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Microgrid Design Toolkit (MDT) User Guide

Software v1.3

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Microgrid Design Toolkit (MDT) User Guide

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Abstract

The Microgrid Design Toolkit (MDT) supports decision analysis for new (“greenfield”) microgrid designs as well as microgrids with existing infrastructure.

The current version of MDT includes two main capabilities. The first capability, the Microgrid Sizing Capability (MSC), is used to determine the size and composition of a new, grid connected microgrid in the early stages of the design process. MSC is focused on developing a microgrid that is economically viable when connected to the grid. The second capability is focused on designing a microgrid for operation in islanded mode. This second capability relies on two models: the Technology Management Optimization (TMO) model and Performance Reliability Model (PRM).

Contents

Figures

1. MDT Process Overview

Welcome to the Microgrid Design Toolkit (MDT). This software readily supports decision analysis for new (“greenfield”) microgrid designs as well as the design of microgrids with existing infrastructure that may be leveraged.

The current version of MDT includes two main capabilities. The first, the Microgrid Sizing Capability (MSC), is used to determine the size and composition of a new, grid-connected microgrid in the early stages of the design process. MSC is focused on developing a microgrid that is economically viable when connected to the grid. The second capability is focused on designing a microgrid for operation in islanded mode. This second capability relies on two models: The Technology Management Optimization (TMO) model and Performance Reliability Model (PRM).

A summary overview of key elements of the MDT interface is provided in

4. Appendix A: MDT Interface Summary Overview.

1.1 Software Installation

The installer files are provided in the download from which you obtained this document. Be sure to run the setup.exe file (as opposed to the MDT-Installer.msi file) because the setup.exe will check for and install prerequisites if necessary.

The first time you run the MDT, it will look for specification databases from prior installations of the tool. If any are found, you will be asked if you want to import and update a specification database (Figure 1). If you have made changes to a previous version’s equipment specification database, you are advised to choose the appropriate version from the list and click “Accept.” The database from the previous version will be copied to the location necessary for the new version. If the database format has changed, it will be automatically updated, and you will be notified when the update is complete. Otherwise, click “Cancel and Use Default Empty DB.”

In addition, if you have stored MDT equipment specification database files elsewhere on your computer and wish to update and use them for the new build, you can use the Browse button to locate the files and they will be copied and then updated.

To change the working copy of the equipment specification database to a different database at any time, please see instructions in section 3.1.1 Restoring an Equipment Specifications Database.

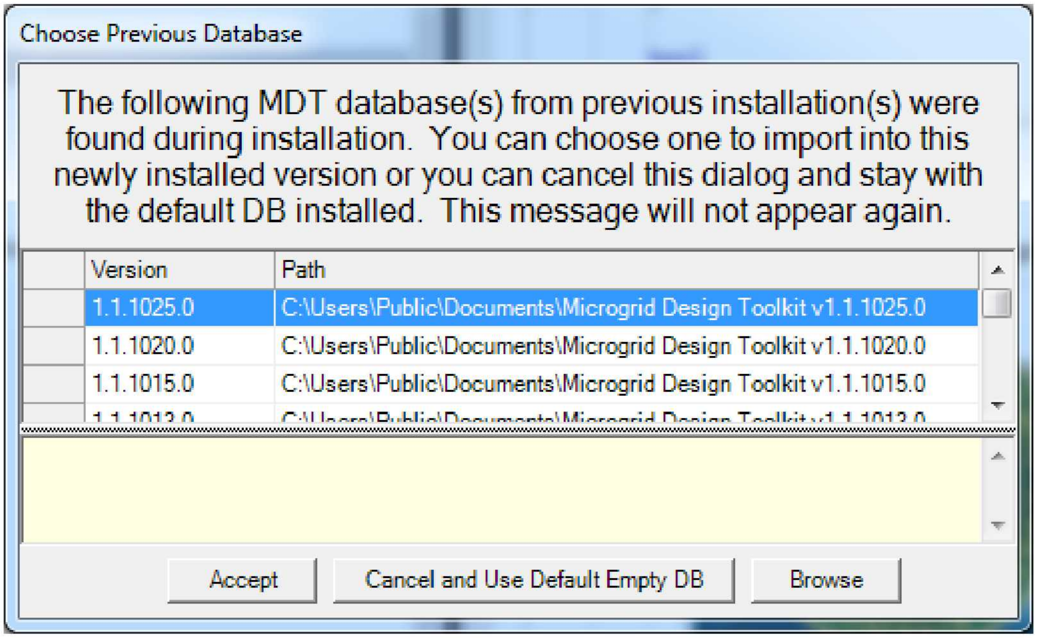


Figure 1. Prompt to use MDT database from a previous installation.

1.2 Pre-work

Before you begin using MDT, you need to define options for the microgrid. Information about your microgrid options will become inputs for MDT. Categories of data that must be gathered before attempting to use the MDT include:

- Identification of the site where the microgrid will be installed
- The high-level requirements and limitations for the microgrid (e.g., the amount of load that will need to be met or physical space limitations)
- Equipment specifications (types) that are available
- Cost for equipment specifications
- Design alternatives that are under consideration

1.3 Modeling Steps

The first step after pre-work is complete is to enter any missing equipment specifications into the tool via the "Edit Specifications" pages in the interface. This step is only applicable to analyses that are focused on islanded mode.

The second step is to enter information about the proposed microgrid design. Depending on the analysis being performed, this information will be entered in the Sizing Inputs or Islanded Inputs section of the tool.

The third step is to run the analysis and view progress via the Progress Monitor.

The final step involves viewing results and interpreting them for decision making.

Remember to save your work often. You may do so conveniently by pressing CTRL-S on any screen at any time (message dialogs excluded).

1.4 Save and Open Input Files

MDT input files are saved as *.mbf files.

To save your microgrid design inputs, you can:

- click the save button on any screen or window.
- press the keyboard keys CTRL-S.
- on the toolbar, go to File -> Save or File -> Save As.

To open an input file, you can:

- click the file open button on the main screen.
- press the keyboard keys CTRL-O.
- on the toolbar, go to File -> Open.

2. Microgrid Sizing Capability (MSC)

The purpose of MSC in the context of MDT is to perform microgrid sizing by identifying the types and quantities of technology to be purchased for use in a microgrid. MSC minimizes the total annual cost of a microgrid while meeting the load requirements of a customer and not surpassing user-specified limits on the amount of technology that can be purchased. Additionally, MSC ensures that the microgrid will pay for itself through annual energy savings within a user-specified amount of time. The result of MSC is a recommendation for how much of each technology to purchase, how much it will cost, and an estimate of the annual savings for that purchase.

To access the MSC input fields, click the Sizing Inputs tab directly above the Input button (Figure 2). This will provide access to the Sizing Input Options.

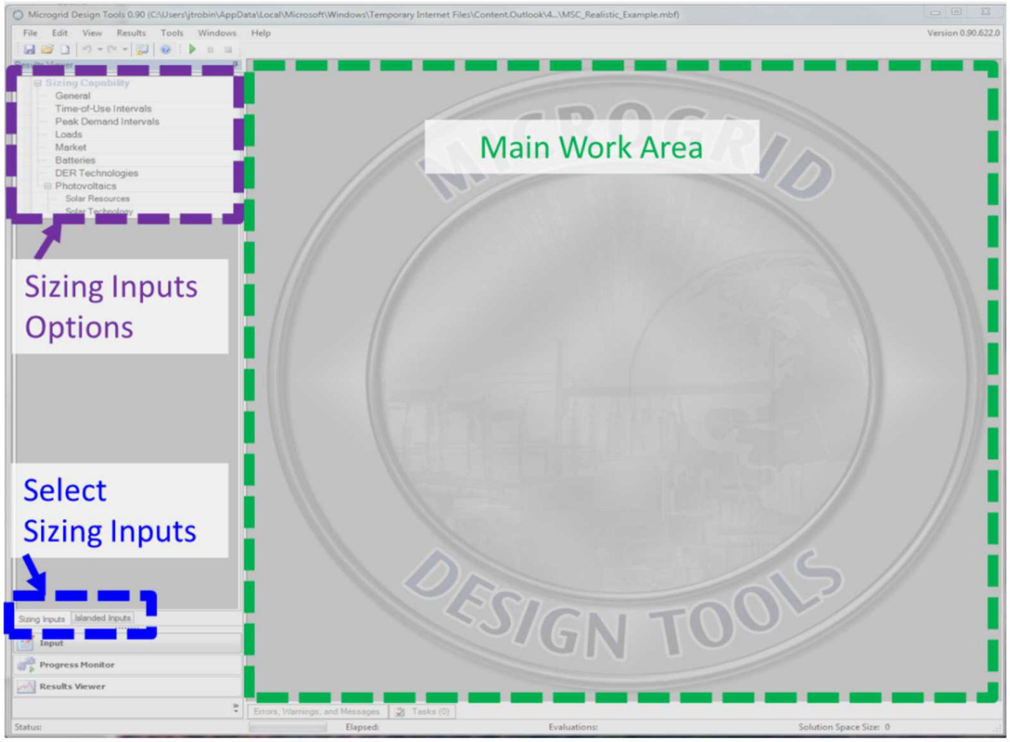


Figure 2. MSC main screen overview.

2.1 General

This section is used to define general inputs related to purchases of microgrid technologies. MSC requires that the selected microgrid technologies can be paid for through energy savings within a specified timeframe.

- **<u>Maximum number of years to payback microgrid purchases</u> (years)** – If the energy savings over this number of years does not exceed the upfront capital cost, then no microgrid purchases will be made.
- **<u>Interest rate for microgrid purchases</u> (%)** – The upfront capital costs are annuitized over the expected lifetime of the purchases. This interest rate is used in the annuity calculations.

2.2 Electrical Loads

This section is used for defining the customer's power load. First, define the load settings (Figure 3). Specify on which day of week the calendar starts by choosing the appropriate day from the Start Day column. The Individual Load Tiers section allows you to define multiple loads per load section. MSC only requires a single load tier, so this section does not need to be modified.

Then, create the energy profile in the Load Data section. There are two methods for creating the energy profile.

Method 1: For each hour in the Time Period column, enter the amount of energy required by the customer into the Load Configuration column for every hour in the calendar year.

Method 2: Import a CSV that contains only one column. That column will populate the Load Configuration column in MSC after clicking the "Import CSV File" button.

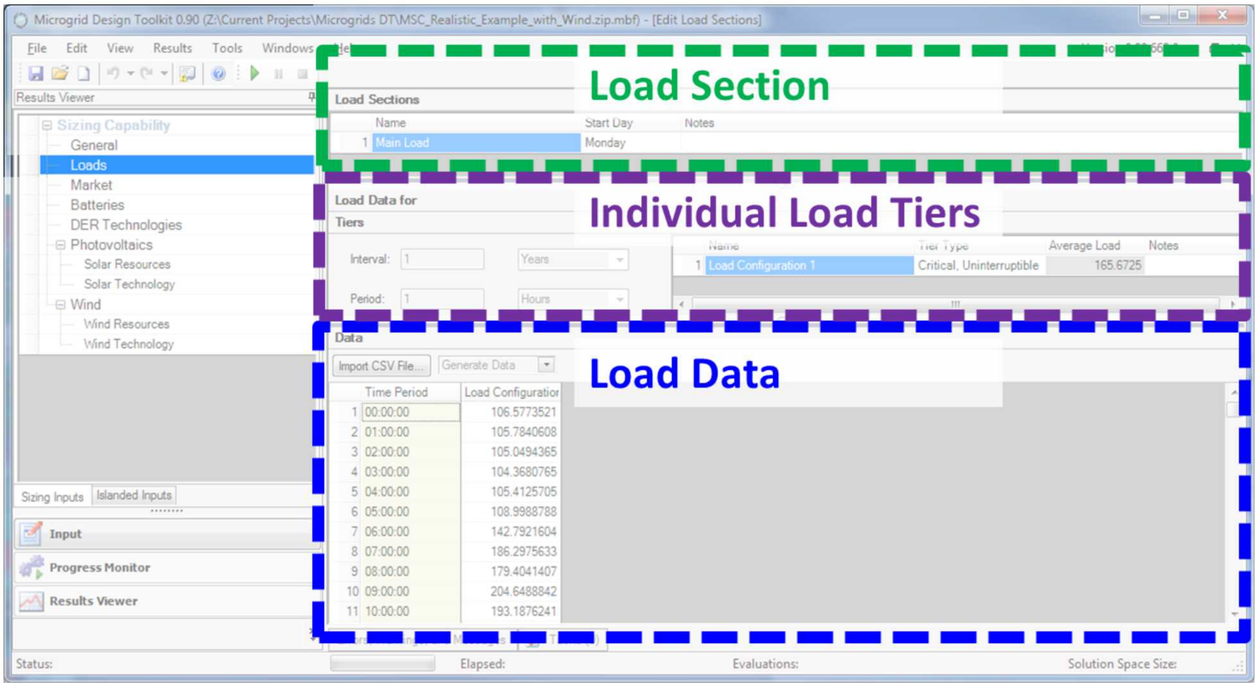


Figure 3. Overview of the Load sizing input page.

2.3 Market

The settings in this section (Figure 4) specify the pricing structure for electricity purchased from the grid as well as energy generated by different fuels, such as natural gas.

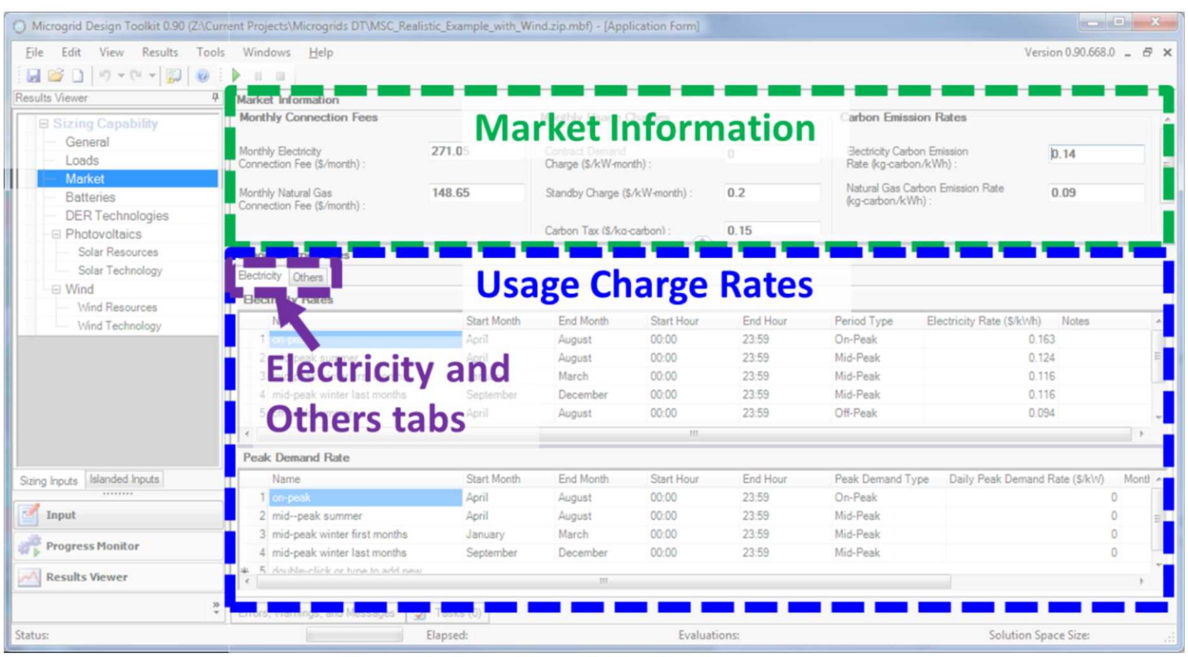


Figure 4. Overview of Market inputs page.

2.3.1 Market Information

This section includes fees, charges, and carbon emission rate data for the utility companies (electric and gas) and are used to determine utility costs. All the inputs provided in this section are single values that are not time dependent.

- **Monthly Electricity Connection Fee** ($/month) **–** The monthly dollar amount charged by the utility company for just being connected to the grid.
- **Monthly Natural Gas Connection Fee** ($/month) **–** The monthly dollar amount charged for just being connected to a natural gas source.
- **Contract Demand Charge** ($/kW-month) **–** The utility company will multiply this dollar amount by the maximum energy load attained by the customer during the full calendar year.
- **Standby Charge** ($/kW-month) **–** The utility company will multiply this dollar amount by the nameplate capacity for an energy-generating source such as PV and wind.
- **Carbon Tax** ($/kg-Carbon) **–** The dollar amount charged per kg of Carbon released by the utility or the microgrid.
- **Electricity Carbon Emission Rate** (kg-Carbon/kWh) **–** Amount of Carbon in kg released by a kWh of energy produced by the utility company.
- **Natural Gas Carbon Emission Rate** (kg-Carbon/kWh) **–** Amount of Carbon in kg released by a kWh of natural gas used for energy production by the microgrid.

2.3.2 Usage Charge Rates

2.3.2.1 Electricity

Select the Electricity tab under Usage Charge Rates (Figure 4) to access the following sections.

2.3.2.1.1 Electricity Rate

This section is used to define electricity usage rates. Electricity is typically priced differently for each season. For example, summer on-peak hours will be different from winter on-peak hours. Usage intervals are defined by season (a set of months), a time of day, and usage period type (on-peak, off-peak, and mid-peak). The set of usage intervals must account for all months and all hours of the day. Electricity rates - in dollars per kWh of electricity - are set for each usage interval.

- **Name –** The name is meant to help the user distinguish electricity usage rates for different months, hours and periods.
- **Start Month –** Starting month for the electricity usage rate.
- **End Month –** Ending month for the electricity usage rate.
- **Start Hour –** Starting hour for the electricity usage rate.
- **End Hour –** Ending hour for the electricity usage rate.
- **Period Type –** Period type for the electricity usage rate. Valid values include on-peak, off-peak, and mid-peak.
- **Electricity Rate** ($/kWh) **–** Dollar amount for the electricity usage rate.
- Notes - User supplied notes for this electricity usage rate.

2.3.2.1.2 Peak Demand Rate

This section is used to define peak demand rates. Utility companies typically charge customers an amount proportional to the maximum energy purchased over a specified time period. These peak demand periods are defined by season (a set of months), a time of day, and peak demand types (on-peak, off-peak, mid-peak, coincident, and non-coincident). The set of peak demand periods must account for all months and all hours of the day. Daily peak demand rates and monthly peak demand rates - in dollars per kWh of electricity - are set for each peak demand period. A daily demand charge is calculated by multiplying the daily peak demand rate by the maximum amount of electricity purchased over all hours in a peak demand type and day. Similarly, a monthly demand charge is calculated by multiplying the monthly peak demand rate by the maximum amount of electricity purchased over all hours in a peak demand type and month.

- **Name** – The name is meant to help the user distinguish peak demand rates for different hours, months and peak demand types.
- **Start Month** – Starting month of the peak demand rate.
- **End Month** – Ending month of the peak demand rate.
- **Start Hour** – Starting hour for the peak demand rate.
- **End Hour** – Ending hour for the peak demand rate.
- **Peak Demand Type** – Peak demand type for the peak demand rate. Valid values include on-peak, off-peak, mid-peak, coincident, and non-coincident.
- **Daily Peak Demand Rate** ($/kW) – Dollar amount for the daily peak demand rate.
- **Monthly Peak Demand Rate** ($/kW) – Dollar amount for the monthly peak demand rate.
- Notes - User supplied notes for this peak demand rate.

2.3.2.2 Others

Select the Others tab under Usage Charge Rates (Figure 4) to access the following sections.

2.3.2.2.1 Natural Gas Rate

This is the dollar amount charged per kWh of natural gas purchased.

- **Name** – The name is meant to help the user distinguish natural gas rates for different months.
- **Start Month** – Starting month of the natural gas rate.
- **End Month** – Ending month of the natural gas rate.
- **Natural Gas Rate** ($/kWh) – This is the cost of natural gas per kWh. Please convert the volume of fuel purchased into kWh and include this converted value in this field.
- Notes - User supplied notes for this natural gas rate.

2.3.2.2.2 Electricity Market (Selling Back to the Grid)

This is the dollar amount received by the customer for each kWh of electricity sold back to the grid.

- **Name** – The name is meant to help the user distinguish electricity sellback rates.
- **Start Month** – Starting month of the electricity sellback rate.
- **End Month** – Ending month of the electricity sellback rate.
- **Day Type** – Day of week for the electricity sellback rate.
- **Start Hour** – Starting hour of the electricity sellback rate.
- **End Hour** – Ending hour of the electricity sellback rate.
- **Electricity Market Rate** ($/kWh) – Dollar amount for the electricity sellback rate.
- Notes - User supplied notes for this electricity market.

2.3.2.2.3 Other Fuels

Other fuels besides natural gas are entered in this section along with the dollar amount charged per kWh of fuel purchased.

- **Fuel Type –** Name of fuel type
- **Rate** ($/kWh) **–** Dollar amount for the fuel.
- Notes – User supplied notes for this fuel type.

2.4 Batteries

The settings in this section characterize the battery to be used in the microgrid. A battery is composed of a power component and an energy component. The power capacity and energy capacity in a battery come in a fixed ratio. If a battery purchase is allowable for use in the microgrid, check the box at the top of the battery section.

2.4.1 Battery Costs

These settings characterize the costs and purchase limit of the battery.

- **Upfront Fixed Capital Cost** ($) **–** The one-time fixed cost for purchasing a battery.
- **Upfront Variable Capital Cost** ($/kW) **–** The one-time cost per kW of power capacity for purchasing a battery.
- **Annual Maintenance Cost** ($/kW-year) **–** Annual maintenance cost charged per year.
- **Equipment Lifetime** (years) **–** Expected lifetime of the battery.
- **Maximum Capacity Allowed** (kW) **–** The battery's purchase limit is based on the battery's power capacity. The purchased battery's power capacity will not exceed this limit.

2.4.2 Battery Characteristics

These settings characterize the losses that occur due to efficiency of the battery.

- **Charging Efficiency** (%) **–** This is the efficiency percentage at which battery charging will occur. If it is 0, the battery will not charge, and if it is 1, all the energy going to the battery will be stored.
- **Discharging Efficiency** (%) **–** This is the efficiency percentage at which battery discharge will occur. If it is 0, all the energy coming from the battery will be wasted, and if it is 1, all the energy coming from the battery will go to the connected component.
- **Fraction of Energy Lost per Hour** (%) **–** Energy leakage from the battery. If it is 0, then no energy is leaked from the battery. If it is 1, then the battery will not hold a charge.
- **Minimum State of Charge** (%) **–** Fraction of capacity at which the battery must be above for it to function.
- **Power/Energy Ratio –** Battery power and battery energy will be purchased in this ratio.

2.5 Distributed Energy Resource (DER) Technologies

The settings in this section characterize the DER technologies to be used in the microgrid. Inputs for wind and photovoltaic technologies are specified in subsequent input pages. New technologies are added by creating a new entry in the DER Technologies section at the top of the page. Check the box under the Gas-Fired field if the DER technology is fueled with natural gas. If the specified DER technology purchase is allowed for use in the microgrid, check the box under the Used field. The settings under DER Information characterize a selected DER technology.

- **Costs**
  - **Upfront Fixed Capital Cost** ($/unit) **–** The one-time fixed cost for purchasing the DER technology.
  - **Variable Maintenance Cost** ($/kWh) **–** The maintenance cost of the DER technology per kWh of operation.
  - **Annual Maintenance Cost** ($/unit-year) **–** Annual fixed maintenance cost charged per year per unit.
- **DER Characteristics**
  - **Nameplate Capacity** (kW) **–** Power rating of the DER technology.
  - **Minimum Load to Operate** (kW) **–** Minimum load at which a DER technology must operate.
  - **Efficiency** (0.0-1.0): Efficiency is the ratio of energy “in” (kWh of gas) to energy “out” (kWh of electricity).
  - **Equipment Lifetime** (years) **–** Expected lifetime of the DER technology.
  - **Fuel Type –** Type of fuel used by the DER technology. Fuel Types are defined in the Market section, under Usage Charge Rates on the “Other” tab (see section 2.3 Market).
- **Requirements**
  - **Maximum Annual Hours of DER Usage** (hours/unit-year) **–** The DER technology will not be used beyond this many hours.
  - **Maximum DER Purchase Allowed** (units) **–** No more than this many units of the DER technology will be purchased.

2.6 Photovoltaics

2.6.1 Solar Resources

This section is used to define photovoltaic energy profiles. To add a new profile, create a new entry in the Solar Resources area (Figure 5). MSC requires the energy profile to be entered at hour intervals, so the Time Information section is not modifiable. There are two methods for creating the energy profile.

Method 1: For each hour in the Time Period column, enter the fraction of nameplate capacity that the photovoltaic technology is expected to output into the Solar Profile column.

Method 2: Import a CSV that contains only one column. That column will populate the Solar Profile column in MSC after clicking the “Import CSV File” button.

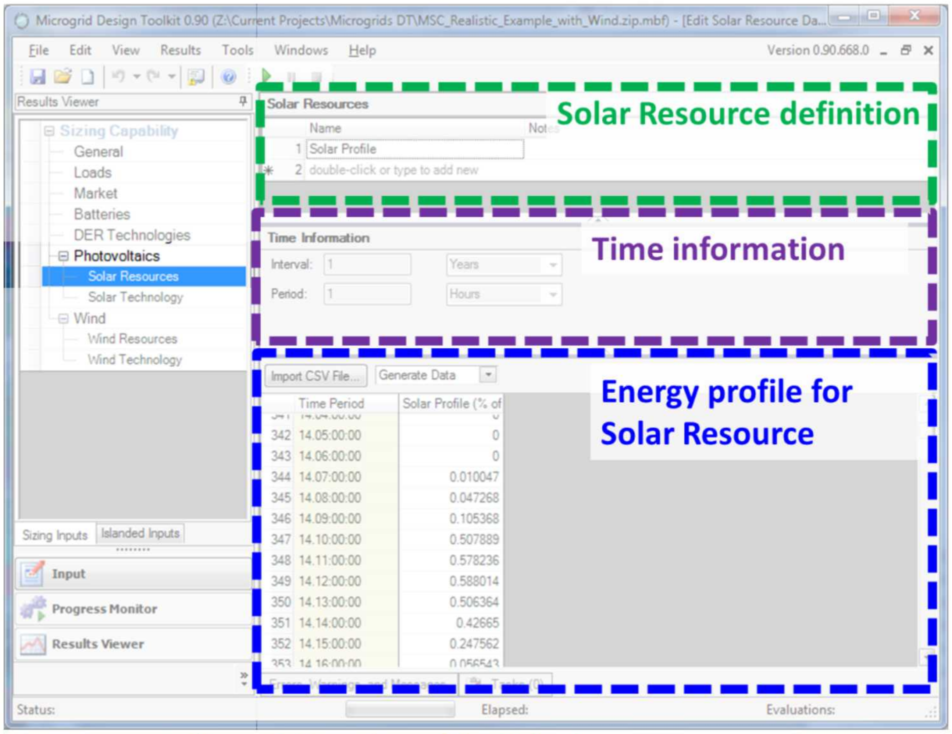


Figure 5. Overview of the Solar Resources page.

2.6.2 Solar Technology

The settings in this section characterize the photovoltaic technology to be used in the microgrid. If a photovoltaics purchase is allowed for use in the microgrid, check the box at the top of the Solar Technology section.

- **Upfront Fixed Capital Cost** ($) **–** The one-time fixed cost for purchasing the photovoltaic technology.
- **Upfront Variable Capital Cost** ($/kW) **–** The one-time cost per kW of nameplate capacity for purchasing photovoltaics.
- **Annual Maintenance Cost** ($/kW-year) **–** Annual maintenance cost charged per year.
- **Equipment Lifetime** (years) **–** Expected lifetime of the photovoltaics technology purchased.
- **Maximum Capacity Allowed** (kW) **–** Photovoltaic capacity will not be purchased beyond this amount.
- **Solar Resource –** The solar profile to be used for photovoltaic purchase. Solar profiles are specified in Photovoltaics under the "Solar Resources" section.

2.7 Wind

2.7.1 Wind Resources

This section is used to define wind energy profiles. To add a new profile, create a new entry in the Wind Resources area (Figure 6). MSC requires the energy profile to be entered at hour intervals, so the Time Information section is not modifiable. There are two methods for creating the energy profile.

Method 1: For each hour in the Time Period column, enter the average power output per wind generator into the Wind Profile column.

Method 2: Import a CSV that contains only one column. That column will populate the Wind Profile column in MSC after clicking the "Import CSV File" button.

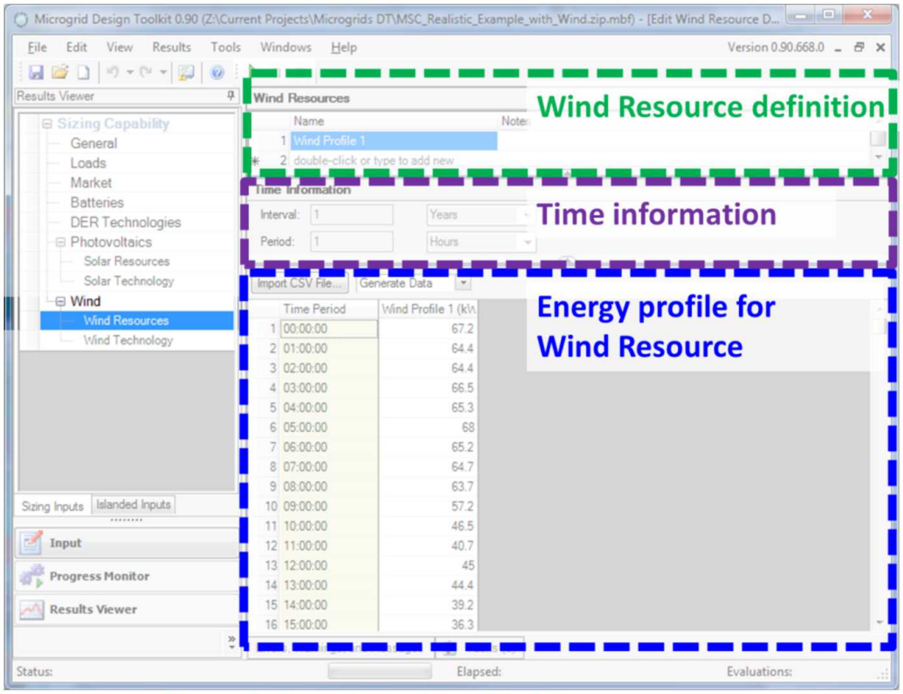


Figure 6. Overview of the Wind Resources page.

2.7.2 Wind Technology

The settings in this section characterize the wind technology to be used in the microgrid. If a wind technology purchase is allowed for use in the microgrid, check the box under "Used" for that wind technology.

- **Upfront Fixed Capital Cost** ($/unit) **–** The one-time fixed cost for purchasing a unit of the wind technology.
- **Annual Maintenance Cost** ($/unit-year) **–** Annual maintenance cost charged per year for a unit of the wind technology.
- **Nameplate Capacity** (kW/unit) **–** Power rating of the wind technology.
- **Equipment Lifetime** (years) **–** Expected lifetime of the wind technology.
- **Maximum Units of Wind Technology Purchase Allowed** (units) **–** No more than this many units of wind technology will be purchased.
- **Wind Resource Profile –** The wind resource profile to be used for the wind technology. Wind resource profiles are specified in the "Wind" section under "Wind Resources." Separate wind profiles can be entered for each wind technology.

2.8 Results Viewer

When entry of all inputs is complete, click the "Run" button at the top of the page. Results will be displayed under the Results Viewer tab. To view the MSC results, select Costs or Investments under Plots (Figure 7). The Cost results (Figure 7) will summarize the costs associated with the selected microgrid. The Investments results page will display the types and quantities of technologies purchased. Three sets of investment results are reported: continuous investments, DER investments, and wind investments (Figure 8).

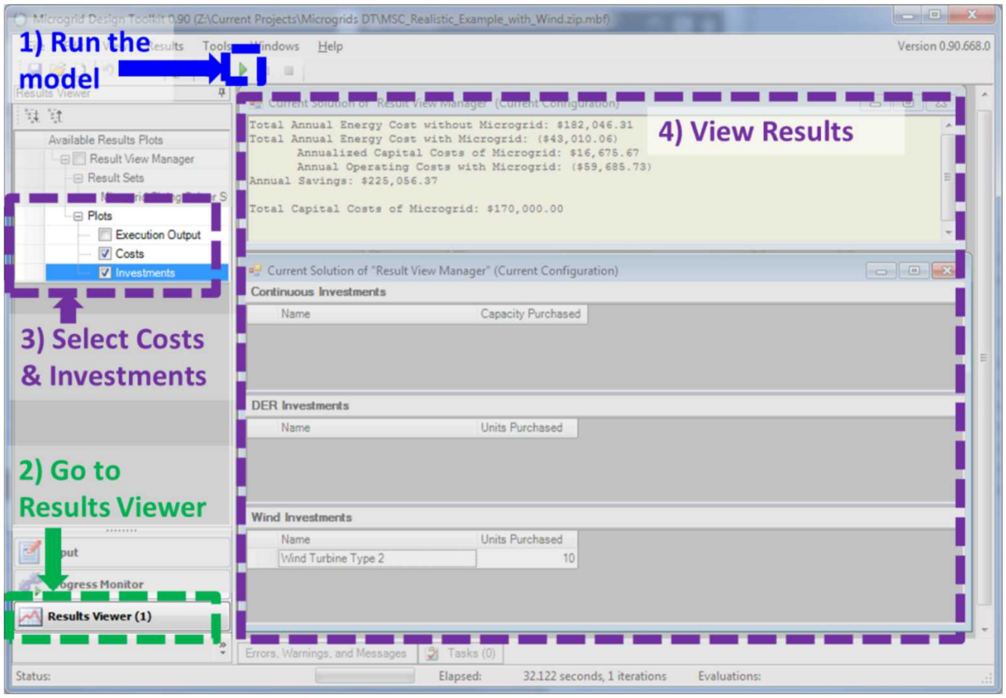


Figure 7. Viewing MSC results.

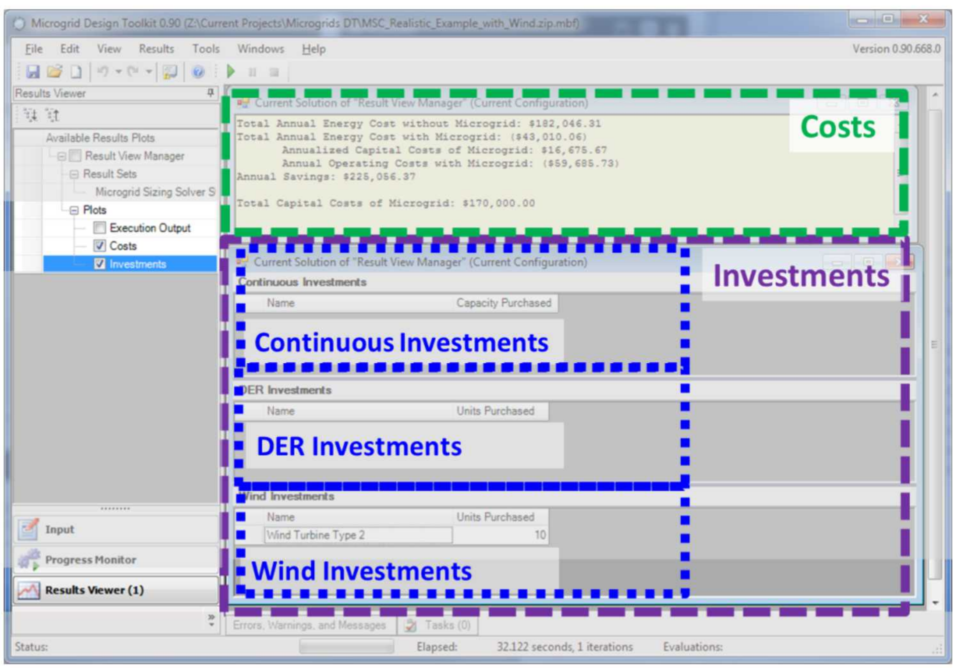


Figure 8. Overview of the MSC Investment results page.

2.8.1 Costs

This section provides information on the costs associated with the microgrid design.

- **Total Annual Energy Cost without Microgrid** ($) **–** Annual cost when all energy is purchased from the utility company, which consists only of utility charges.
- **Total Annual Energy Cost with Microgrid** ($) **–** Includes charges from the utility, operating and maintenance (O&M) costs for the microgrid, and annualized capital costs for microgrid technology purchases.
    - **Annualized Capital Costs of Microgrid** ($) **–** Annualized capital cost portion of total annual energy costs with microgrid.
    - **Annualized Operating Costs with Microgrid** ($) **–** Utility and O&M portion of total annual energy costs with microgrid.
- **Annual Operating Savings** ($) **–** Difference in operating costs with a microgrid versus no microgrid. Annualized capital costs are not included.
- **Total Capital Costs of Microgrid** ($) **–** Total upfront cost of all microgrid purchases. The annual savings times the number of years to pay back the capital costs will be greater than or equal to the upfront capital costs.

2.8.2 Investments

This section identifies the types and quantities of microgrid technologies that were selected by the optimization model. If no technologies are selected, then a microgrid is not cost effective compared to purchasing all energy from the utility.

- **Solar** (kW) **–** Capacity of the photovoltaic technology to purchase.
- **Battery Energy** (kWh) **–** Capacity of the battery energy technology to purchase.
- **Battery Power** (kW) **–** Capacity of the battery power technology to purchase.
- **DER Investments** (Units) **–** The number of units of each DER technology to purchase.
- **Wind Investments** (Units) **–** The number of units of each wind generation technology to purchase.

2.8.3 Save Results

Results are saved in a file separate from the inputs. MDT results files are saved as *.mof files. To save your results:

1. Right click on “Result View Manager” in the left navigation (Figure 9).
2. Select “Rename” from the menu.
3. A new window will open. Type in a new name for your result set.
4. Click “OK.”
5. Select the checkbox next to you renamed result set.
6. Go to “Results” in the toolbar.
7. Select “Save Selected.”
8. Enter a name for your results set file.
9. Click “Save.”

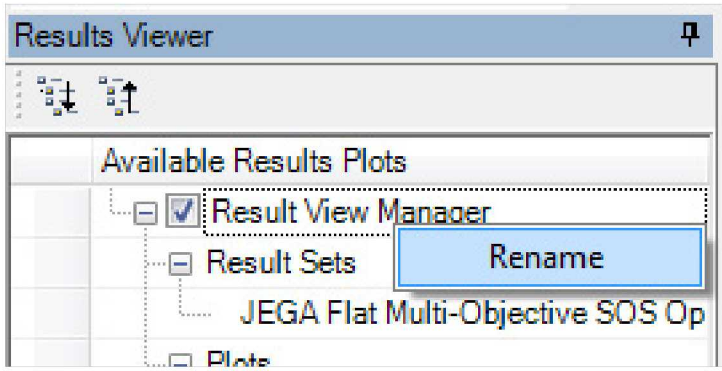


Figure 9. Renaming a result set before saving.

2.8.4 Open Results

To open a previously saved result set:

1. Go to "Results" in the toolbar.
2. Select "Load."
3. Locate your file (which will have file extension *.mof).
4. Click "Open."
5. Go to the Results Viewer tab to view your results.

You can open as many result sets as necessary (Figure 10). They do not have to be related to the current input values. You can view the inputs of any result set at any time by right-clicking on the entries within the "Results Sets" header and choosing "View Input."

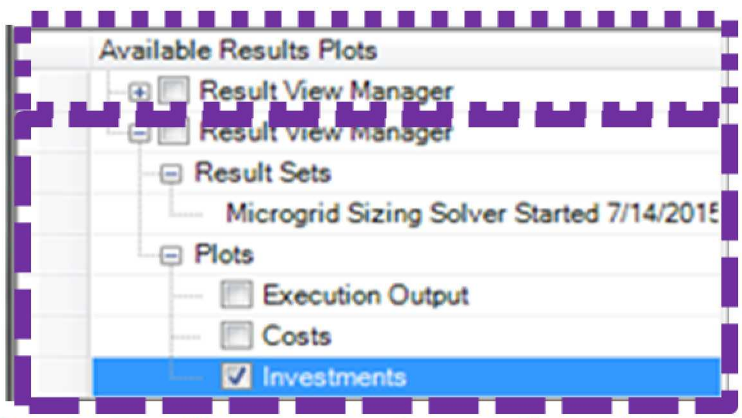


Figure 10. Two different result sets open in the Results Viewer.

2.8.5 View Input for a Result Set

To view the input file for a result set:

1. Locate your result set in the Results Viewer navigation.
2. Under the "Result Sets" header, right click on the solution set previously generated by the solver (Figure 11).
3. Select "View Input."
4. You will receive a message window: "This capability is strictly for viewing the input of the chosen results. Any changes made will not be stored/propagated back to the results."
5. Click "OK."
6. A new window will open where you can view the inputs related to your result set. While you can edit the fields, you cannot save any changes or run a new analysis from this view.

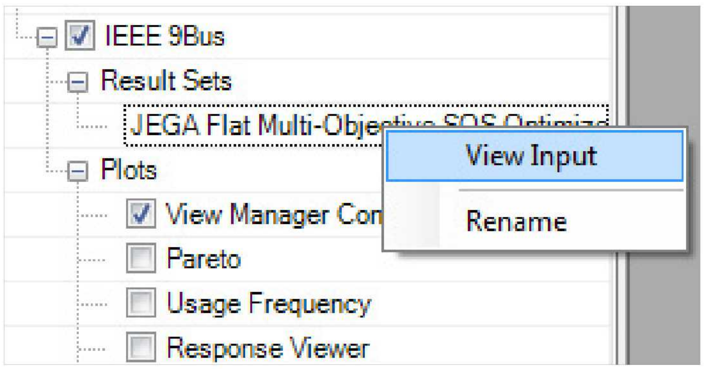


Figure 11. Opening the input set that created this result set.

2.8.6 Close a Result Set

To close a result set:

1. Select the checkbox next to your result set name.
2. Go to "Results" in the toolbar.
3. Select "Remove Selected."
4. The result set should be removed from the Results Viewer navigation.

3. Islanded Mode

This capability is focused on designing a microgrid for operation in islanded mode. This relies on two models: the Technology Management Optimization (TMO) model and Performance Reliability Model (PRM). The first step is to gather equipment specifications and enter them into the tool via the "Edit Specifications" page in the interface. The second step is to enter information about the proposed microgrid design. Entering the microgrid design will go faster if the equipment specifications are entered first.

To access the Islanded Mode input fields, click the Islanded Inputs tab directly above the Input Editor button in the lower left corner of the screen (Figure 12). This will provide access to the Islanded Inputs pages.

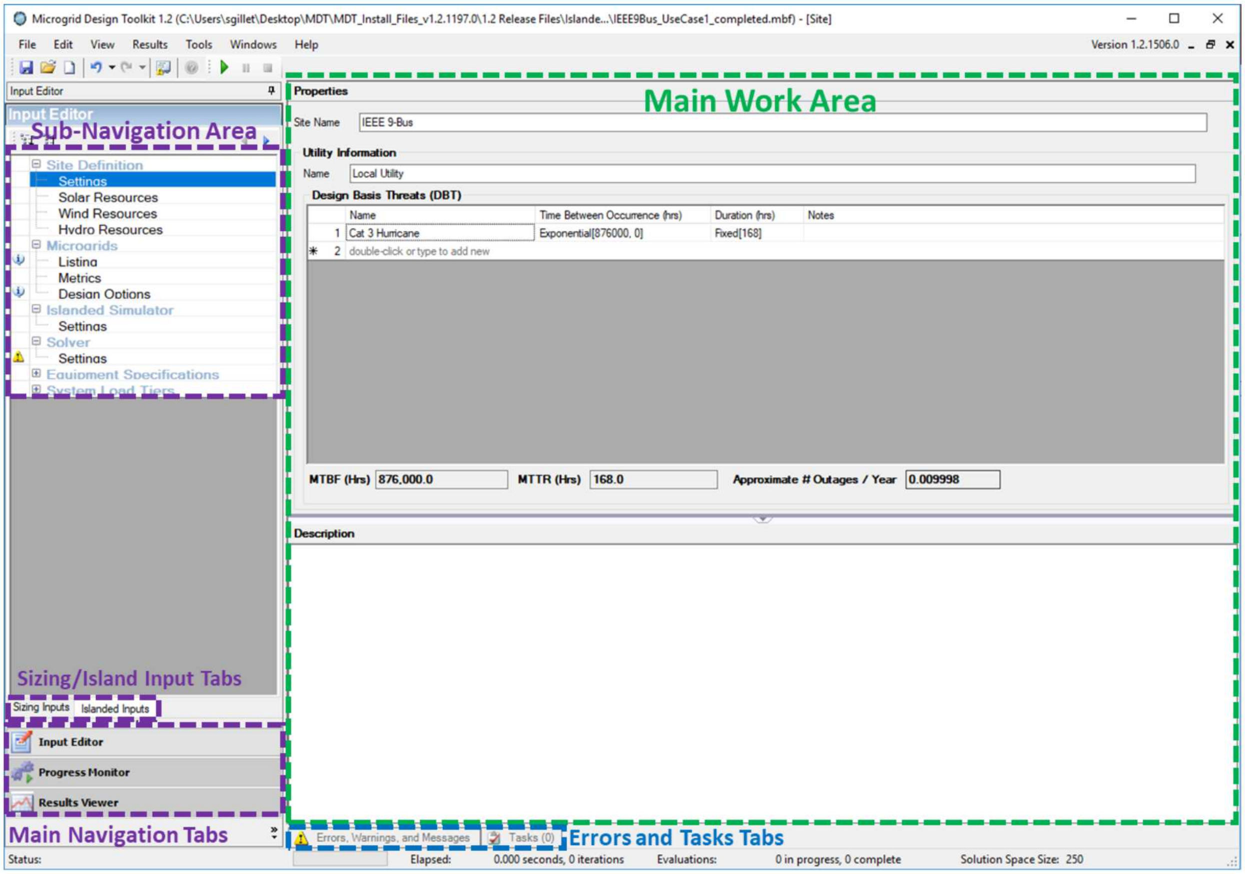


Figure 12. Islanded mode main screen overview.

Pages have two main areas.

- The **page navigation** area is located on the left side of the page (highlighted in purple in Figure 12).
- The **main work area** (highlighted in green Figure 12) is the largest panel on the screen. This is where elements (components of a microgrid) are added and modified.

3.1 Editing Specifications

The equipment specifications are accessed in the sub navigation area or via a button on the toolbar (Figure 12). Equipment specifications should be entered into MDT *before* creating your Microgrid Options. Entering equipment specifications first will decrease the time needed to create the microgrid. The different types of equipment and required information are listed below.

The tool includes dummy equipment specifications as examples. These examples can be removed or modified as needed.

It is not currently possible to merge equipment specification database files. If two or more people have different versions of the database, there is no automated way to merge them. Databases will need to be manually merged by adding the necessary equipment specifications through the MDT interface.

3.1.1 Restoring an Equipment Specifications Database

The first time you run the MDT, it will look for specification databases from prior installations of the tool. If any are found, you will be prompted as to whether you want to import and update a specification database (Figure 13). If you have made changes to a previous version's equipment specification database, you are advised to choose the appropriate version from the list and click "Accept." The database from the previous version will be copied to the location necessary for the new version. If the database format has changed, it will be automatically updated. Otherwise, click "Cancel and Use Default Empty DB."

In addition, if you have stored MDT equipment specification database files elsewhere on your computer and wish to update and use them for the new build, you can use the Browse button to locate and choose the files which will then be will be copied and updated.

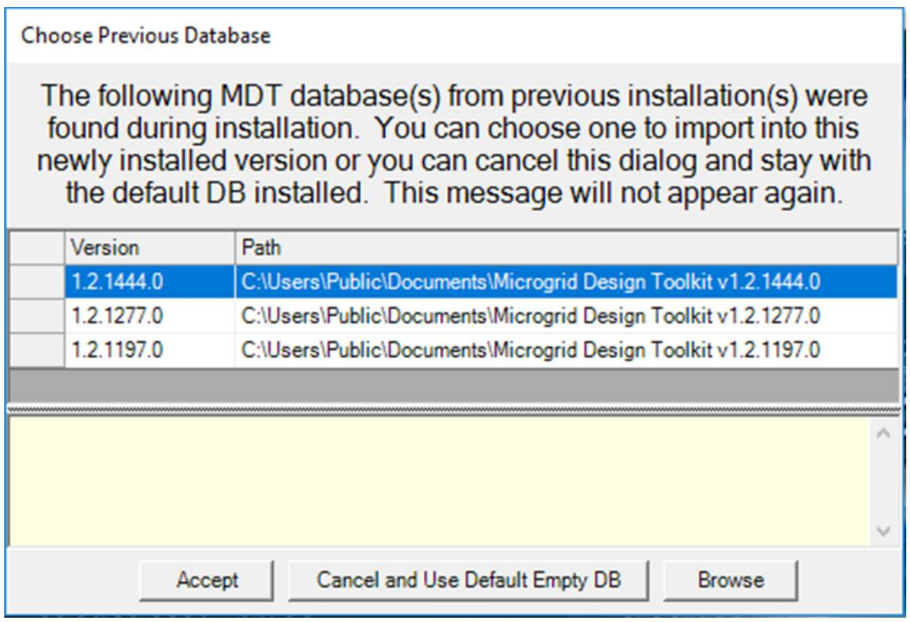


Figure 13. Prompt to include MDT databases from a previous installation.

As mentioned, this process will only occur automatically the first time you run the MDT. If you wish to change your working copy of the equipment specification database to a prior database at any time, choose Tools/Options from the main menu in the MDT and check the box next to "Execute Database Manager on Next Invocation." Close and restart the MDT and the Choose Previous Database dialog will appear as it did the first time the software was started.

3.1.2 Equipment Specifications

In this section, you will define equipment that can be used for any and all analyses. Each equipment specification table has a "No equipment" specification which cannot be removed. This "No equipment" specification is a way to tell the MDT that there is an explicit option to put no equipment at a location.

Required fields are displayed in bold font in the sections below. Default values are provided for all fields, some of which may be empty fields or no value. One helpful feature that can be used wherever a “notes” section is available in MDT is the ability to generate a “Task” in the tab near the errors, warnings, and messages. By typing “todo:” followed by user-entered text in the notes section, the new task will be created. This provides an easy method of creating reminders. Please note that weight and volume are for the specific piece of equipment and can be useful for applications where microgrid equipment needs to be transported to location.

To **add a new item**:

- Double click in an empty row.
  or
- Begin typing a name into an empty row.

To **remove an item**:

- Click on the row number (first column) to highlight the row.
- Press the “Delete” key on the keyboard.

MDT supports **undo** and **redo** of actions.

- Click the Undo or Redo button to view a dropdown of all past actions.
- Select the action to undo/redo.
- The tool will update accordingly.

To **save all changes** made in this window, click the Save button in the toolbar.

<u>Failure Modes</u>

Failure modes define the ways that each equipment type can break. The failure modes defined in the specifications input should describe normal wear and tear events for the associated asset type. For example, a type of diesel generator may have a piston failure mode that occurs on average every 15,000 hours of operations. These modes should be specific to the type of equipment, but not specific to particular deployment scenarios. If there are special failure modes corresponding to how/where an instance of the equipment is used (e.g., in the desert, on a ship), that should be defined as part of the microgrid definition.

You can define as many failure modes as needed, including the mean time between failures (MTBF) and mean time to repair (MTTR). They are defined in hours. Please see 5. Appendix B: Failure Mode Distributions for a description of each distribution and for recommendations on when to use each one.

3.1.2.1 Line Specifications

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **<u>Name</u>** – Name for the line.
- <u>Failure Modes</u> (hours) – The failure modes intrinsic to lines of this type. If no failure modes are defined, this equipment will never fail. MDT will give you an informational note about equipment that does not have an assigned failure mode, but it is not a requirement.

    - A dropdown arrow opens a detailed Failure Modes input grid with Name, MTBF, MTTR, and Notes fields. MTBF and MTTR default units are hours.
- Impedance/Resistance – The real part of impedance (Cartesian) for this line on a per unit basis.
- Capacity (kW) – The maximum amount of power the line can pass.
- Cost ($/unit length) – The purchase cost of the line, per unit length. The default unit for length is feet.
- Operational Cost ($/unit length/hr of usage) – The operational cost of this type and size of line. The default unit for length is feet.
- Weight (lbs/unit length) – The weight of this type and size of line. The default unit for length is feet.
- Volume (ft^3/unit length) – The geometrical volume of this type of line, per unit length. The default unit for length is feet.
- Notes – User supplied notes for this line.

3.1.2.2 Switch Specifications

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the switch.
- Failure Modes (hours) – The failure modes intrinsic to switches of this type. If no failure modes are defined, this equipment will never fail. MDT will give you an informational note about equipment that does not have an assigned failure mode, but it is not a requirement.
    - A dropdown arrow opens a detailed Failure Modes input grid with Name, MTBF, MTTR, and Notes fields. MTBF and MTTR default units are hours.
- Impedance/Resistance – The real part of impedance (Cartesian) for this line on a per unit basis.
- Cost ($) – The purchase cost of this type and size of switch.
- Operational Cost ($/hr of usage) – The operational cost of this type and size of switch.
- Volume (ft^3) – The volume of this type and size of switch.
- Weight (lbs) – The weight of this type and size of switch.
- Notes – User supplied notes for this switch.

3.1.2.3 Diesel Generator Specifications

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the diesel generator.
- **Capacity** (kW) – Nameplate capacity. The maximum amount of power that this type of generator can supply. MDT expects a value greater than zero.
- **Performance Values** – The fuel use (gallons/kW/hour) and efficiency (fraction) characteristics of this type of generator. Click on “Edit to See Values” dropdown.
    - A dropdown arrow opens a detailed input grid with fuel use and efficiency input fields. Values are specified for 0%, 25%, 50%, 75%, and 100% of generator’s nameplate capacity. Note that the units of fuel use are different for the 0% entry in that they do not include energy output in the denominator.

- Voltage/Real (V) – The real part of voltage (Cartesian) for this generator.
- Failure Modes (hours) – The failure modes intrinsic to diesel generators of this type. If no failure modes are defined, this equipment will never fail. MDT will give you an informational note about equipment that does not have an assigned failure mode, but it is not a requirement.
    - A dropdown arrow opens a detailed Failure Modes input grid with Name, MTBF, MTTR, and Notes fields. MTBF and MTTR default units are hours.
- **Startup Time** (hours) – The amount of time from when the generator is started until it is capable of full output power (excluding any synchronization delays). Default is the equivalent of 10 seconds.
- **Start Probabilities** (fraction) – The probability of successful startup for this type of generator on the first and subsequent attempts.
- Start Failure MTTR – The mean time to repair a generator that fails to start. The default is no MTTR, which results in non-repairable start failures.
- Recoverable Heat Rate – The amount of heat that can be recovered from this generator as it operates in kW heat recovered per kW electricity produced. This heat can be used to serve thermal loads.
- Cost ($) – The purchase cost of this type and size of generator.
- Operational Cost ($/hr of usage) – The operational cost of this type and size of generator.
- Weight (lbs) – The weight of this type and size of generator.
- Volume (ft^3) – The volume of this type and size of generator.
- Notes – User supplied notes for this diesel generator.

3.1.2.4 Diesel Tank Specifications

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the diesel tank.
- **Capacity** (gallons) – The maximum amount of fuel that this type of diesel tank can hold. MDT expects a value greater than zero.
- Cost ($) – The purchase cost of this type and size of diesel tank.
- Weight (lbs) – The weight of this type and size of diesel tank.
- Volume (ft^3) – The volume of this type and size of diesel tank.
- Notes – User supplied notes for this diesel tank.

3.1.2.5 Natural Gas Generator Specifications

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the natural gas generator.
- **Capacity** (kW) – Nameplate capacity. The maximum amount of power that this type of natural generator can supply. MDT expects a value greater than zero.
- **Performance Values** – The fuel use (gallons/kW/hour) and efficiency (fraction) characteristics of this type of generator. Click on "Edit to See Values" dropdown.
    - A dropdown arrow opens a detailed input grid with fuel use and efficiency input fields. Values are specified for 0%, 25%, 50%, 75%, and 100% of generator's nameplate

capacity. Note that the units of fuel use are different for the 0% entry in that they do not include energy output in the denominator.

- Voltage/Real (V) – The real part of voltage (Cartesian) for this generator.
- Failure Modes (hours) – The failure modes intrinsic to generators of this type. If no failure modes are defined, this equipment will never fail. MDT will give you an informational note about equipment that does not have an assigned failure mode, but it is not a requirement.
  - A dropdown arrow opens a detailed Failure Modes input grid with Name, MTBF, MTTR, and Notes fields. MTBF and MTTR default units are hours.
- **Startup Time** (hours) – The amount of time from when the generator is started until it is capable of full output power (excluding any synchronization delays). Default is the equivalent of 10 seconds.
- **Start Probabilities** (fraction) – The probability of successful startup for this type of generator on the first and subsequent attempts.
- Start Failure MTTR – The mean time to repair a generator that fails to start. The default is no MTTR, which results in non-repairable start failures.
- Recoverable Heat Rate – The amount of heat that can be recovered from this generator as it operates, in kW heat recovered per kW electricity produced. This heat can be used to serve thermal loads.
- Cost ($) – The purchase cost of this type and size of generator.
- Operational Cost ($/hr of usage) – The operational cost of this type and size of generator.
- Weight (lbs) – The weight of this type and size of generator.
- Volume (ft^3) – The volume of this type and size of generator.
- Notes – User supplied notes for this natural gas generator.

3.1.2.6 Solar Generator Specifications

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the solar generator.
- **Capacity** (kW) – The maximum amount of power that this type of solar generator can supply. MDT expects a value greater than zero.
- Voltage/Real (V) – The real part of voltage (Cartesian) for this generator.
- Failure Modes (hours) – The failure modes intrinsic to solar generators of this type. If no failure modes are defined, this equipment will never fail. MDT will give you an informational note about equipment that does not have an assigned failure mode, but it is not a requirement.
  - A dropdown arrow opens a detailed Failure Modes input grid with Name, MTBF, MTTR, and Notes fields. MTBF and MTTR default units are hours.
- Cost ($) – The purchase cost of this type and size of solar generator.
- Operational Cost ($/hr of usage) – The operational cost of this type and size of solar generator.
- Weight (lbs) – The weight of this type and size of solar generator.
- Volume (ft^3) – The volume of this type and size of solar generator.
- Notes – User supplied notes for this solar generator.

3.1.2.7 Wind Generator Specifications

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the wind generator.
- **Capacity** (kW) – Nameplate capacity. The maximum amount of power that this type of wind generator can supply. MDT expects a value greater than zero.
- Voltage/Real (V) – The real part of voltage (Cartesian) for this generator.
- Failure Modes (hours) – The failure modes intrinsic to wind generators of this type. If no failure modes are defined, this equipment will never fail. MDT will give you an informational note about equipment that does not have an assigned failure mode, but it is not a requirement.
  - A dropdown arrow opens a detailed Failure Modes input grid with Name, MTBF, MTTR, and Notes fields. MTBF and MTTR default units are hours.
- Cost ($) – The purchase cost of this type and size of wind generator.
- Operational Cost ($/hr of usage) – The operational cost of this type and size of wind generator.
- Weight (lbs) – The weight of this type and size of wind generator.
- Volume (ft^3) – The volume of this type and size of wind generator.
- Notes – User supplied notes for this wind generator.

3.1.2.8 Hydro Generator Specifications

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the hydro generator.
- Capacity (kW) – The maximum amount of energy the hydro generator can supply
- Failure Modes (hours) – The failure modes intrinsic to batteries of this type. If no failure modes are defined, this equipment will never fail. MDT will give you an informational note about equipment that does not have an assigned failure mode, but it is not a requirement.
  - A dropdown arrow opens a detailed Failure Modes input grid with Name, MTBF, MTTR, and Notes fields. MTBF and MTTR default units are hours.
- Voltage/Real (V) – The real part of voltage (Cartesian) for this generator.
- Cost ($) – The purchase cost of this type and size of hydro generator.
- Operational Cost ($/hr of usage) – The operational cost of this type and size of hydro generator.
- Volume (ft^3) – The volume of this type and size of hydro generator.
- Weight (lbs) – The weight of this type and size of hydro generator.
- Notes – User supplied notes for this hydro generator.

3.1.2.9 Battery Specifications

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the battery.
- **Max Charge Rate** (kW) – The maximum amount of power that this type of battery can absorb. MDT expects a value greater than zero.
- **Max Discharge Rate** (kW) – The maximum amount of power that this type of battery can supply. MDT expects a value greater than zero.
- **Energy Capacity** (kWh) – The total amount of energy that this type of battery can hold. MDT expects a value greater than zero.
- Efficiencies (%) – The charging and discharging efficiency values of this battery (i.e., for every kWh sent to the battery, what percentage is stored and returned versus lost to heat).

- **Minimum State of Charge** (%) – The minimum state of charge to which this type of battery can be drained.
- **Maximum State of Charge** (%) – The maximum state of charge to which this type of battery can be charged.
- Desired State of Charge (%) – The desired state of charge for this type of battery. Not used in the current version of MDT.
- Failure Modes (hours) – The failure modes intrinsic to batteries of this type. If no failure modes are defined, this equipment will never fail. MDT will give you an informational note about equipment that does not have an assigned failure mode, but it is not a requirement.
    - A dropdown arrow opens a detailed Failure Modes input grid with Name, MTBF, MTTR, and Notes fields. MTBF and MTTR default units are hours.
- Voltage/Real (V) – The real part of voltage (Cartesian) for this generator.
- Cost ($) – The purchase cost of this type and size of battery.
- Operational Cost ($/hr of usage) – The operational cost of this type and size of battery.
- Weight (lbs) – The weight of this type and size of battery.
- Volume (ft^3) – The volume of this type and size of battery.
- Notes – User supplied notes for this battery.

3.1.2.10 Uninterruptible Power Supply (UPS) Specifications

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the UPS.
- **Max Charge Rate** (kW) – The maximum amount of power that this type of UPS can absorb. MDT expects a value greater than zero.
- **Max Discharge Rate** (kW) – The maximum amount of power that this type of UPS can supply. MDT expects a value greater than zero.
- **Energy Capacity** (kWh) – The total amount of energy that this type of UPS can hold. MDT expects a value greater than zero.
- Efficiencies (%) – The charging and discharging efficiency values of this UPS (i.e., for every kWh sent to the UPS, what percentage is stored and returned versus lost to heat).
- Voltage/Real (V) – The real part of voltage (Cartesian) for this generator.
- **Minimum State of Charge** (%) – The minimum state of charge to which this type of UPS can be drained.
- **Maximum State of Charge** (%) – The maximum state of charge to which this type of UPS can be charged.
- Desired State of Charge (%) – The desired state of charge for this type of UPS. Not used in the current version of MDT.
- Failure Modes (hours) – The failure modes intrinsic to UPSs of this type. If no failure modes are defined, this equipment will never fail. MDT will give you an informational note about equipment that does not have an assigned failure mode, but it is not a requirement.
    - A dropdown arrow opens a detailed Failure Modes input grid with Name, MTBF, MTTR, and Notes fields. MTBF and MTTR default units are hours.
- Cost ($) – The purchase cost of this type and size of UPS.
- Operational Cost ($/hr of usage) – The operational cost of this type and size of UPS.
- Weight (lbs) – The weight of this type and size of UPS.

- Volume (ft^3) – The volume of this type and size of UPS.
- Notes – User supplied notes for this UPS.

3.1.2.11 Inverter Specifications

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the inverter.
- Failure Modes (hours) – The failure modes intrinsic to inverters of this type. If no failure modes are defined, this equipment will never fail. MDT will give you an informational note about equipment that does not have an assigned failure mode, but it is not a requirement.
  - A dropdown arrow opens a detailed Failure Modes input grid with Name, MTBF, MTTR, and Notes fields. MTBF and MTTR default units are hours.
- Voltage/Real (V) – The real part of voltage (Cartesian) for this generator.
- Cost ($) – The purchase cost of this type and size of inverter.
- Operational Cost ($/hr of usage) – The operational cost of this type and size of inverter.
- Weight (lbs) – The weight of this type and size of inverter.
- Volume (ft^3) – The volume of this type and size of inverter.
- Notes – User supplied notes for this inverter.

3.1.2.12 Transformer Specifications

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the transformer.
- **Capacity** (*A*) – The maximum amount of current that this type of transformer can pass. MDT expects a value greater than zero.
- Failure Modes (hours) – The failure modes intrinsic to transformers of this type. If no failure modes are defined, this equipment will never fail. MDT will give you an informational note about equipment that does not have an assigned failure mode, but it is not a requirement.
  - A dropdown arrow opens a detailed Failure Modes input grid with Name, MTBF, MTTR, and Notes fields. MTBF and MTTR default units are hours.
- Impedance/Resistance – The real part of impedance (Cartesian) for this line on a per unit basis.
- Cost ($) – The purchase cost of this type and size of transformer.
- Operational Cost ($/hr of usage) – The operational cost of this type and size of transformer.
- Weight (lbs) – The weight of this type and size of transformer.
- Volume (ft^3) – The volume of this type and size of transformer.
- Notes – User supplied notes for this transformer.

3.1.3 System Load Tiers

This section allows you to define the load tiers and set their priority. Actual loads will be defined as part of your Microgrid definition. MDT contains four default tiers of load which can be modified by the user (add new, modify existing, or remove existing). The default tiers are Critical, Uninterruptible (0); Critical, Interruptible (1); Priority (2); and Non-Priority (3). Though available in the same navigation form as the specifications, the load tiers are stored with the problem specific inputs (Site definition), not in the specifications database.

3.1.3.1 Load Tiers

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the load tier.
- **Priority** – The priority of this load tier relative to all other load tiers. 0 (zero) is the highest priority; priority decreases with increasing values.
- Notes – User supplied notes for this load tier.

3.2 Site Definition

The site refers to the geographic location where the microgrid(s) will be located. Site definition describes the overall system being analyzed with user defined attributes. There can be more than one microgrid at a given site.

3.2.1 Settings

The Settings section (Figure 14) allows the user to set some basic information about the site, including the name of the utility serving the site when it is not in islanded mode, as well as a list of utility failure modes that would cause a utility outage and trigger use of the microgrid in islanded mode.

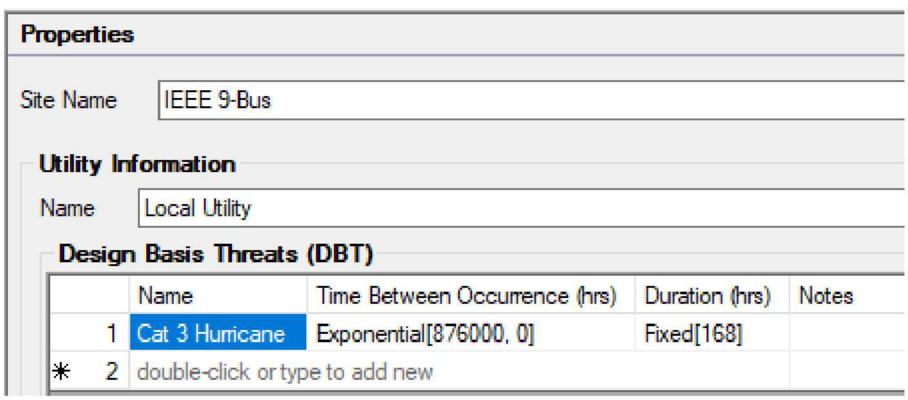


Figure 14. Site Definition: Settings overview.

- Properties
    - **Name** – Name of the Site.
- Utility Information
    - Name – Name of the utility that serves the Site at which the microgrid will exists (if applicable).

Failure Modes (hours) – Entries in this table define failure modes for the utility. Note that this is different from the failure modes listed under equipment specifications or equipment within the microgrid. Here, the failure modes refer to events, such as a hurricane, that could cause a utility outage. Each failure mode is given a name, a mean time between failures (MTBF) and a mean time to repair (MTTR). The user also has the option of adding notes. For the MTBF and MTTR, the user selects a probability distribution and some associated parameters. For descriptions of the distributions, see 5. Appendix B: Failure Mode Distributions.

3.2.2 Solar Resources

The Solar Resources section (Figure 15) is intended to provide information about sunlight available at that site. This attribute does not reflect installed solar power equipment, but instead reflects the amount and characteristics of the naturally occurring resource at that geographic location. Wind and solar generation capacity for each microgrid at the site can be input under the Microgrid -> Listing section.

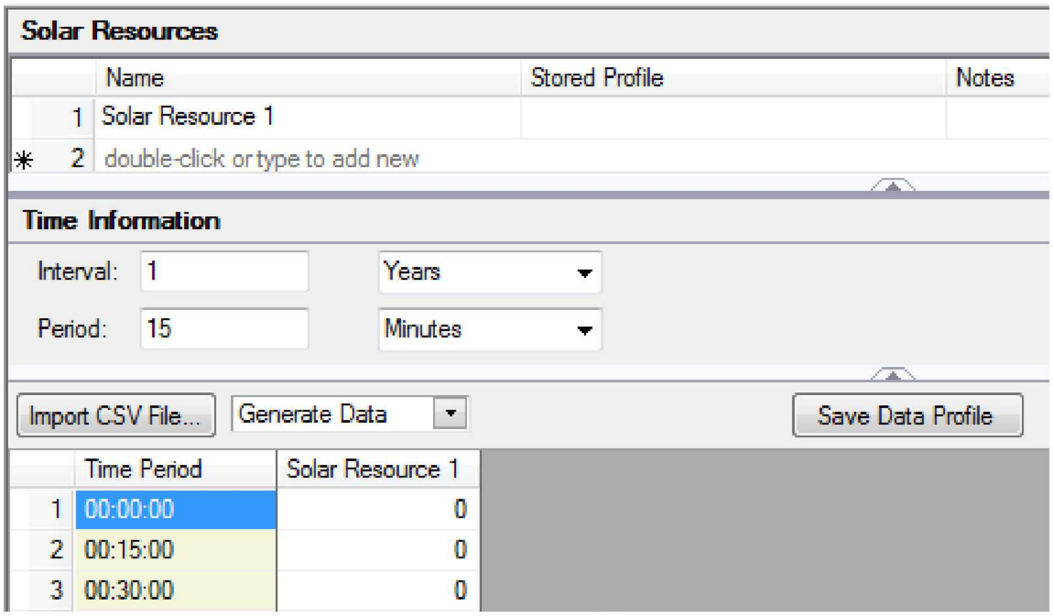


Figure 15. Solar Resources definition screen.

The first table lists the name of each resource and any associated user-entered notes. When a solar resource is highlighted in that table, a Time Information table appears below the Solar Resources table which shows the amount generated by that resource over time. The values are applied as % of nameplate capacity of any generation assets to which the resource is assigned when computing solar power output. The time period display format is d.hh:mm:ss.

Time Translation	MDT Time Period Display
1 hour (1st hour)	01:00:00
23 hours, 59 minutes	23:59:00
1 day, 23 hours, 59 minutes, 59 seconds	1.23:59:59
539 days, 47 minutes, 20 seconds	539.00:47:20

- Name – The user chooses a name for the solar resources they would like represented.
- Stored Profile – The chosen stored profile for this resource if one has been chosen. Selection can be done within the cell.
- Time Information
  - Interval – The length of time for which collected data exists or for which you would like to generate data. Use the dropdown menu to select Hours, Days, Weeks, or Years.

  - Period – The amount of time between data samples for the collected or generated data (i.e., data was collected every 15 minutes). Use the dropdown menu to select Seconds, Minutes, Hours, Days, or Weeks.
- Import CSV file – This allows the user to import the Solar Resource by Time Period information. MDT expects a comma-separated values (CSV) file with two columns. Do not include column titles. Each row must have a single value: <load value>. Each row must be on a new line. Time periods must be numbered numerically. Each row must be on a new line. The time period translation is defined in the Period field (described above) so ensure that time/period matches the amount of data (e.g. 1 year + 1 hour = 8760 rows of data). Data may also be copied and pasted from an Excel file. Example:

  1, 0.6869384
  2, 0.9839202
  3, 1.2930249
  4, 1.34901281
- Generate Data – This will create notional but realistic data for the Solar Resource value in each time period. The control is a drop-down editor that allows one to specify the following parameters for generating data:
  - Yearly Sinusoidal Variation
    - Amplitude – The magnitude of the sinusoidal variation in % of generator output.
    - Phase Shift (Degrees) – The shift of the sinusoid used to determine when the peak will occur during the year.

    The default yearly sinusoid is a modest magnitude wave that peaks in the summer time.

  - Daily Sinusoidal Variation
    - Amplitude – The magnitude of the sinusoidal variation in % of generator output.
    - Phase Shift (Degrees) – The shift of the sinusoid used to determine when the peak will occur during the day.

    The default daily sinusoid is a wave of modest magnitude that peaks at midday.

  - Gaussian Noise
    - Mean – The mean of a normal distribution from which random deviations are drawn. Deviations are from nominal for a resource data point where nominal is defined by the yearly and daily sinusoids.
    - Standard Deviation – The average distance from the mean of deviations from nominal.

    The default noise level for solar data is a 0.5% shift up and down at 1 standard deviation with a mean of 0. This degree of noisiness will depend on the overall magnitude of the load at any point in time.

- Save Data Profile – Name and save a load profile. Saved data profiles will be available for use in subsequent models as well.

3.2.3 Wind Resources

The Wind Resources section (Figure 16) is intended to provide information about wind that could be made available at the site. This attribute does not reflect installed wind power equipment, but instead reflects the amount and characteristics of the naturally occurring resource at that geographic location. Wind and solar generation capacity for each microgrid at the site can be input under the Microgrid -> Listing section.

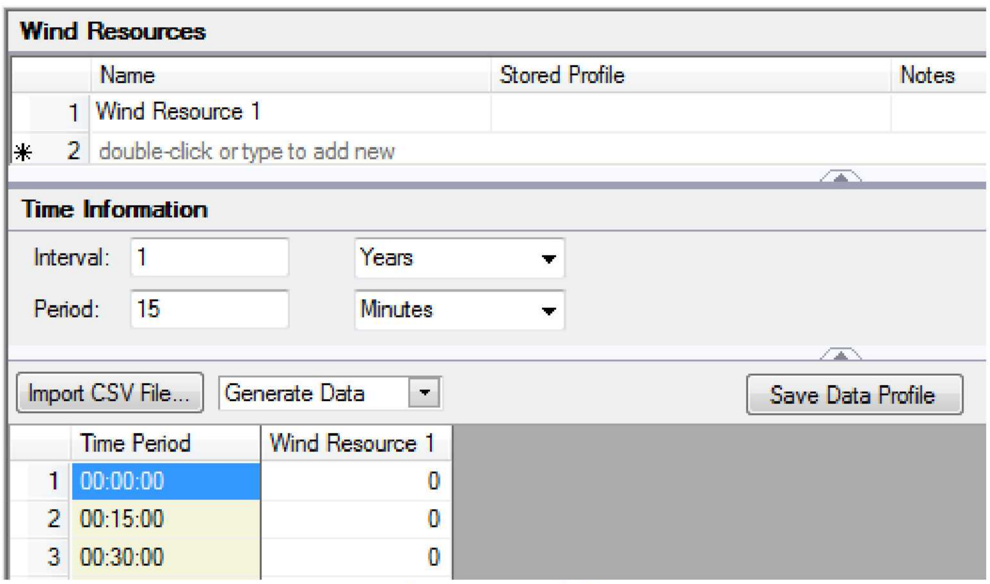


Figure 16. Wind Resources definition screen.

The first table lists the name of each resource and any associated user-entered notes. When a wind resource is highlighted in that table, a Time Information table appears below the Wind Resources table which shows the amount generated by that resource over time. The values are applied as % of nameplate capacity of any generation assets to which the resource is assigned when computing wind power output. The time period display format is d.hh:mm:ss.

Time Translation	MDT Time Period Display
1 hour (1st hour)	01:00:00
23 hours, 59 minutes	23:59:00
1 day, 23 hours, 59 minutes, 59 seconds	1.23:59:59
539 days, 47 minutes, 20 seconds	539.00:47:20

- Name – The user chooses a name for the wind resources they would like represented.
- Stored Profile – The chosen stored profile for this resource, if one has been chosen. Selection can be done within the cell.
- Time Information

    - Interval – The length of time for which collected data exists or for which you would like to generate data. Use the dropdown menu to select Hours, Days, Weeks, or Years.
    - Period – The amount of time between data samples for the collected or generated data (i.e., data was collected every 15 minutes). Use the dropdown menu to select Seconds, Minutes, Hours, Days, or Weeks.
- Import CSV file – This allows the user to import the Wind Resource by Time Period information. MDT expects a comma-separated values (CSV) file with two columns. Do not include column titles. Each row must have a single value: <load value>. Each row must be on a new line. The time period translation is defined in the Period field (described above) so ensure that time/period matches the amount of data (e.g. 1 year + 1 hour = 8760 rows of data). Data may also be copied and pasted from an Excel file. Example:

    1, 0.6869384
    2, 0.9839202
    3, 1.2930249
    4, 1.34901281

- Generate Data – This will create notional data for the Wind Resource value in each time period. The control is a drop-down editor that allows one to specify the following parameters for generating data:
    - Yearly Sinusoidal Variation
        - Amplitude – The magnitude of the sinusoidal variation in % of generator output.
        - Phase Shift (Degrees) – The shift of the sinusoid used to determine when the peak will occur during the year.

        The default yearly sinusoid is a low magnitude wave that peaks in the winter.

    - Daily Sinusoidal Variation
        - Amplitude – The magnitude of the sinusoidal variation in % of generator output.
        - Phase Shift (Degrees) – The shift of the sinusoid used to determine when the peak will occur during the day.

        The default daily sinusoid is a wave of modest magnitude that peaks at night.

    - Gaussian Noise
        - Mean – The mean of a normal distribution from which random deviations are drawn. Deviations are from nominal for a resource data point where nominal is defined by the yearly and daily sinusoids.
        - Standard Deviation – The average distance from the mean of deviations from nominal.

        The default noise level for wind data is a 10% shift up and down at 1 standard deviation with a mean of 0 (moderately noisy).

- Save Data Profile – Name and save a load profile. Saved data profiles will be available for use in subsequent models as well.

3.2.4 Hydro Resource

The Hydro Resources section (Figure 17) is intended to provide information about hydro that could be made available at the site. This attribute does not reflect installed wind power equipment, but instead reflects the amount and characteristics of the naturally occurring resource at that geographic location. Hydro, wind and solar generation capacity for each microgrid at the site can be input under the Microgrid -> Listing section.

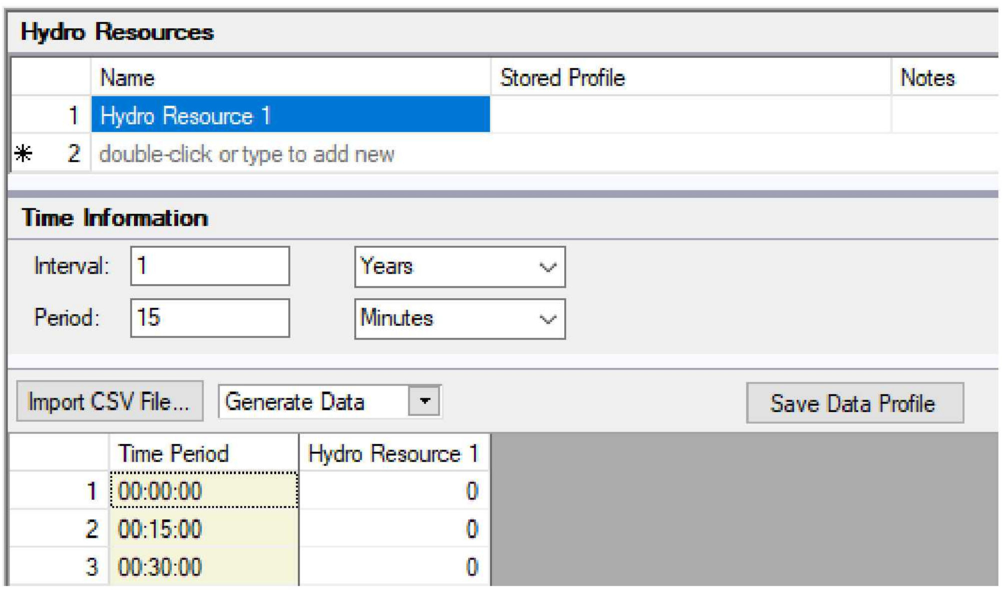


Figure 17. Hydro Resources Definition screen.

The first table lists the name of each resource and any associated user-entered notes. When a hydro resource is highlighted in that table, a Time Information table appears below the Hydro Resources table which shows the amount generated by that resource over time. The values are applied as % of nameplate capacity of any generation assets to which the resource is assigned when computing hydro power output. The time period display format is d.hh:mm:ss.

Time Translation	MDT Time Period Display
1 hour (1st hour) 23 hours, 59 minutes 1 day, 23 hours, 59 minutes, 59 seconds 539 days, 47 minutes, 20 seconds	01:00:00 23:59:00 1.23:59:59 539.00:47:20

- Name – The user chooses a name for the hydro resources they would like represented.
- Stored Profile – The chosen stored profile for this resource, if one has been chosen. Selection can be done within the cell.
- Time Information
  - Interval – The length of time for which collected data exists or for which you would like to generate data. Use the dropdown menu to select Hours, Days, Weeks, or Years.

- Period – The amount of time between data samples for the collected or generated data (i.e., data was collected every 15 minutes). Use the dropdown menu to select Seconds, Minutes, Hours, Days, or Weeks.

- Import CSV file – This allows the user to import the Hydro Resource by Time Period information. MDT expects a comma-separated values (CSV) file with two columns. Do not include column titles. Each row must have a single value: <load value>. Each row must be on a new line. The time period translation is defined in the Period field (described above) so ensure that time/period matches the amount of data (e.g. 1 year + 1 hour = 8760 rows of data). Data may also be copied and pasted from an Excel file. Example:

  1, 0.6869384
  2, 0.9839202
  3, 1.2930249
  4, 1.34901281

- Generate Data – This will create notional data for the Hydro Resource value in each time period. The control is a drop-down editor that allows one to specify the following parameters for generating data:
  - Yearly Sinusoidal Variation
    - Amplitude – The magnitude of the sinusoidal variation in % of generator output.
    - Phase Shift (Degrees) – The shift of the sinusoid used to determine when the peak will occur during the year.

    The default yearly sinusoid is a low magnitude wave that peaks in the winter.

  - Daily Sinusoidal Variation
    - Amplitude – The magnitude of the sinusoidal variation in % of generator output.
    - Phase Shift (Degrees) – The shift of the sinusoid used to determine when the peak will occur during the day.

    The default daily sinusoid is a wave of modest magnitude that peaks at night.

  - Gaussian Noise
    - Mean – The mean of a normal distribution from which random deviations are drawn. Deviations are from nominal for a resource data point where nominal is defined by the yearly and daily sinusoids.
    - Standard Deviation – The average distance from the mean of deviations from nominal.

    The default noise level for hydro data is a 10% shift up and down at 1 standard deviation with a mean of 0 (moderately noisy).

- Save Data Profile – Name and save a load profile. Saved data profiles will be available for use in subsequent models as well.

3.3 Microgrids

To create a new microgrid, go to the Microgrids -> Listing section of the Input Editor tab.

Enter the following information in the table to begin to define your microgrid. Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name –** Name for the microgrid option.
- **Spinning Reserve** (%) – The requested amount of online generation above current load conditions.
- **Min Running Fossil Generators** – The minimum allowable number of fossil fuel generators that must be running at any time on this microgrid, if possible.
- Fixed Cost ($) – The cost of all fixed assets on this microgrid. This is a field calculated by MDT based on the equipment added to this microgrid. This excludes the cost of any assets which are 1) treated as a variable (more than one specification is selected) or 2) included in a complex decision variable or design option. This field is not editable.
- Fixed Weight (lbs) – The total weight of all fixed assets on this microgrid. This is a field calculated by MDT based on the equipment added to this microgrid. This excludes the weight of any assets which are 1) treated as a variable (more than one specification is selected) or 2) included in a complex decision variable or design question. This field is not editable.
- Fixed Volume (ft^3) – The volume of all fixed assets on this microgrid. This is a field calculated by MDT based on equipment on the microgrid. This excludes the volume of any assets which are 1) treated as a variable (more than one specification is selected) or 2) included in a complex decision variable or design question. This field is not editable.
- Average Fixed Load (kW) – This field is calculated by MDT based on the average loads for all defined busses. This field is not editable.
- Notes – User supplied notes for this microgrid option.

There is an ellipsis button in the name field as shown in Figure 18 below that can be used to edit the elements of the microgrid. However, a more convenient means of editing the microgrid is described in the following sections.

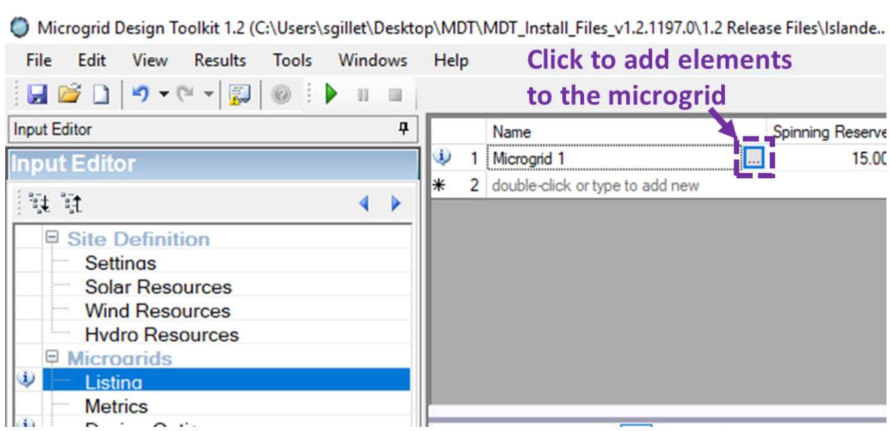


Figure 18. Click the button next to a microgrid name to add elements.

3.3.1 Diagramming a Microgrid

Once the microgrid is created, the diagram window below will become active. A microgrid can be designed using the diagramming feature or through tabular entry (see sections 3.3.2 Microgrid Input Form Overview through 3.3.7 Complex Design Elements).

3.3.1.1 Overview

The diagram allows you to view the topology of your microgrid. You can click on any icon and move it on the screen.

To view asset properties, click on any node or line (highlighted in purple in Figure 19). The properties will be displayed on the lower right side of the screen in the Properties window (highlighted in green in Figure 19). Make sure the Properties tab is selected (right side of Figure 19). Assets can be expanded to view details and specification information. The diagram can also be copied to an image to be used in reports or presentations.

The asset menu on the left (highlighted in red in Figure 19) allows you to add new assets to the diagram.

The menu across the top of the diagram tool (Figure 19) allows you to:

- Reset – Reset the diagram layout. Choose whether to maintain the current asset locations or to reset assets to the default locations.
- Copy image – Copy the diagram as an image so that it can be pasted into other documents.
- Export image – Export/save the diagram as an image. “Diagram” will save the image with a white background. “Visible in view” will save the image with a transparent background and bold font.
- Print – Print the diagram.
- Display diesel tank connections – Toggle to either display or hide. This designates if the location of diesel tanks and their connections.
- Control Line style – Select how line angles should be drawn (Bezier, line, rounded line) or how line crossovers should be drawn (rounded line with jump gaps or with jump overs).
- Control Line angle – Set the line angle style for the diagram. If orthogonal is selected, right angles are drawn. If orthogonal is not selected, then options in the line style menu will not impact the diagram (except for Bezier and line).
- Zoom Full Diagram – Zooms to a view which displays the entire diagram representation of the microgrid.
- Reset Form Layout – Resets the microgrids listing display as seen in Figure 19. This is very useful for resetting the view to return to the original format if windows and tabs are rearranged in a manner that is challenging to undo. The reset from layout button will additionally recover lost or missing tabs within the properties window displayed in green in Figure 19.

The tabs on the right of the diagram tool (highlighted in green in Figure 19) display:

- Complex Options – Gives the user access to drop down menus for all complex design options within the microgrid. These drop-down menus allow complex design options to be selected within the microgrid as well as allow the user to display specific realizations of the complex design options. For more information see section *3.3.7 Complex Design Elements*.

- Properties – Displays the properties of microgrid components that are selected within the microgrid display. If no components are selected then displays the properties of the microgrid itself, including the total generation and load data for the microgrid.
- Identified Paths – Displays a list of all paths between nodes within the microgrid, including path priority ranking, see section *3.3.1.5 Microgrid Paths* for more details.
- Variable Summary – Displays a summary of all the variables within the microgrid, including all complex design variables and all options for equipment with multiple allowable specifications, see section *3.3.1.7 Microgrid Variable Summary*.
- Pre-Defined Loads – Displays a list of all previously defined electrical loads within the microgrid, see section *3.3.1.8 Microgrid Pre-defined Loads* for more details.
- Voltage Areas – Displays a list of all the voltage areas within the microgrid. This list can be used to modify voltage areas voltage levels. Additionally, by double clicking on one, the user can zoom to the voltage area within the microgrid. See *3.3.1.6 Microgrid Voltage Areas* for more details.

The tabs on the bottom left of Figure 19 highlighted in orange display:

- Dependencies – Displays a list of the user defined dependencies (necessitations) between microgrid design options (simple or complex). For more information on how to create dependencies see section
- Find Nodes – Opens a search tab which enables user to find nodes by modifiable key word searches, for more details see section *3.3.1.10 Find Nodes Functionality*.

Hovering over an asset type in the asset menu (Figure 20) will highlight those assets in the diagram and in the diagram overview. Here, all transformers are highlighted. Clicking on a highlight button will toggle the highlighting of the asset type until the button is clicked again.

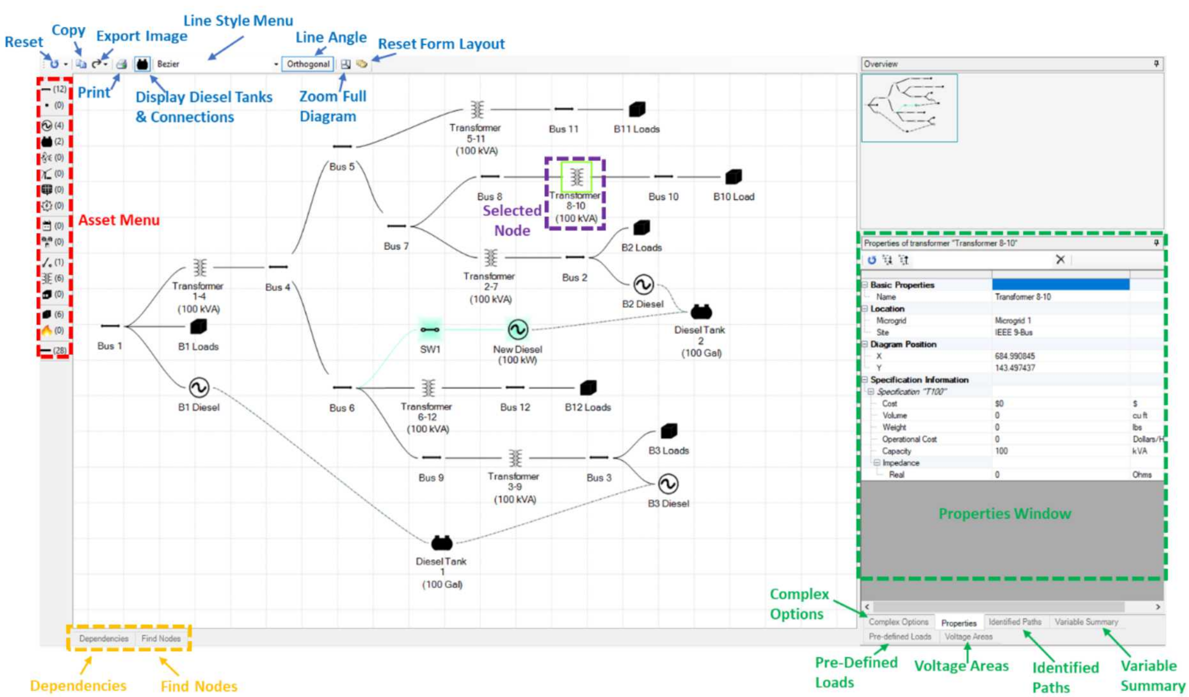


Figure 19. Overview of Diagram page.

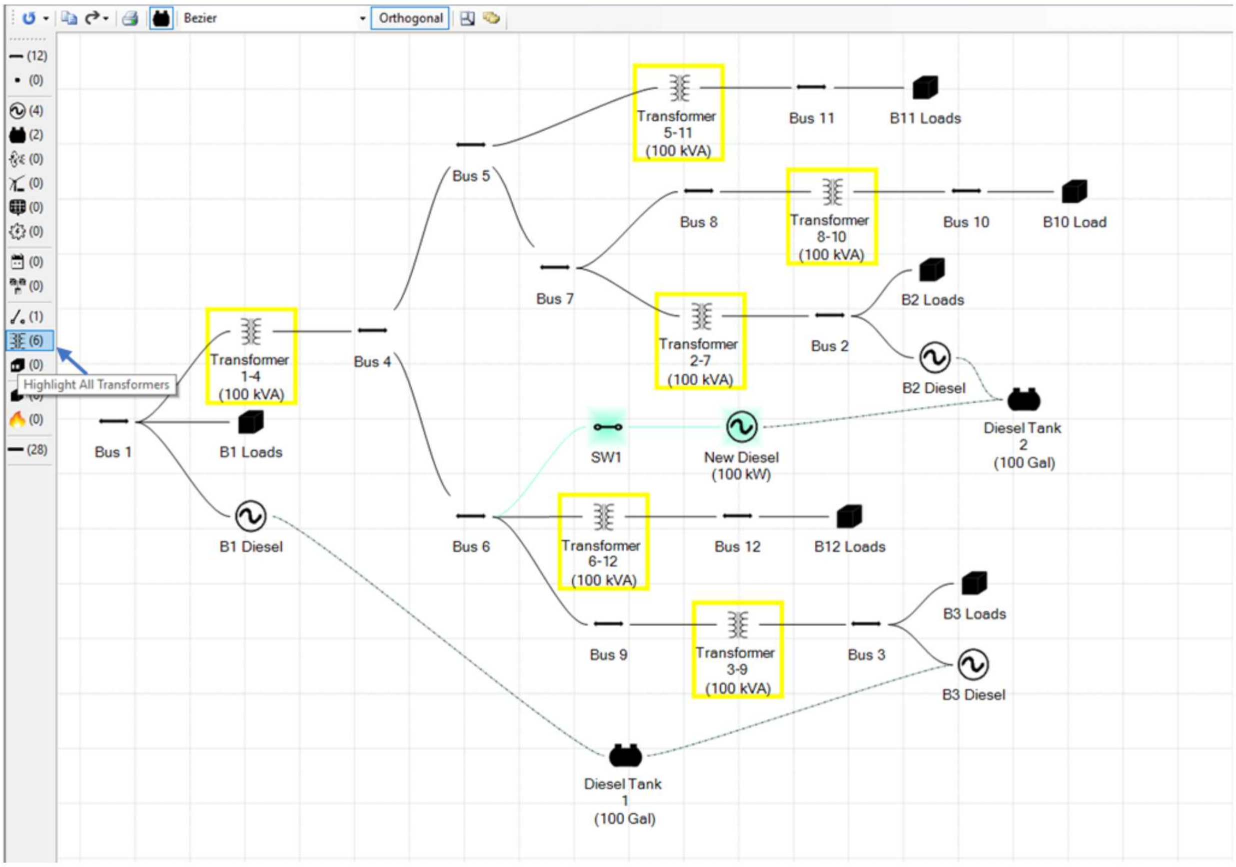


Figure 20. Highlighting assets in the diagram.

3.3.1.2 Adding Assets to the Microgrid

Definitions for all assets can be found in section 3.3.6 Simple Design Elements. To add an asset to the microgrid, click on an item in the asset menu (Figure 21) and drag the item into the workspace. The following assets can be added directly to the workspace:

- Busses
- Nodes
- Diesel Tanks
- Switches
- Transformers
- Thermal Loads

The following assets must be connected to a bus or to bus-connected intermediate asset. This means these assets can only be added to the diagram using method 1 described below.

- Diesel Generators
- Natural Gas Generators
- Wind Generators
- Solar Generators
- Hydro Generators

- Batteries
- UPSs
- Inverters
- Load Sections

Lines cannot be added to the diagram by dragging off the menu. They are automatically added when two assets are connected or can be drawn directly on the graph as described below.

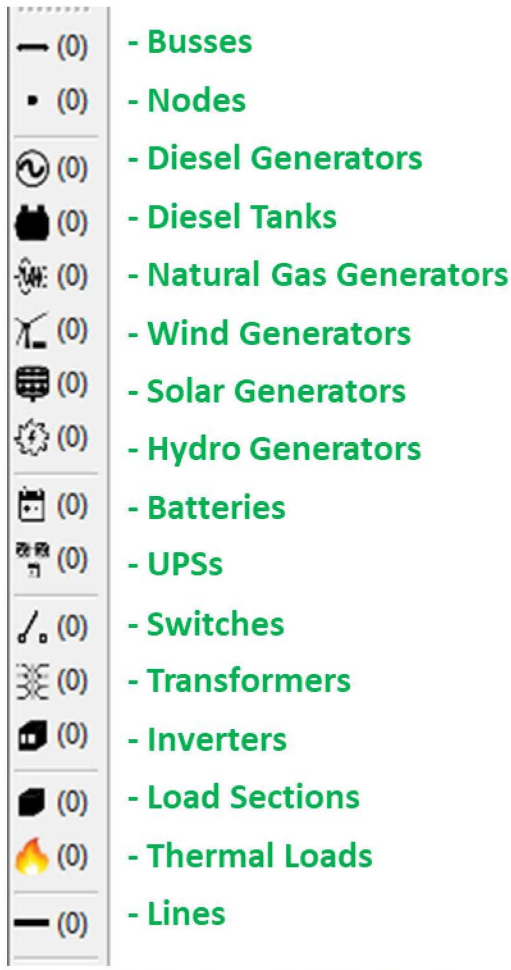


Figure 21. Assets available in the diagram.

There are several ways to connect two assets in the diagram.

1. Add a new asset to an existing asset.
    a. Drag a new asset on top of an existing asset and release it. The line connecting the two assets will automatically be added.
2. Connect two existing assets.
    a. Hover over an existing asset.
    b. Dots will appear around the icon.
    c. Click on a dot and then drag the cursor to another asset. The line connecting the two assets will automatically be added.
3. Re-link Assets

   a. Click on a line within the microgrid display
   b. Click on the small green triangle on the side of the line you'd like to disconnect
   c. Drag this line to a new object and the line will result in a new asset connection within the microgrid.
   d. Some new connections are infeasible and will not be allowed by this relink functionality.
4. Drop Replacement
   a. Select a new asset and drag it onto the microgrid display
   b. While holding shift down drag the new asset on top of an existing asset
   c. MDT will replace the current asset and retain any relevant asset connections from the original.
   d. This is subject to feasibility and will not work as intended if invalid connections are attempted.

Table 1 shows the legal asset connections.

If the two assets cannot be connected, a warning message will be displayed, and no line will appear to connect the assets. Assets like switches and transformers can be dropped directly on lines to become part of the path between two other assets.

To remove an asset or a line from the diagram, select the asset or line and then click the "Delete" key. Alternatively, right click and choose the "Delete *" item in the context menu. Multiple assets can be deleted simultaneously using the delete key once they are selected. Note here that the context menu will only allow deletion of a single item at a time.

To rename an asset on the diagram, click on its text to begin editing.

To view a specific asset in the diagram, hover over the icon in the asset menu. This will highlight all instances of the asset in the diagram (Figure 20).

Table 1. Legal asset connections in the diagram tool.

	Busses	Nodes	Diesel Generators	Diesel Tanks	Natural Gas Generators	Wind Generators	Solar Generators	Hydro Generators	Batteries	UPSs	Switches	Transformers	Inverters	Load Sections	Thermal Loads
Busses	x	X	x		x	x	x	x	x	x	x	x	x	x	
Nodes	x	X									x	x			
Diesel Generators	x			x							x	x	x		x
Diesel Tanks			x												
Natural Gas Generators	x										x	x	x		x
Wind Generators	x										x	x	x		
Solar Generators	x										x	x	x		
Hydro Generators	x										x	x	x		
Batteries	x										x	x	x		
UPSs	x										x	x	x	x	
Switches	x	X	x		x	x	x	x	x	x	x	x	x	x	
Transformers	x	X	x		x	x	x	x	x	x	x	x	x	x	
Inverters	x		x		x	x	x	x	x	x	x	x		x	
Load Sections	x									x	x	x	x		
Thermal Loads			x		x										

The above table is a guide. There are specific circumstances under which some of the connections shown above are not allowed. For example, a generator (wind, solar, etc.) cannot be connected to a switch or transformer that is connected to more than one bus. The software will display explanations when it rejects a connection describing the reasons.

3.3.1.3 Editing Asset Attributes

Every asset, including lines, has attributes that need to be defined. A red exclamation icon will appear on all assets that have not been fully defined. Double click on any asset to open a window where attributes can be defined. Instructions and field definitions are available in section 3.3.6 Simple Design Elements.

- 3.3.6.1 Busses
- 3.3.6.2 Electrical Loads
- 3.3.6.3 Thermal Loads
- 3.3.6.4 Diesel Generators
- 3.3.6.5 Natural Gas Generators

- 3.3.6.6 Solar Generators
- 3.3.6.7 Wind Generators
- 3.3.6.8 Hydro Generators
- 3.3.6.9 Batteries
- 3.3.6.10 Uninterruptible Power Supplies (UPS)
- 3.3.6.11 Inverters
- 3.3.6.12 Nodes
- 3.3.6.13 Switches
- 3.3.6.14 Transformers
- 3.3.6.15 Lines
- 3.3.6.16 Diesel Tanks

3.3.1.4 Complex Design Elements

Complex design elements can be created by either joining simple design elements or by tabular entry. See section 3.3.7 Complex Design Elements for instructions.

If your microgrid option contains complex design elements, you can view the different configurations. For each complex design option created, there will be a dropdown menu on the Complex Options tab of the Properties window. You can select a realization to view. Hovering over each realization option in the dropdown menu will highlight the elements that are a part of that realization. Double clicking the colored area around the selection box will scroll any visible assets of the complex option in to view. Figure 22 shows a realization with no power plant. Figure 23 shows another power plant realization, where the power plant diagram is highlighted in green (at the bottom of the diagram) when you hover over the dropdown menu.

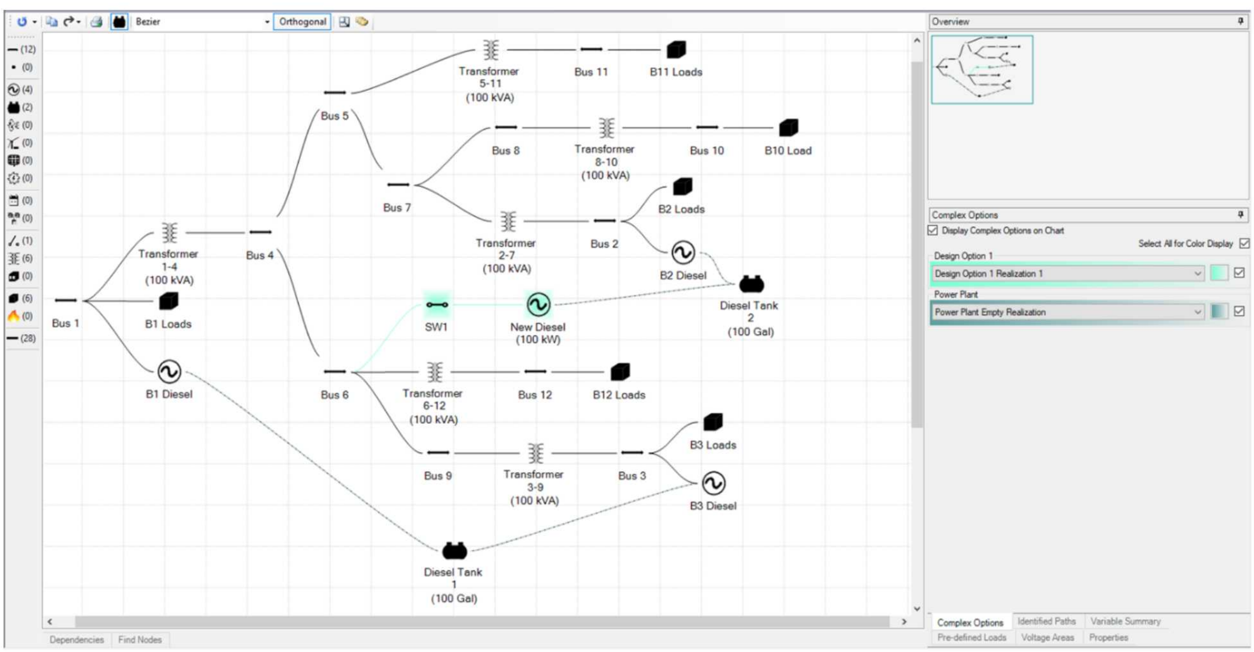


Figure 22. Diagram of the realization with no power plant.

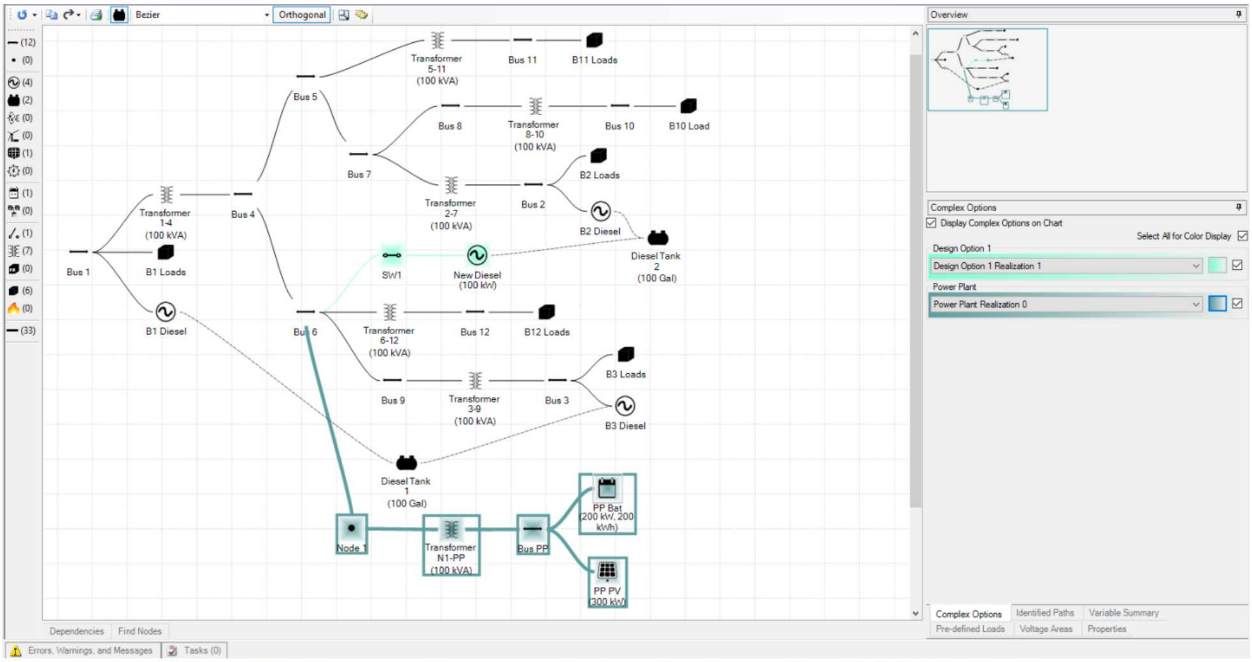


Figure 23. Diagram of a power plant realization option highlighted in blue.

3.3.1.5 Microgrid Paths

Identified Paths is another tab. It lists all the paths in the microgrid where a path is defined as a connection between two busses (or nodes) or a connection between a bus and a terminal component such as a generator or battery. A path may have intermediate assets on it such as transformers, switches, lines, etc. Paths are automatically discovered by the application. Hovering over each path in the table highlights the corresponding elements in the diagram (Figure 24). Double-clicking on an entry in the table will scroll the path into view. Normally closed paths have higher priority than normally open paths, if two paths exist on the same node then the normally closed one will have a higher priority than a normally open one. Note that path priority scores scale backwards, i.e. priority 0 is more important than priority 2.

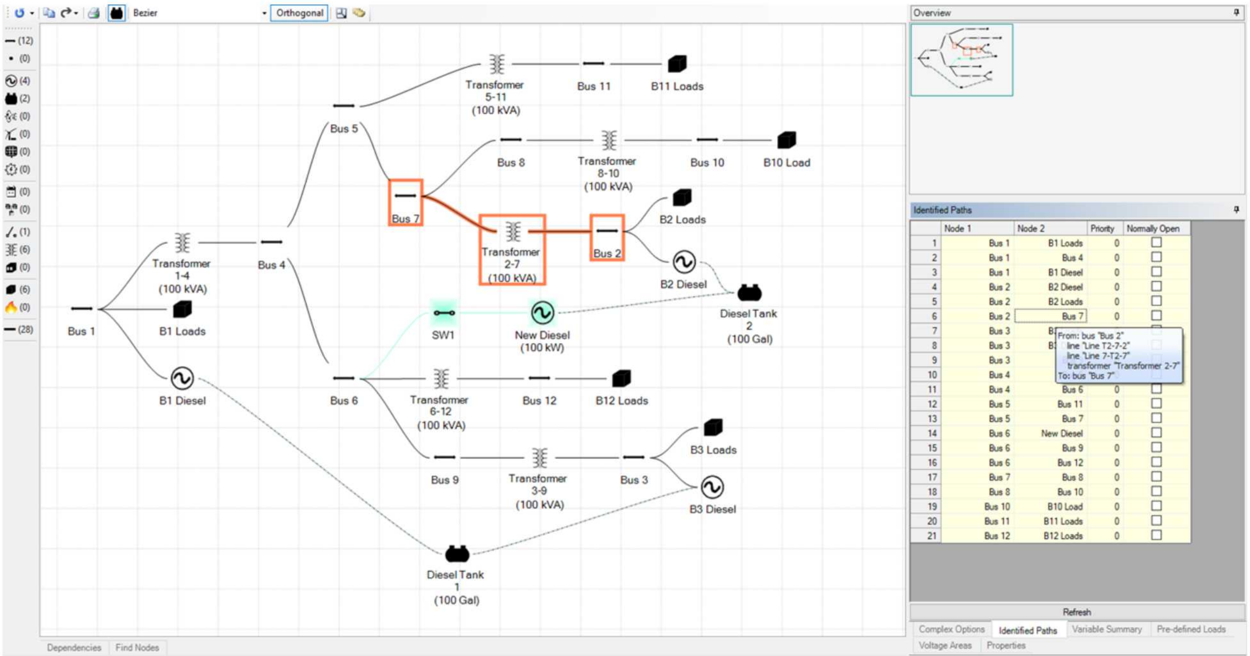


Figure 24. Diagram where a line/path is highlighted in orange.

3.3.1.6 Microgrid Voltage Areas

Voltage areas are parts of the microgrid which have a common voltage, each voltage area is connected to others by a transformer within the microgrid. All equipment within a voltage area must share the same voltage level. If this is not the case, then MDT will display an error message to inform the user of this. Voltage areas are only required if powerflow is selected within the MDT islanded simulator settings see *3.3.3 Microgrid Powerflow Calculations*.

3.3.1.7 Microgrid Variable Summary

Variable Summary is another tab within the microgrid display (Figure 25). Each asset that is set as a variable is listed, along with the allowable specifications. If there is a complex design option, it lists the number of possible realizations. Hovering over an entry in the summary list will highlight the asset(s) associated with the variable. In the case of a complex option, the highlighted elements will be determined by the currently selected realization as described above.

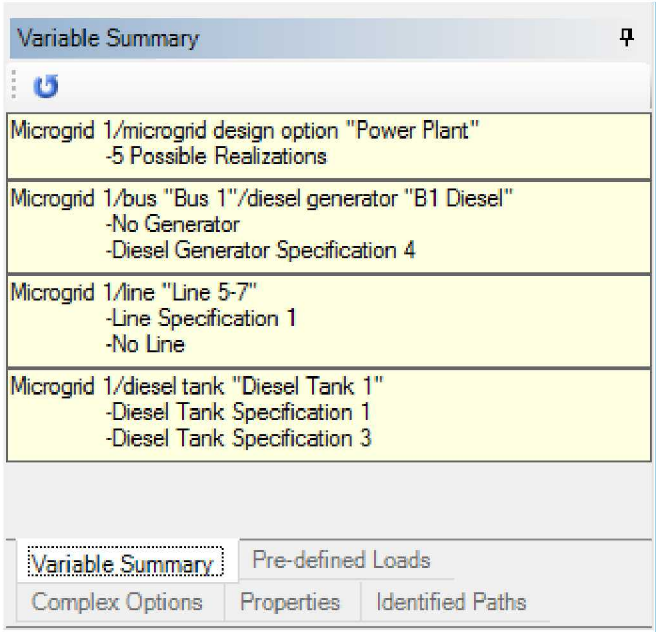


Figure 25. Variable Summary tab for a diagram.

Double-clicking on an entry in the summary list will scroll the associated assets into view.

3.3.1.8 Microgrid Pre-defined Loads

Another tab titled Pre-defined Loads is shown in Figure 26. This tab shows the list of all found stored load profiles previously saved. You can search the list using the text box at the top of the list. You may also drag and drop load sections directly from this list onto the microgrid by selecting and dragging items from it.

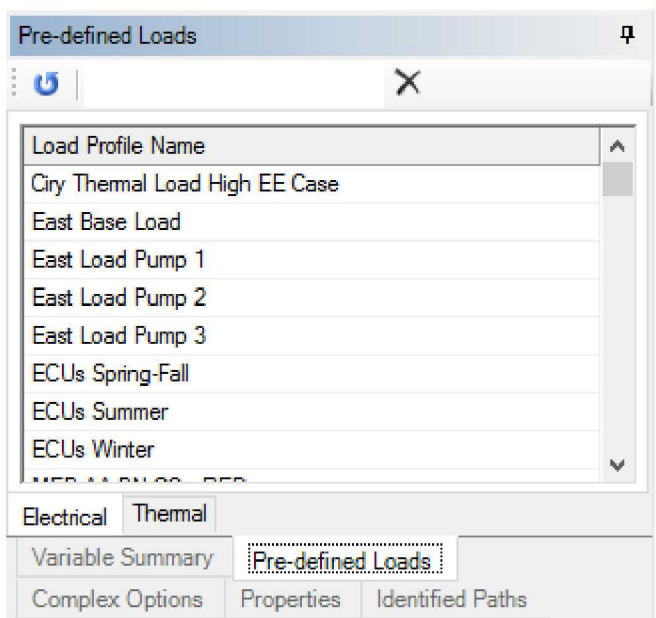


Figure 26. Pre-defined Loads tab for a diagram.

3.3.1.9 Microgrid Option Dependencies

Dependencies (necessitations) can be defined within the microgrid connecting specific realizations of design options and only allowing microgrid realizations that meet these requirements to be feasible. First select the target design option and realization, then select the design options and realizations which the target design option necessitates (requires). Please note (as displayed below in Figure 27) that a target design option can be connected to multiple options using 'or' logic, in the example below B1 Diesel/DG100 necessitates B2 Diesel/DG100 or B3 Diesel/DG100 for the microgrid design to be feasible.

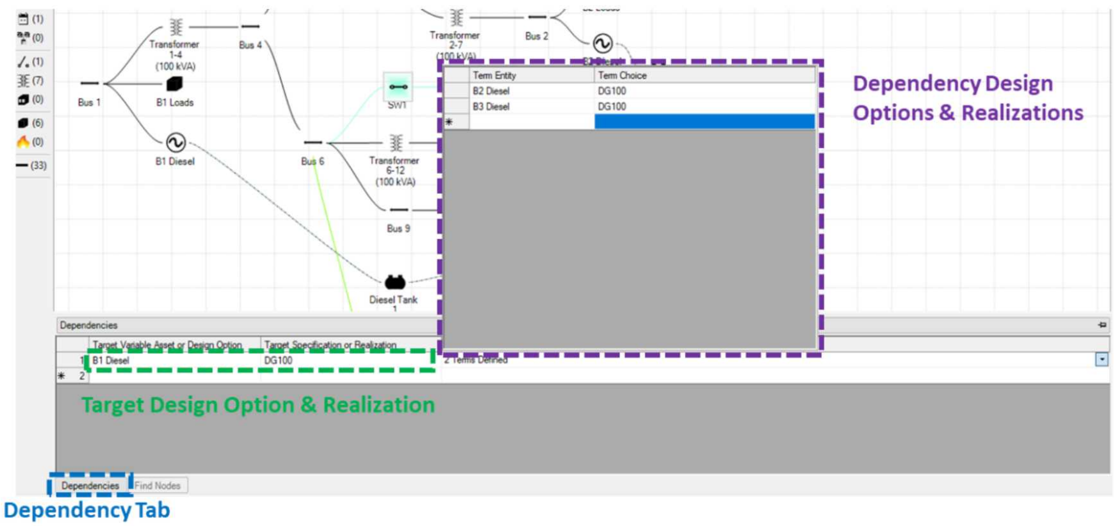


Figure 27. Microgrid Option & Realization Dependencies

If on the other hand you wanted to stipulate that B1 Diesel/DG100 required B2 Diesel/DG100 'and' B3 Diesel/DG100, you would define them as two separate dependencies.

Note that you cannot necessitate more than 1 specification or realization for the same asset or complex design option with 'and' because the selections are mutually exclusive. I.E. generator specification X cannot necessitate battery specification Y and battery specification Z of the same battery on the grid because these two battery specifications are mutually exclusive. The model will still run, however, all microgrid solutions will be displayed as infeasible.

3.3.1.10 Find Nodes Functionality

The 'Find Nodes' functionality allows the user to find specific design options within the microgrid using a modifiable keyword search. There are many options for how to perform the key word search for design options within the microgrid, these are highlighted in green in Figure 28 below. The *Scroll Real Time* option zooms the microgrid view to nodes which match the key word search within the microgrid display as you type.

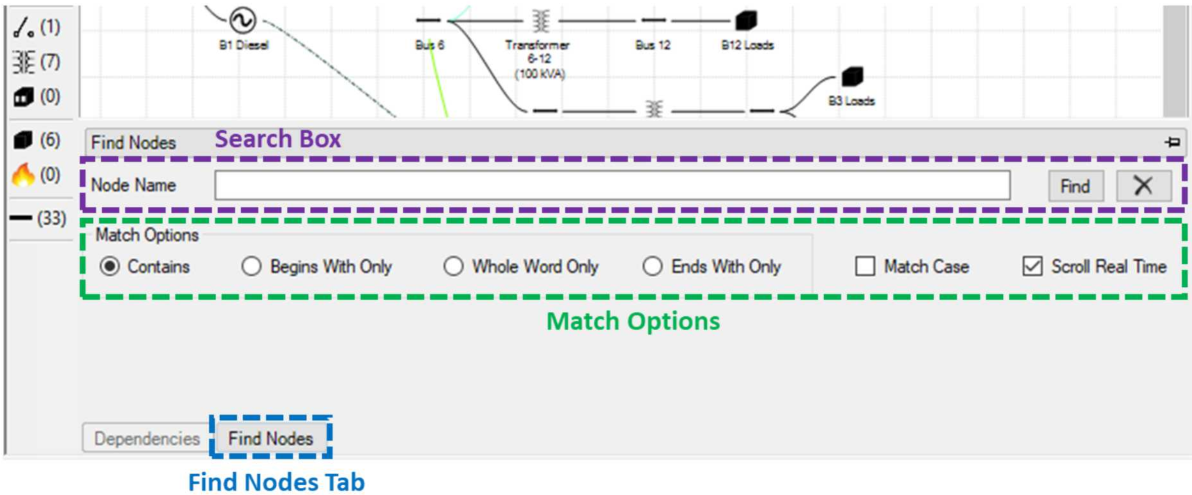


Figure 28. Find Nodes Key Word Search

3.3.1.11 Diagram Group Boxes

Within a microgrid display group boxes can be created to aid the user in organizing the microgrid. These boxes don't have any impact on the simulation or optimization of the microgrid. To create a group box, hold the alt key and drag the box in the microgrid. Once created an additional tab will occur on the right side of the microgrid display allowing the box to be edited (text can be moved, renamed, new color, etc.). See Figure 29 below for an example of a group box and the tab for editing group boxes.

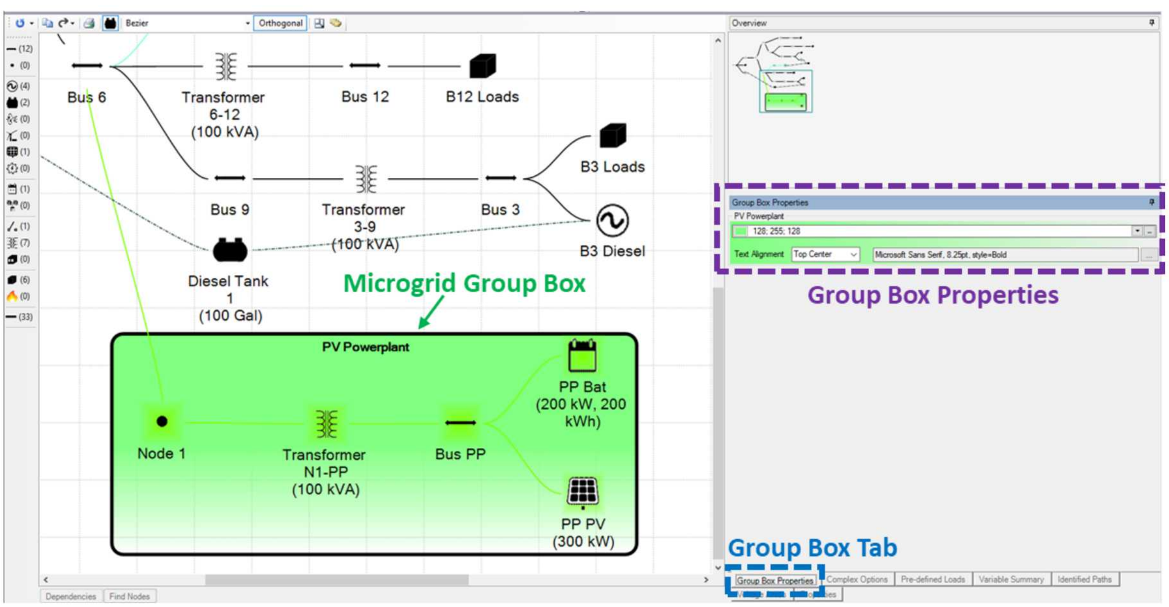


Figure 29. Diagram Group Box

3.3.2 Microgrid Input Form Overview

Figure 30 provides an overview of the microgrid input form. This page is accessed by clicking the ellipses button next to the microgrid name.

To **close a window:**

- Click “Finish” to close the window and save all changes made.
- Click “Cancel” to close the window and cancel any changes made since the last save after opening the dialog box.

To **move to a new element page**:

- Click on the element in the navigation area.
  or
- Click the “Previous Form” button to move to the previous element page (move up the page navigation list).
  or
- Click the “Next Form” button to move to the next element page (move down the page navigation list).

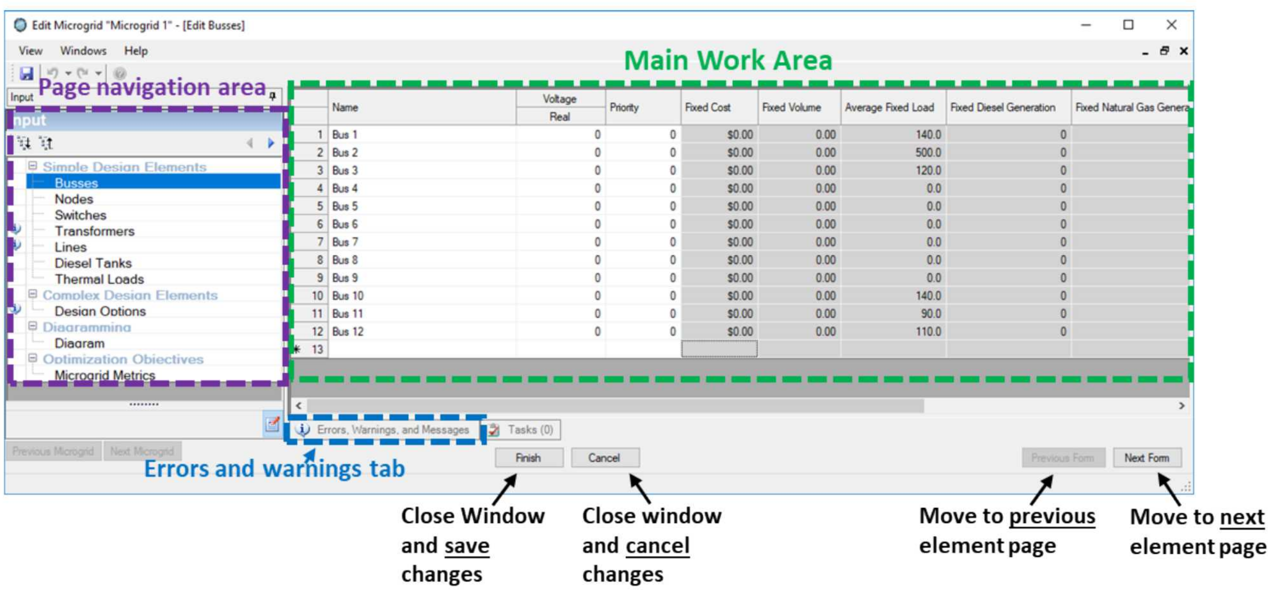


Figure 30. Microgrid Input Form overview.

3.3.3 Microgrid Powerflow Calculations

MDT can include DC powerflow calculations as part of the optimization and simulation. MDT can solve the powerflow system of equations to provide the user with information about power flowing through components, system losses, and equipment capacity overloads. To use the powerflow capability, you must provide additional inputs for many pieces of equipment including primarily voltage levels and resistance values. These inputs must be supplied for relevant equipment specifications as stipulated in the equipment specification descriptions (see section *3.1.2 Equipment Specifications*) and for other entities like busses and nodes.

Internally, the powerflow solver uses a per-unit system to ease the burden of dealing with multiple voltage levels on a grid. To do so correctly, the software parses the grid into voltage areas as introduced in section *3.3.1.6 Microgrid Voltage Areas*. Voltage areas are separated by transformers. Regardless of the actual voltage level on either side of a transformer (as indicated by the voltage level of the bus or node it is attached to), the transformer will serve as a break between voltage areas.

Figure 31 below shows a grid with 2 voltage areas. One is highlighted in green and the other is not highlighted. The transformers that separate one area from the other are highlighted with maroon circles.

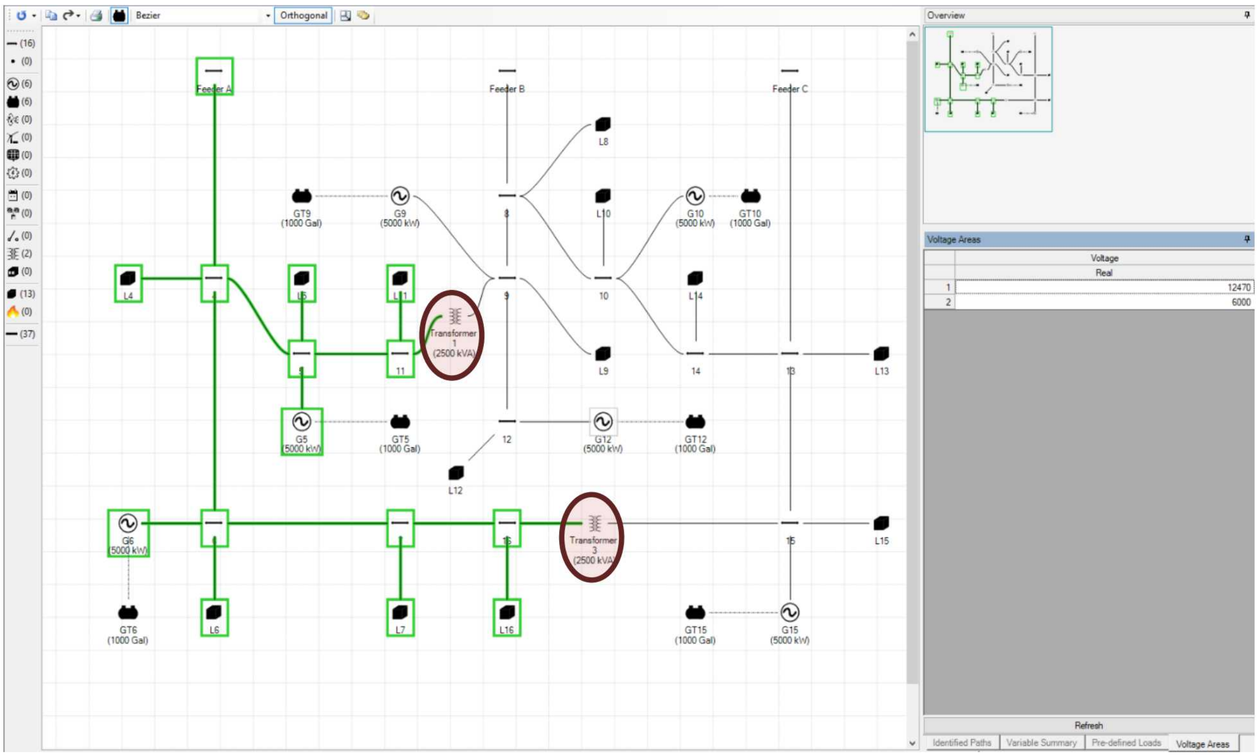


Figure 31. An example grid with 2 voltage areas separated by transformers

Be aware that adding powerflow calculations to the simulation can add significant runtime to the optimization process. How much depends on many factors such as how variable the grid is in terms of load values, renewable resource values, and so on.

Many outputs result from the powerflow calculations and some metrics are available to help guide the optimizer on the basis of those calculations. Those outputs are discussed in detail *in 3.3.9.8 Powerflow Metrics*.

To enable powerflow calculations within MDT, select DC Powerflow Calculations from the powerflow drop down on the right side of the islanded simulator settings page as seen in Figure 46.

3.3.4 Editing Elements

Figure 32 shows the main edit features on an element page.

To **add a new item**:

- Double click in an empty row.
  or
- Begin typing a name into an empty row.

To **add more details** about an item, click the button next to the name field.

To **remove an item**:

- Click on the row number (first column) to highlight the row.
- Press the “Delete” key on the keyboard.

MDT supports **undo** and **redo** of actions.

- Click the Undo or Redo button to view a dropdown of all past actions.
- Select the action to undo/redo.
- The tool will update accordingly.

To **save all changes** made in this window, click the Save button in the toolbar or press ctrl-s.

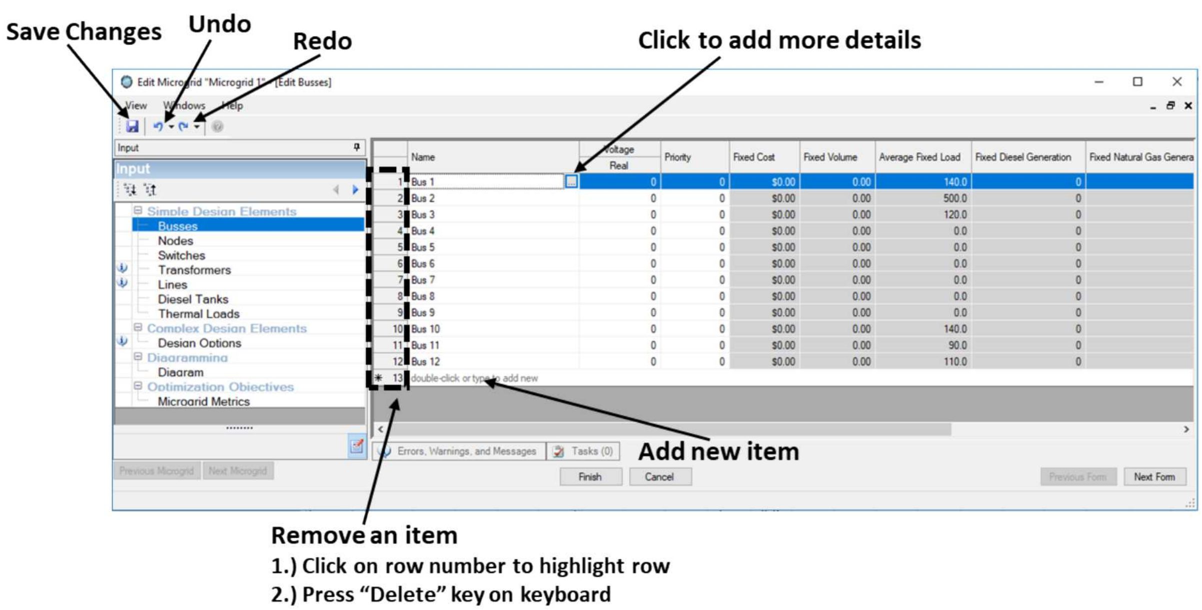


Figure 32. Editing elements.

3.3.5 Simple versus Complex Design Elements

After clicking the button to add elements to a microgrid, you will see the window with element options. These design options are considered “simple” if no coordination is required between decisions. They are considered “complex” if coordination between more than one asset is necessary as part of a design option. A complex design option will include combinations of simple design elements.

For example, when considering a design option to use distributed generation to serve a load, the complex design option could include a switch, some lines, and a diesel generator (see Figure 33). There could be multiple specifications for a simple design element within that complex design option, such as three different specification options for that diesel generator.

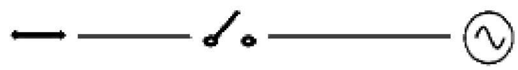


Figure 33. Example of a complex design option of a switch and diesel generator.

This concept is useful because it prevents the use of unnecessary equipment. For example, if the design option considered a single simple design element at a time, then a configuration without the diesel generator could still include the switch and the line that were connecting the generator to the relevant bus. They would be serving no purpose but could be included in a design. The concept of complex design options allows for reflecting dependencies between different elements.

3.3.6 Simple Design Elements

The different microgrid input form (highlighted in green in Figure 34) are accessible via links located beneath the Simple Design Elements header (highlighted in purple in Figure 34).

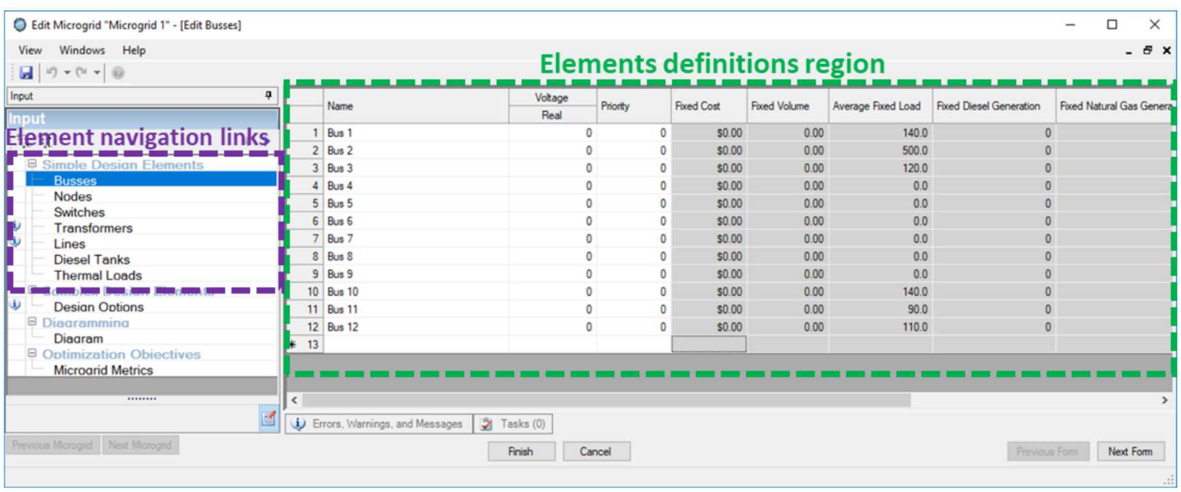


Figure 34. Simple Design Elements navigation.

All elements have a baseline specification, allowable specifications and retrofit costs. A baseline specification is used for defining elements in the existing grid system. If this element currently does not exist, set the baseline specification to the “null” specification. If the element does exist in the current system, select the type of equipment already in place.

If the goal is to continue using existing equipment,

1. Set the allowable specification to the same type of equipment.
2. Do not select any other equipment in this menu.
3. Enter the retrofit cost if the equipment will require modifications in order to be used in a microgrid. In this case, this retrofit cost will be included in the fixed cost calculations.

If the goal is to allow the model to optimize the equipment selection,

1. Select 2 or more allowable specifications, including the baseline if you wish, which can be considered by the model.
2. Enter the retrofit cost if the existing (baseline) equipment will require modifications in order to be used in a microgrid should it be selected. This retrofit cost will be included in the variable cost calculations for a solution only if the model selects the "baseline" equipment from the allowable specification options.

3.3.6.1 Busses

It is important to know the difference between a bus and a node. In an MDT diagram, the node is a simple junction point where two or more lines meet. A bus can have elements attached to it (loads, generators, etc.). Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the bus.
- Voltage/Real (V) – The real part of voltage (Cartesian) for this bus. This is used for DC powerflow, AC powerflows are currently not modeled.
- **Priority** – The priority of this bus relative to all other busses. 0 (zero) is the highest priority.
- Fixed Cost ($) – The total cost of all non-variable assets and components of this bus.
- Fixed Volume (cu ft) – The total volume of all non-variable assets and components at this bus.
- Fixed Weight (lbs.) – The total weight of all non-variable assets and components at this bus.
- Average Fixed Load (kW) – This field is calculated by MDT from the average loads defined for this bus. This field is not editable.
- Fixed Diesel Generation (kW) – The total amount of diesel generation on this bus that is not subject to modification by the model (non-variable).
- Fixed Natural Gas Generation (kW) – The total amount of natural gas generation on this bus that is not subject to modification by the model (non-variable).
- Fixed Solar Generation (kW) – The total amount of solar generation on this bus that is not subject to modification by the model (non-variable).
- Fixed Wind Generation (kW) – The total amount of wind generation on this bus that is not subject to modification by the model (non-variable).
- Fixed Hydro Generation (kW) – The total amount of hydro generation on this bus that is not subject to modification by the model (non-variable).
- Notes – User supplied notes for this bus.

Click in the Name field. Click the button with an ellipsis (highlighted in purple in Figure 35) to begin adding elements to your bus as seen in Figure 36. A new window will open with element options. Additionally, this can be accessed by double clicking on a bus node within the microgrid diagram as seen in Figure 19.

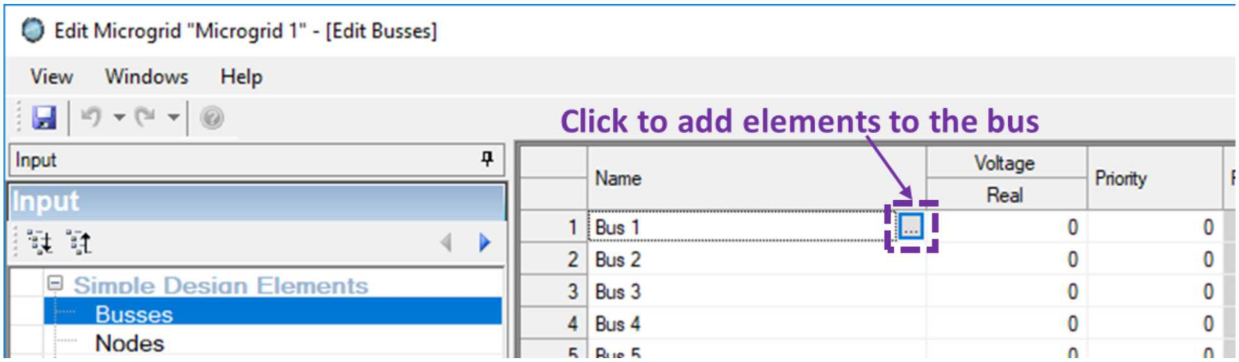


Figure 35. Click the button next to a bus name to add elements.

The different input forms (highlighted in green in Figure 36) are accessible via links located on the left (highlighted in purple in Figure 36). When you have completed entering information about busses, click the "Finish" button at the bottom of the screen to close the window.

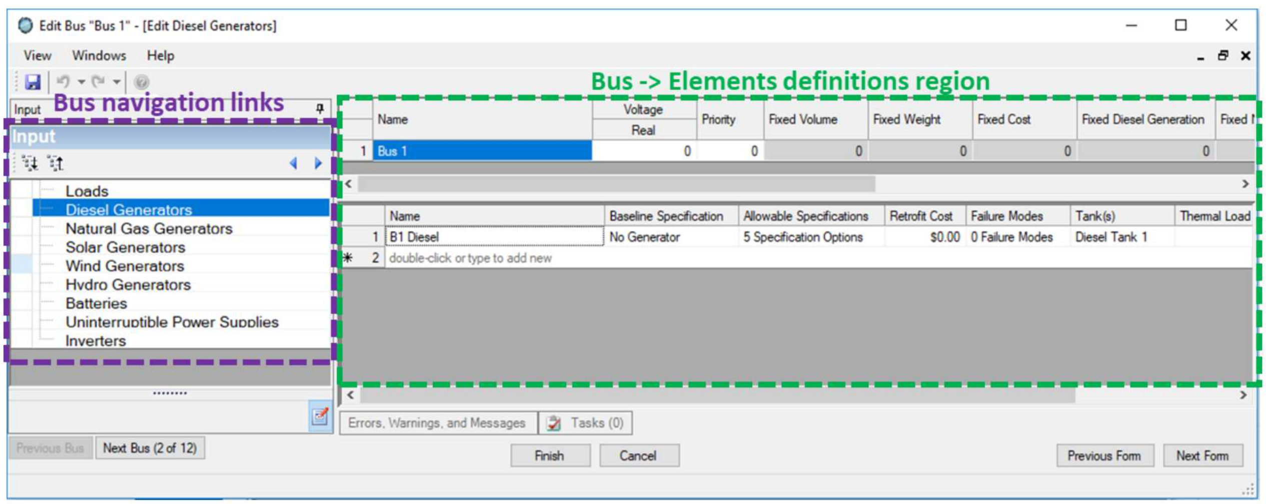


Figure 36. Simple Design Elements -> Bus page overview.

3.3.6.2 Electrical Loads

A load section is a group of electrical loads that can be connected and disconnected as a chunk; they have a single disconnect point. Each load in a load section can have its own tier type (critical, priority, non-priority, user defined). If you want to be able to disconnect specific loads individually, they should be created in different load sections.

If your load section has multiple loads, select each load individually from the table to add data (collected or tool-generated) about that load.

Load Section (highlighted in green in Figure 37)

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value. To view the fields displayed in Figure 37 select the bus that is connected to the load as displayed in Figure 35.

- **Name** – Name for the load section.
- **Priority** – The priority of this load section relative to all other load sections. 0 (zero) is the highest priority.
- Voltage/Real (V) – The real part of voltage (Cartesian) for this load.
- Average Load (kW) - This field is calculated by MDT as the sum of the average loads for the individual load tiers. This field is not editable.
- Notes – User supplied notes for this load section.
- *Individual loads* (highlighted in purple in Figure 37)
    - **Name** – Name for the individual load.
    - **Tier Type** – The load tier (critical, priority, non-priority) of this load.
    - Average Load (kW) – The average load for the tier, calculated from the Data section. This field is not editable.
    - Notes – User supplied notes for this individual load.
    - *Load Data* (emphasized in blue in Figure 37)
        - **Interval** – The length of time for which collected data exists or for which you would like to generate data. Use the dropdown menu to select Days, Weeks, or Years.
        - **Period** – The time period for the collected or generated data (i.e., data was collected every 15 minutes). Use the dropdown menu to select Seconds, Minutes, or Hours. The time period display format is d.hh:mm:ss.

Time Translation	MDT Time Period Display
23 hours, 59 minutes	23:59:00
1 day, 23 hours, 59 minutes, 59 seconds	1.23:59:59
539 days, 47 minutes, 20 seconds	539.00:47:20

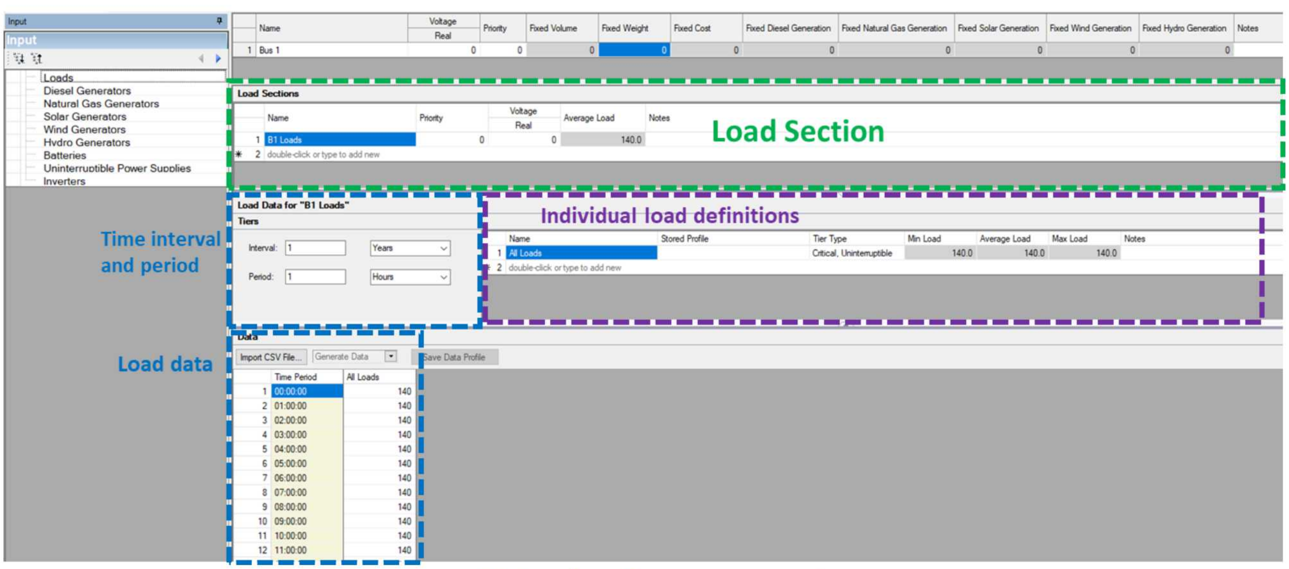


Figure 37. Load section page overview

- *Data* (highlighted in blue in Figure 37)
    - Import CSV file – This allows the user to import the bus load data by Time Period. MDT expects a comma-separated values (CSV) file with two columns. Do not include column titles. Each row must have two values separated by a comma: <time period>, <load value>. Each row must be on a new line. Time periods must be numbered numerically. The time period translation is defined in the Period field (described above). Data may also be copied and pasted from an Excel file. Example:

        1, 0.6869384
        2, 0.9839202
        3, 1.2930249
        4, 1.34901281

    - Generate Data – To have the tool generate data, click on the data column for the appropriate load name. Click on the Generate Data dropdown menu (Figure 38). Enter parameters for the load data characteristics. Baseline Magnitude – The nominal magnitude of the load being defined. It is about this value that the sinusoidal and noise variations will be generated.
        - Yearly Sinusoidal Variation
            - Amplitude - The magnitude of the sinusoidal variation in kW of load.
            - Phase Shift (Degrees) - The shift of the sinusoid used to determine when the peak will occur during the year.

            The default yearly sinusoid is a wave that peaks in the summer time.

        - Daily Sinusoidal Variation
            - Amplitude - The magnitude of the sinusoidal variation in kW of load.
            - Phase Shift (Degrees) - The shift of the sinusoid used to determine when the peak will occur during the day.

            The default daily sinusoid is a wave that peaks at midday.

        - Gaussian Noise – Noise can create values greater than the selected amplitude values.
            - Mean - The mean of a normal distribution from which random deviations are drawn. Deviations are from nominal for a resource data point where nominal is defined by the yearly and daily sinusoids.
            - Standard Deviation - The average distance from the mean of deviations from nominal.

            The default noise level for load data is a 10% shift up and down at 1 standard deviation with a mean of 0 (moderately noisy).

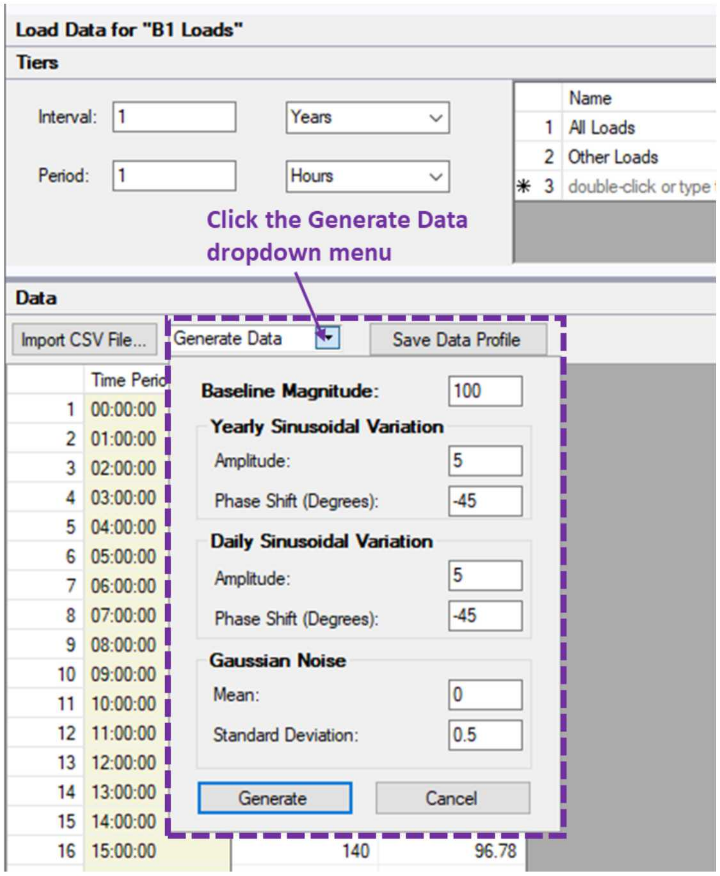


Figure 38. Automated generation of data for a load.

3.3.6.3 Thermal Loads

A thermal load represents a heat sink in the microgrid to which heat energy from fossil generators may be applied. To edit a thermal load, double-click the icon in the microgrid after having dropped one in.

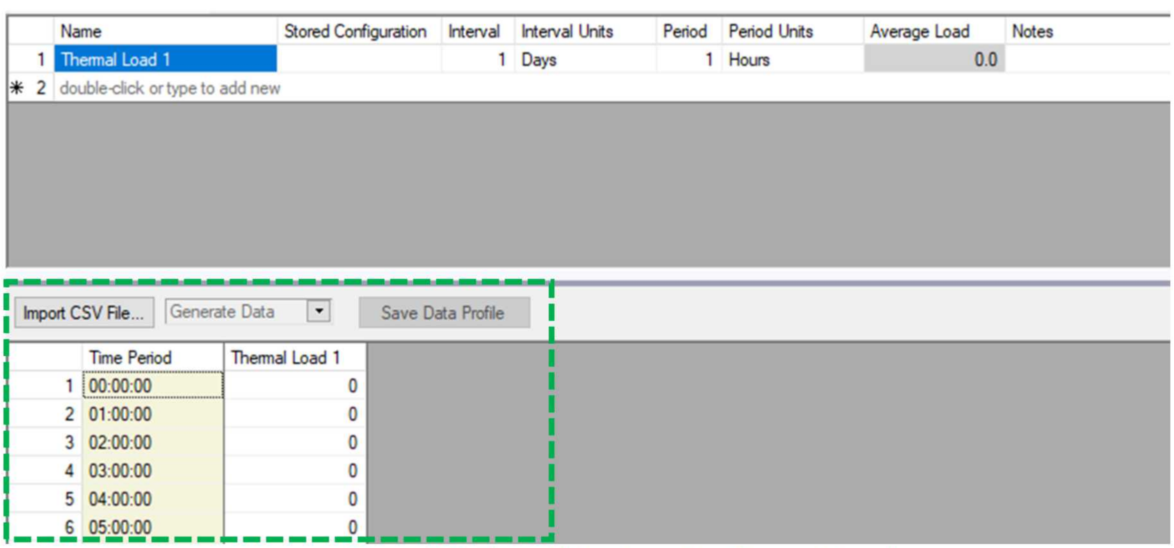


Figure 39. The editing form for Thermal Loads

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the load section.
- Stored Configuration – The currently chosen stored thermal load configuration if one.
- **Interval** – The length of time for which collected data exists or for which you would like to generate data. Use the dropdown menu to select Days, Weeks, or Years.
- **Interval Units** – The time units of the interval. Use the drop-down menu in the cell to choose.
- **Period** – The time period for the collected or generated data (i.e., data was collected every 15 minutes). Use the dropdown menu to select Seconds, Minutes, or Hours. The time period display format is d.hh:mm:ss.
- **Period Units** – The time units of the period. Use the drop-down menu in the cell to choose.

Time Translation	MDT Time Period Display
23 hours, 59 minutes	23:59:00
1 day, 23 hours, 59 minutes, 59 seconds	1.23:59:59
539 days, 47 minutes, 20 seconds	539.00:47:20

- Average Load (kW) - This field is calculated by MDT as the sum of the average loads for the individual load tiers. This field is not editable.
- Notes – User supplied notes for this load section.
- Data (highlighted in green in Figure 39)
  - Import CSV file – This allows the user to import the bus load data by Time Period. MDT expects a comma-separated values (CSV) file with two columns. Do not include column titles. Each row must have two values separated by a comma: <time period>, <load value>. Each row must be on a new line. Time periods must be numbered numerically. The time period translation is defined in the Period field (described above). Data may also be copied and pasted from an Excel file. Example:
    - 1, 0.6869384
    - 2, 0.9839202
    - 3, 1.2930249
    - 4, 1.34901281
  - Generate Data – To have the tool generate data, click on the data column for the appropriate load name. Click on the Generate Data dropdown menu. Enter parameters for the load data characteristics. Baseline Magnitude – The nominal magnitude of the load being defined. It is about this value that the sinusoidal and noise variations will be generated.
    - Yearly Sinusoidal Variation
      - Amplitude - The magnitude of the sinusoidal variation in kW of load.
      - Phase Shift (Degrees) - The shift of the sinusoid used to determine when the peak will occur during the year.

      The default yearly sinusoid is a wave that peaks in the summer time.
    - Daily Sinusoidal Variation
      - Amplitude - The magnitude of the sinusoidal variation in kW of load.
      - Phase Shift (Degrees) - The shift of the sinusoid used to determine when the peak will occur during the day.

The default daily sinusoid is a wave that peaks at midday.

- Gaussian Noise – Noise can create values greater than the selected amplitude values.
    - Mean - The mean of a normal distribution from which random deviations are drawn. Deviations are from nominal for a resource data point where nominal is defined by the yearly and daily sinusoids.
    - Standard Deviation - The average distance from the mean of deviations from nominal.

The default noise level for load data is a 10% shift up and down at 1 standard deviation with a mean of 0 (moderately noisy).

3.3.6.4 Diesel Generators

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the diesel generator.
- **Baseline Specification** – The specification describing the current (existing) generator.
- **Allowable Specifications** – Select one or more of the diesel generators defined in the Specifications section. Selecting more than one specification makes the selected generator a decision variable. The model will help you determine which option is best for your microgrid design.
- Retrofit Cost ($) – The cost associated with using the baseline specification (existing equipment) in a microgrid solution.
- Failure Modes (hours) – Based on the specification(s) selected above, this generator will inherit the failure modes defined for the selected specifications in the Specifications section. If necessary, *additional* failure modes can be defined for this generator in this field. These failure modes would be dependent on how/where this generator is used. Failure modes that are generic to all generators should be defined in the Specifications section.
- **Tank(s)** – Select one or more of the diesel tanks defined in this microgrid. Selecting more than one tank makes the selected tank(s) a decision variable. The model will help you determine which option is best for your grid design.
- **Thermal Load** – The thermal load connected to this generator, if one is present. This generator will serve any recoverable heat to the specified thermal load.
- **Networked** – This designates if the generator has the necessary controls to participate in the microgrid. If not (leave unchecked), this means the generator can only operate when on an isolated bus.
- Notes– User supplied notes for this diesel generator.

3.3.6.5 Natural Gas Generators

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the natural gas generator.

- **Baseline Specification** – The specification describing the current (existing) generator.
- **Allowable Specifications** – Select one or more of the natural generators defined in the Specifications section. Selecting more than one specification makes the selected generator a decision variable. The model will help you determine which option is best for your microgrid design.
- Retrofit Cost ($) – The cost associated with using the baseline specification (existing equipment) in a microgrid solution.
- Failure Modes (hours) – Based on the specification(s) selected above, this generator will inherit the failure modes defined for the selected specifications in the Specifications section. If necessary, *additional* failure modes can be defined for this generator in this field. These failure modes would be dependent on how/where this generator is used. Failure modes that are generic to all generators should be defined in the Specifications section.
- **Thermal Load** – The thermal load connected to this generator, if one is present. This generator will serve any recoverable heat to the specified thermal load.
- **Networked** – This designates if the generator has the necessary controls to participate in the microgrid. If not (leave unchecked), this means the generator can only operate when on an isolated bus.
- Notes– User supplied notes for this natural gas generator.

3.3.6.6 Solar Generators

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the solar generator.
- **Baseline Specification** – The specification describing the current (existing) generator.
- **Allowable Specifications** – Select one or more of the solar generators defined in the Specifications section. Selecting more than one specification makes the selected generator a decision variable. The model will help you determine which option is best for your microgrid design.
- Retrofit Cost ($) – The cost associated with using the baseline specification (existing equipment) in a microgrid solution.
- Failure Modes (hours) – Based on the specification(s) selected above, this generator will inherit the failure modes defined for the selected specifications in the Specifications section. If necessary, *additional* failure modes can be defined for this generator in this field. These failure modes would be dependent on how/where this generator is used. Failure modes that are generic to all generators should be defined in the Specifications section.
- **Networked** – This designates if the generator has the necessary controls to participate in the microgrid. If not (leave unchecked), this means the generator can only operate when on an isolated bus.
- **Solar Resource** – The solar energy availability profile for where this generator will be located. Solar resources are defined under Site Definition.
  Notes – User supplied notes for this solar generator.

3.3.6.7 Wind Generators

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the wind generator.
- **Baseline Specification** – The specification describing the current (existing) generator.
- **Allowable Specifications** – Select one or more of the wind generators defined in the Specifications section. Selecting more than one specification makes the selected generator a decision variable. The model will help you determine which option is best for your microgrid design.
- Retrofit Cost ($) – The cost associated with using the baseline specification (existing equipment) in a microgrid solution.
- Failure Modes (hours) – Based on the specification(s) selected above, this generator will inherit the failure modes defined for the selected specifications in the Specifications section. If necessary, *additional* failure modes can be defined for this generator in this field. These failure modes would be dependent on how/where this generator is used. Failure modes that are generic to all generators should be defined in the Specifications section.
- **Networked** – This designates if the generator has the necessary controls to participate in the microgrid. If not (leave unchecked), this means the generator can only operate when on an isolated bus.
- **Wind Resource** – The wind energy availability profile for where this generator will be located. Wind resources are defined under Site Definition.
- Notes– User supplied notes for this wind generator.

3.3.6.8 Hydro Generators

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the hydro generator.
- **Baseline Specification** – The specification describing the current (existing) generator.
- **Allowable Specifications** – Select one or more of the hydro generators defined in the Specifications section. Selecting more than one specification makes the selected generator a decision variable. The model will help you determine which option is best for your microgrid design.
- Retrofit Cost ($) – The cost associated with using the baseline specification (existing equipment) in a microgrid solution.
- Failure Modes (hours) – Based on the specification(s) selected above, this generator will inherit the failure modes defined for the selected specifications in the Specifications section. If necessary, *additional* failure modes can be defined for this generator in this field. These failure modes would be dependent on how/where this generator is used. Failure modes that are generic to all generators should be defined in the Specifications section.
- **Networked** – This designates if the generator has the necessary controls to participate in the microgrid. If not (leave unchecked), this means the generator can only operate when on an isolated bus.
- **Hydro Resource** – The hydro energy availability profile for where this generator will be located. Hydro resources are defined under Site Definition.
- Notes– User supplied notes for this hydro generator.

3.3.6.9 Batteries

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the battery.
- **Baseline Specification** – The specification describing the current (existing) battery.
- **Allowable Specifications** – Select one or more of the batteries defined in the Specifications section. Selecting more than one specification makes the selected battery a decision variable. The model will help you determine which option is best for your microgrid design.
- Retrofit Cost ($) – The cost associated with using the baseline specification (existing equipment) in a microgrid solution.
- Failure Modes (hours) – Based on the specification(s) selected above, this battery will inherit the failure modes defined for the selected specifications in the Specifications section. If necessary, *additional* failure modes can be defined for this battery in this field. These failure modes would be dependent on how/where this battery is used. Failure modes that are generic to all batteries should be defined in the Specifications section.
- Notes – User supplied notes for this battery.

3.3.6.10 Uninterruptible Power Supplies (UPS)

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the UPS.
- **Load Section** – Select a Load Section defined under this bus's load.
- **Baseline Specification** – The specification describing the current (existing) UPS.
- **Allowable Specifications** – Select one or more of the UPSs defined in the Specifications section. Selecting more than one specification makes the selected UPS a decision variable. The model will help you determine which option is best for your microgrid design.
- Retrofit Cost ($) – The cost associated with using the baseline specification (existing equipment) in a microgrid solution.
- **Failure Modes (hours)** – Based on the specification(s) selected above, this UPS will inherit the failure modes defined for the selected specifications in the Specifications section. If necessary, *additional* failure modes can be defined for this UPS in this field. These failure modes would be dependent on how/where this UPS is used. Failure modes that are generic to all UPSs should be defined in the Specifications section.
- Notes – User supplied notes for this UPS.

3.3.6.11 Inverters

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the inverter.
- **Load Section** – Select a Load Section defined under this bus's Load.
- **Baseline Specification** – The specification describing the current (existing) inverter.
- **Allowable Specifications** – Select one or more of the inverters defined in the Specifications section. Selecting more than one specification makes the selected inverter a decision variable. The model will help you determine which option is best for your microgrid design.
- Retrofit Cost ($) – The cost associated with using the baseline specification (existing equipment) in a microgrid solution.

- <u>Failure Modes</u> (hours) – Based on the specification(s) selected above, this inverter will inherit the failure modes defined for the selected specifications in the Specifications section. If necessary, *additional* failure modes can be defined for this inverter in this field. These failure modes would be dependent on how/where this inverter is used. Failure modes that are generic to all inverters should be defined in the Specifications section.
- <u>Notes</u> – User supplied notes for this inverter.

3.3.6.12 Nodes

It is important to know the difference between a bus and a node. In a one line diagram, the node is a simple junction point where two or more lines meet. A bus can have elements attached to it (loads, generators, etc.). Required fields are displayed in bold font.

- **<u>Name</u>** – Name for the diesel node.
- <u>Voltage/Real</u> (V) – The real part of voltage (Cartesian) for this node. This is used for DC powerflow, AC powerflows are currently not modeled.
- <u>Notes</u> – User supplied notes for this node.

3.3.6.13 Switches

Switches are considered automatic since the simulator assumes that it can open and close switches at will. To create a manual switch which is always closed but fails open, create two nodes connected by a line. The line must be defined with the desired reliability characteristics (failure modes) of the manual switch. This line must be defined in the Line Specifications section.

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **<u>Name</u>** – Name for the switch.
- **<u>Default State</u>** – Whether this switch is normally open or closed.
- **<u>Baseline Specification</u>** – The specification describing the current (existing) switch.
- **<u>Allowable Specifications</u>** – Select one or more of the switches defined in the Specifications section. Selecting more than one specification makes the selected switch a decision variable. The model will help you determine which option is best for your microgrid design.
- <u>Retrofit Cost</u> ($) – The cost associated with using the baseline specification (existing equipment) in a microgrid solution.
- <u>Failure Modes</u> (hours) – Based on the specification(s) selected above, this switch will inherit the failure modes defined for the selected specifications in the Specifications section. If necessary, *additional* failure modes can be defined for this switch in this field. These failure modes would be dependent on how/where this switch is used. Failure modes that are generic to all switches should be defined in the Specifications section. Note that all switches in the MDT fail open.
- <u>Notes</u> – User supplied notes for this switch.

3.3.6.14 Transformers

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **<u>Name</u>** – Name for the transformer.

- **<u>Baseline Specification</u>** – The specification describing the current (existing) transformer.
- **<u>Allowable Specifications</u>** – Select one or more of the transformers defined in the Specifications section. Selecting more than one specification makes the selected transformer a decision variable. The model will help you determine which option is best for your microgrid design.
- <u>Retrofit Cost</u> ($) – The cost associated with using the baseline specification (existing equipment) in a microgrid solution.
- <u>Failure Modes</u> (hours) – Based on the specification(s) selected above, this transformer will inherit the failure modes defined for the selected specifications in the Specifications section. If necessary, *additional* failure modes can be defined for this transformer in this field. These failure modes would be dependent on how/where this transformer is used. Failure modes that are generic to all transformers should be defined in the Specifications section.
- <u>Notes</u> – User supplied notes for this generator.

3.3.6.15 Lines

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **<u>Name</u>** – Name for the line.
- **<u>First Node</u>** – The first asset to be connected by the line. Equipment and loads attached to a bus can be selected. In the dropdown menu, expand the bus to find its elements and loads.
- **<u>Second Node</u>** – The second asset to be connected by the line. Equipment and loads attached to a bus can be selected. In the dropdown menu, expand the bus to find its elements and loads.
- **<u>Length</u> (ft)** – The length between the two nodes. Length will be used for powerflow calculations once implemented in the MDT. Currently, length is used only to compute the cost of a line which is defined per unit length.
- **<u>Baseline Specification</u>** – The specification describing the current (existing) line.
- **<u>Allowable Specifications</u>** – Select one or more of the lines defined in the Specifications section. Selecting more than one specification makes the selected line a decision variable. The model will help you determine which option is best for your microgrid design.
- <u>Retrofit Cost</u> ($) – The cost associated with using the baseline specification (existing equipment) in a microgrid solution on a per unit length basis.
- <u>Failure Modes</u> (hours) – Based on the specification(s) selected above, this line will inherit the failure modes defined for the selected specifications in the Specifications section. If necessary, *additional* failure modes can be defined for this line in this field. These failure modes would be dependent on how/where this line is used. Failure modes that are generic to all lines should be defined in the Specifications section.
- <u>Notes</u> – User supplied notes for this line.

3.3.6.16 Diesel Tanks

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **<u>Name</u>** – Name for the diesel tank.
- **<u>Initial Quantity</u>** (gallons) – The initial amount of fuel in the tank. If the tank is full (regardless of tank size due to specification selection), enter -1.
- **<u>Baseline Specification</u>** – The specification describing the current (existing) tank.

- **Allowable Specifications** – Select one or more of the diesel tanks defined in the Specifications section. Selecting more than one specification makes the selected diesel tank a decision variable. The model will help you determine which option is best for your microgrid design.
- Retrofit Cost ($) – The cost associated with using the baseline specification (existing equipment) in a microgrid solution.
- Notes – User supplied notes for this diesel tank.

3.3.7 Complex Design Elements

Complex design elements are combinations of simple design elements that should be considered together as a package. Complex design options are alternative configurations which reflect dependencies between these simple design elements that would be used together by considering them as a single package.

The simple elements within a complex element have a baseline specification and allowable specifications just as described in 3.3.6 Simple Design Elements. The application creates "Realizations" of the complex element based on the variability of the simple elements within it. It is these realizations that are the choices the optimizer uses.

It is important when creating complex design options that allowable specifications for all the simple design elements in the option are reasonable. Issues can arise when simple design element options within a complex design option are incompatible. Most commonly this occurs when a simple design element has one of its allowable specifications set to the "No ****" option. For example, in the power plant complex option as seen in Figure 23, if we allow the transformer in the powerplant to have an allowable specification of "No Transformer". one of our complex design options will have all the equipment for the power plant except for the transformer which in this case is not a reasonable result. See Figure 40 below for a display of this troublesome realization.

Please note that when a complex design option is created within MDT an "empty" realization is automatically created which involves a null selection for all the simple design elements within the complex design option so it is often not necessary to include the null specification in any of the allowable specifications of the equipment.

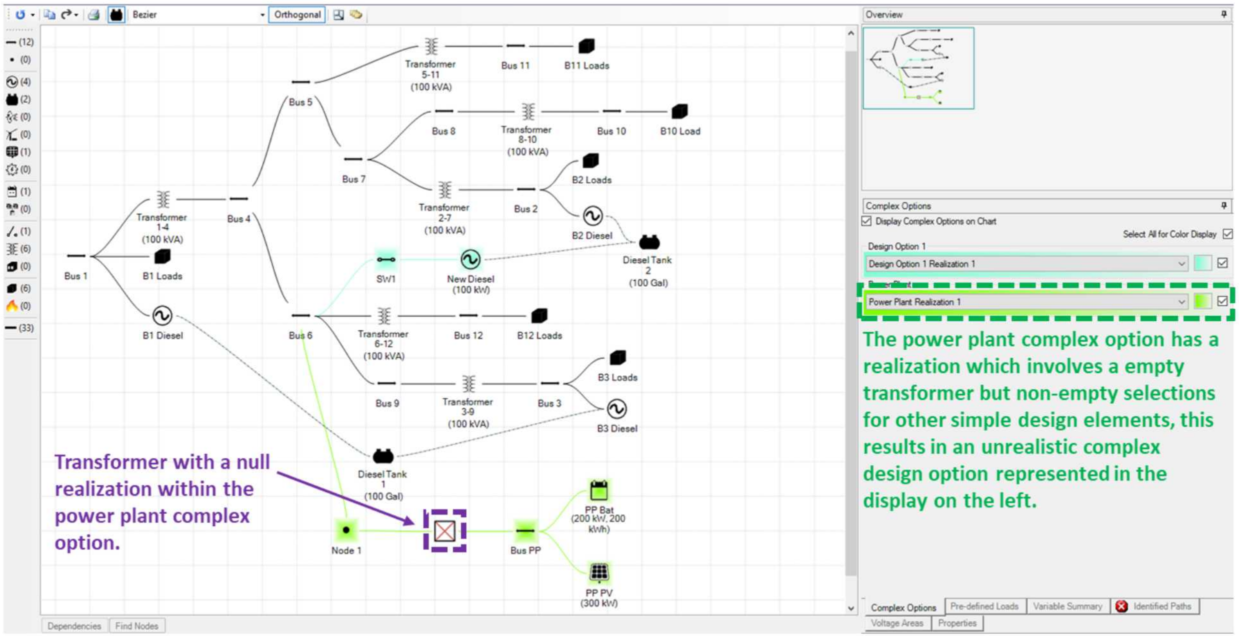


Figure 40. Faulty Realization of a Complex Design Option

3.3.7.1 Visual Complex Design Element Creation

The easiest way to create a complex design option is to create simple elements (3.3.1.1 Overview), then turn a set of them into a complex option. This can be done by selecting the simple elements you'd like to turn into a complex option, right clicking on any of the selected objects, and choosing *Make Complex Option* from the pop-up menu. Once created visually, this complex option can then be further refined and edited via the tabular design process as seen in the subsequent section 3.3.7.2 Tabular Complex Design Element Creation and Defining

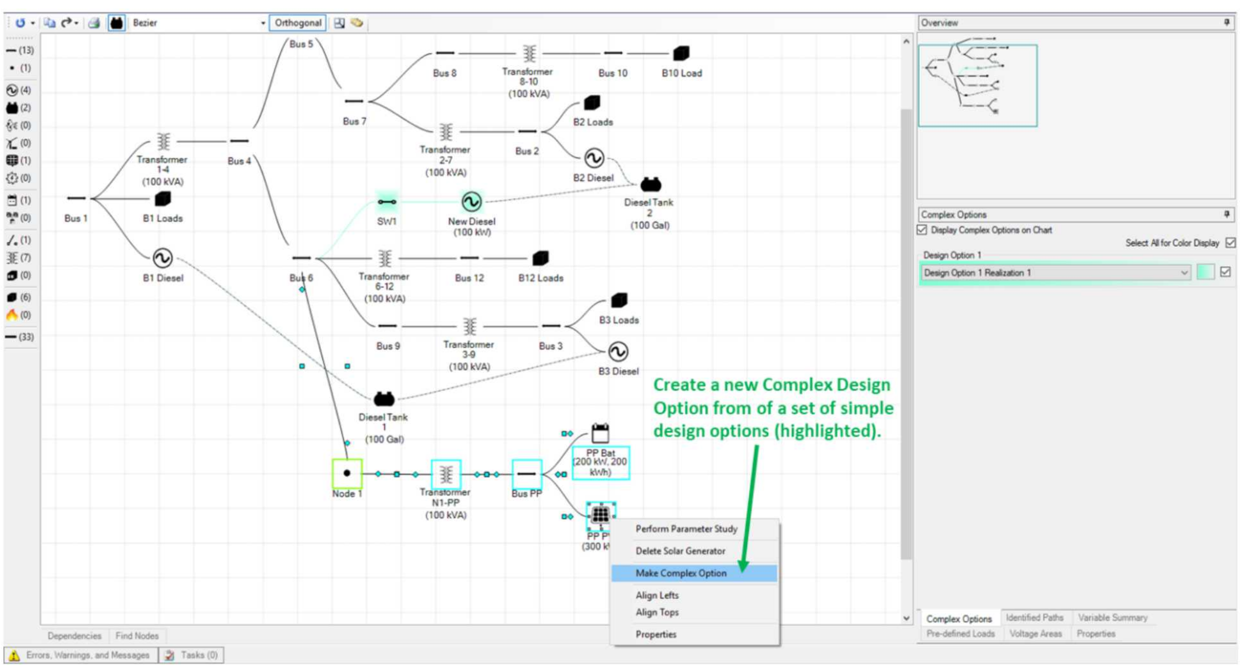


Figure 41. Visual creation of a complex design element.

3.3.7.2 Tabular Complex Design Element Creation and Defining

To create a new complex design option via tabular input, on the Microgrids window, go to the Complex Design Elements -> Design Options section of the Inputs tab. It is often easier to create the complex design element within the microgrid diagram by combining simple elements, see Figure 41 Once created, enter the following information in the table to define your design option, accessed by the Microgrid view and selecting the complex design elements tab, see Figure 42. Required fields are displayed in bold font.

- **Name** – Name for this design option.
- Enumerated Size – The computational size of this design option when fully enumerated out. This is based on the number of decision variables included in the design option. This field is calculated by the tool and is not editable.
- **Realizations** – Realizations reflect the enumerated possible design combinations given the variable features of the design option. This field is generated by the tool. To view and reduce the allowable realizations, click the "View/Edit" button. See section 3.3.7.4 Realizations for more details.
- Notes – User supplied notes for this design option.

A complex design option has all the same element fields as the simple design element section. The different input forms (highlighted in green in Figure 42) are accessible via tabs located at the bottom of the Design Options screen (highlighted in purple in Figure 42). If there is more than one design option listed in the table, click on the row of a design option to view its elements.

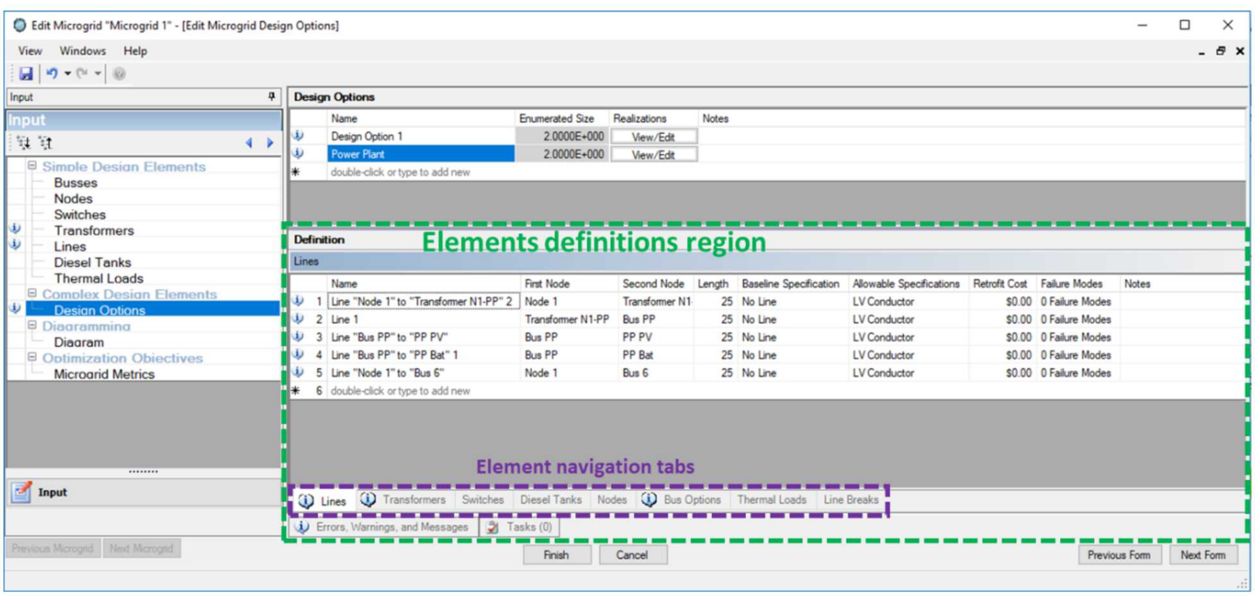


Figure 42. Complex Design Elements navigation.

3.3.7.3 Enumerated Size

This integer reflects the size of this design option when fully enumerated. This value accounts for any realizations that have been de-selected using View/Edit.

3.3.7.4 Realizations

Realizations reflect the enumerated possible design combinations given the variable features of the design option. Click on "View/Edit" to view and select the realizations that you would like included in the analysis. Reducing the number of realizations is desirable in order to limit unnecessary computation. For example, if there are 3 places on the same bus where a battery of common size might go, there could be realizations which differ from each other only in the placement of fewer than 3 of those batteries on the bus. If this difference is not meaningful in terms of the design (which it likely is not), then there could be many unnecessary realizations that the model will consider. Eliminating the "duplicate" realizations that do not differ in a meaningful way can improve run time of the model and make results more useful.

3.3.7.5 Lines

Please see the Lines section under 3.3.6 Simple Design Elements for description.

3.3.7.6 Transformers

Please see the Transformers section under 3.3.6 Simple Design Elements for description.

3.3.7.7 Switches

Please see the Switches section under 3.3.6 Simple Design Elements for description.

3.3.7.8 Diesel Tanks

Please see the Diesel Tanks section under 3.3.6 Simple Design Elements for description.

3.3.7.9 Nodes

Please see the Nodes section under 3.3.6 Simple Design Elements for description.

3.3.7.10 Bus Options

It is important to know the difference between a bus and a node. In a one-line diagram, the node is a simple junction point where two lines meet. A bus can have elements attached to it (loads, generators, etc.). A bus option can apply to an existing bus (defined under Simple Design Elements) or a new bus can be created.

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Double click in the Name field. Select an existing bus or click "Create New and Close." Either selection will auto-populate the Bus field (below). Type in a name for this bus option.
- **Bus** – If you selected an existing bus above, this field will be populated with that bus. If you created a new option above, a default bus name is provided, but you can rename it.
- Enumerated Size – The size of this bus option when fully enumerated out. This is based on the number of decision variables included in the bus option. This field is calculated by the tool and is not editable.
- Notes – User supplied notes for this bus option.

Click on the Bus Options row to begin adding elements (highlighted in blue in Figure 43). The different input form (highlighted in green in Figure 43) are accessible via tabs located on the bottom of the screen (highlighted in purple in Figure 43).

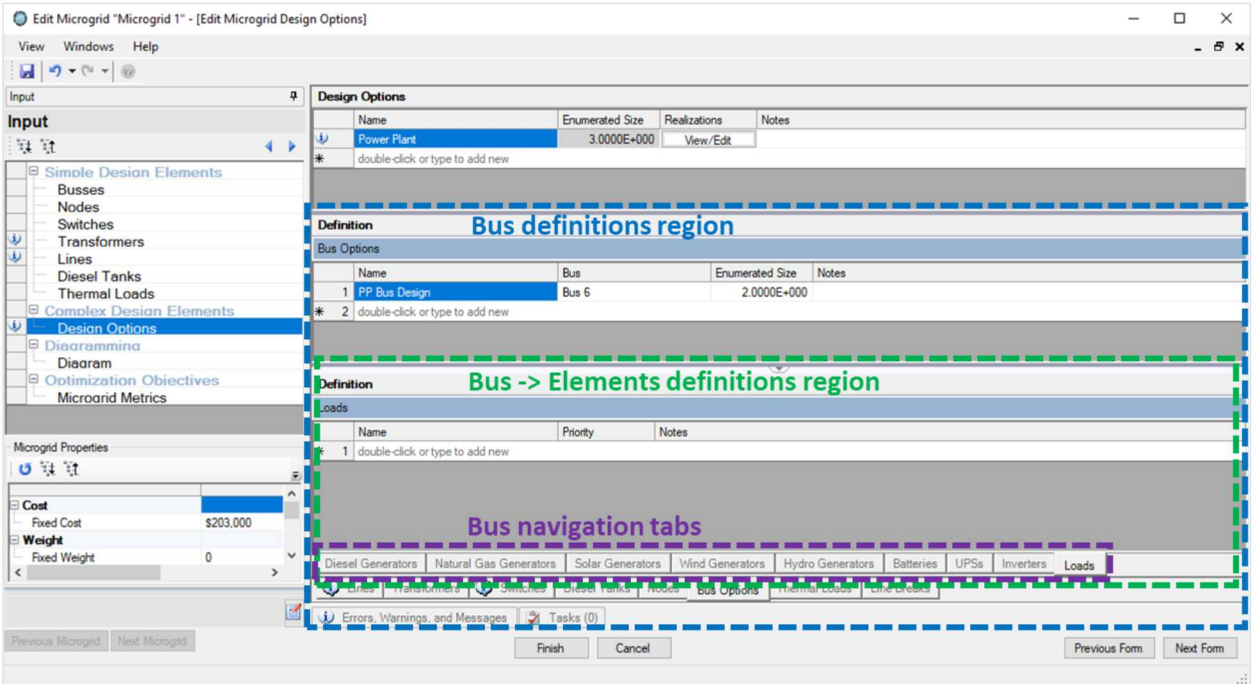


Figure 43. Complex Design Elements -> Bus Options page overview.

A bus option has all the same elements as a Simple Design Element bus. Please see the Busses section under 3.3.6 Simple Design Elements for element descriptions:

- Electrical Loads – Click in the Name field. Click the ellipses button (highlighted in purple in Figure 44). A new window will open. Define the loads and add load data to the load section. When you have completed entering information about busses, click the “OK” button at the bottom of the screen to close the window.
- Diesel Generators
- Natural Gas Generators
- Solar Generators
- Wind Generators
- Hydro Generators
- Batteries
- Uninterruptible Power Supplies (UPS)
- Inverters

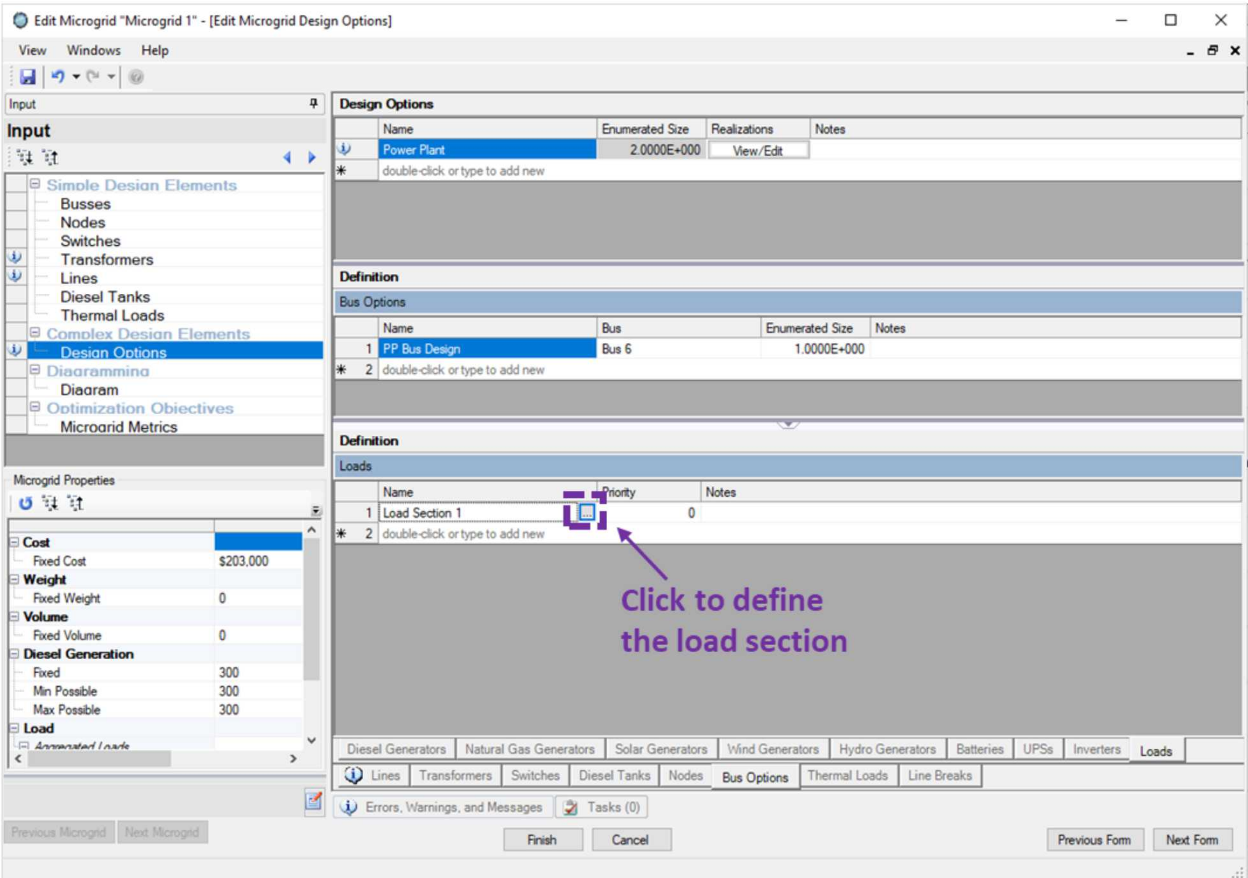


Figure 44. Click the button next to a load section name to define it.

3.3.7.11 Line Breaks

A line break describes where a node may be inserted into an existing part of the microgrid (defined under Simple Design Elements). To insert the new node, an existing line may need to be broken so that a junction can be inserted and run out to the new node, bus, or asset.

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name**- Name for this line break.
- **Node** – Select the new node to be inserted into the microgrid.
- **Line** – Select the line to be broken. This field is populated by the lines created under Simple Design Elements.
- **Distance (ft)** – The distance from the new node to the first node of the broken line. Distance is used for computing cost, weight, and volume.
- Notes – User supplied notes for this line break.

3.3.8 Diagramming

The diagram allows you to view the topology of your microgrid. This diagram tool is the same as the one that appears on the Microgrids Site Definition page. See section 3.3.1 Diagramming a Microgrid for instructions.

3.3.9 Microgrid Metrics

The MDT optimization objectives are made up of metrics which are numerical measures of microgrid performance. Metrics however do not have to be attached to the optimization as objectives and can just be measured/recorded for the microgrid. Additional information about how to use metrics within the optimization is in the following sections.

Microgrid performance and cost metrics are predefined in MDT. In this section, you can define which metrics to include in your analysis and set the optimization limit and objective values. By default, the following metric is included, but this can be removed:

- Purchase Cost

Each metrics section has two columns: Available Metrics and Chosen Metrics.

- **To add a metric:** Double click on a metric in the Available Metrics column. This metric will then appear in the Chosen Metrics column.
- **To remove a metric:** Click on the row number of the metric you would like to remove in either the chosen metric section or the summary of metrics. Press the “Delete” button on your keyboard.

To include a metric in your analysis, it must appear in the Chosen Metrics column.

To exclude a metric from your analysis,

- Remove it from the Chosen Metrics column.
  or
- Uncheck the “Selected” checkbox. This allows you to ignore a metric without removing it and losing its information (limit, objective, relative importance, etc.).

To include a metric in your analysis, but exclude it from impacting the optimization (i.e. a metric that is not an objective):

- Set the “Relative Importance” to 0. This metric will still be computed and reported, but it will have no impact on the optimization. If the limit of this metric is violated, it will NOT cause a configuration to be flagged as infeasible.
  or
- Do not add the metric to a Response Function Group (see section 3.5.2 Response Groups). This metric will still be computed and reported, but it will have no impact on the optimization. If the limit of this metric is violated, it WILL cause a configuration to be flagged as infeasible.

Once a metric is added to the chosen metric section some parameters (fields) will need to be filled in so that MDT knows how to interpret this metric for optimization. The following fields are required for every metric regardless of which available metric it comes from, note here that some of these will require additional inputs specified in the subsections below.

Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Modify the metric name if needed.
- **Selected** – If checked, this metric will be computed. Otherwise, this metric will not be computed. This allows you to ignore a metric without removing it and losing its information (limit, objective, relative importance).
- Units – The units that describe the value of this metric.
- **Limit** – The value that this metric must achieve in the optimization. This is the worst acceptable value.
- **Objective** – The value that would be nice to achieve in the optimization. Values beyond the objective are not as valuable (point of diminishing returns).
- **Relative Importance**
    - The importance of this metric in comparison to the other metrics included in the analysis. This can be any non-negative real number. Note that importance values will not necessarily have a linear relationship because they are applied to a normalized metric value. The relative importance values reflect an interval relationship of priority between metrics.
    - If set to 0: This metric will be computed and reported, but it will have no impact on the optimization. If the limit of this metric is violated, it will not cause a configuration to be flagged as infeasible.
- **Limit Stiffness** – By default, Medium is selected. Selecting Hard means the model must meet the Limit value if possible, and will sacrifice any amount of performance to obtain this limit; the limit is a hard constraint. If any or all metrics are set to Hard, the model may not be able to find a valid configuration but it will report the solution that it found to be the least egregious.
- **Improvement Type** – For each metric MDT will automatically select the improvement type based on the metric (cost is minimized, energy availability is maximized, etc.) but you may change it if necessary. Selecting an odd improvement type for a metric will result in a warning but not an error (i.e. maximize cost).
    - Minimize – The model will minimize the metric value. The Objective value should be less than the Limit value.
    - Maximize – The model will maximize the metric value. The Objective value should be greater than the Limit value.
    - Seek Value – Seek value will try to come as close as possible to a value set by the user. The value being sought should be entered as the Objective. The limit entered by the user will be “mirrored” on the other side of the objective to create bounds. For example, an objective of 2000 with a limit of 1000 will generate another limit of 3000 that gets used by the model.

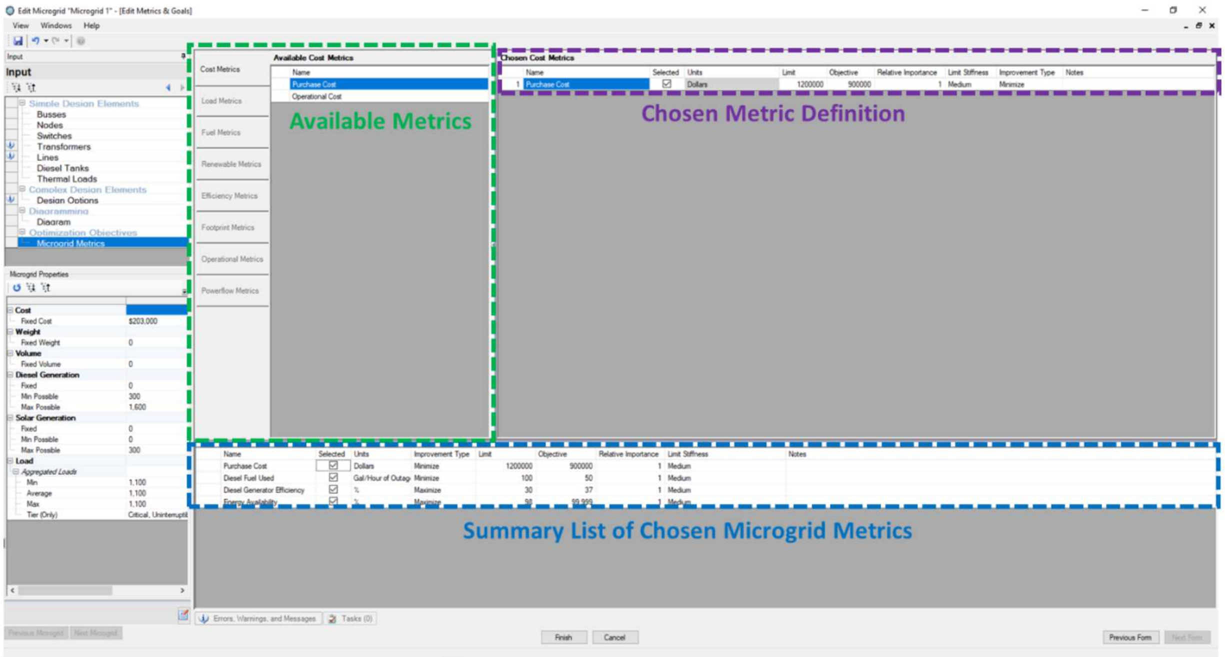


Figure 45. Microgrid Metrics

3.3.9.1 Cost Metrics

3.3.9.1.1 Purchase cost

Each specification for every variable asset has a cost value. For any given candidate configuration, the cost values for all specifications of all chosen assets are added to the total. Therefore, the costs of only variable assets and components are added to the total. Fixed assets (those with only one specification) do not tally into the total purchase cost.

3.3.9.1.2 Operational cost

Each specification for most variable asset types has an operational cost value. An exception is the diesel tank asset. Operational cost values are expressed in $/hour of usage for asset types. For any given candidate configuration, the usage statistics are computed and used to tally the total operational cost for the system.

3.3.9.2 Load Metrics

Additional fields are required for Load metrics. Required fields are displayed in bold font. Default values are provided for all fields, some of which may be empty fields or no value.

- **Load Tier** – Select the load tier for this metric. Create or choose a separate metric for each load tier of interest. MDT necessitates that if the following available load metrics are chosen more than once they have different load tiers corresponding to loads within the microgrid listing.
- **Phase** – The simulation phase to which to apply this metric.

3.3.9.2.1 Magnitude of LNS

The magnitude of Load Not Served (LNS) metric applies to a specific tier of load. A separate metric can be defined for each tier. The value is the total LNS for the tier divided by the total amount of time for all utility outages for which any load of the specified tier went unserved. As such, it discounts any time for outages in which the tier of load was fully served for the entire duration. Its units are in kWh/hour of outage (where outage refers to utility outages).

3.3.9.2.2 Frequency of LNS

The frequency of LNS metric applies to a specific tier of load. A separate metric can be defined for each tier. It is the percentage of outages that suffered some amount of LNS for the specified tier in the normal microgrid operations mode. Therefore, it discounts any tier level LNS that occurred during the microgrid startup phase. Its units are %.

3.3.9.2.3 Energy Availability

The Energy Availability metric applies to a specific tier of load. A separate metric can be defined for each tier. It is the percentage of all post-startup load that was served for the specified tier. Therefore, it discounts any tier level LNS that occurred during the microgrid startup phase. Its units are %.

3.3.9.3 Fuel Metrics

3.3.9.3.1 Diesel Fuel Used

The instantaneous diesel fuel usage rate is a function of the current utilization rate of a generator. Each generator's fuel utilization curve is provided in units of Gallons/kW/hr and consists of four values: the fuel usage rate with the generator loaded at 0% (idle), 25%, 50%, 75%, and 100%. Values for utilization rates in between those percentages are interpolated. Thus, a generator operating at 50% utilization will use the amount of fuel indicated by the utilization curve value for 50%. The total fuel used for that generator is the integrated usage rate over all runtime. The total fuel used for the system is the sum of all generator fuel usage. This value is reported as an average over the total time of utility power outage (Gallons/hour of outage). Because the PRM will simulate over many outages whose durations may be variable, reporting a value in units of "Gallons/utility outage" would be dubious.

3.3.9.3.2 Natural Gas Used

Natural gas used is computed the same way as diesel fuel used, except that the units are Million BTUs/W/hr.

3.3.9.4 Renewable Metrics

3.3.9.4.1 Average Renewable Penetration

The instantaneous Renewable Penetration is the ratio of total power provided by renewables (wind, solar PV and hydro in the MDT) to the total load served. Average renewable penetration is the instantaneous penetration integrated over time and divided by the total time.

3.3.9.4.2 Average Energy Supplied by Renewables

The average energy supplied by renewables (wind, solar PV and hydro in the MDT) to the total load. At all times in the simulation, the amount of the current total load being supplied by renewable resources is tallied (in kW). That quantity integrated over the full time of the simulation gives the overall average for energy supplied by renewables (kWh).

3.3.9.4.3 Average Renewable Energy Spilled

The average renewable energy spilled is the total amount of renewable energy that was generated but that could not be used due to of lack of demand. This represents the amount that had to be curtailed.

3.3.9.5 Efficiency Metrics

3.3.9.5.1 Diesel Generator Efficiency

The instantaneous diesel generator efficiency is a function of the current running rate (utilization rate) of the generator. Each generator's efficiency curve is provided in units of % and consists of four values: the efficiency with the generator loaded at 0% (idle), 25%, 50%, 75%, and 100%. Values for utilization rates in between those percentages are interpolated. Thus, a generator operating at 50% utilization will operate at the efficiency level indicated by the utilization curve value for 50%. The average efficiency for that generator is the integrated efficiency over all runtime divided by total runtime. The total efficiency for the system is the time integrated efficiency of all generators divided by the total runtime of all generators. The units are %.

3.3.9.5.2 Diesel Generator Utilization

The average utilization for a generator is the integrated utilization rate over all runtime divided by total runtime. The total utilization for the system is the time integrated utilization of all generators divided by the total runtime of all generators. The units are %.

3.3.9.5.3 Natural Gas Generator Efficiency

Natural gas efficiency is computed the same way as diesel fuel efficiency.

3.3.9.5.4 Natural Gas Generator Utilization

The average utilization for a generator is the integrated utilization rate over all runtime divided by total runtime. The total utilization for the system is the time integrated utilization of all generators divided by the total runtime of all generators. The units are %.

3.3.9.6 Footprint Metrics

3.3.9.6.1 Volume

Each specification for every variable asset can be given a volume value. For any given candidate configuration, the volume values for all specifications of all chosen assets are added to the total. Therefore, the volumes of only variable assets and components are added to the total. Fixed assets (those with only one specification) do not tally into the total volume.

3.3.9.6.2 Weight

Each specification for every variable asset can be given a weight value. For any given candidate configuration, the weight values for all specifications of all chosen assets are added to the total. Therefore, the weights of only variable assets and components are added to the total. Fixed assets (those with only one specification) do not tally into the total weight.

3.3.9.7 Operational Metrics

3.3.9.7.1 Spinning Reserve – Average Percentage

A desired spinning reserve percentage is entered as part of the microgrid definition (See section 3.3 Microgrids). However, this is only a target for the simulation. The simulation may not be able to respect the requested value. If it cannot be respected, you may wish to use that information to disadvantage the solution in favor of solutions for which it can be respected. This metric allows one to do that.

3.3.9.7.2 Fossil-Off Time Percentage

For system in which it is both possible and allowed, this metric allows the designer to favor designs that meet specified goals for the amount of time the system operates without using any fossil generation. This is typically accomplished through a combination of the use of renewables and storage. In order for fossil off time to occur with good probability, the microgrid setting for the minimum allowable fossil generators should be set to 0.

3.3.9.8 Powerflow Metrics

3.3.9.8.1 Average Overload Duration

The average duration of overload periods for all capacity limited assets in the grid. Whenever conditions are such that a capacity limited asset is overloaded, the total duration of the overload, regardless of magnitude, is tracked and tallied. This is an overall measure and gives no indication of magnitude or specific asset.

3.3.9.8.2 Maximum Overload Duration

The maximum duration of any overload periods for all capacity limited assets in the grid. Whenever conditions are such that a capacity limited asset is overloaded, the total duration of the overload, regardless of magnitude, is tracked and tallied. This is an overall measure and gives no indication of magnitude or specific asset.

3.4 Islanded Simulator Settings

Islanded simulator settings are used by the Performance Reliability Model (PRM) portion of MDT.

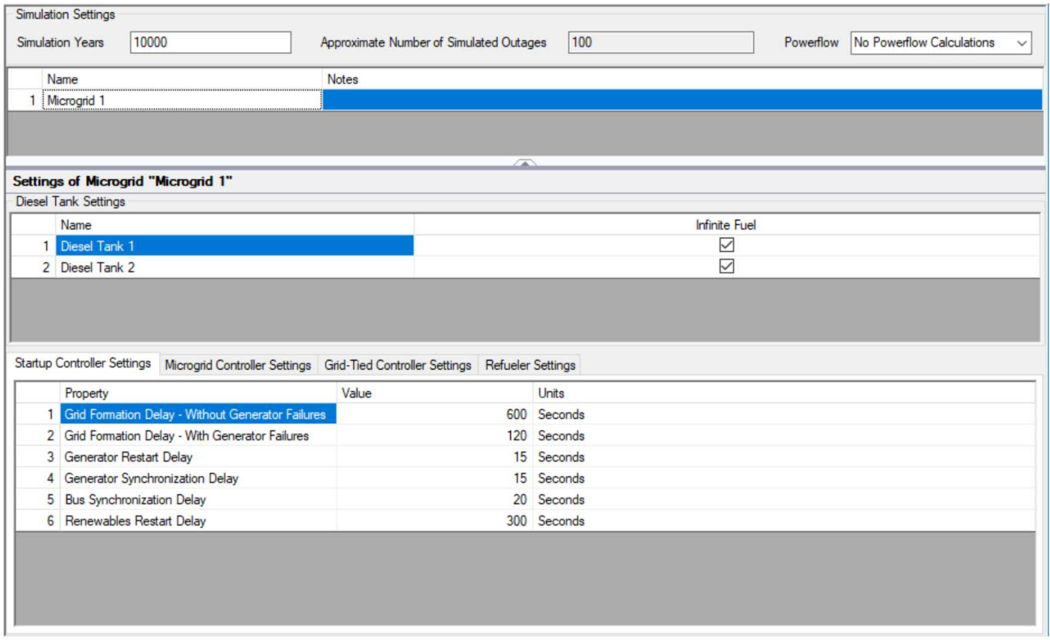


Figure 46. Islanded Simulator Settings screen.

3.4.1 Simulation Settings

The simulation settings (Figure 46) control some aspects of the PRM.

- **Simulation years** – This sets the number of simulation years that the simulation will run each time it is executed. If, for example, the user would like 1000 outage replications for an outage that occurs approximately once per year, they would set simulation years to 1000. The total simulation years must be sufficiently long that, based on the MTBF and MTTR values of all failure modes of the utility, the desired number of outages are expected to occur.
- Approximate Number of Simulated Outages – This is computed based on the simulation years and the failure statistics of the local utility as described in section 3.2.1 Settings.
- **Powerflow** – Select whether powerflow calculations will be part of the MDT islanded simulator, please note here that having powerflow calculations will necessitate powerflow specifications for microgrid equipment (such as voltages, resistances, etc.). Currently only DC powerflow is enabled for the MDT islanded simulator. See section *3.3.3 Microgrid Powerflow Calculations* for more details.
- **Name** – the name of the microgrid(s) being analyzed. This table is auto-populated based on the microgrids created under Microgrids -> Listing.
- Notes – notes about the microgrid.

3.4.2 Settings of the Microgrid

The microgrid simulation settings control some aspects of the islanded operations simulator which are specific to each microgrid. First, select a microgrid from the table at the top of the page (if there is more than one). Next, enter the following information about the selected microgrid:

- **Diesel Tank Settings** – For each diesel tank named, there is a checkbox provided where the user can select whether to use an "infinite fuel" assumption.
  - **Infinite fuel** – If checked, the simulator will allow the diesel tank to use whatever fuel it needs during the simulation, as though it had infinite supply. The amount used will still be tracked by the simulator. This mode should be checked when the user would like to know how much fuel will be required, but does not want availability of fuel for the generators to be a limiting factor in the analysis. Note that when multiple fuel tank specifications have been provided as options but infinite fuel is checked, the model will ignore varying tank sizes but still take into account differences in cost. This will likely result in the model always selecting the least expensive specification, since cost is the only discriminator.
- **Startup Controller Settings** – These settings allow to user to modify some information about startup delays that occur when the microgrid enters islanded mode at the start of any simulated utility outage.
  - **Property** – This is a description of the type of delay.
    - **Grid Formation Delay – Without Generator Failures**
      One of the first things the startup controller does at the onset of an outage is to start all backup generators. Some may fail to start. This delay is in place to avoid attempting to form the microgrid for very short outages. This is employed if all backup generators start properly.
    - **Grid Formation Delay – With Generator Failures**
      This delay is similar to the Grid Formation Delay – Without Generator Failures except that it is employed if one or more of the backup generators failed to start. In that case, there may be critical load at high risk and waiting a shorter time to form the microgrid may reduce that risk.
    - **Generator Restart Delay**
      This is the amount of time that the controller waits before attempting to restart a generator that failed to start. The number of restart attempts and the likelihood of each one succeeding are defined as part of the generator's specification.
    - **Generator Synchronization Delay**
      This is the amount of time that it takes to synchronize a generator onto an energized bus.
    - **Bus Synchronization Delay**
      This is the amount of time it takes to synchronize two energized busses together.
    - **Renewables Restart Delay**
      This is the amount of time the controller will wait once the microgrid is fully formed to re-attach any renewables that were disconnected at the onset of the outage.
  - **Value** – the number of units of delay.
  - **Units** – the units associated with the delay (for example, seconds).
- **Microgrid Controller Settings** – These settings allow to user to modify some information that impacts the simulation during islanded mode. A full description of the workings of the microgrid controllers is out of scope for this document. However, as much information is needed to help one make a selection of different controller types is given where appropriate.
  - **Controller** – This is selected from the drop-down menu above the property sections, note that all subsequent fields are the same for either controller. The only difference

between the two selections is in how the batteries are dispatched. The discussion of each will describe how they differ.

- **Standard Microgrid Controller**
  The standard microgrid controller treats batteries as a source of last resort. If once all other assets are dispatched to their full output potential there is still not enough power to serve loads, then the batteries are called upon to make up the difference.
  Charging is done if there is excess online generation (solar, wind, or fossil up to the spinning reserve rate).
- **Battery user Microgrid Controller**
  The battery user controller does something like a cycle charging dispatch scheme whereby the battery is used whenever possible to avoid bringing another fossil asset online. This can result in peak shaving, diesel fuel use reduction, and if settings allow, maximized fossil-off runtime. This may come at the cost of additional wear-and-tear on the battery.
  Charging is done similarly to the standard controller.

- **Property** – This is a description of the type of delay, duration, or demand requirement.
  - **Generator Restart Delay**
    This is the amount of time that the controller waits before attempting to restart a generator that failed to start. The number of restart attempts and the likelihood of each one succeeding are defined as part of the generator's specification.
  - **Generator Synchronization Delay**
    This is the amount of time that it takes to synchronize a generator onto an energized bus.
  - **Bus Synchronization Delay**
    This is the amount of time it takes to synchronize two energized busses together.
  - **Forecast Duration for Generator Dispatch**
    When attempting to dispatch generators, the MG controller may forecast expected load over some length of time in order to do so more effectively. This parameter defines that length of time. It generally makes sense to be aware of the discretization of loads when setting this parameter.
  - **Minimum Power Demand Before Dispatch**
    This value is the percentage of online spinning generation capacity below which the controller should consider a re-dispatch of generation assets.
- **Value** – the number of units of delay.
- **Units** – the units associated with the delay (for example, seconds or %).

- **Grid-Tied Controller Settings** – If the *Track All Features* box is unchecked, then the failure modes are ignored for all equipment during periods of grid-tied operation. There are eight additional boxes which allow the user to further specify specific failure modes to ignore within the microgrid including failures for Lines, Transformers, Switches, Solar Generators, Wind Generators, Hydro Generators, Batteries, UPS and Inverters.

  To ignore a failure mode means to "pause" the accumulation of failure time. For example, consider ignoring line failures. The line may have been operating for 20 hours since its last repair, and it may have 10 more hours before the next failure when an outage ends (bulk grid returns to operation). The failure time accumulation will remain at 20 hours throughout the period of bulk grid operability and then start accumulating against the remaining 10 hours when the next grid failure (outage) occurs. Note that repairs are not ignored. If an asset failed when the grid-tied operation begins (or resumes), it will continue to accumulate repair time and be repaired when the time arrives.

- **Refueler Settings** – These settings describe the refueling scheme for the diesel generators (when the infinite fuel assumption is not in use).
  - **Time of Day** – the time of day that the first refueling occurs after the utility outage.
  - **Period** – the hours between each refueling.
  - **Maximum Quantity per Delivery** – The maximum amount of fuel delivered each time a refueling occurs. There is no priority scheme currently included for the order in which generators are refueled when the maximum quantity is not enough to meet fuel demand. The default value of -1 indicates that an unlimited amount of fuel can be delivered at each refueling.

3.5 Solver Settings

3.5.1 Solver Settings

Settings related to the MDT optimization solver are listed below, it is recommended that the default values are used in most cases.

- Name – The name of the solver settings, MDT will automatically create a name for the solver, however, the user can change it to any non-empty string. This input is not used for much of anything in the application and so can be safely left at its default.
- Notes – User input field for notes about the solver settings.
- Random Seed – The random seed is a very useful and important input. The random seed has a strong influence on the progression of the algorithm. It is the seed value provided to the random number generator used by the optimizer. Given a seed, the exact sequence of random numbers is fixed and can be reproduced. Because of this, the random seed input provides a means of exactly reproducing not just a given solution but the path by which it was obtained. The default of 0 is used as a special value to indicate to the optimizer that it should choose a random seed based on the current time and processor clock. Note that if the evaluation concurrency (see below) is greater than 1, results may not be repeatable.
- Evaluation Concurrency – MDT supports the evaluation of multiple microgrid designs simultaneously via multi-threading. The amount by which this quickens the solution process depends strongly on the size of the problem and the number of processors/cores you have available on your machine. This input will default to the total number of "cores" available on your machine which considers the number of processors and the number of cores on each. If you don't wish to "swamp" your computer when running MDT, you may also set it lower although the minimum allowable input is 1.
- History Length – This input controls the maximum number of iterations worth of data that are stored as the algorithm runs. This input can help to control the amount of memory required by MDT which can become important when problem size gets large. For example, if this input is set

to 20, only the data for the 20 most recent iterations will be available, plotted on Progress Plots, and browsable in the "Summary" Form. A value of -1 indicates that all iteration data should be stored. This input must be -1 or greater than 0.

- Print Each Population to a File – This input specifies whether MDT should write a file containing every member of the population at every iteration. This is not checked by default. If checked, you will see many files that look like "population#.dat" appear in the directory of your input file.
- Store all Generated Designs Internally – This input indicates whether MDT should keep an internal record of all designs that it evaluates over the entire solution process. Doing this allows MDT to avoid re-evaluation of previously evaluated designs as well as some other operations having to do with duplication. However, especially for large solution space optimizations, storing all visited solutions can have significant memory ramifications. Therefore, if you are having trouble with memory usage, it is recommended that you uncheck this option.
- Logging Level – This input controls the amount of information written into the MDT Log Files when the optimizer is run. The default setting is equal to the "Normal" level. The entries in the drop-down list are in order of decreasing verbosity. This input is especially useful if you are running into trouble with MDT. In that case, increasing the logging level to its maximum setting ("Debug") can help determine what the issue is in some cases.
- Log File – This field shows the name of the log file to which the algorithm will write complete with path. This field is not editable. It is there only for reference.
- Initial Population Size – Algorithms such as those used by the MDT operate by keeping a "population" of candidate solutions at all times. This input allows you to control the initial size of the population. The actual size may change as the algorithm runs. This input is also very important to the outcome of the optimization. The population size is a control that has a strong influence on the amount of both exploration and exploitation that takes place. In general, this value should range from ~100 to ~1000 with larger values being better suited to large solution spaces.

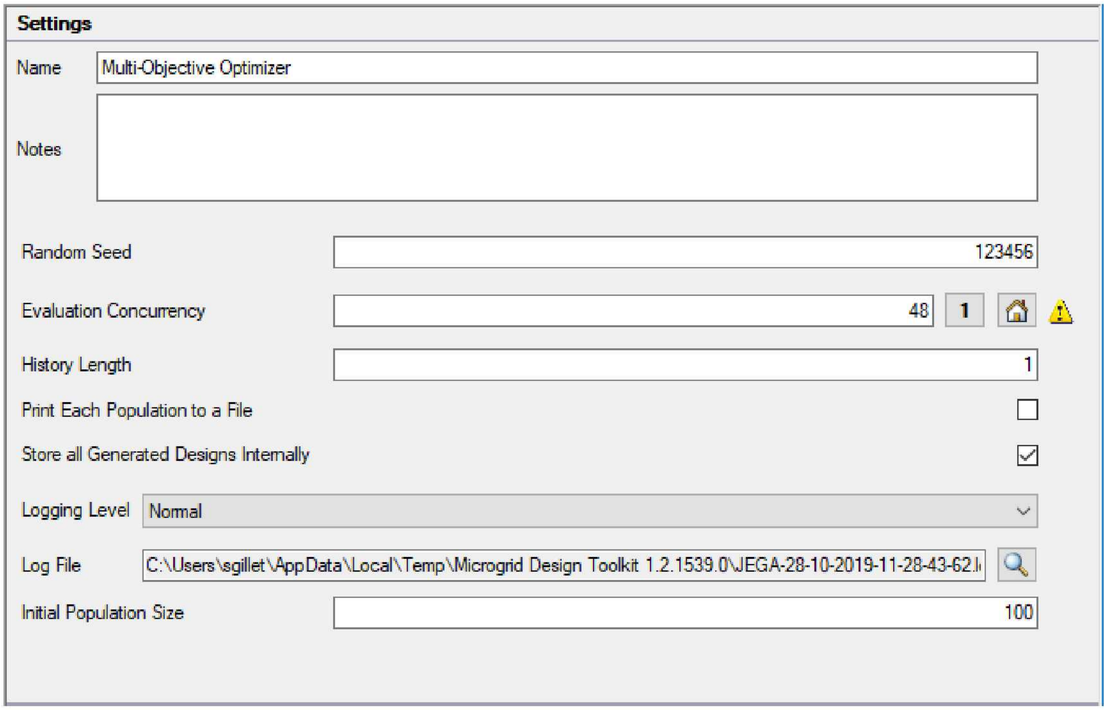


Figure 47. Solver Settings

3.5.2 Response Groups

Microgrid metrics (Response Functions) must be added to a Response Function Group if you want them to be included in the optimization.

If you do not add the metric to a Response Function Group, this metric will still be computed and reported, but it will have no impact on the optimization. If the limit of this metric is violated, it WILL cause a configuration to be flagged as infeasible.

Please see 3.3.9 Microgrid Metrics for additional methods for excluding metrics from analysis calculations.

Creating Response Function Groups

1. In the Response Function Groups list, create one or more groups.
    a. Type in a Name in an empty row. Add notes about the group (optional).
2. Add metrics (Response Functions) to each group.
    a. In the Response Function Groups list, click on the row number to select a group.
    b. All metrics defined under 3.3.9 Microgrid Metrics are presented in the Unused Response Functions list.
    c. In the Unused Response Functions list, click on the row number of a metric to select it.
    d. Click the left arrow button to add the metric to the group (Figure 48).
    e. The metric should now appear in the Response Functions list.
    f. Add additional metrics to the group, if applicable.

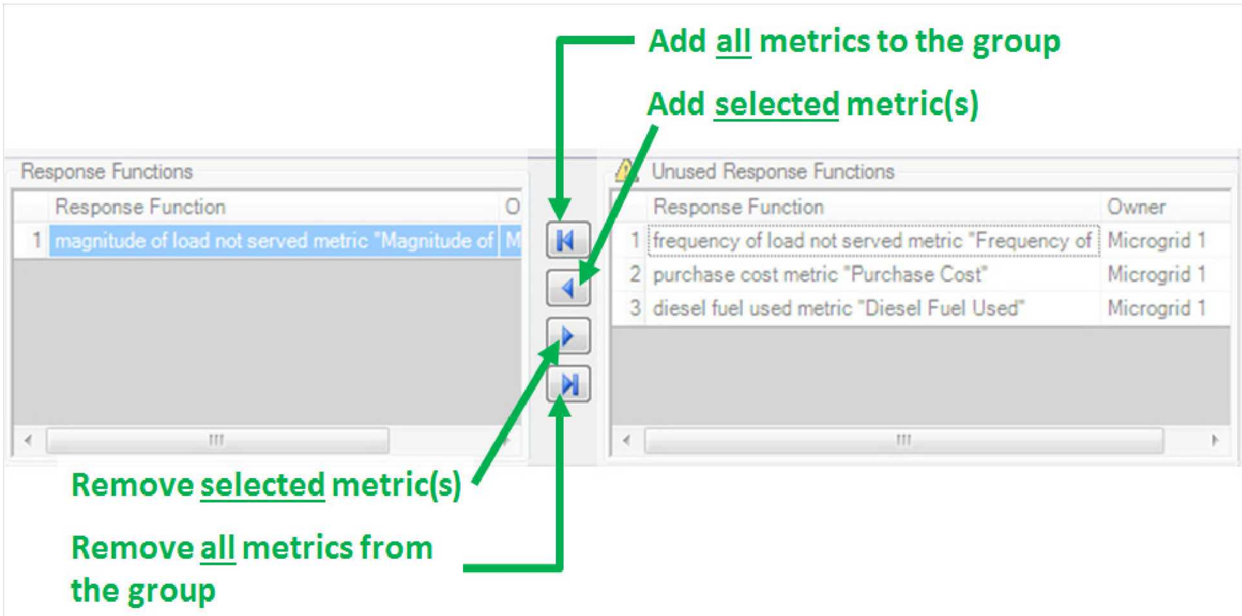


Figure 48. Adding and removing metrics from Response Function Groups.

3. Review the metrics in each group (Figure 49, Figure 50).
    a. In the Response Function Groups list, click on the row number to select a group.
    b. The Response Functions list displays the metrics in the selected group.

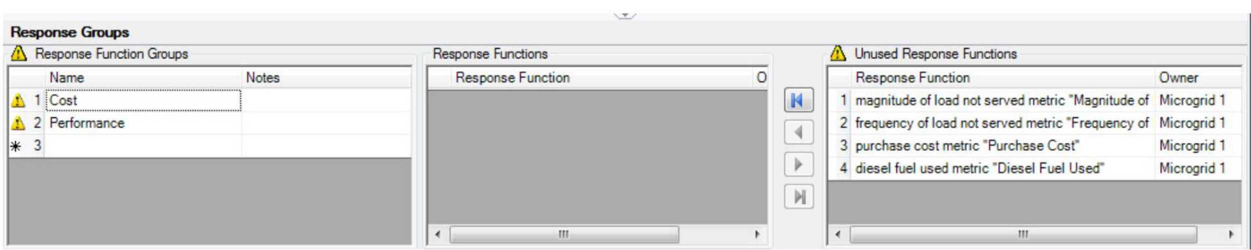


Figure 49. The "Cost" Response Function Group is empty. It contains no metrics.

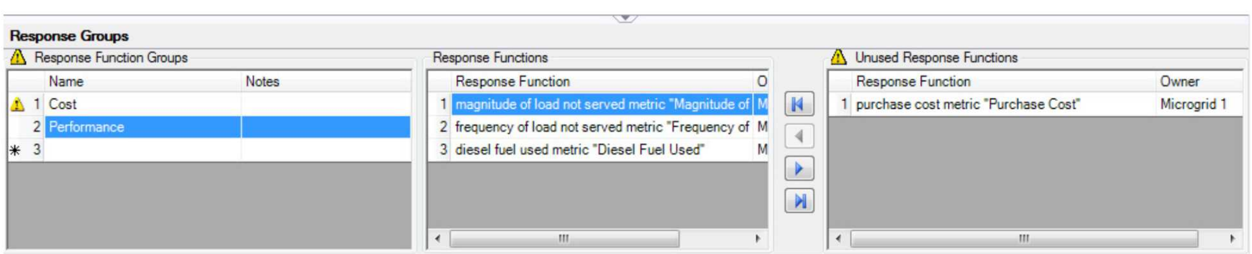


Figure 50. The "Performance" Response Function Group contains three metrics.

Modifying Response Function Groups

- Remove a metric from a group.
    1. In the Response Function Groups list, click on the row number to select a group.
    2. The Response Functions list displays the metrics in the selected group.
    3. In the Response Functions list, click on the row number of a metric to select it.

4. Click the right arrow button to remove the metric from the group (see Figure 50).
5. The metric should now appear in the Unused Response Functions list.

- Remove a group.
  1. In the Response Function Groups list, click on the row number to select a group.
  2. Press the "Delete" key on your keyboard.
  3. The group should be removed from the list.

3.6 Progress Monitor

The progress monitor allows the user to view various progress indicators while the solver is running. The progress monitor will only appear if the solver runtime is relatively long. There are several possible runtime progress plots, including:

- Response Function Progress Plots
- Fitness Progress Plots
- Feasibility Progress Plots

The available progress plots are shown below (Figure 51).

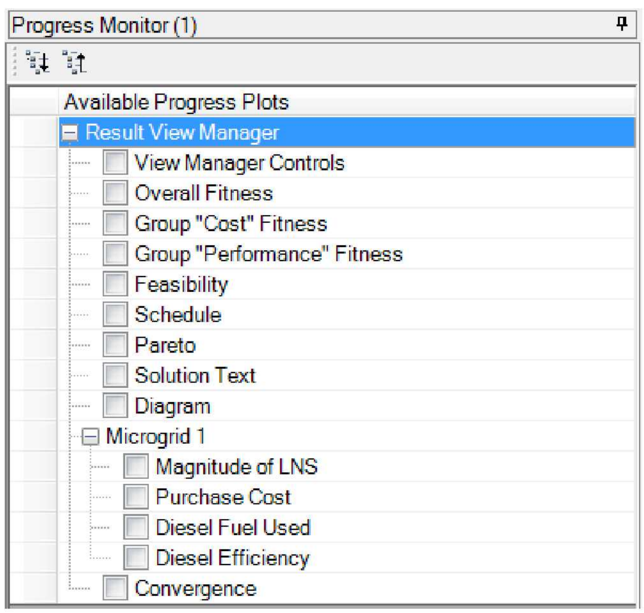


Figure 51. The Progress plots, which are available during lengthy model runs.

To view a progress plot, check the box next to the desired plot. The progress will update in real time as the solver continues to run. These plots can be used to monitor the progress of the solver and potentially even identify problems during the run that may prompt one to cancel, make changes, and try again.

3.7 Results Viewer

The Results Viewer will only be active when the model has run (otherwise there are no results available to view). Previously generated results may also be loaded into MDT (see section 3.7.2 Open Results). The Results Viewer should be thought of as an interactive information visualization tool rather than a simple display of static plots. All plots are interactive. This is because the MDT does not tell you the "right" answer for your microgrid design. Rather, it helps you to explore all the efficient configurations found and understand the design tradeoffs, allowing you to make an informed decision.

All available result windows are listed in the Results Viewer (highlighted in purple in Figure 52). Check the checkboxes of the plots in the Results Viewer to open the windows. (highlighted in green in Figure 52). The primary window is the "Results" window at the bottom of the list. It is displayed automatically when results become available. It is highlighted in green in Figure 52.

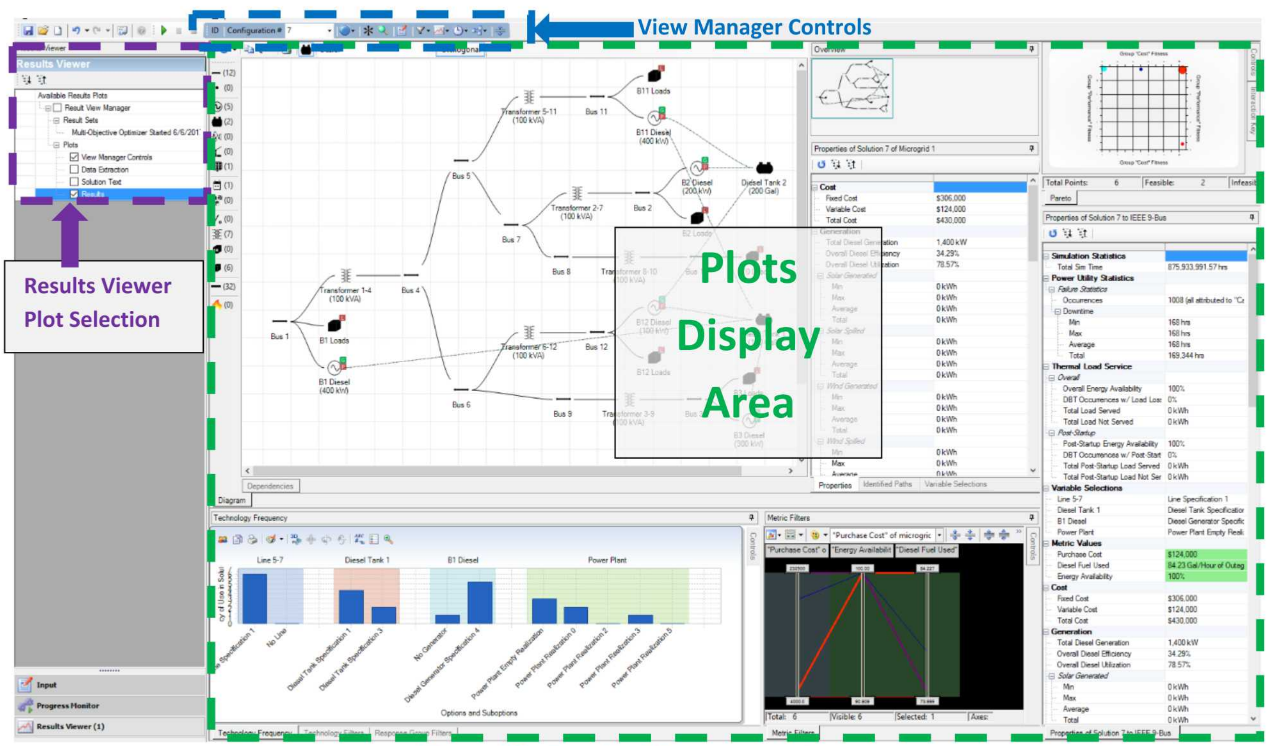


Figure 52. Results Viewer overview.

The main results window contains several views laid out on tab panels. The tabs can be moved around and arranged in different ways. All the views as well as those of other forms are linked. Selecting a configuration or filtering on one view will cause the same configuration and filters to apply to all other views. Since multiple views can be viewed at the same time, this feature becomes useful in ensuring all views are displaying information about the same data set.

Most view images can be copied-and-pasted into other tools. Most have a Controls tab in the upper right corner. Click on the Controls tab, and then click on the Copy icon . Next, paste the image into the application of your choice.

For all views, it is important to understand the following terms:

- All solutions – All configurations, ignoring selections and filters.
- Single solution – A single configuration which is manually selected.
- Selected solutions – A single or multiple configurations which are manually selected.
- Visible solutions – Configurations that meet all visibility filter options that are applied. Filter options could include the feasibility condition, boundary conditions set in the Response Function plots, and specification filters in the Technology Filters plot.

Before describing each of the available windows and views, information on how to save and load results is provided.

3.7.1 Save Results

Results are saved in a file separate from the inputs. MDT results files are saved as *.mof files. You may choose to rename your solution set(s) prior to saving them. To do so, right click on the relevant "Result View Manager" in the left navigation (Figure 53).

1. Select "Rename" from the menu.
2. A new window will open. Type in a new name for your result set.
3. Click "OK."

To save your results,

1. Select the checkbox next to you renamed result set.
2. Go to "Results" in the toolbar.
3. Select "Save Selected."
4. Enter a name for your results set file.
5. Click "Save."

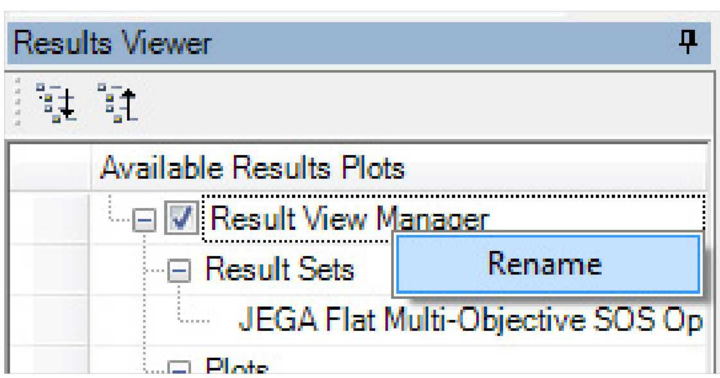


Figure 53. Renaming a result set before saving.

3.7.2 Open Results

To open a previously saved result set,

1. Go to "Results" in the toolbar.
2. Select "Load."
3. Locate your file (which will have file extension *.mof).
4. Click "Open."
5. Go to the Results Viewer tab to view your results.

You can open as many result sets as necessary (Figure 54). They do not have to be related to the current input values. You can view the inputs of any result set at any time by right-clicking on the entries within the "Results Sets" header and choosing "View Input."

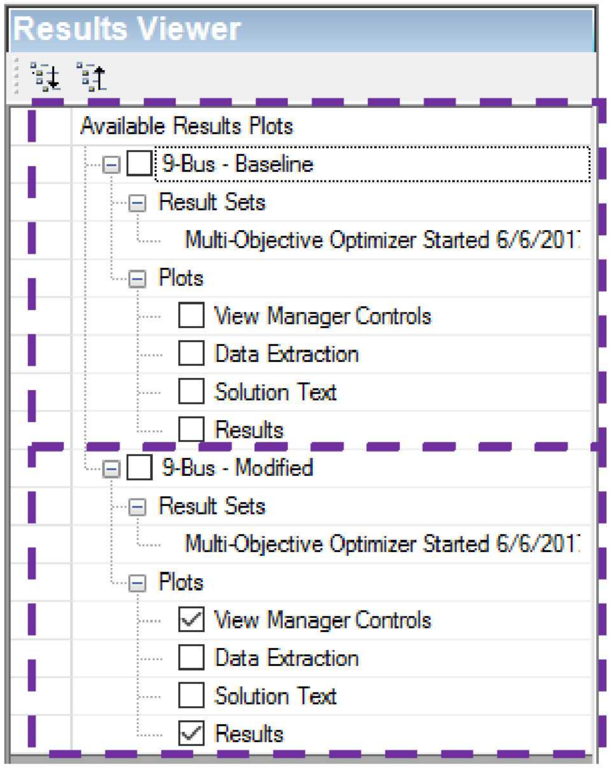


Figure 54. Two different result sets open in the Results Viewer.

3.7.3 View Input for a Result Set

To view the input file for a result set:

1. Locate your result set in the Results Viewer navigation.
2. Under the "Result Sets" header, right click on the solution set previously generated by the solver. (Figure 55).
3. Select "View Input."
4. You will receive a message window: "This capability is strictly for viewing the input of the chosen results. Any changes made will not be stored/propagated back to the results."
5. Click "OK."
6. A new window will open where you can view the inputs related to your result set. While you can edit the fields, you cannot save any changes or run a new analysis from this view.

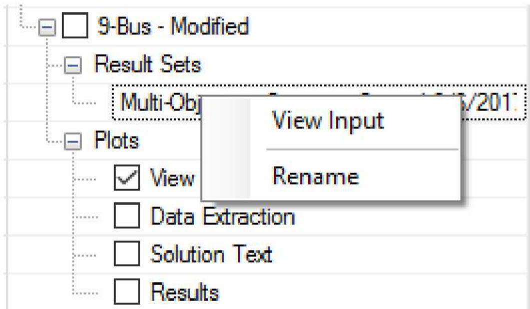


Figure 55. Opening the input set that created this result set.

3.7.4 Close a Result Set

To close a result set:

1. Select the checkbox next to your result set name.
2. Go to "Results" in the toolbar.
3. Select "Remove Selected."
4. The result set should be removed from the Results Viewer navigation.

3.7.5 Manually Create and Save a Solution

Microgrid configurations (solutions) can be created by the user and stored as a result. This is useful for comparing solutions that interest the user to the optimal results from MDT. To get started manually creating a solution select a configuration and then click the Edit Current Solution Manually button in the view manager controls section of the MDT results (see Figure 56 below.)

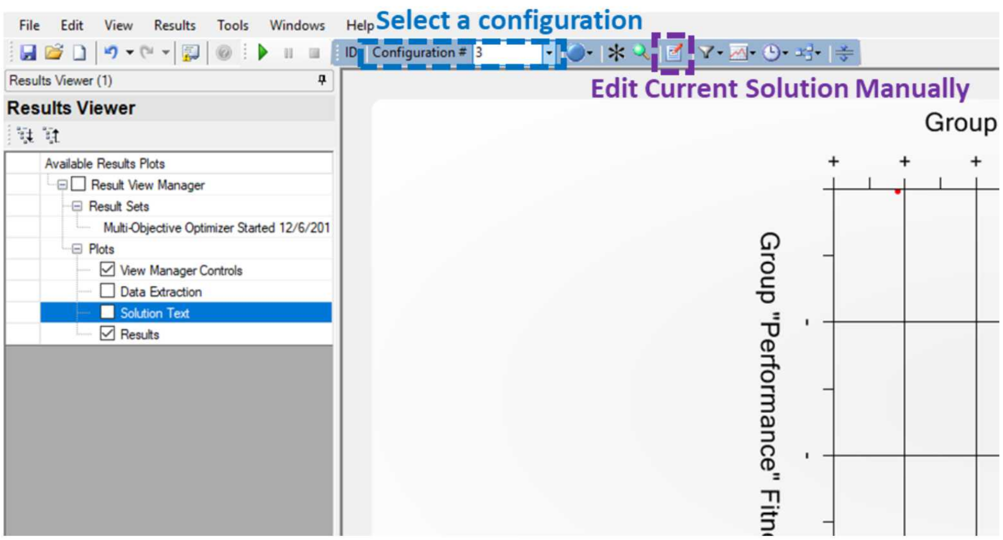


Figure 56. Select & Edit Solution

Clicking the edit current solution manually will open a new window which displays all the design options and specific realizations for that solution. This can then be edited by right clicking on design option realizations to see all and select specific realizations, see Figure 57 below.

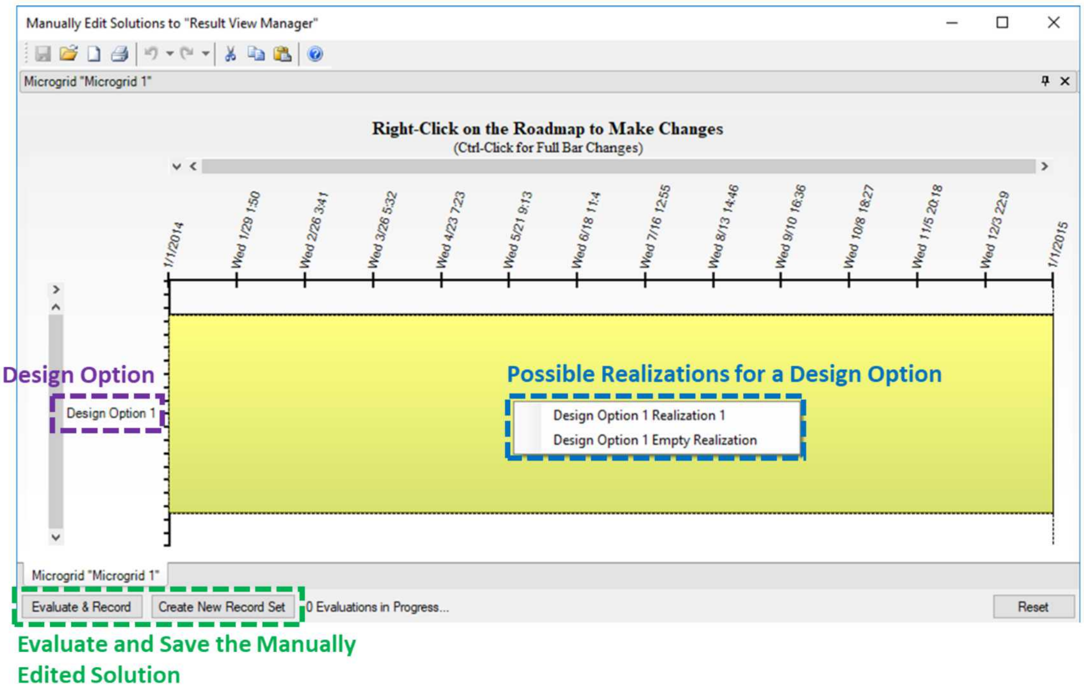


Figure 57. Edit Solution Window

Clicking the *Evaluate & Record* button will run an MDT evaluation of the user defined solution and store the microgrid metrics for it. While the *Manually Edit Solutions* window is open the user can continue to create user defined solutions and evaluate them, even when a previous solution is still being evaluated. Once all user defined solutions have been created and evaluated clicking the *Create New Record Set* button will create an MDT result set containing all the evaluated user defined solutions which can then be saved as a new result, explored using all of MDTs result functionality and compared to MDT optimized results.

3.7.6 View Manager Controls

The “View Manager Controls” checkbox in the plots navigation opens a toolbar (highlighted in blue in Figure 52) that allows you to see the currently selected configuration and which filters are current applied (Figure 58).

The **Configuration #** dropdown menu shows you the currently selected configuration. As you select different configurations in the plots, this menu will update. You can also select a configuration from this menu, and this will highlight this configuration in the plots.

The asterisk icon will update the Configuration # menu and highlight (in the plots) the configuration with the **highest overall fitness solution**.

The magnifying glass icon will update the Configuration # menu and highlight (in the plots) the configuration that is the closest to feasible. This is useful when the MDT was unable to satisfy all metric limits with any configurations.

The **filter manager** allows you to see all the filters that are currently applied. It also allows you to clear all the filters that have been applied.

- Selection Filters – A single configuration or multiple configurations which are manually selected.
- Visibility Filters – Filter options could include the feasibility condition, boundary conditions set in the Response Function plots, and specification filters in the Technology Filters plot.
- Highlight Filters – These filters are applied to the configurations to determine which ones should be highlighted. These are generally transient filters and do not persist long in this list.
- Color Filters – These filters are applied to the configurations in order to determine with which color they should be displayed on the plots. These filters include "Color by Feasibility" on Pareto plot; color scheme changes on the Response Function/Response Function Group Filters plots

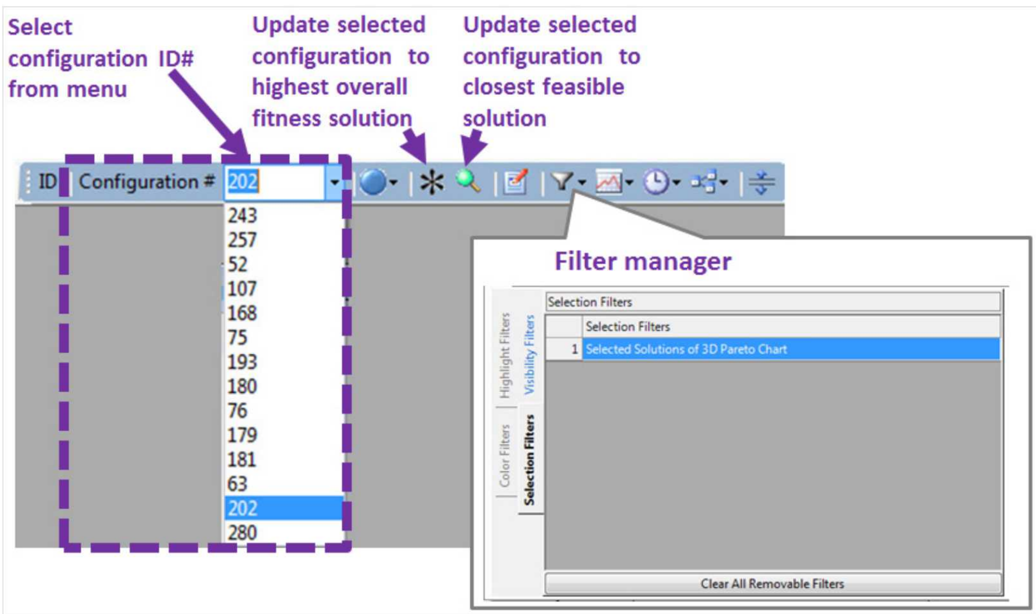


Figure 58. Overview of the View Manager Controls toolbar.

3.7.7 "Results" Window Views

The main result window is available in the list and is titled "Results." It contains several views laid out on tab panels. The tabs can be moved around and arranged in different ways.

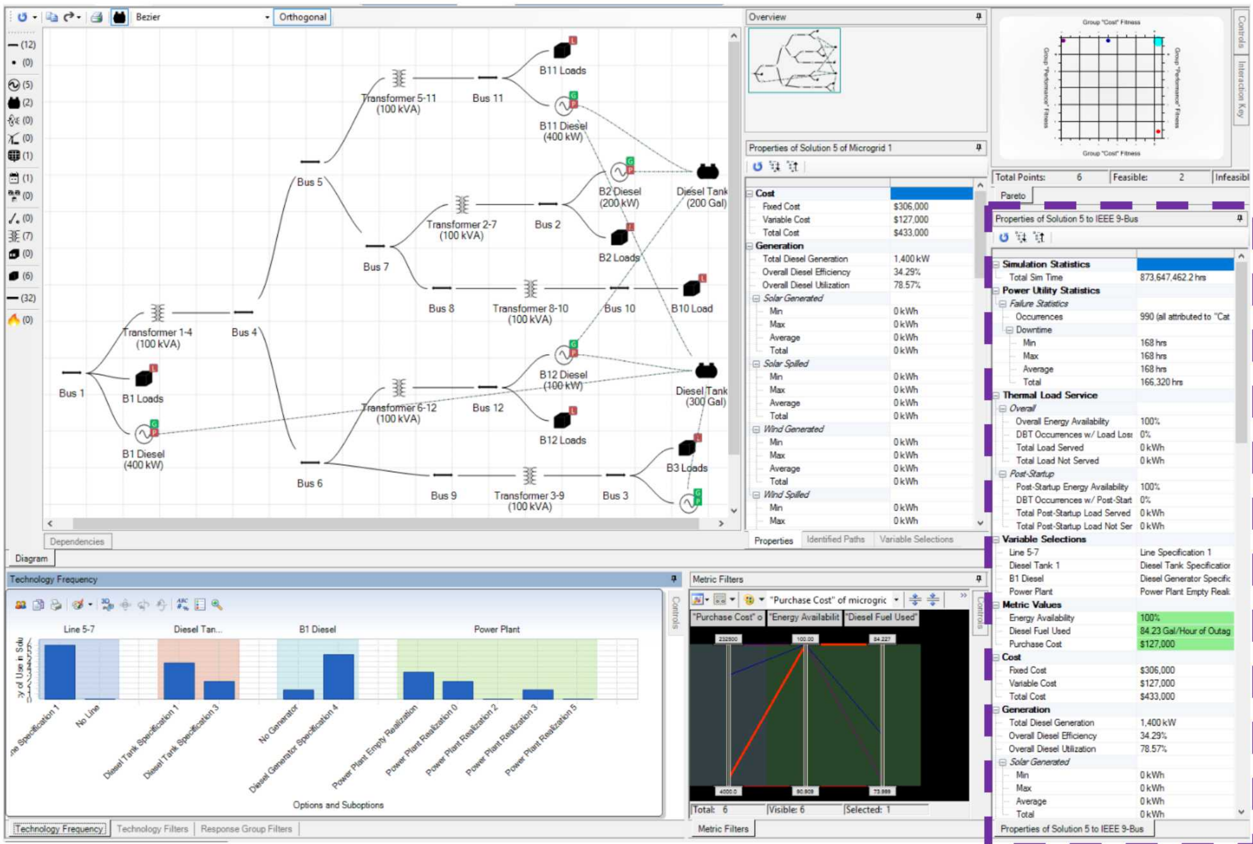


Figure 59. The main "Results" window of views.

Solution Properties Grid

Figure 59 shows the form. There are tabs along the bottom of several of the views indicating that other views can be seen in those locations. Each of those tabs can be moved around and docked along with other views. The following views are part of the "Results" window available.

3.7.7.1 Solution Properties Grid

The solution properties grid is along the right-hand side of the form by default. It is highlighted in purple in Figure 59 above. It displays properties of the currently selected solution including what variable selections have been made, what the resulting metric values are (colored green if the limit is met and red otherwise), along with many other statistics describing the solution at a high level.

3.7.7.2 Pareto

The Pareto frontier shows a set of points that is efficient, meaning that it would be impossible to make an improvement on one axis without a reduction on the other. Each point in the Pareto frontier represents a complete, unique microgrid design. Figure 60 shows an example Pareto frontier. Point "A" is the highest cost, highest performing configuration. Point "B" is the lowest cost, lowest performing configuration. There are many options in between representing different tradeoffs. Given any point on the chart, no improvement in cost can be made without a corresponding decrease in performance. The reverse is also true.

This example shows two objective dimensions: cost and performance. MDT supports up to five dimensions, which are the Response Function Groups defined under 3.5 Solver Settings on the Input tab.

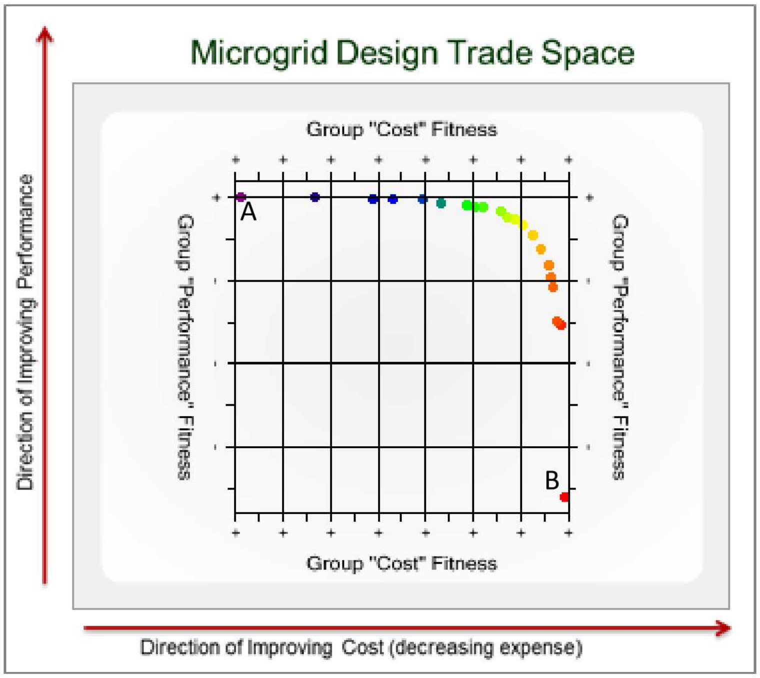


Figure 60. Guide to understanding Pareto frontiers.

To select a single configuration, click on a point (Figure 61). Or, you can use the “View Manager Controls” toolbar to select a specific configuration by using the “Configuration #” dropdown menu.

To select multiple configurations, hold down your left mouse key and draw a box (“box select”) around all points of interest or left click on all the solutions of interest while holding Ctrl.

To display the configuration number of the points, click on the Controls tab in the upper right corner of the Pareto plot window (highlighted in purple in Figure 61). Select “Show Point Labels.”

To turn the graph gridlines on/off, click on the Controls tab in the upper right corner of the Pareto plot window. Select/deselect “Show Grids.”

If in three dimensions then to rotate the pareto display hold down shift, left click on the plot and drag the cursor.

To view only feasible configurations (configurations that meet all limits), click on the Controls tab in the upper right corner of the Pareto plot window. Select “Show Feasible Points Only.”

To view all configurations (both feasible and infeasible) on the Pareto frontier, click on the Controls tab in the upper right corner of the Pareto plot window. Select “Show All Points.”

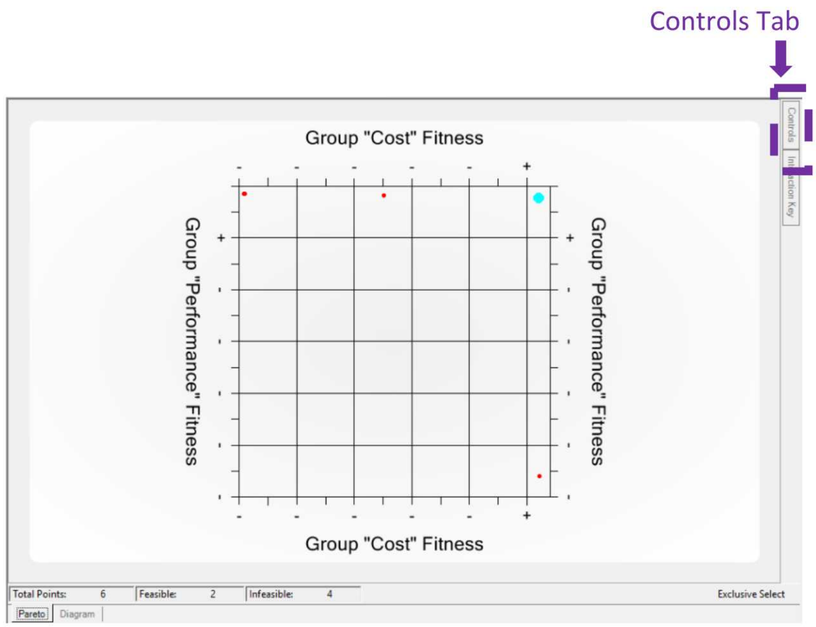


Figure 61. Pareto plot with one configuration selected (blue point).

3.7.7.3 Result Diagram

The result diagram is similar to the input diagram in appearance, but its operation is different. First and foremost, it does not support the alteration of the microgrid via drag-n-drop nor does it allow the alteration of microgrid assets by double-clicking. It does allow moving items around on the canvas. Another difference is that the properties grid will contain result information as well as the input information. Finally, the items on the diagram may be decorated with additional icons that give visual indications about simulation results. For example, all assets with reliability failures will have an R icon as shown in Figure 62.

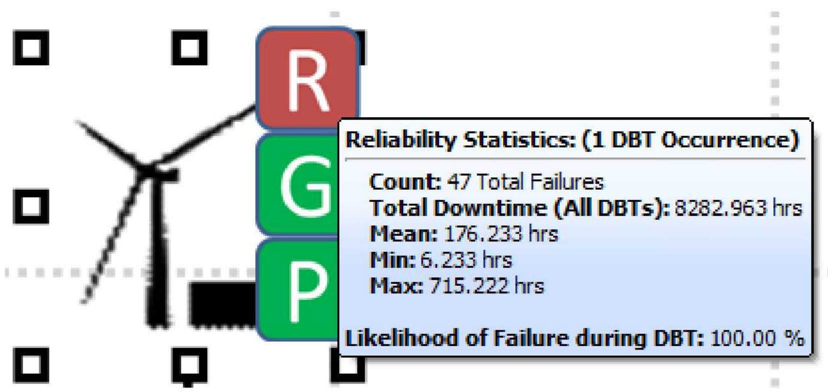


Figure 62. Unreliable Grid Asset in Result View

Hovering over the icon shows the information as displayed. Other icons include those that indicate some performance information (P), generator statistic information (G), and load service information (L). Each of these may be red or green depending on the results obtained.

If powerflow is enable for the model, two additional icons will appear in the results diagram. Powerflow statistics ( ) and overload statistics ( ), hovering over these icons will display powerflow information from simulation results.

In some cases, it may be possible for an asset to have been assigned the null specification resulting in its absence from the solution while the connecting electrical lines may not be null. In that case the asset will appear on the diagram as a black box with a red X in it (☒) indicating that there is a placeholder there for diagramming purposes but that there is no actual asset there.

3.7.7.4 Technology Frequency

Technology frequency displays the frequency that each equipment specification was chosen across all configurations (Figure 63). Only equipment specifications that are part of a decision variable are displayed. The different color blocks represent the equipment type, and the bars represent the selection frequency for each specification.

The Controls tab (highlighted in purple in Figure 63) allows you to view equipment selection by:

- all solutions
- all visible solutions
- all selected solutions

Configuration selection and filtering must be done via the other plot windows.

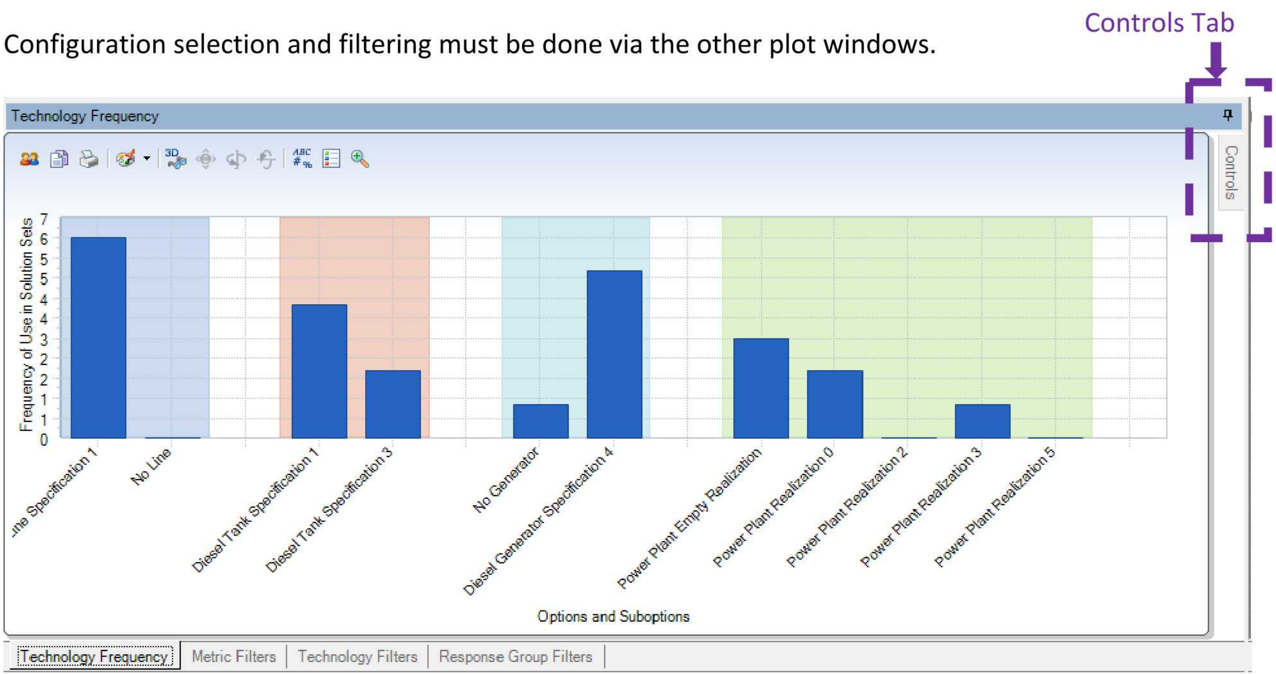


Figure 63. Usage Frequency displays the frequency of selection for each equipment specification.

3.7.7.5 Technology Filters

Technology Filters helps you to understand the relationship/correlation among equipment specification selections across configurations. Only equipment specifications that are part of a decision variable are displayed. Each equipment specification shows the number of configurations in which it appears out of the total configuration set.

Figure 64 shows an example for a configuration set with eighteen options. This shows that B1 Diesel is set to Example Diesel 1 in 9 solutions, Example 300 in 4 solutions, and no generator is used in 5 solutions; the model never picks diesel generators of sizes 200, 400 or 500. Select or deselect specifications under each equipment type. The other specifications will update accordingly. Deselected specifications will be highlighted in red. Figure 65 shows the plot after all complex design options are deselected, except for the Power Plant Realization 1 option. Note that the total configuration set value has updated to 6. This updated plot shows that Realization 1 is only used in solutions with B2 Diesel generator of type Example 300 and Example Diesel 1; Example 300 and No Generator are now grayed out since they are never used in a solution with Realization 1.

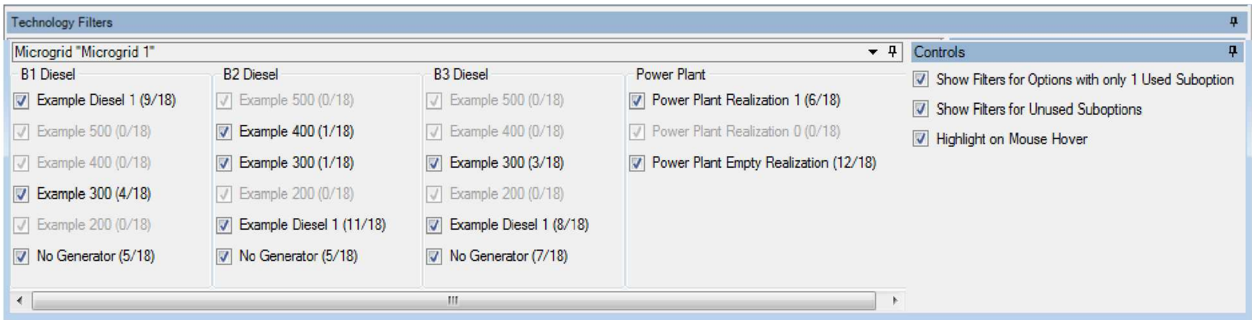


Figure 64. Technology Filters with all configurations displayed.

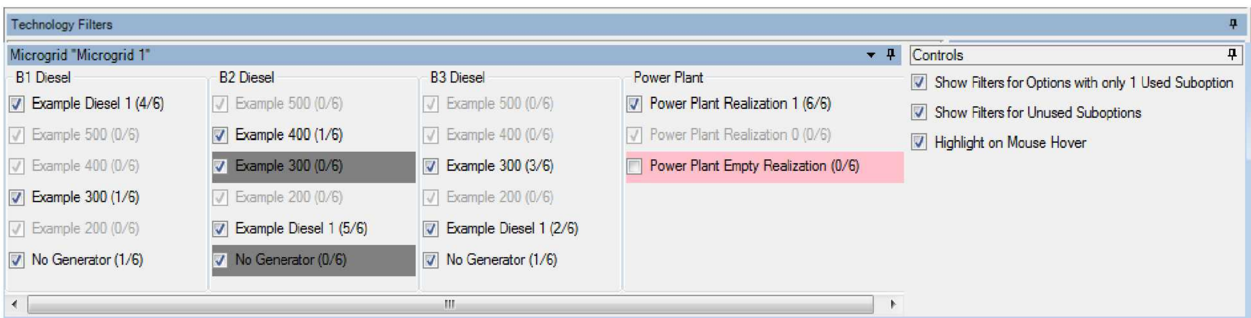


Figure 65. Technology Filters where only the Power Plant Realization 1 option is selected.

3.7.7.6 Response Function Filters

Response Function Filters displays the metric values of all configurations on a parallel coordinates plot. Each configuration is represented by a line. Only metrics that belong to Response Function Groups, defined under 3.5 Solver Settings on the Input tab, are displayed. Metrics with the same background color belong to the same Response Function Group. The order of the columns cannot be modified.

Click on a line to highlight a specific configuration (Figure 66).

The axes display the maximum and minimum values for each metric across all configurations. The configuration set can be filtered by clicking on the max or min axis point and dragging it along the axis (Figure 67). Configurations that do not meet this constraint are removed from the plot. The arrow buttons in the upper right-hand corner will minimize and maximize the range values for each axis.

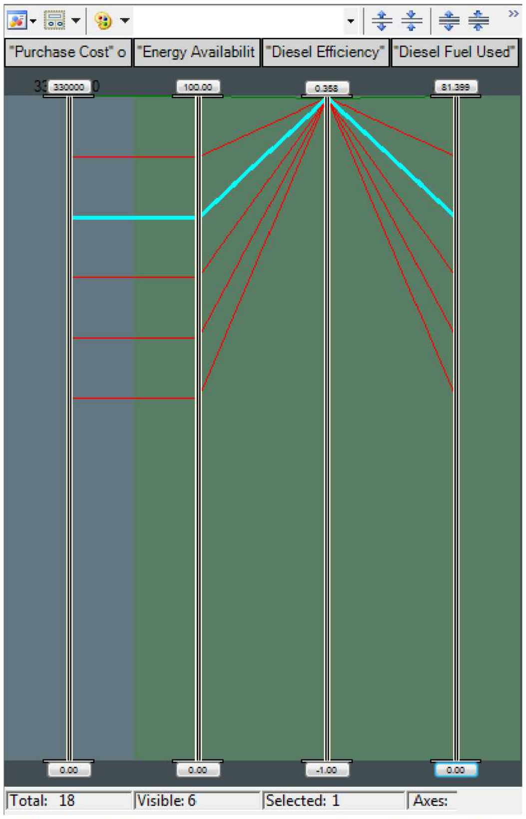


Figure 66. Response Function Filters plot displaying all configurations (One highlighted).

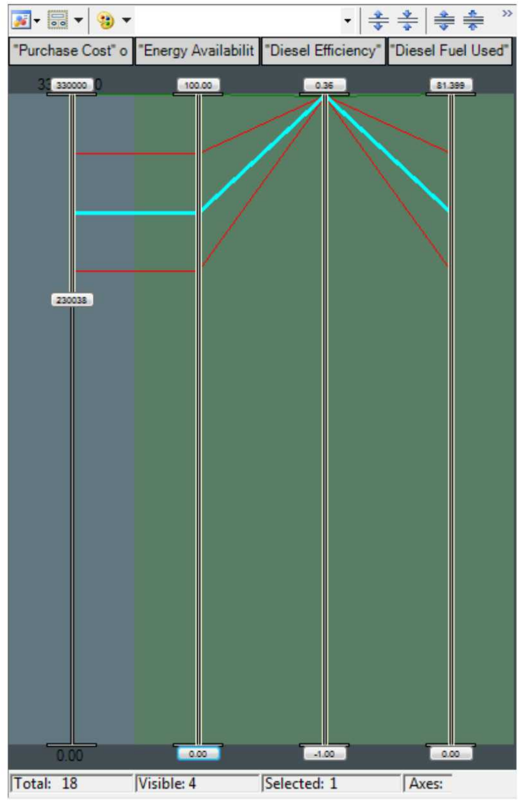


Figure 67. Response Function Filters plot where the minimum value of the "Purchase Cost" metric has been increased. (Two configurations filtered out).

To make the axes min/max values easier to view, turn on the Grids view. Click on the Layout Options menu on the toolbar and select "Show Grids." This will display a table above and below the plot area (Figure 68). Instead of sliding the axes endpoints to filter the configurations, you can modify the values in the table to move the endpoints.

- The bottom row of the top table moves the maximum value endpoint.
- The top row of the bottom table moves the minimum value endpoint.

To rescale the axes:

- Change the top row of the top table to rescale the maximum value.
- Change the bottom row of the bottom table to rescale the minimum value.

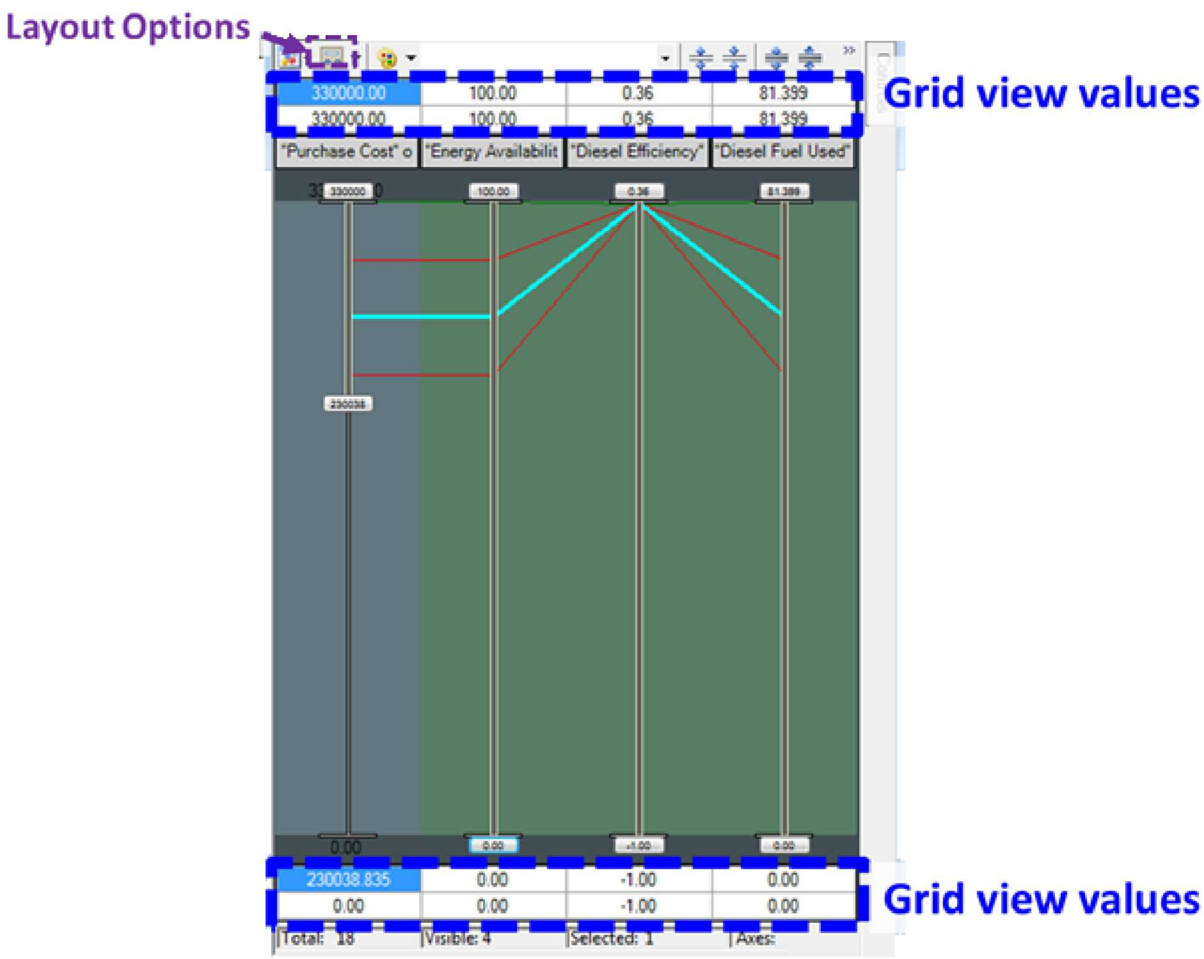


Figure 68: The grids view of Response Function Filters.

To use the gradient or "Rainbow" effect, you must select a metric using the dropdown menu. After selecting a metric, choosing "Rainbow" in the "Rescale Color/Select Line Color Scheme" menu (Figure 69) will display the lines representing each solution in different colors based on the value of the metric that was selected, going from red to purple. It is also possible to view the same ordering via a gradient of colors from a primary to a secondary color of the user's choosing.

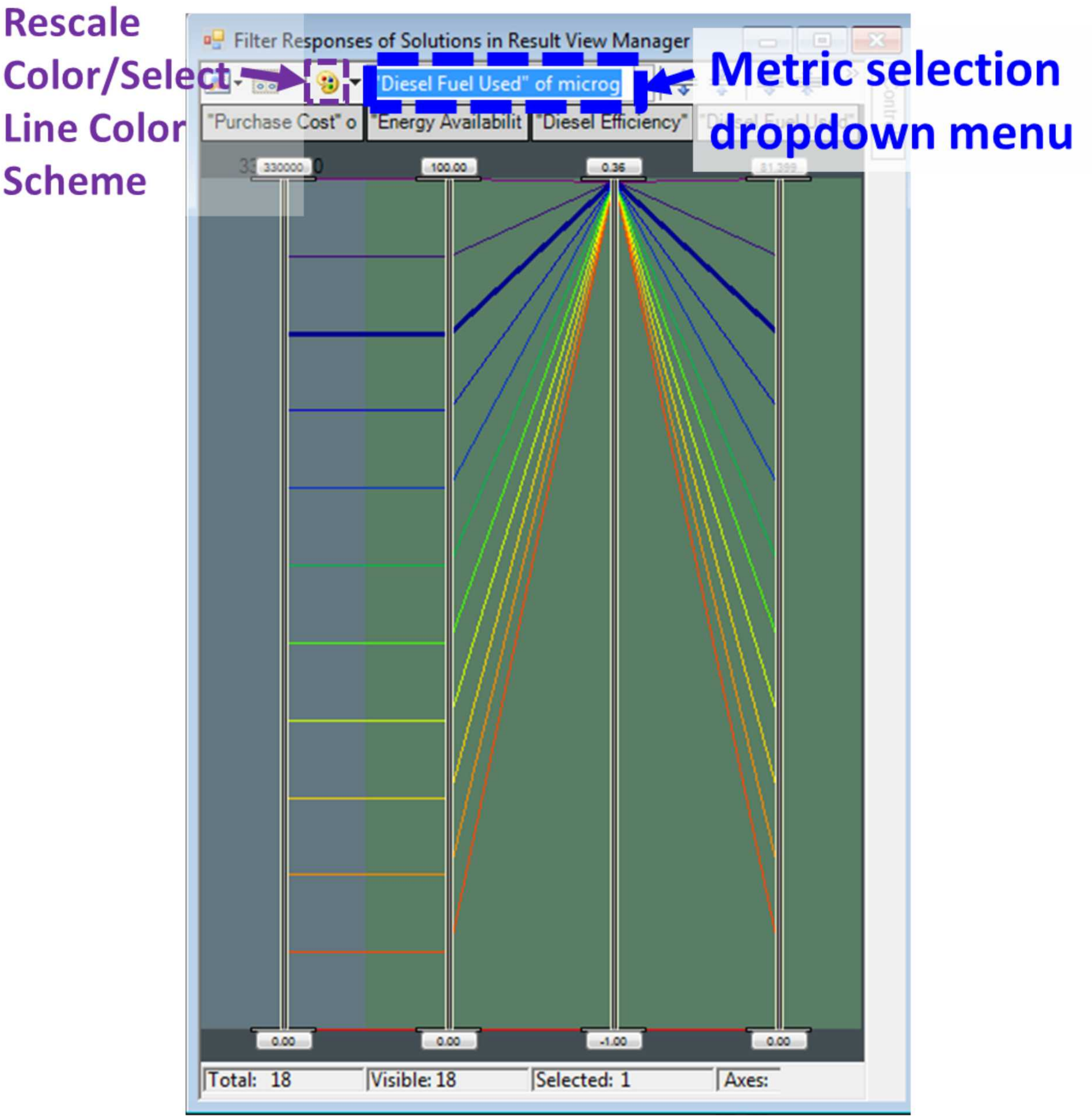


Figure 69: Rainbow view of the Response Function Filter.

This view allows quick understanding of which solutions perform best for the selected metric, and how those solutions perform on the other metrics.

3.7.7.7 Response Function Group Filters

Response Function Group Filters displays the Response Function Group values of all configurations on a parallel coordinates plot. Each configuration is represented by a line. The order of the columns cannot be modified. Only the Response Function Groups, defined under 3.5 Solver Settings on the Input tab, are displayed. To view the individual metrics within a group, please use the Response Function Filters plot.

Click on a line to highlight a specific configuration (Figure 70).

The axes display the maximum and minimum values for each group across all configurations. The configuration set can be filtered by clicking on the max or min axis point and dragging it along the axis (Figure 71). Configurations that do not meet this constraint are removed from the plot.

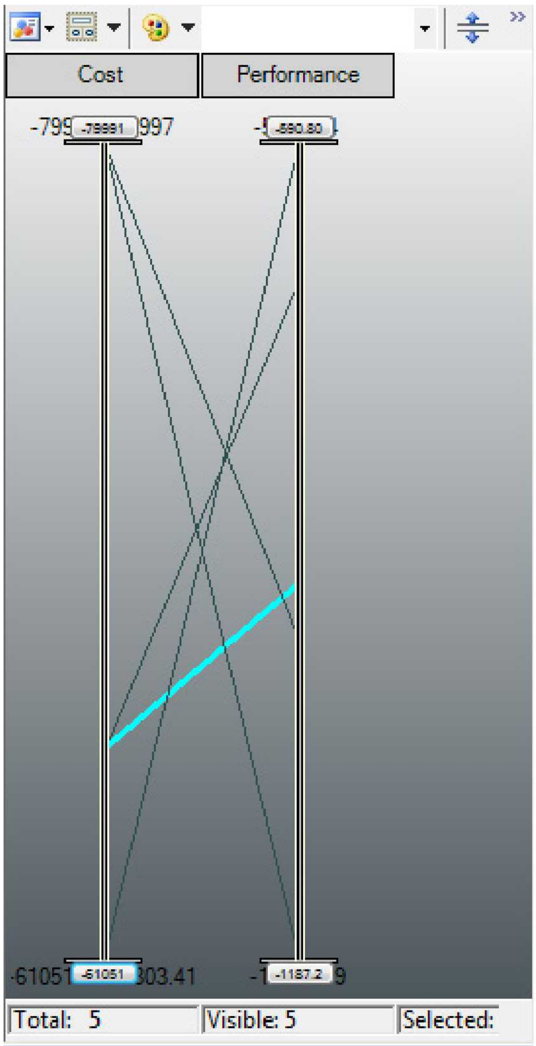


Figure 70. Response Function Group Filters plot displaying all configurations (One highlighted).

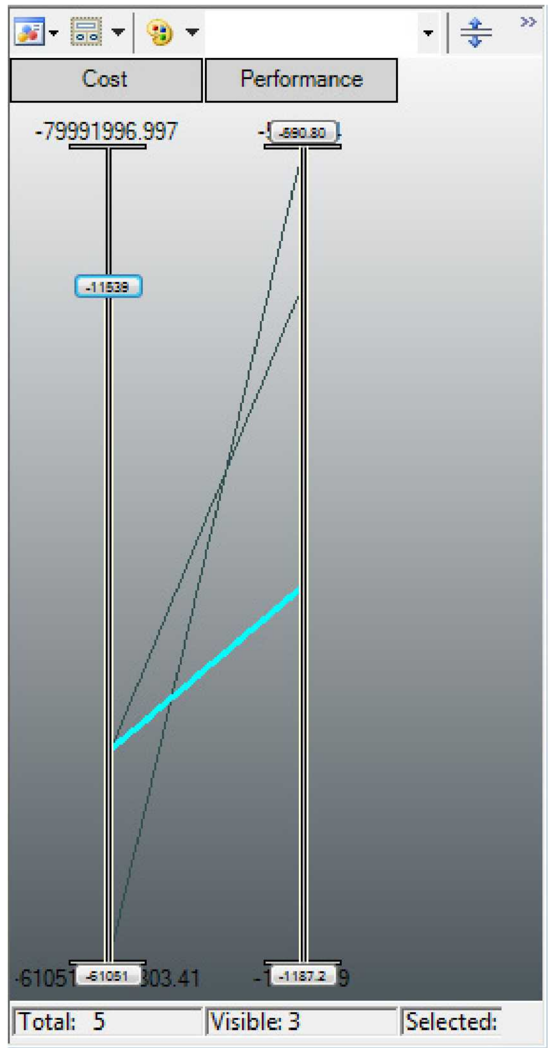


Figure 71. Response Function Group Filters plot where the maximum value of the Cost group has been decreased (Two configurations filtered out).

3.7.8 Other Window Views

The following plots display information about a single configuration. The solution must be selected on one of the other plots or by using the View Manager Controls toolbar.

3.7.8.1 Solution Text

Solution Text displays all the data and output messages from the models for a single configuration. If you can't find the data you need in the other plots, it is mostly likely found here. The configuration must be selected on one of the other plots or by using the View Manager Controls toolbar.

If equipment had no failure modes defined, you will see the note, "This item could not fail."

The very bottom of the page lists the equipment specifications selected for this configuration. Only equipment specifications that are part of a decision variable are displayed. It also lists the values for the metrics.

3.7.8.2 Data Extraction

Data Extraction allows you to extract the results data from MDT. A data table is displayed at the bottom of the window (highlighted in green in Figure 72). This data can be copied-and-pasted to Excel.

The Data Selection Controls at the top of the window allow you to filter what data is displayed.

- The checkboxes on the left control which columns are displayed (highlighted in purple in Figure 72).
- The "Show – Response" checkboxes control which rows are displayed (highlighted in blue in Figure 72).
    - The Annotations field is the text generated by PRM.
- The radio boxes on the left control which configurations are displayed (highlighted in brown in Figure 72).
    - Show All Solutions – All configurations, ignoring selections and filters.
    - Show Selected Only – A single configuration or multiple configurations which are manually selected.
    - Show Visible Only – Configurations that meet all filter options that are applied. Filter options could include the feasibility condition, boundary conditions set in the Response Function plots, and specification filters in the Technology Filters plot.
    - Show Current Only - The manually selected configuration. The configuration must be selected on one of the other plots or by using the View Manager Controls toolbar.

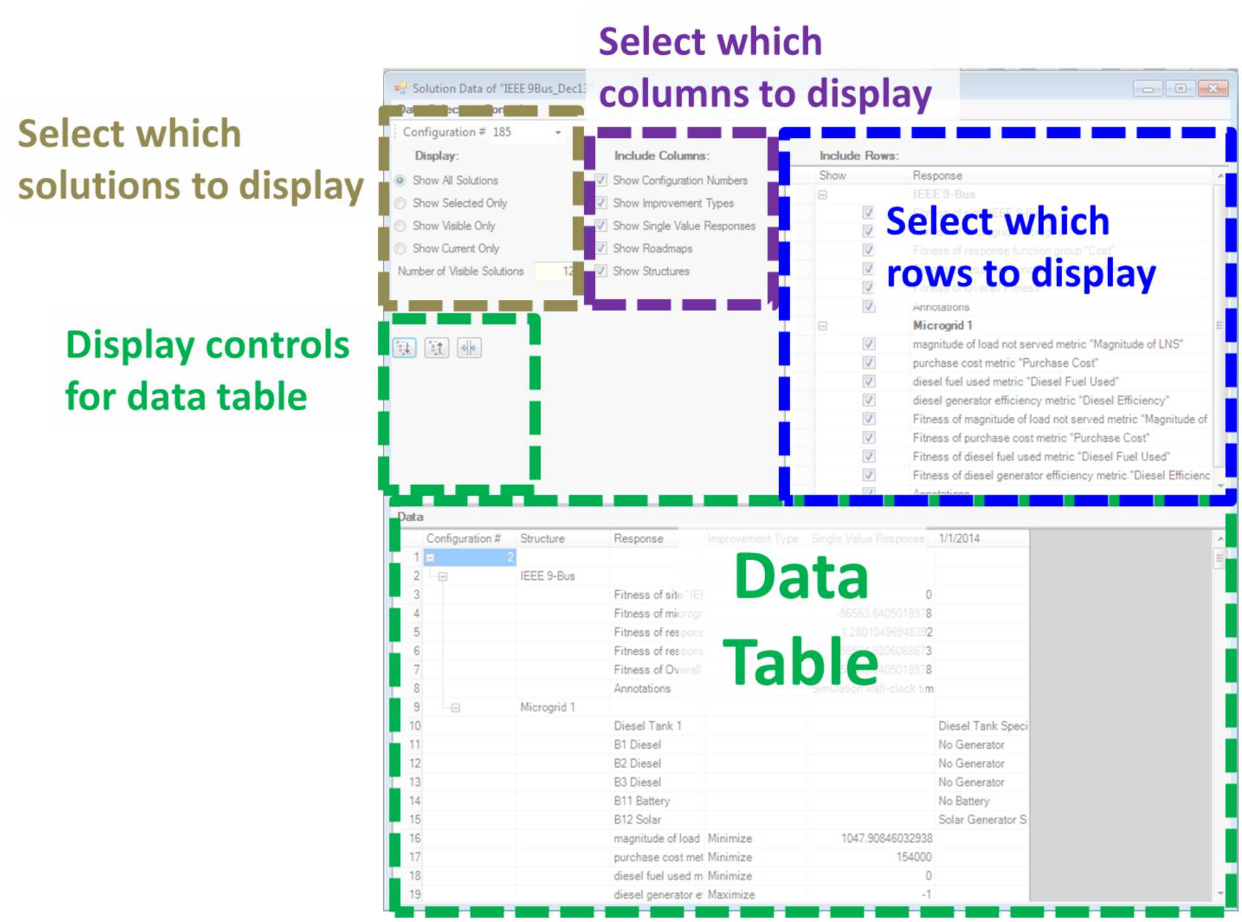


Figure 72. Overview of the Data Extraction plot.

4. Appendix A: MDT Interface Summary Overview

This appendix provides a summary overview of key elements of the MDT interface.

4.1 MDT Main Screen

There are three main areas of MDT. They are accessed via tabs at the bottom left corner of the screen (*Main navigation tabs* in Figure 73).

- **Input**, where the microgrid information is input into MDT.
- **Progress Monitor**, where the user can view the progress of the model run.
- **Results Viewer**, where model results are displayed.

Pages within each section are accessed via links in the upper left corner of the screen (*Sub-navigation area* in Figure 73). When the Input tab (under *Main navigation tabs* in Figure 73) is selected, the user can choose whether to display Sizing Inputs or Islanded Inputs (using the tabs just above the main navigation tabs) depending on the analysis being performed. Islanded Inputs is the default mode.

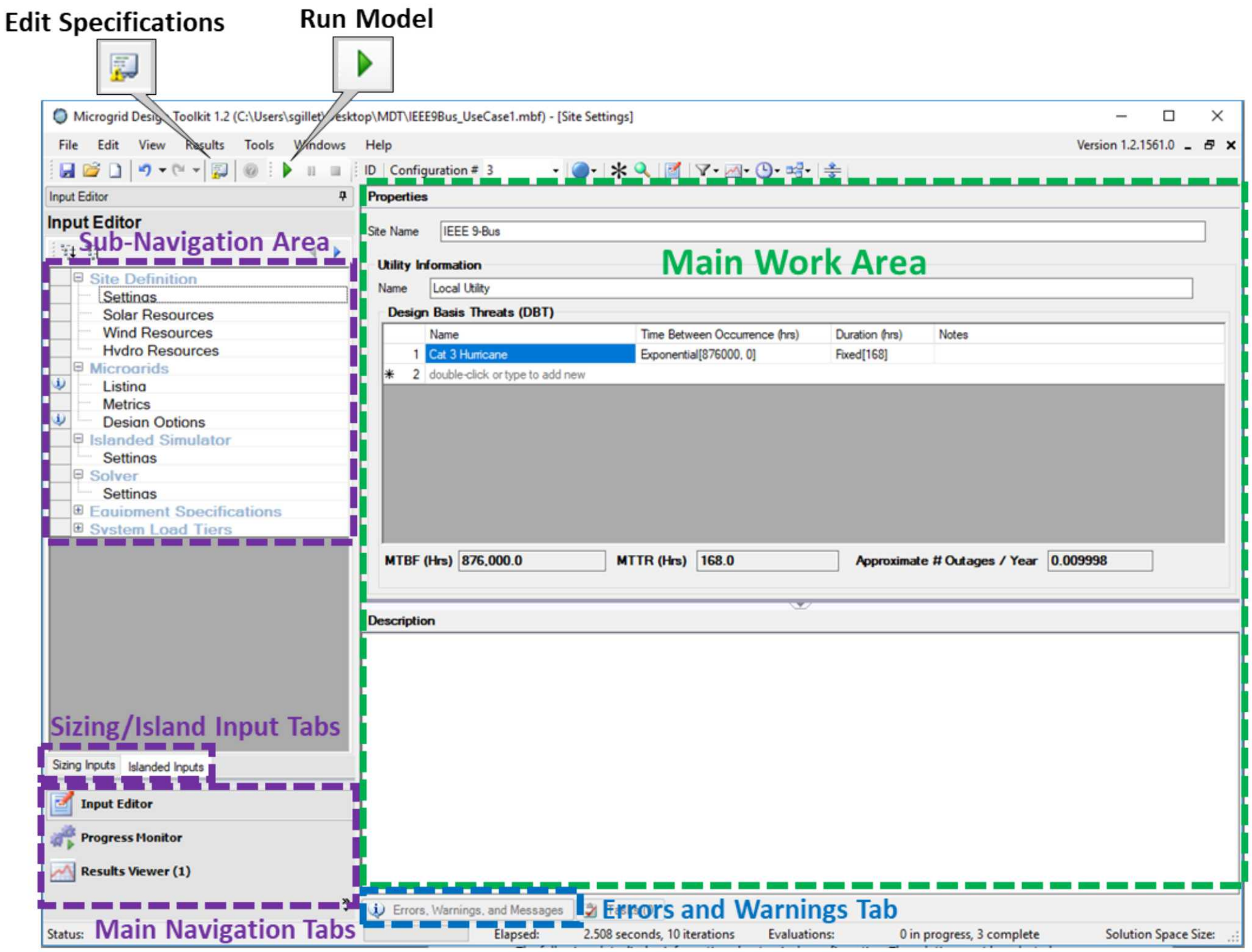


Figure 73. MDT main screen overview.

Pages have two main areas.

- The **page navigation** area is located on the left side of the page (highlighted in purple in Figure 73).
- The **main work area** (highlighted in green in Figure 73) is the largest panel on the screen. This is where elements are added and modified.

Errors  **and warnings**  for all pages are accessible through the "Errors, Warnings, and Messages" tab at the bottom of the screen (highlighted in blue in Figure 73). Errors and warnings are also displayed on the input form next to the elements with problems.

Specifications can be accessed through the Edit menu or via a button on the toolbar.

The **model** is run via the Play (green triangle) button on the toolbar. When the Sizing Inputs tab is selected the MSC model will be solved when Play is selected. When the Islanded Inputs tab is selected the TMO/PRM model will be solved when Play is selected.

4.2 Sizing Inputs

4.2.1 Editing Inputs

To access the MSC input fields, click the Sizing Inputs tab directly above the Input button (Figure 74). This will provide access to the Sizing Input Options. The inputs pages are accessed through the left navigation area.

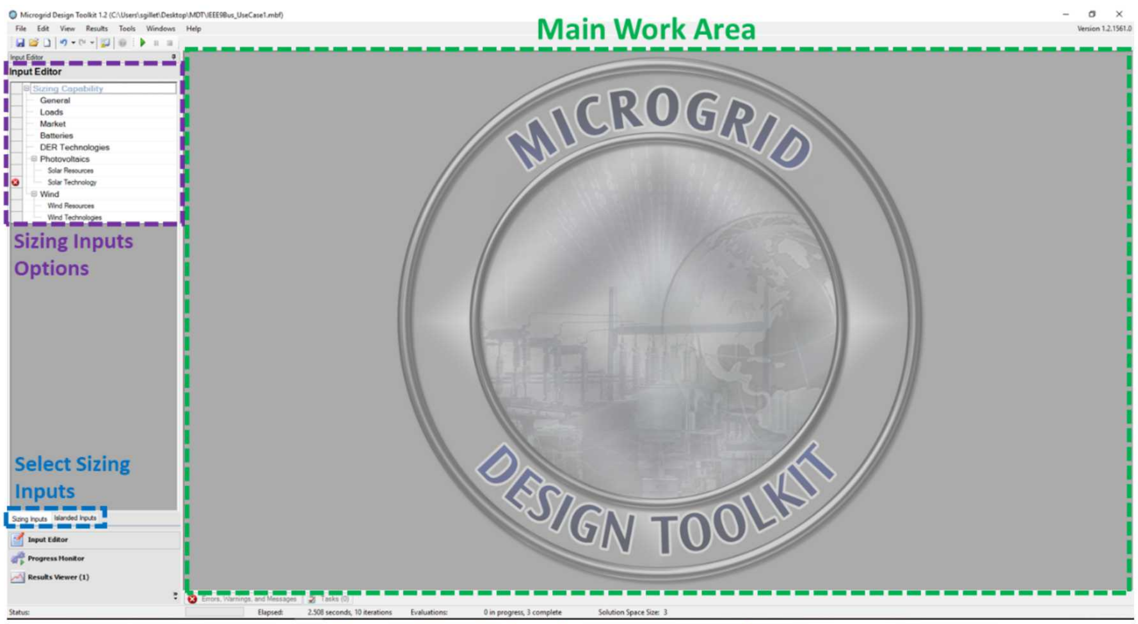


Figure 74. MSC main screen overview.

4.2.2 Results Viewer

When entry of all inputs is complete, click the “Run” button at the top of the page. Results will be displayed under the Results Viewer tab. To view the MSC results, select Costs or Investments under Plots (Figure 75). The Cost results will summarize the costs associated with the selected microgrid. The Investments results page will display the types and quantities of technologies purchased. Three sets of investment results are reported: continuous investments, DER investments, and wind investments.

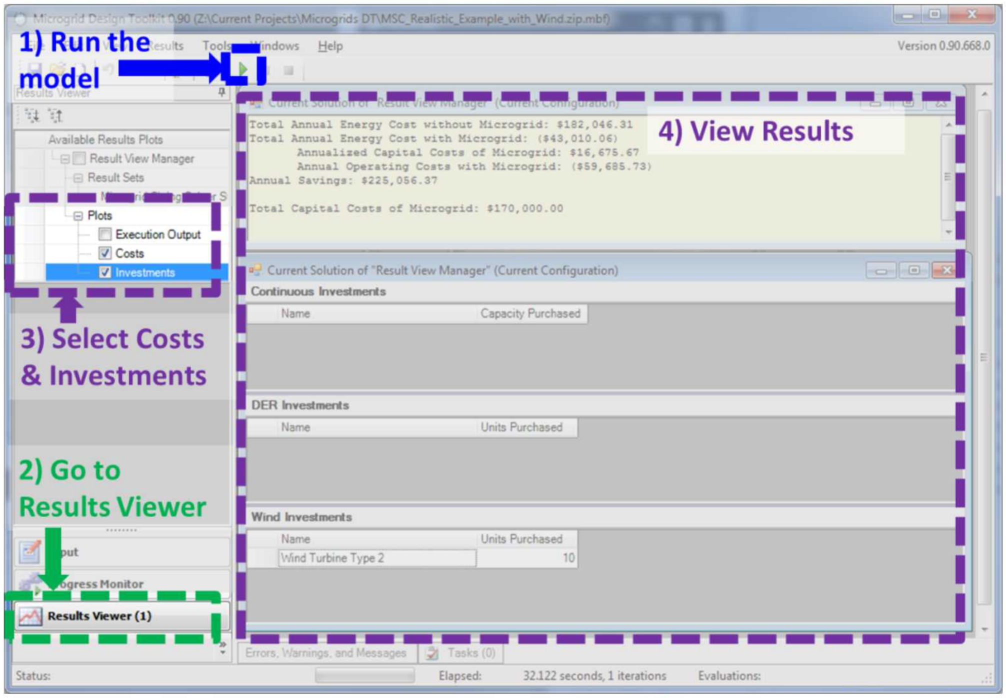


Figure 75. Viewing MSC results.

4.2.2.1 Save and Open Results Files
To save and open input files, see section 1.4 Save and Open Input Files. MDT results files are saved as *.mof files.

To save your results:
- check the box next to your result set name.
- on the toolbar, go to Results -> Save Selected.

To open a results file:
- on the toolbar, go to Results -> Load.

4.3 Islanded Inputs

4.3.1 Diagramming a Microgrid
Once the microgrid is defined, the diagram window below will become active. A microgrid can be designed using the diagramming feature or through tabular entry (see sections 4.3.2 Element Pages and 4.3.3 Editing Elements: Tabular Entry). Assets can be added and modified directly in the diagram.

4.3.2 Element Pages
Figure 76 provides an overview of the element pages.

To **close a window:**
- Click “Finish” to close the window and save all changes made.
- Click “Cancel” to close the window and cancel any changes made since the last save after opening the dialog box.

To **move to a new element page**:

- Click on the element in the navigation area.
  or
- Click the “Previous Form” button to move to the previous element page (move up the page navigation list).
  or
- Click the “Next Form” button to move to the next element page (move down the page navigation list).

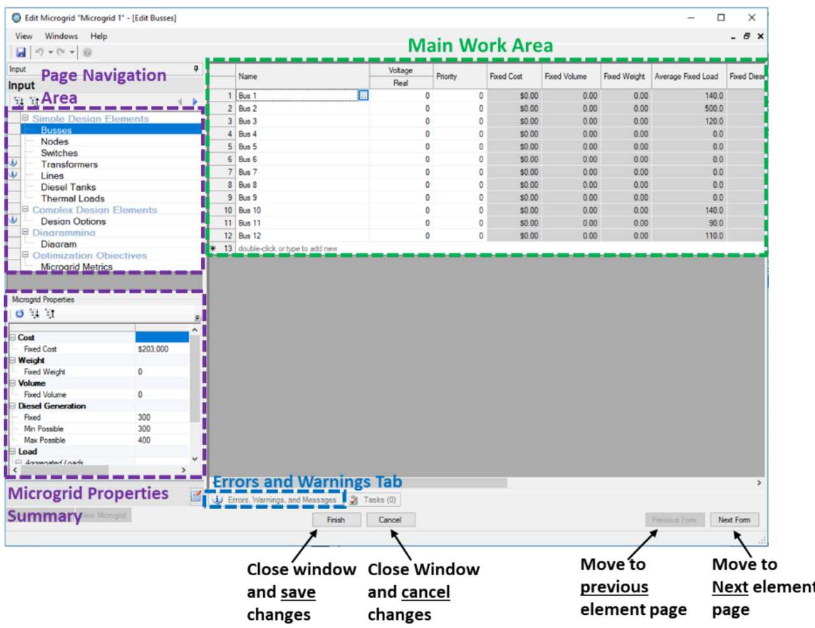


Figure 76. Microgrid Input Form overview.

4.3.3 Editing Elements: Tabular Entry

Figure 77 shows the main edit features on an element page.

To **add a new item**:

- Double click in an empty row.
  or
- Begin typing a name into an empty row.

To **add more details** about an item, click the button next to the name field.

To **remove an item**:

- Click on the row number (first column) to highlight the row.
- Press the “Delete” key on the keyboard.

MDT supports **undo** and **redo** of actions.

- Click the Undo or Redo button to view a dropdown of all past actions.
- Select the action to undo/redo.
- The tool will update accordingly.

To **save all changes** made in this window, click the Save button in the toolbar.

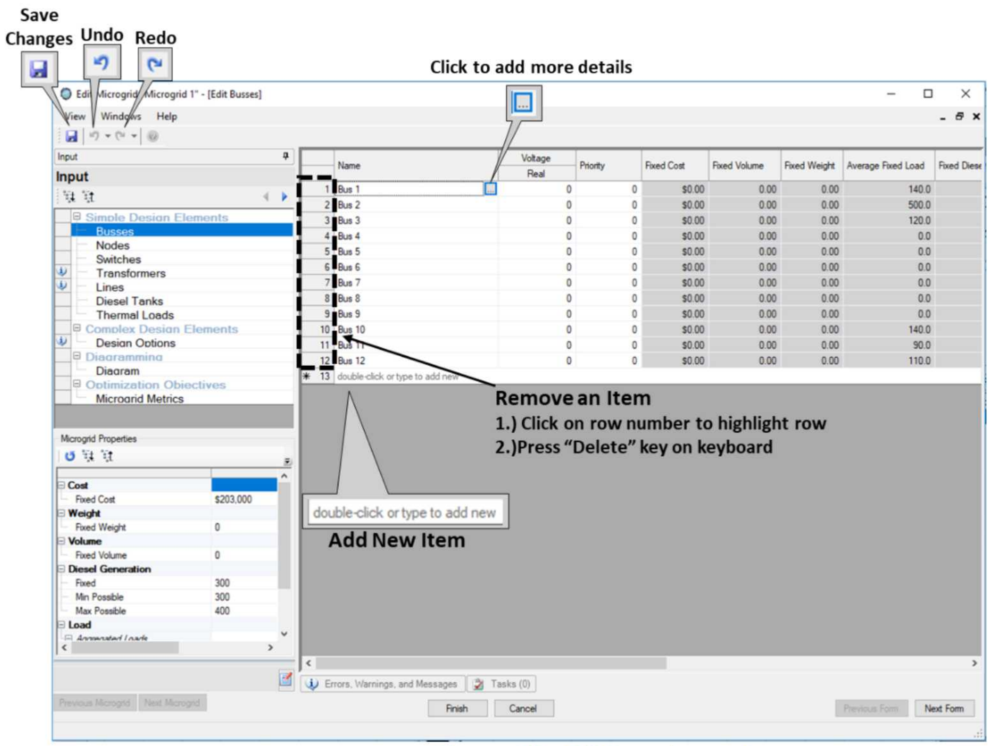


Figure 77. Editing elements.

4.3.3 Results Viewer

The Results Viewer will only be active when the model has run or previously generated results have been loaded into MDT (see section 3.7.2 Open Results). Otherwise, there are no results available to view. There are three main areas of the Results Viewer:

- **Plot selection** menu (highlighted in purple in Figure 78) allows you to select which plots to display.
- **View Manager Controls** (highlighted in blue in Figure 78) toolbar allows you to see the currently selected configuration and filters being applied to the plots. This toolbar can be displayed/hidden via the plot selection menu. This is not applicable for MSC analyses.
- **Plots display area** (highlighted in green Figure 78) can display multiple plots at once. Plot windows can be resized and moved.

All plots are interactive and are linked. Selecting a configuration or filtering on one plot will cause the same configuration and filters to apply to all other plots. Since multiple plots can be open at the same time, this feature becomes useful in ensuring all plots are displaying information about the same data set. In Figure 78, you will see a bright blue dot or line in three of the plots, which represent the same configuration.

All plot images can be copied-and-pasted into other tools. Every plot window has a Controls tab in the upper right corner. Click on the Controls tab, and then click on the Copy icon. Next, paste the image into the tool of your choice.

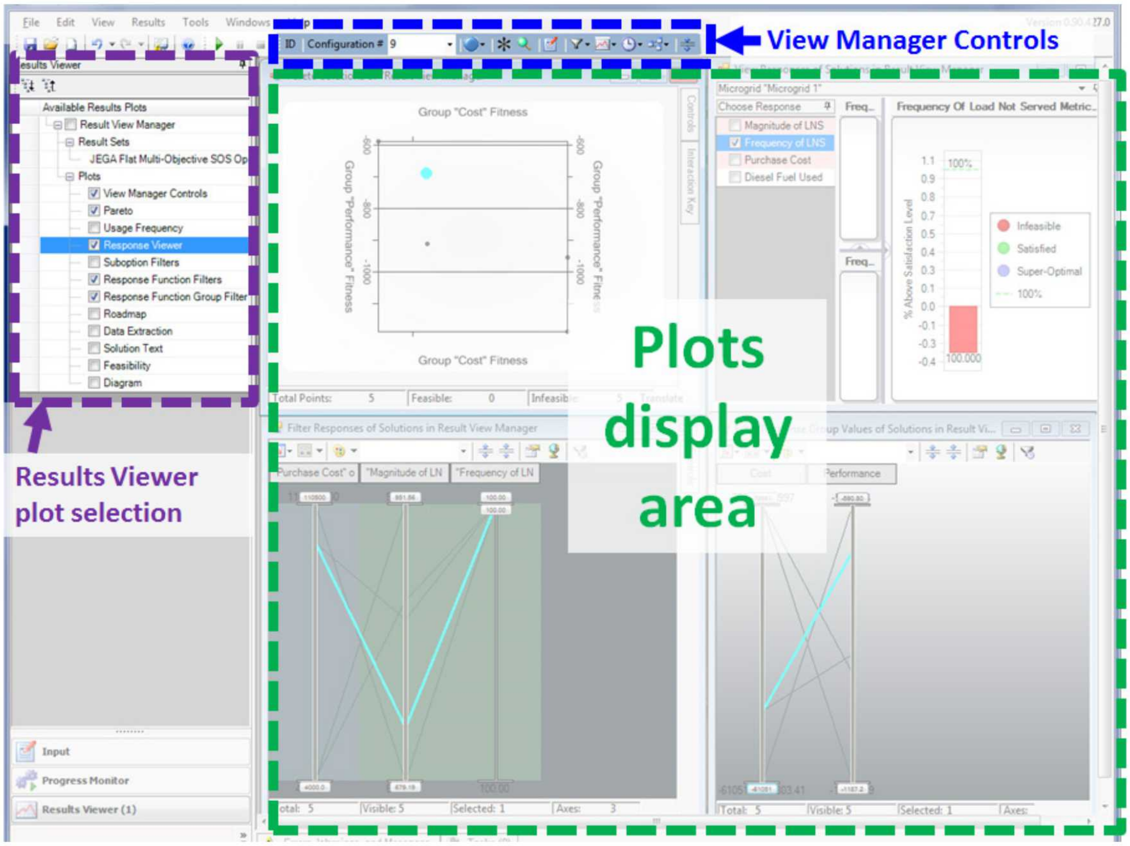


Figure 78. Results Viewer page overview.

4.3.3.1 Save and Open Results Files

To save and open input files, see section 1.4 Save and Open Input Files. MDT results files are saved as *.mof files.

To save your results:

- check the box next to your result set name.
- on the toolbar, go to Results -> Save Selected.

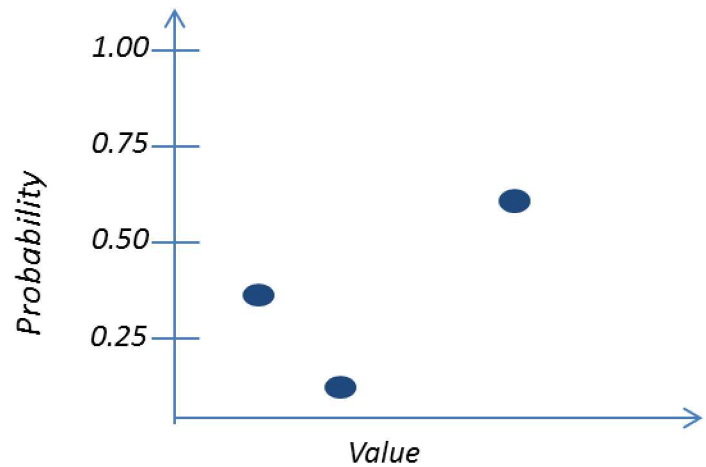
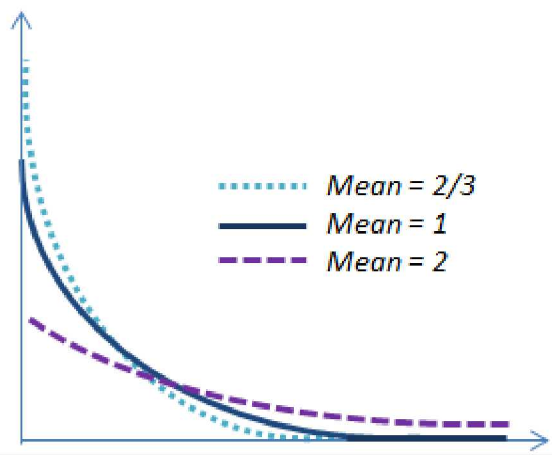
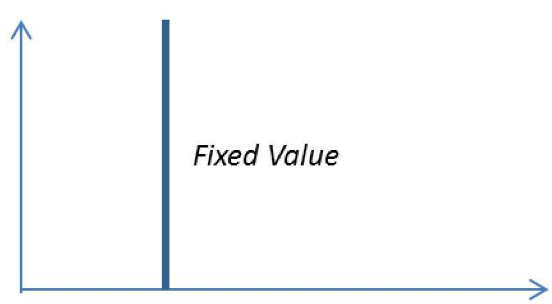
To open a results file:

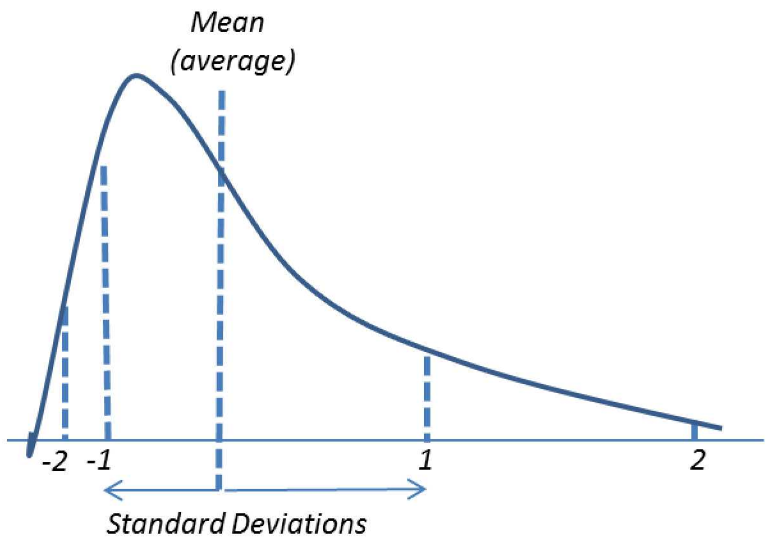
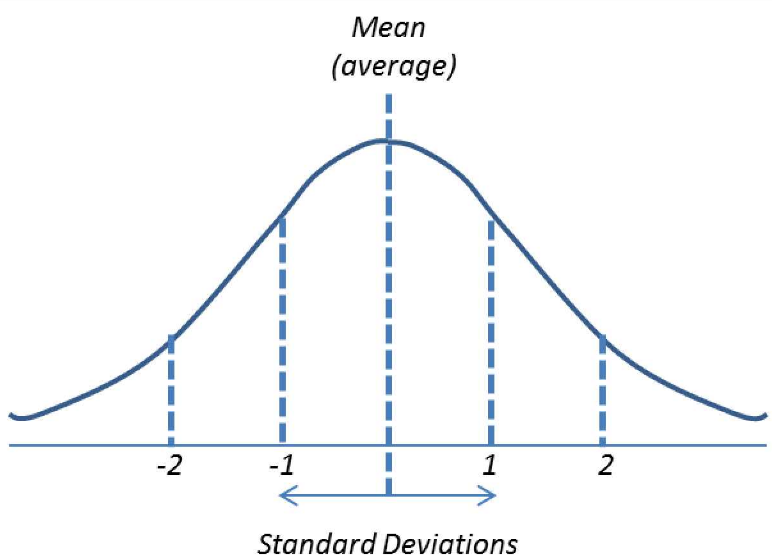
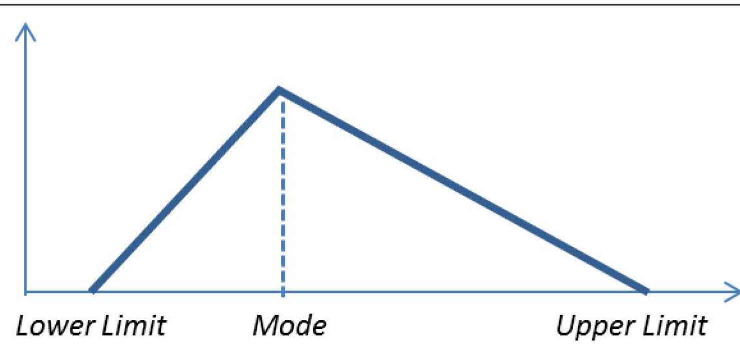
- on the toolbar, go to Results -> Load.

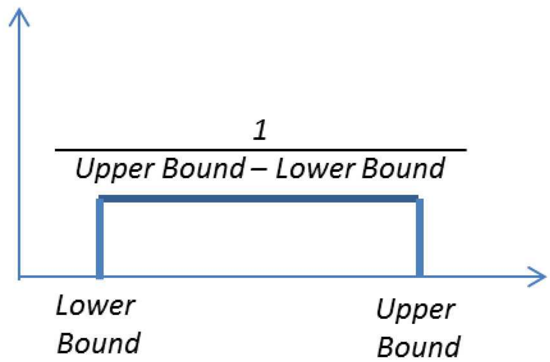
5. Appendix B: Failure Mode Distributions

Failure modes define the ways that each equipment type can break as described in section 3.1.2 Equipment Specifications.

You can define as many failure modes as needed, including the mean time between failure (MTBF) and mean time to repair (MTTR). They are defined in hours. This section provides a description of each distribution and recommendations on when to use each one.

Discrete Parameters: • Values and their Probabilities *(1 or more. Probabilities must add up to 100%)*	
Exponential Parameters: • Mean (1/Lambda) • Location	
Fixed Parameters: • Fixed Value	

Log Normal Parameters: • Mean • Standard Deviation	
Normal Parameters: • Mean • Standard Deviation	
Triangular Parameters: • Lower Limit • Mode • Upper Limit	

Uniform **(aka rectangular distribution)** Parameters: • Lower Bound • Upper Bound	
Placement Parameters: • Initial Distribution • Subsequent Distribution	The initial and subsequent distributions can be any distribution described in this appendix. The initial distribution is used only the first time that the placement distribution is used. All subsequent uses involve the subsequent distribution. An example of the usefulness of this distribution would be if you wanted to have the first occurrence of some event happen after 6 months and every subsequent occurrence to happen with a mean of 1 year between occurrences.
Time of Year Biased Parameters: • Number of Years Distribution • Time of Year Distribution	The number of years and time of year distributions can be any distribution described in this appendix. The number of years distribution is used to draw a value that determines the number of years between occurences of an event. The time of year distribution is used to get a number of hours into the year that the event happens. Both distributions are used each time the Time of Year Biased distribution is asked to produce a value. An example of the usefulness of this distribution might be to define a 10 year avalanche that occurs on average once every 10 years and is normally distributed around 8700 hours (some time in December).

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