure
Various	Ratings	“Not Rated” or “Satisfactory” determined for different conductors for maximum potential fault current
GPR	Results	Grid potential rise – the maximum voltage on the earth grid during a fault

Output	Location	Comments on input
Distance to 430V contour	Results	The separation required between the earthing system and Telstra
Distance to Urban limit	Results	The horizontal distance before soil voltage falls below TDU limit – Please note Argon software assumes 100 contacts a year, while the standard for distribution is 135 contacts a year.
Distance to MEN limit	Results	The horizontal distance before soil voltage falls below TDMEN limit
Distance to backyard limit	Results	The horizontal distance before soil voltage falls below TDB limit
Min HV/LV electrode separation	Results	The required separation between HV and LV electrode system, for this value to be accurate the ***"Number of connected customers"*** must be filled out for common and separately earthed designs
Touch Voltage to asset	Results	Difference in potential between the GPR and the soil voltage 1m from the asset
Max step voltage	Results	The maximum difference of one soil voltage to the soil voltage 1m away.

5.2 Circuit overview

The circuit overview page shows a circuit diagram to visually represent the earthing system circuit. Key outputs are shown along with a visual representation of the alternative current paths present in different configurations.

Output	Details
Separate/Common Design	Shows whether the design is separate or common earthed
Z_source	The source impedance in ohms
Voltage	The nominal phase to phase system voltage
Metallic return current	The amount of current returning via a metallic return path (where this available)
EPR	The calculated EPR in Volts
HV grid	The resistance in Ohms of the HV earth grid
HV grid current	The current determined to be flowing into the local HV earthing system
Fault Current	The total maximum fault current
Protection Current	The minimum fault current the protection device will see
MEN Voltage limit	The TDMEN voltage limit (see EDI001)
EPR below limit?	Yes/No – is the EPR below the limit (TDMEN*F factor)
HV-LV separation	The required separation between HV and LV earth grids – only required for single customer substations

Output	Details
LV grid	The resistance in Ohms of the LV earth grid
MEN	The resistance in Ohms of the LV MEN
MEN current	The amount of current determined to be flowing into the LV MEN

6.0 USING 3E

It is essential that before using 3E to undertake a distribution earthing design, the designer has familiarised themselves with company standards EDI100 and EDI001, and are familiar with the earthing design process.

When installing a new earthing system in an urban area, the first preference should be to pursue a common earthed design. If a common earthed design can't be achieved using 3E, yet the designer believes this to be the best option, a risk based design may be undertaken as described in EDI100. In rural locations, or where common earthing is not practical, a separate earthed design will be necessary.

The first step in any earthing design is to gather the data necessary to perform the design. The designer will first need to determine:

- The soil resistivity of the site – measurements undertaken
- The fault level – from the standards website
- The ZS bonding arrangement – from the standards website

Once this is complete, the designer will need to enter the information associated with the project, and the data they have gathered into 3E.

6.1 Soil resistivity

The soil resistivity tab in 3E can be used to calculate a two layered soil model for use in the earthing design. The accuracy of the model will depend entirely on the accuracy of the measurements taken. The designer must enter the measurements taken (in Ohms) and the spacing at which they were taken (in metres). A minimum of 5 measurements (with spacing's up to at least 16 metres) are required to provide an accurate model.

Once the measurement data has been entered, click the *Calculate* button. The tool will then determine a two layered soil model as described in IEEE Std 81. The soil resistivity as a function of electrode separation, a is given by:

$$\rho_c(a) = \rho_1\left[1 + 4\sum_{n=1}^{\infty}\left(\frac{K^n}{\sqrt{1+\left(\frac{2nh}{a}\right)^2}} - \frac{K^n}{\sqrt{4+\left(\frac{2nh}{a}\right)^2}}\right)\right]$$

Where

- ρ_1 is the first layer resistivity
- ρ_2 is the second layer resistivity
- h is the first layer depth
- $K = \frac{\rho_2 - \rho_1}{(\rho_2 + \rho_1)}$

The calculation minimises the error between the modelled values and measured values:

$$\epsilon = \sqrt{\sum_{i=0}^{N} \left(\frac{\rho_{m,i} - \rho_{c,i}}{\rho_{m,i}} \right)^2}$$

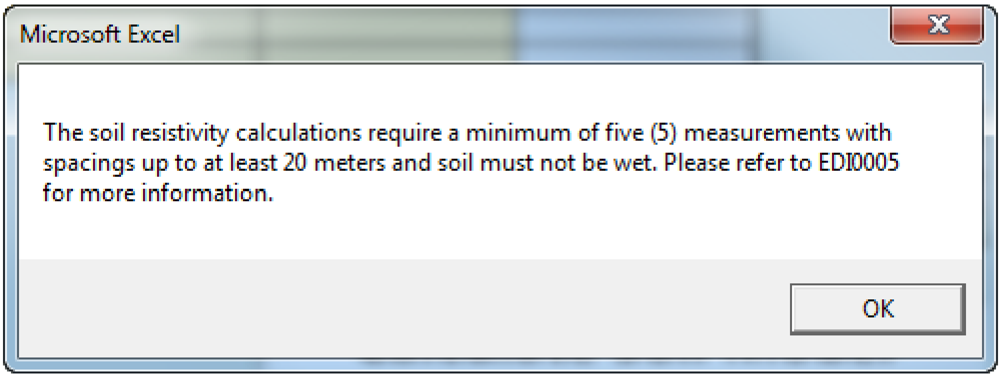
Where

- i is the i[th] value in the measurement or computation
- N is the total number of measurements

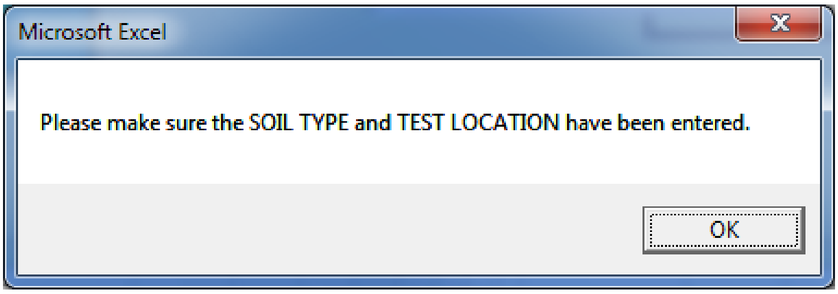
By varying ρ_1, ρ_2 and h.

Erroneous measurements will make the model inaccurate. It is essential that the designer is trained in the measurement of soil resistivity, is familiar with the operation and limitations of the instrument used. The designer should also understand the potential sources of error in measurement and how to avoid these.

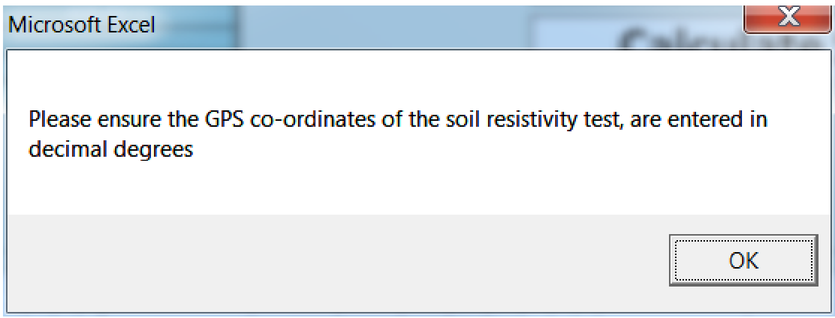
When there are insufficient measurements or spacings are not at least 20m the following error will show:



3E will also show the following error if certain values have not been filled.



3E will also enforce the use of the decimal degrees GPS co-ordinates for the soil resistivity test. If the values are not entered, the following error will appear.



6.2 Common earthed design

When undertaking a common earthed design using 3E, the objective is to limit the EPR (Earth potential rise) of the earthing system during an earth fault such that all touch voltages on the system will be of low risk. The EPR (or GPR – grid potential rise) will depend on the system impedance. The system impedance of a common earthed system is the combined resistance of the local earthing system and the impedance of the connection to the MEN.

To complete the design the user is required to enter in system parameters as described in section 4.0. Once the appropriate figures are entered and the earthing configuration is set to *Common* then the tool will analyse whether the location is suitable for common earthing. If the system is assessed to be suitable (in line with the requirements of Annexure 4 of EDI100), then the sidebar will display a green status "**COMPLIANT COMMON EARTH DESIGN**". A *yes* will also appear next to the *EPR below limit?* box in the circuit overview tab. If this is not the case then the system has not been deemed to be appropriate for common earthing under the level 1 and 2 assessment criteria of Annexure 4 in EDI100. Assessment under the level 3 criteria is still a design option in this circumstance.

Note that in most circumstances where there is metallic return to the source a compliant common earthed design should be found.

For common earthed designs, 3E will prominently display the following statements on the sheet on the side bar.

- **COMPLIANT COMMON EARTH DESIGN**
- **NON COMPLIANT COMMON EARTH DESIGN**

This will give a clear indication to the designer the status of the common earthed design.

6.3 Separately earthed design

The current version of 3E will clearly show that a design is separately earthed down the side bar, however it will not show a status of compliant and non-compliant separately earthed design, as does a common earth design.

Where the location has not been found to be appropriate for common earthing a separately earthed design is required. The objective for this design is to ensure that the surface voltage within 1m of conductive objects that are accessible to staff and public are controlled to acceptable levels. Of particular concern to the designer are objects such as long metallic fences and household taps, as these conductive objects stay close to 0V when the soil voltage rises. This could result in large touch voltages. The design is also required to control touch voltages to isolated conductive objects, such as concrete poles and traffic signposts.

To undertake this design with the 3E tool the designer shall enter in all appropriate system parameters as described in section 4.0. The designer shall also enter in information about conductive objects and their distance from the nearest earth electrode. The EPR values at these assets can then be compared against the appropriate limit found under the limits section. See EDI0001 for more information on the selection of appropriate limits.

If the design ensures that the EPR at the conductive objects is less than the relevant limit then the design is compliant with the criteria, provided that either primary earth fault or SEF protection will operate. In this circumstance the designer shall confirm that all other touch and step voltages are within acceptable limits.

6.4 Incomplete earthing designs

When earthing designs using 3E are missing required information, the status bar will turn yellow, with the following text "**DESIGN INCOMPLETE – PLEASE MAKE SURE ALL VALUES ARE FILLED IN**". Once all the required values are filled the bar will change status and colour.

7.0 FINALISING THE DESIGN

When a compliant design has been reached using the 3E tool it is still a requirement of NSW Workplace Health and Safety Legislation (2011) to ensure that all other design options are considered and applied where it is practical to do so (hence the addition of the “ALARP Design sheet”). EDI0001 gives guidance on this process.

Following this process and when the designer is satisfied with the design, the 3E calculations can be submitted with all other design information as a soft copy or by printing out the main page worksheet.

8.0 COMMISSIONING CHECKS

The current version of 3E includes the ability to validate the design using actual commissioning test measured resistance if they vary from the designed resistance. When “Yes” is selected in the commissioning check section, the actual measured resistance can be applied into the 3E tool to confirm that the constructed earthing performs within the bounds as the designer intended.