SafeGrid Reference Manual

Version 2.1

This reference manual provides an overview of the features and instructions on how to use SafeGrid earthing analysis software.

Visit the website www.elek.com.au/safegrid.htm for the latest updates.

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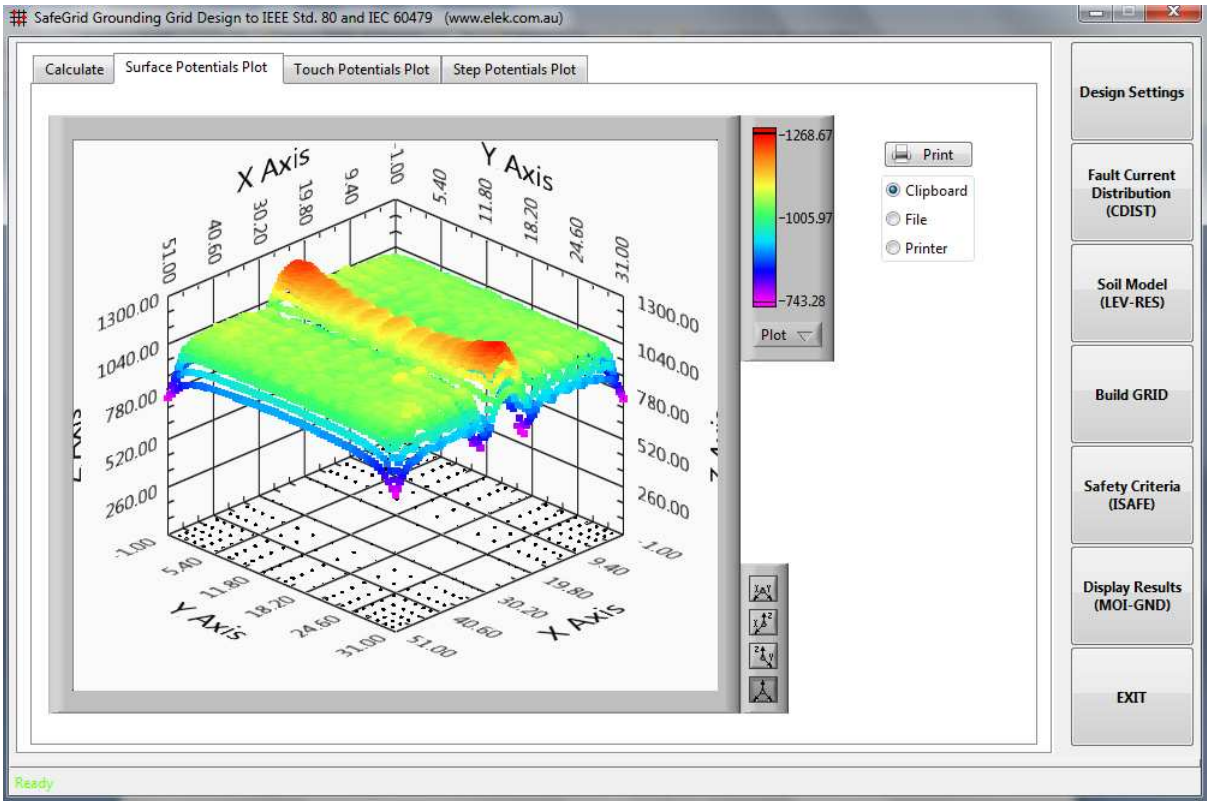

1. Design Settings

Defining the design settings is the first step in performing a grounding system analysis.

The sub-section numbers for this Section align with the highlighted regions in Figure 1.

1.1 Soil Characteristics

The following soil resistivity models can be used:

a) Two-layer, horizontally stratified
b) Uniform (homogeneous)

The soil model can either be determined from field measurements using the soil modelling program (LEV-RES) or explicitly specified.

Specifying the soil model

This approach is useful for when the soil resistivity model is already known.

Select the option **Specify soil model parameters** from the Design Settings screen.

Enter the top and bottom layer resistivity and the depth of the top layer. To specify a uniform soil model then enter the top and bottom layer resistivity as the same value.

Note: The computation time required for a two-layer is greater than for a uniform model.

Determine values using soil modelling program (LEV-RES)

When this selection is made SafeGrid will disregard soil model data which is entered manually and use the model determined from measurement values entered into the LEV-RES analysis module.

Refer to Section 3 for instructions on how to use the LEV-RES module.

Note: If the LEV-RES model is not entered correctly or if the model is invalid then SafeGrid will revert to using the data in the manual entry fields.

1.2 Grid Energisation

Use the Grid Energisation frame to specify the current injected into the ground electrode or the voltage (GPR) of the electrode.

Current (A): <Default > Specifies the current injected into the ground electrode, in amperes. The value can be specified explicitly by selecting the **Use Specified Value** option, or the program deduce the amount of fault current discharged in the main grounding grid from the fault current distribution calculation (the option called **Determine using fault current distribution program (CDIST)**). Note that if the results of the fault current calculation are not available for any reason, the program reverts to using the specified value.

Voltage (V): Specifies the GPR of the Main-Ground electrode, in volts.

Note that a value must be entered for the **Magnitude**.

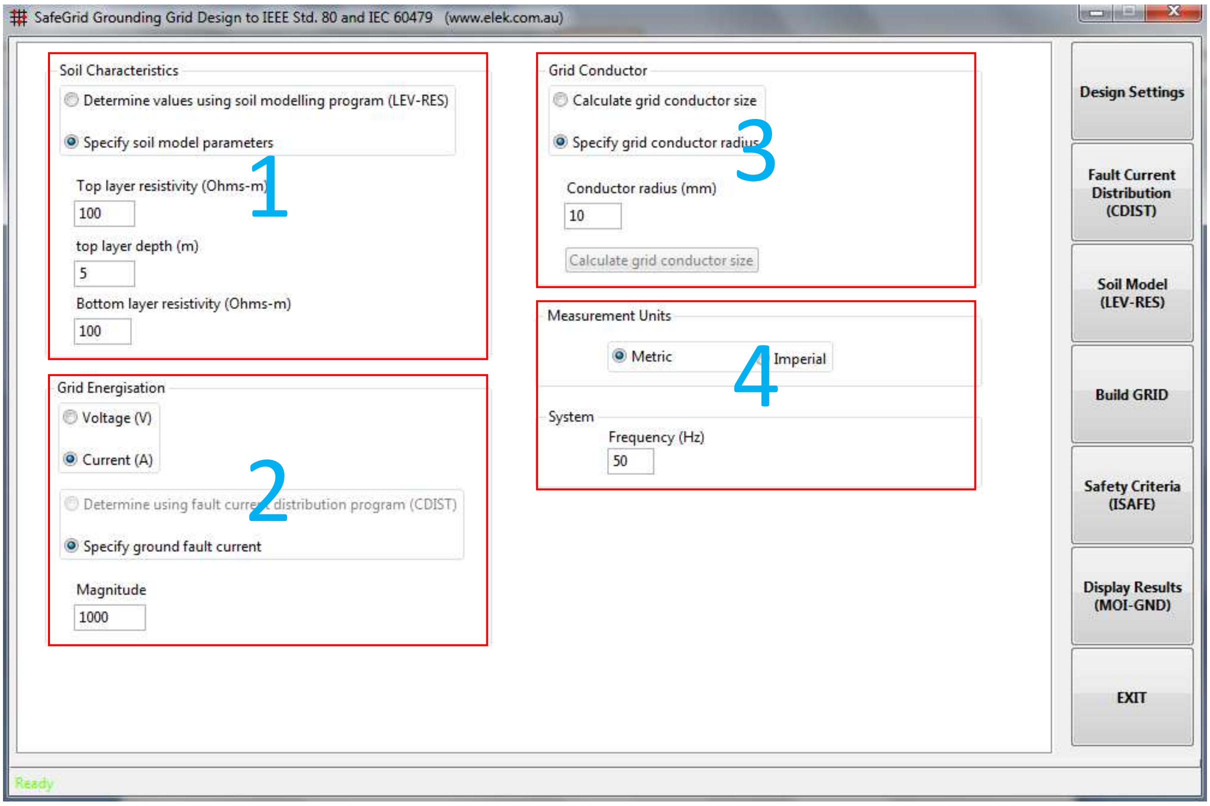

Figure 1. Design Settings window where: 1. Soil Characteristics; 2. Grid Energisation; 3. Grid Conductor; 4. Measurement Units and System Frequency.

1.3 Grid Conductor

The grid conductor size can be specified explicitly or calculated according to the method in IEEE Std 80. The same conductor size applies for all conductors including main grid conductors and rods.

Calculate grid conductor size

By selecting **Calculate grid conductor size** this enables the button for opening the conductor size calculator (shown in Figure 2).

Symmetrical RMS current magnitude – This is the magnitude of the maximum fault current expected to flow in the conductor (this is often assumed to the total available fault current), with no dc offset included. The effect of the dc offset is introduced by specifying the Decrement factor.

Maximum fault duration – Enter the maximum duration, in seconds.

Ambient temperature – This is the highest expected conductor temperature, before the fault is initiated. It must be specified in degrees Celsius.

Maximum allowable temperature – This is the allowable temperature limit: it can be the fusing temperature of the conductor or a limit based on the type of connections made between conductors or a limit imposed by the presence of nearby flammable materials. If **Fusing temperature** is selected then the fusing temperature will be obtained for the

Conductor material specified. If **Other** is selected then the temperature limit must be specified, even if it is higher than the fusing temperature.

Decrement factor – specifies the multiplicative constant by which the symmetrical RMS fault current magnitude must be increased in order to obtain an equivalent RMS current magnitude which accounts for the dc component of the fault current waveform. This DC component is zero when the fault is initiated at the point in the sinusoidal current cycle where the current amplitude is zero; the DC component is a maximum when the fault is initiated at the peak current value.
The overall DC component is negligible when the fault duration is long (e.g., 0.5 to 1.0 s or more) or when the X/R ratio at the fault location is less than 5.
Specify a value of 1 if there is to be no DC offset. Otherwise, enter a **User-specified** or compute from the **X/R ratio** and the system operating frequency. The X/R ratio is the ratio of the reactive component of the system subtransient fault impedance to its resistive component.

1.4 Measurement Units

The measurement units can be set to either Metric or Imperial. This makes SafeGrid compatible with earth grid designs from all around the world.

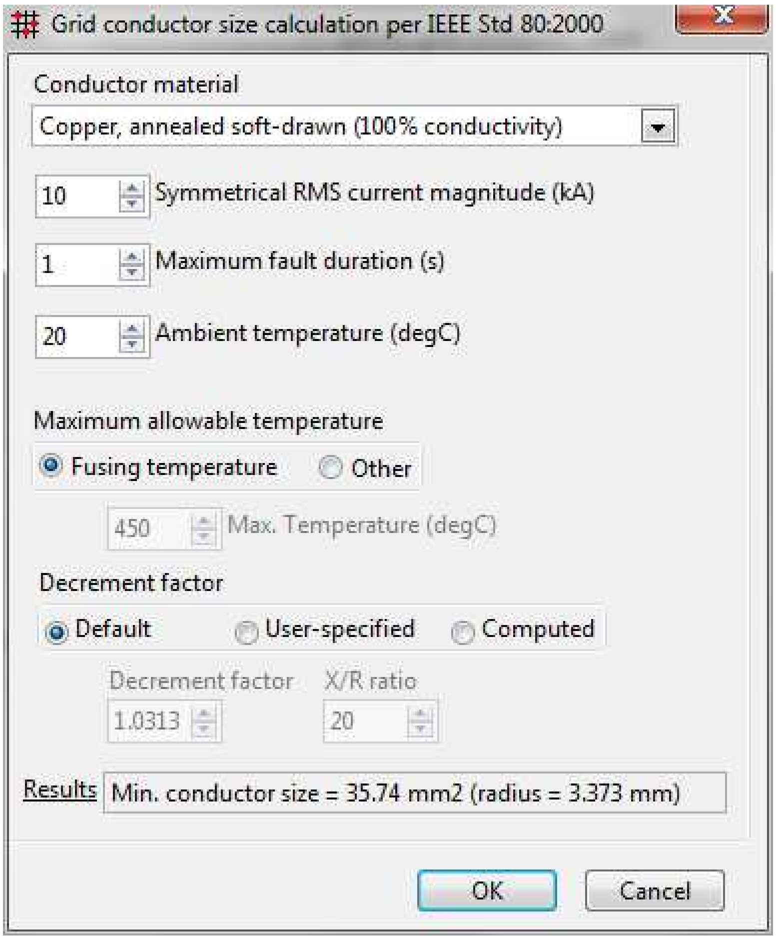

Figure 2. Grid conductor size calculation according to IEEE Std 80 method.

2. Soil Model (LEV-RES)

The LEV-RES module uses a powerful optimisation algorithm which can interpret field measurement data and deduce the soil structure which best matches the measurements.

The sub-section numbers for this Section align with the highlighted regions in Figure 3.

2.1 Resistivity measurement versus calculated model plot

This plot displays the soil resistivity field measurements versus the soil resistivity model.

2.2 Soil Model Results

The results from the calculation of the soil model are displayed in this field.

No. of function calls – Displays the total number of iterations performed by the optimisation algorithm. This is an indication of how difficult it was to find an optimal model. Note this does not apply for a uniform soil model as the optimisation algorithm is not used.

R-square – Indicates how well the model fits the field measurement data. The closer this value is to 1 the better the model.
Note suspect field measurement values can be excluded from the calculations by setting the **Included?** field in the Field Measurements table to False. This may improve the R-square value.

Model parameters – Returns the standard soil resistivity model parameters.

2.3 Field Measurements

The field measurement data can be entered into the table by pressing the **Add** button and clicking on the fields in the table which contain <Click>. Field measurements can be removed by highlighting the row of the table and pressing **Remove**. All measurements in the table are removed by pressing the **Reset** button.

For Wenner measurements, the **Spacing** is the distance between any pair of adjacent pins.

2.4 Soil Model

The soil model can be either **Uniform** or **Horizontal 2-layer**. The general rule for choosing a uniform model is if the difference between the extreme values of measurements is less than 30%.

A two-layer model will always produce more accurate results than a uniform model; however, will also increase computation time significantly.

2.5 Probe Options

The standard modelling equations in-built to LEV-RES are valid for electrode spacings much larger than electrode length (or burial depth, if spherical sources are used). Wenner has developed an equation that takes into account the depth of a point source, but it is not applicable to spikes that are commonly used as electrodes. LEV-RES will optionally use an exact equation that takes the lengths of the probes into consideration.

Checking **Account for probe depth?** may improve the R-square value.

2.6 Measurement

Field measurements can be entered as either apparent **Resistance (Ohms)** values or **Resistivity (Ohms-m)**.

Note some soil resistivity meters may display the measurements in ohms-m, having already converted from resistance (Ohms).

2.7 Remove outliers

This is a statistical tool which allows the user to identify suspect field measurement data. As with any statistics it should be used with caution. It may be used to improve the R-square value.

Values which are determined to be outliers in accordance with **Advanced** settings are excluded from the calculation by automatically setting the **Included?** field for the corresponding measurement to FALSE.

This option can be turned on or off at any time.

Note the user can **Include All Measurements** by right-clicking the Field Measurements table.

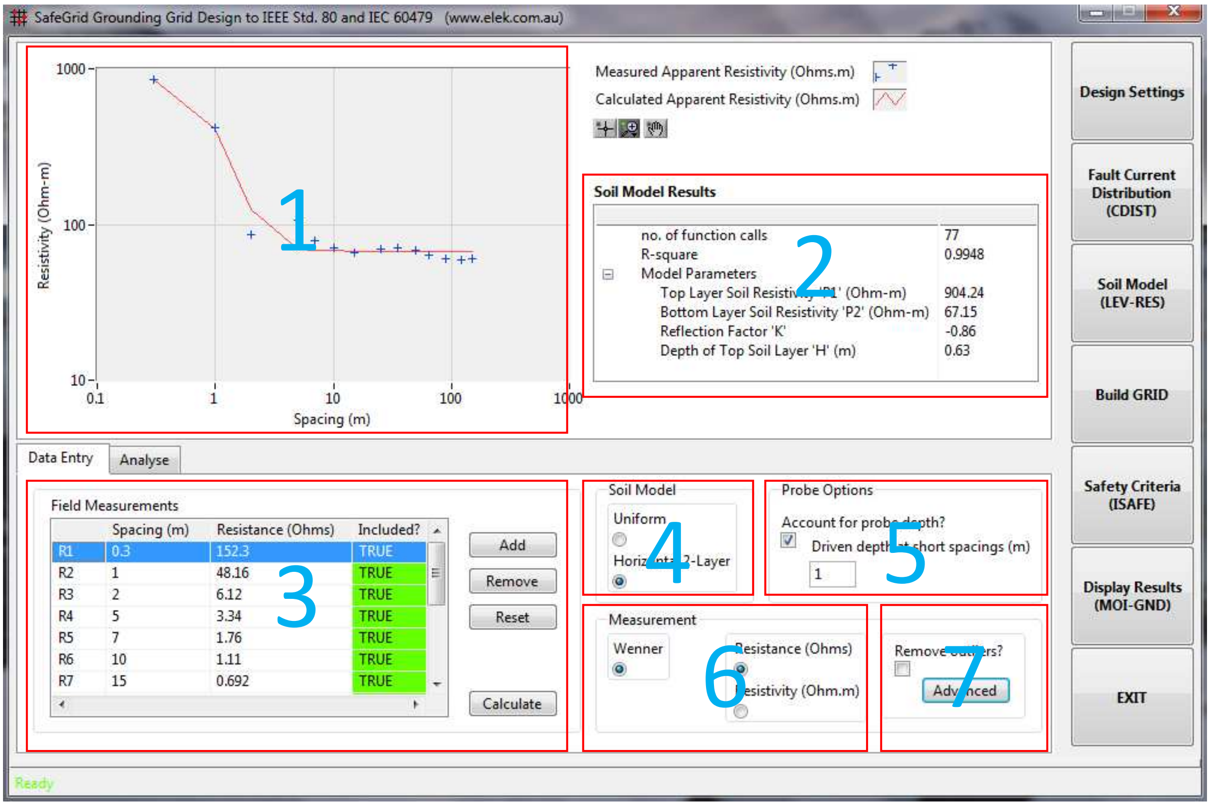

Figure 3. Soil Model (LEV-RES) window where: 1. Resistivity measurement versus calculated model plot; 2. Soil Model Results; 3. Field Measurements table; 4. Soil Model; 5. Probe Options; 6. Measurement type; 7. Remove outliers.

3. Build Grid

The Grid module is a powerful tool which allows the construction of arbitrary 3D ground electrode configurations both of a simple or complex nature.

Grids can either be built using the inbuilt editing tools or by loading custom grids from CAD files.

The sub-section numbers for this Section align with the highlighted regions in Figure 4.

3.1 Grid XY Preview

This display field illustrates the three-dimensional grid which is currently loaded in the X-Y plane. The dimensions for the grid are displayed. The three main entities for the grid representation are displayed according to the legend.

3.2 Grid Properties

These properties apply when building a grid against the **Grid co-ordinates**.

No. of parallel conductors (Nx) – The number of (vertical) conductors which will appear along the x-axis when a grid is built. The minimum number is 2.

No. of parallel conductors (Ny) – The number of (horizontal) conductors which will appear along the x-axis when a grid is built. The minimum number is 2.

Compression ratio (x-axis) – Bunches the conductors (along the x-axis) towards the edge of the grid more closely together. The ratio of distance between successive pairs of conductors decreases by this factor.

Compression ratio (y-axis) – Bunches the conductors (along the y-axis) towards the edge of the grid more closely together. The ratio of distance between successive pairs of conductors decreases by this factor.

No. segments (desired) – Useful if more conductor segmentation is required. The program divides the longest conductors in half until the desired value is reached. Has no effect if the number of segments desired is less than the minimum determined automatically by conductor intersections. Note that this <u>should be manually set to 1 each time the grid is built</u> otherwise the previous number of segments shall be applied for the new grid.

3.3 Grid co-ordinates

In these fields the X,Y and Z co-ordinates of the four corners for a grid are defined to be built. A grid is defined as a three-dimensional (flat) plane.

Point A – Bottom left-hand corner. Only the depth of Point A can be specified as it is placed at a fixed 0, 0 reference position.

Point B – Bottom right-hand corner.

Point C – Top left-hand corner.

Point D – top right-hand corner. The position of this point is determined by the position of the other three (A, B and C) points.

Press **Build GRID** to create the grid as defined by the **Grid co-ordinates**.

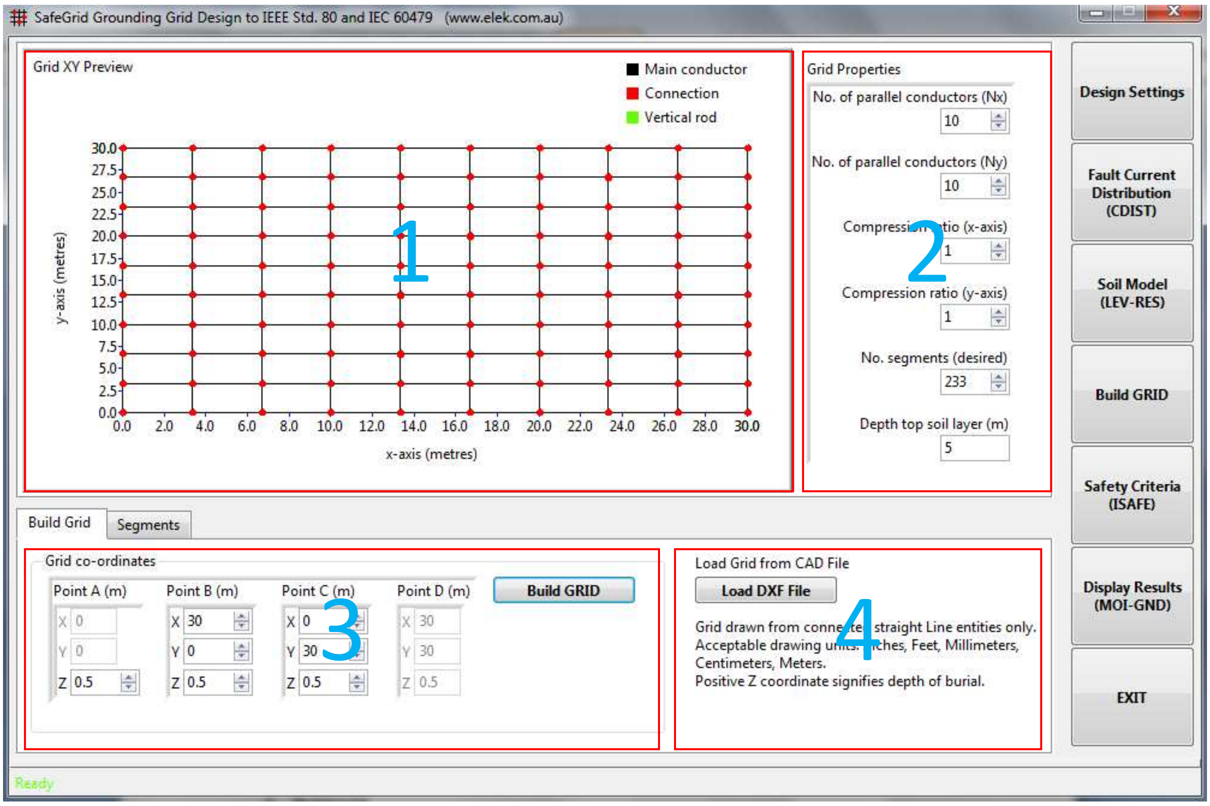

Figure 4. Build GRID window where: 1. Grid XY Preview; 2. Grid Properties; 3. Grid co-ordinates; 4. Load Grid from CAD File.

3.4 Load Grid from CAD File

This allows arbitrary grids to be loaded from CAD files in DXF format.

The grid drawn in CAD must consist only of straight Line entities. It must be ensured that the lines are snap connected (where necessary) otherwise an undesired current discontinuity will occur.

The screen shown in Figure 5 needs to be completed.

Lines to include – Specifies whether to load all Line entities from all layers (not recommended) or only those Line entities associated with specified **Layer Name(s)**. More than one layer can be specified by separating the layer names with a comma [,].

Depth of burial – Specifies whether to load all grid conductors at the same depth or to use the depth of burial assigned as z-coordinate Line entity attributes in the CAD file (this assumes that the drawing has been done in 3D).

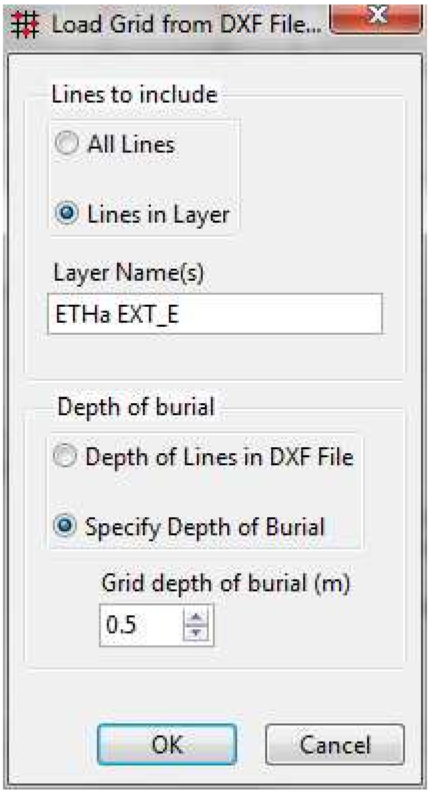

Figure 5. Load Grid from DXF File options

3.5 Segments

Used to (a) manually alter the grid using an Operation function; and (b) assign the segment number to which the actual fault current will be applied during analysis.

Add Segment – Connects a segment between two points (either a midpoint or endpoint) on the grid. To use press the button and then move the cursor onto the Grid XY Preview. Place and then click the desired position for the new segment start point and then move and click to where the segment should end. The new segment will be added to the table.
Note the new segment start and endpoint must not cross any other conductors or it will not be added.

Remove Segment – First highlight (select) a segment (row) in the table. Scroll through the segments in the table (up/down buttons on the keyboard) until the desired segment to be removed is found. Then press the Remove Segment button to remove.

Add Rod Conductor – Press this button then move the cursor onto the Grid XY Preview. Press the button again to add a new rod conductor at the desired location. Specify the **Length of the rod conductor**. Note the rod starts at the depth of the connection point.

Undo – Any of the aforementioned Operation(s) can be undone by pressing this button. Press it more than once to undo a series of operations.

Fault location – the **Segment no.** of the grid to which the fault is to be applied. SafeGrid considers the impedance of the grid conductors. Therefore the location of the fault affects the impedance seen by the fault and hence the current distribution.

4. Safety Criteria (ISAFE)

This screen is used to control the safety analysis carried out. It allows the selection of quantities which should be analysed, the region where they should be analysed and the values that are considered safe for these quantities.

The sub-section numbers for this Section align with highlighted regions in Figure 6.

4.1 Determine Safety For…

Touch Voltages – Check this option to activate the safety analysis for touch voltages.

Step Voltages – Check this option to activate the safety analysis for step voltages.

4.2 Safety Criteria

Use Safe Allowable Values as Plotting Threshold – Check this option if you want the program to use the safe allowable values defined below as a plotting threshold when producing plots. If this option is selected, only those regions where the touch voltage (or step voltage) is larger than the safe allowable value will be coloured.

Maximum GPR of Grid – Maximum allowed GPR for the grounding grid.

Allowable Touch Voltage – This value is computed from the selected Fault Clearing Time and Insulating Surface Layer Resistivity as well as other parameters from the Advanced Safety screen. This field cannot be edited.

Allowable Step Voltage – This is the largest acceptable value for step voltages. This value is computed from the selected Fault Clearing Time and Insulating Surface Layer Resistivity as well as other parameters from the Advanced Safety screen. This field cannot be edited.

Fault Clearing Time – Defines the fault clearing time (in seconds) for which the safety analysis should be carried out.

Insulating Surface Layer Resistivity (Ohm-m) – Defines the resistivity (in Ohm-m) of the insulating layer of material covering the ground. The thickness of this layer and other attributes can be defined in the Advanced Safety screen.

Insulating Surface Layer Depth (m) – Defines the depth of the insulating surface layer.

4.3 Region Where Safety Criteria is Assessed

There are two options for defining the region where the safety analysis should be carried out (a) along a line; or (b) over an area. A preview for the grid and the points where safety is calculated is shown. The **Refresh** button should be pressed before performing analysis to update the profile.

Plot Surface Voltages – Voltages can be determined along a line (faster) or over an area. The more points there are the slower the computation will be.

Maximum spacing between points – This specifies the maximum spacing between points at which voltages will be determined which applies along lines or over areas.

Grid border offset for voltage profiles – Controls the distance that separates the safety area that is used for the safety analysis for both touch and step voltages from the boundary of the grid.

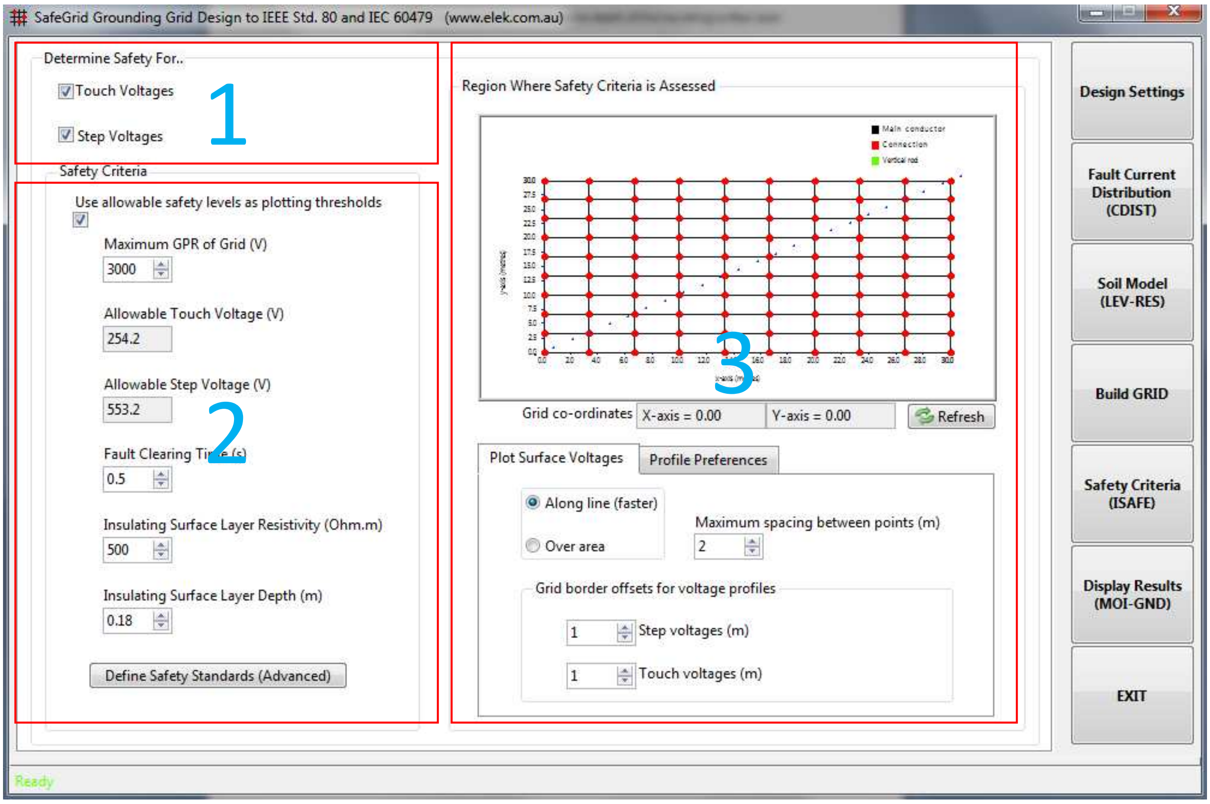

Figure 6. Safety Criteria (ISAFE) window where: 1. Determine Safety For..; 2. Safety Criteria; 3. Region Where Safety Criteria is Assessed.

4.4 Define Safety Standards (Advanced)

The advanced safety screen gives access to all the parameters for establishing allowable safety criteria limits. SafeGrid allows safety criteria to be determined based on the IEEE or IEC methods.

Refer to the following standards for further explanations about the principles involved:

IEEE Std 80 – 2000 IEEE Guide for Safety in AC Substation Grounding

IEC 60479 – Effects of current on human beings and animals

Once appropriate safety criteria have been determined then press **Accept and Update Safety Criteria** to accept and return to Safety Criteria screen.

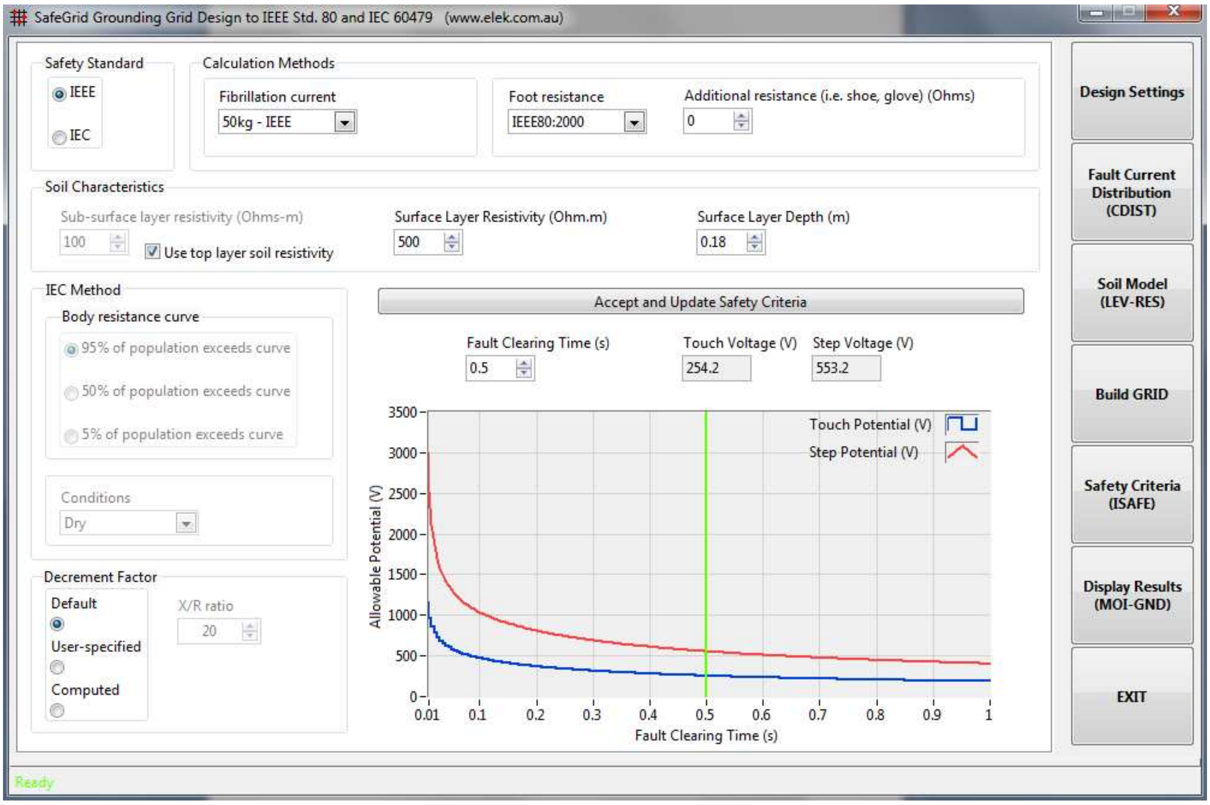

Figure 7. Define Safety Standards (Advanced) window.

5. Display Results (MOI-GND)

This module of SafeGrid facilitates the main calculations to be performed and allows the results to be analysed. The advanced grounding algorithm is based on Maxwell's Method of Images.

The sub-section numbers for this Section align with highlighted regions in Figure 8.

5.1 Summary of User Inputs

These are the main input parameters used for defining the grid and performing the analysis.

5.2 Segmentation

Segment for Maximum Accuracy? – Checking of this box will (usually) significantly increase the segmentation (division into smaller sections) of the grid done before analysis. SafeGrid will decide which segments to divide based on scientific theory and experience gained by the developers.

Refer to end of this Section for more information regarding conductor segmentation.

5.3 Results

Both the calculated Grid Impedance in Ohms and the Grid Potential Rise (GPR) in Volts is displayed after the calculations are completed.

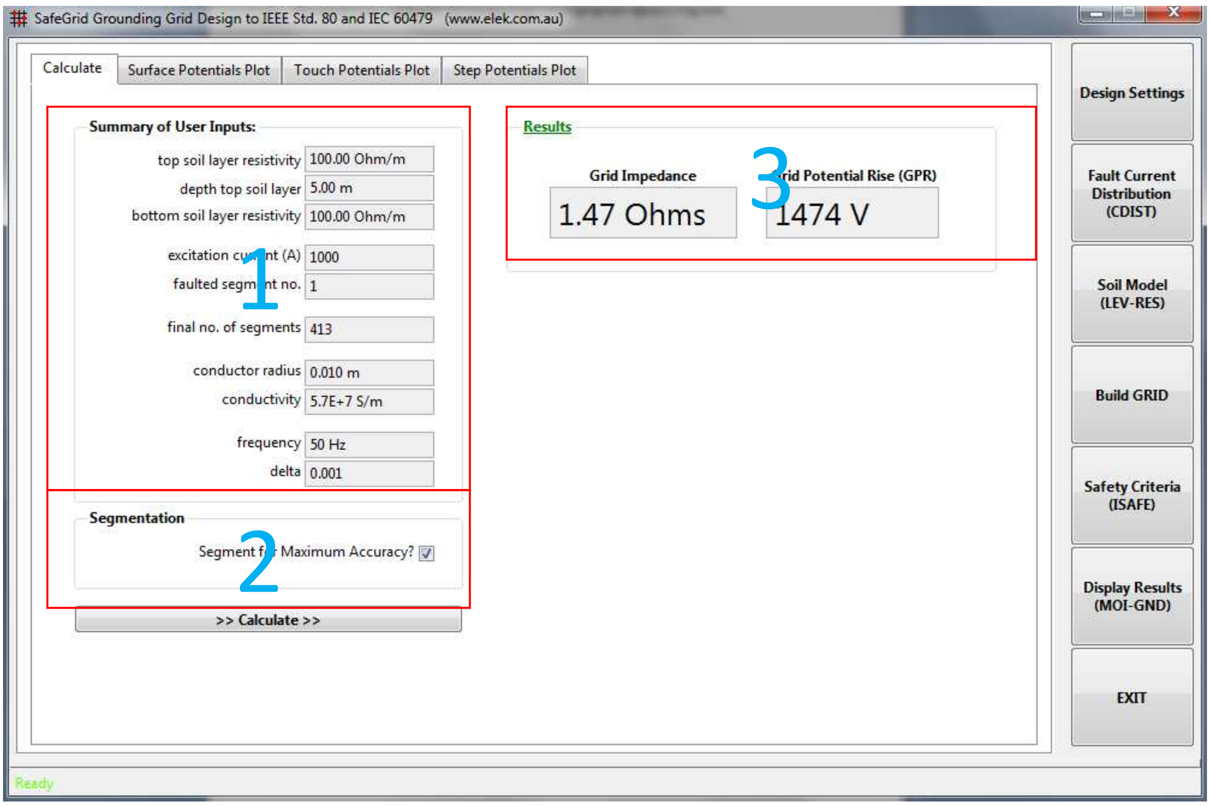

Figure 8. Display Results (MOI-GND) window where: 1. Summary of User Inputs; 2. Segmentation; 3. Results.

5.4 Potential Plots

A range of potential plots are displayed after a calculation is performed. These can be viewed (and rotated) in three (X-Y-Z) dimensions or numerous other axes combinations such as X-Y, Z-X or Z-Y.

The displayed potentials are those measured at the surface of the ground (Z = 0). The grid is also displayed where the black circles represent the conductor intersection points.

Unsafe Potentials? – Checking this box results in only those potentials which exceed the associated Safety Threshold being displayed. Therefore if no potentials (colours) are displayed then there are no unsafe areas.

Note that Safety Thresholds can be recalculated using ISAFE and plotted without recalculating the surface potentials. Check and then un-check the **Unsafe Potentials?** to refresh the Safety Threshold(s).

Cursor Position – A cursor can be displayed and moved on the graphs according to X and Y coordinates entered. The cursor will snap to the nearest point where the potential has been calculated.

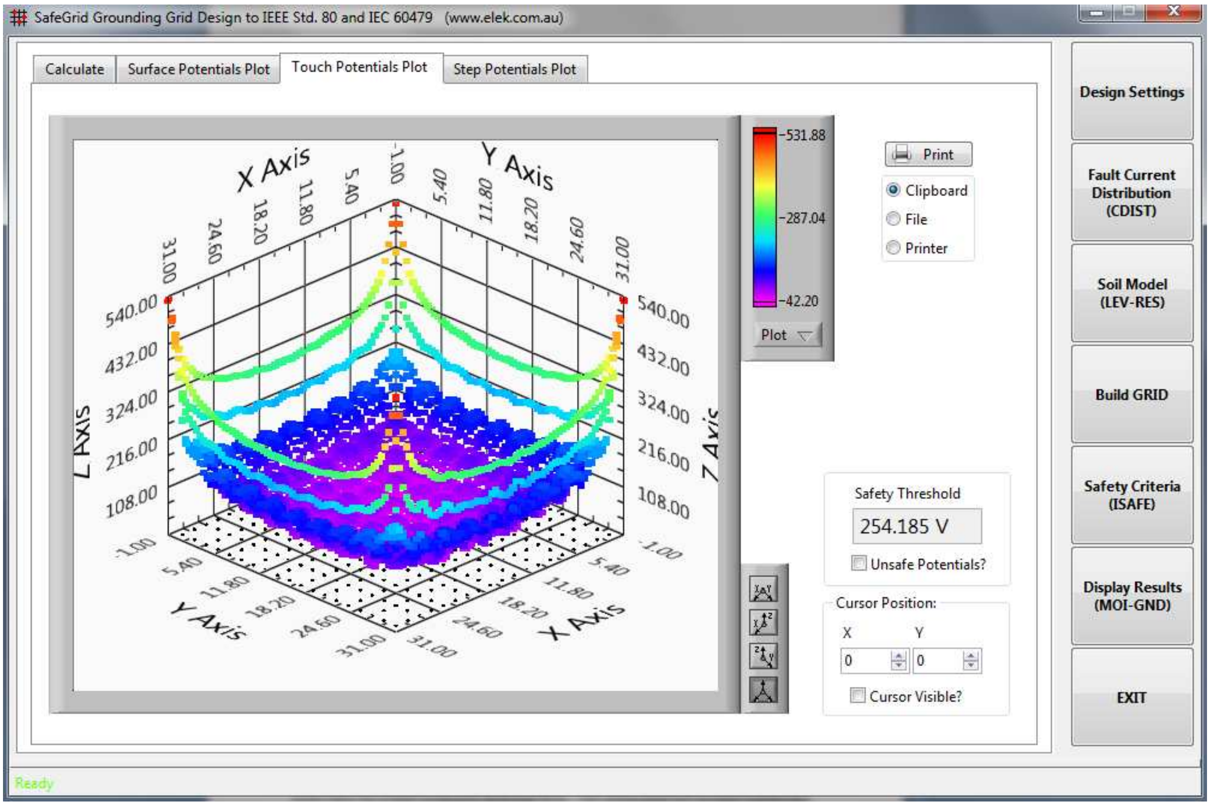

Figure 9. Touch Potential Plot displaying all (including safe and unsafe) potentials.

6. Information regarding conductor segmentation:

In most cases, the accuracy of MOI-GND results is improved when the original conductors are subdivided into smaller conductors called segments[1]. Part of the subdivision process is performed automatically by the program, while the rest of the process is controllable to a degree.

Conductors are subdivided according to the following four-step procedure:

1. The original conductors are automatically subdivided at a soil layer boundary.
2. Each conductor segment is further subdivided at its points of intersection with other conductors.
3. If the **No. Segments (desired)** is specified, then the longest conductors resulting from Steps 1, 2 and 3 are further subdivided until the specified totals are reached. This process is performed separately on each electrode.
4. If the **Segment for Maximum Accuracy?** is selected then the program applies an advanced segmentation procedure which ensures the greatest accuracy is achieved by the most efficient means.

The variable **No. Segments (desired)** indicates the minimum total number of conductors desired in the conductor network. Note that this number may be exceeded in some cases due to subdivision at nodes (i.e. locations where conductors contact each other) or at soil boundaries.

[1] There is a trade-off between the number of segments and the required time for computation.