

Printed July 2016  
Unlimited Release  
SAND2015-8593 0

# Microgrid Design Toolkit (MDT) User Guide

Software v1.1

Prepared by  
Sandia National Laboratories  
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.



U.S. DEPARTMENT OF  
**ENERGY**



**Sandia National Laboratories**

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

**NOTICE:** This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government, nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represent that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof, or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof, or any of their contractors.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from  
U.S. Department of Energy  
Office of Scientific and Technical Information  
P.O. Box 62  
Oak Ridge, TN 37831

Telephone: (865) 576-8401  
Facsimile: (865) 576-5728  
E-Mail: [reports@osti.gov](mailto:reports@osti.gov)  
Online ordering: <http://www.osti.gov/scitech>

Available to the public from  
U.S. Department of Commerce  
National Technical Information Service  
5301 Shawnee Rd  
Alexandria, VA 22312

Telephone: (800) 553-6847  
Facsimile: (703) 605-6900  
E-Mail: [orders@ntis.gov](mailto:orders@ntis.gov)  
Online order: <http://www.ntis.gov/search>



# **Microgrid Design Toolkit (MDT)**

## **User Guide**

### **Software v1.1**

Sandia National Laboratories  
P.O. Box 5800  
Albuquerque, New Mexico 87185-MS1188

#### **Abstract**

The Microgrid Design Toolkit (MDT) most readily supports decision analysis for new (“greenfield”) microgrid designs, but can also be used to evaluate microgrids with existing infrastructure under some limitations.

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 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 refining a microgrid design for operation in islanded mode. This second capability relies on two models: the Technology Management Optimization (TMO) model and Performance Reliability Model (PRM).

## Contents

1. MDT Process Overview .....	9
1.1 Software Installation.....	9
1.2 Pre-work.....	10
1.3 Modeling Steps.....	10
1.4 Save and Open Input Files .....	10
2. Microgrid Sizing Capability (MSC).....	11
2.1 General.....	11
2.2 Loads .....	12
2.3 Market.....	13
2.3.1 Market Information.....	13
2.3.2 Usage Charge Rates.....	14
2.4 Batteries .....	16
2.4.1 Battery Costs.....	16
2.4.2 Battery Characteristics .....	16
2.5 Distributed Energy Resource (DER) Technologies .....	17
2.6 Photovoltaics .....	18
2.6.1 Solar Resources.....	18
2.6.2 Solar Technology.....	19
2.7 Wind.....	19
2.7.1 Wind Resources .....	19
2.7.2 Wind Technology .....	20
2.8 Results Viewer .....	21
2.8.1 Costs .....	22
2.8.2 Investments .....	22
2.8.3 Save Results .....	23
2.8.4 Open Results.....	24
2.8.5 View Input for a Result Set .....	25
2.8.6 Close a Result Set.....	25
3. Islanded Mode.....	27
3.1 Editing Specifications .....	28
3.1.1 Restoring an Equipment Specifications Database .....	28

3.1.2 Equipment Specifications .....	28
3.1.3 System Load Tiers .....	34
3.2 Site Definition .....	35
3.2.1 Settings.....	35
3.2.2 Wind Resources .....	36
3.2.3 Solar Resources.....	38
3.3 Microgrids .....	40
3.3.1 Diagramming a Microgrid.....	41
3.3.2 Element Pages Overview .....	48
3.3.3 Editing Elements .....	49
3.3.4 Simple versus Complex Design Elements .....	50
3.3.5 Simple Design Elements .....	51
3.3.6 Complex Design Elements .....	63
3.3.7 Diagramming .....	67
3.3.8 Optimization Objectives .....	68
3.4 Islanded Simulator Settings.....	79
3.4.1 Simulation Settings .....	79
3.4.2 Settings of the Microgrid .....	80
3.5 Solver Settings .....	82
3.5.1 Response Groups .....	82
3.6 Progress Monitor .....	84
3.7 Results Viewer .....	85
3.7.1 Save Results .....	86
3.7.2 Open Results .....	87
3.7.3 View Input for a Result Set .....	88
3.7.4 Close a Result Set.....	88
3.7.5 View Manager Controls.....	89
3.7.6 Multiple Configuration Plots.....	90
3.7.7 Single Configuration Plots .....	99
4. Appendix A: MDT Interface Summary Overview.....	105
4.1 MDT Main Screen .....	105
4.2 Sizing Inputs.....	106

4.2.1 Editing Inputs .....	106
4.2.2 Results Viewer .....	106
4.3 Islanded Inputs .....	107
4.3.1 Diagramming a Microgrid.....	107
4.3.2 Element Pages.....	107
4.3.3 Editing Elements: Tabular Entry.....	108
4.3.3 Results Viewer .....	109
5. Appendix B: Failure Mode Distributions.....	111

## Figures

Figure 1. Prompt to include MDT databases from a previous installation.....	9
Figure 2. MSC main screen overview. ....	11
Figure 3. Overview of the Load sizing input page. ....	12
Figure 4. Overview of Market inputs page. ....	13
Figure 5. Overview of the Solar Resources page.....	18
Figure 6. Overview of the Wind Resources page. ....	19
Figure 7. Viewing MSC results.....	21
Figure 8. Overview of the MSC Investment results page. ....	21
Figure 9. Renaming a result set before saving.....	23
Figure 10. Two different result sets open in the Results Viewer. ....	24
Figure 11. Opening the input set that created this result set.....	25
Figure 12. Islanded mode main screen overview.....	27
Figure 13. Prompt to include MDT databases from a previous installation.....	28
Figure 14. Site Definition: Settings overview.....	35
Figure 15. Wind Resources definition screen. ....	36
Figure 16. Solar Resources definition screen.....	38
Figure 17. Click the button next to a microgrid name to add elements.....	40
Figure 18. Overview of Diagram page. ....	42
Figure 19. Highlighting assets in the diagram. ....	42
Figure 20. Assets available in the diagram. ....	43
Figure 21. Diagram of the realization with no power plant.....	46
Figure 22. Diagram of a power plant realization option highlighted in green.....	46
Figure 23. Diagram where a line/path is highlighted in orange.....	47
Figure 24. Variable Summary tab for a diagram. ....	47
Figure 25. Element pages overview.....	48
Figure 26. Editing elements. ....	49
Figure 27. Example of a complex design option of a switch and diesel generator.....	50
Figure 28. Simple Design Elements navigation. Elements are accessed via links below the Simple Design Elements header. ....	51
Figure 29. Click the button next to a bus name to add elements.....	52
Figure 30. Simple Design Elements -> Bus page overview. Bus elements are accessed via links on the left side of the screen. ....	53
Figure 31. Load section page overview. ....	55
Figure 32. Automated generation of data for a load. ....	56
Figure 33. Complex Design Elements navigation. Elements are accessed via tabs along the bottom of the screen. ....	64
Figure 34. Complex Design Elements -> Bus Options page overview. Bus elements are accessed via tabs near the bottom of the screen.....	65
Figure 35. Click the button next to a load section name to define it. ....	66
Figure 36. Islanded Simulator Settings screen. ....	79
Figure 37. Adding and removing metrics from Response Function Groups. ....	82

Figure 38. The "Cost" Response Function Group is empty. It contains no metrics.....	83
Figure 39. The "Performance" Response Function Group contains three metrics.....	83
Figure 40: The progress plots, which are available during lengthy model runs. ....	84
Figure 41. Results Viewer overview. ....	85
Figure 42. Renaming a result set before saving. ....	86
Figure 43. Two different result sets open in the Results Viewer. ....	87
Figure 44. Opening the input set that created this result set. ....	88
Figure 45. Overview of the View Manager Controls toolbar. ....	89
Figure 46. Guide to understanding Pareto frontiers. ....	90
Figure 47. Pareto plot with one configuration selected. The selected configuration is highlighted as a bright blue point.....	91
Figure 48. Usage Frequency displays the frequency of selection for each equipment specification. ....	92
Figure 49. Suboption Filters with all configurations displayed. ....	93
Figure 50. Suboption Filters where only the Power Plant Realization 1 option is selected. Deselected options are highlighted in red.....	93
Figure 51. Response Function Filters plot displaying all configurations. One configuration is highlighted. ....	94
Figure 52. Response Function Filters plot where the minimum value of the "Purchase Cost" metric has been increased. Two configurations are filtered out. ....	94
Figure 53: The grids view of Response Function Filters is an alternate method of viewing and filtering. ....	95
Figure 54: Rainbow view of the Response Function Filter.....	96
Figure 55. Response Function Group Filters plot displaying all configurations. One configuration is highlighted. ....	97
Figure 56. Response Function Group Filters plot where the maximum value of the Cost group has been decreased. Two configurations are filtered out.....	97
Figure 57. Overview of the Data Extraction plot.....	98
Figure 58. Response Viewer displaying a configuration's performance against the Frequency of LNS metric (shown as satisfaction level). ....	100
Figure 59. Roadmap for a single configuration that displays the selected equipment specifications....	101
Figure 60. Overview of a Diagram for a single configuration. ....	103
Figure 61. MDT main screen overview. ....	105
Figure 62. MSC main screen overview. ....	106
Figure 63. Viewing MSC results.....	107
Figure 64. Element pages overview.....	108
Figure 65. Editing elements. ....	109
Figure 66. Results Viewer page overview. ....	110

## 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 capability, the Microgrid Sizing Capability (MSC), is used to determine the size and composition of a new 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 refining a microgrid design 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 4. Appendix A: MDT Interface Summary Overview.

### 1.1 Software Installation

The installer files are provided in the download in 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 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, and you will be notified when the update is complete. Otherwise, click “Cancel and Use Default Empty DB”.

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.

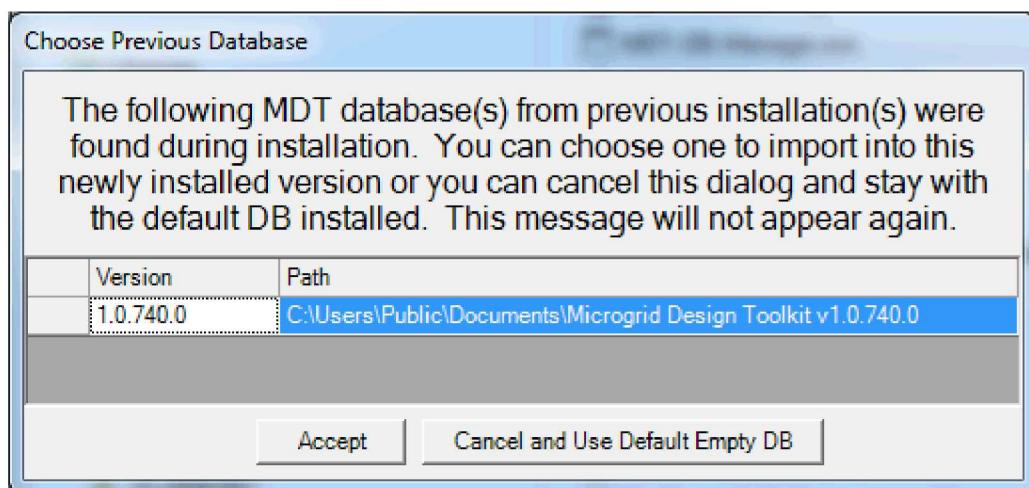


Figure 1. Prompt to include MDT databases from a previous installation.

## 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 (islanded mode analysis)

## 1.3 Modeling Steps

The first step after pre-work is complete is to gather equipment specifications and enter them into the tool via the “Edit Specifications” page 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

1. click the file open button on the main screen.
2. press the keyboard keys CTRL-O.
3. 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.

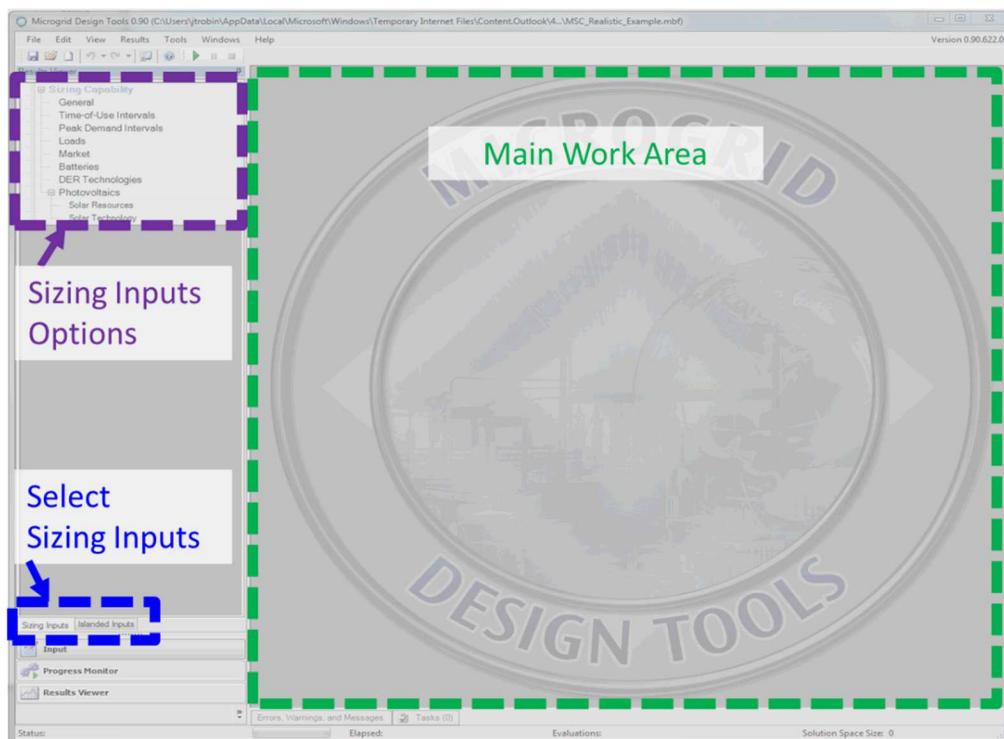


Figure 2. MSC main screen overview.

### 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.

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

## 2.2 Loads

This section is used for defining the customer's energy load. First, define the load settings (Figure 3). Specify the day of week that the calendar starts on 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.

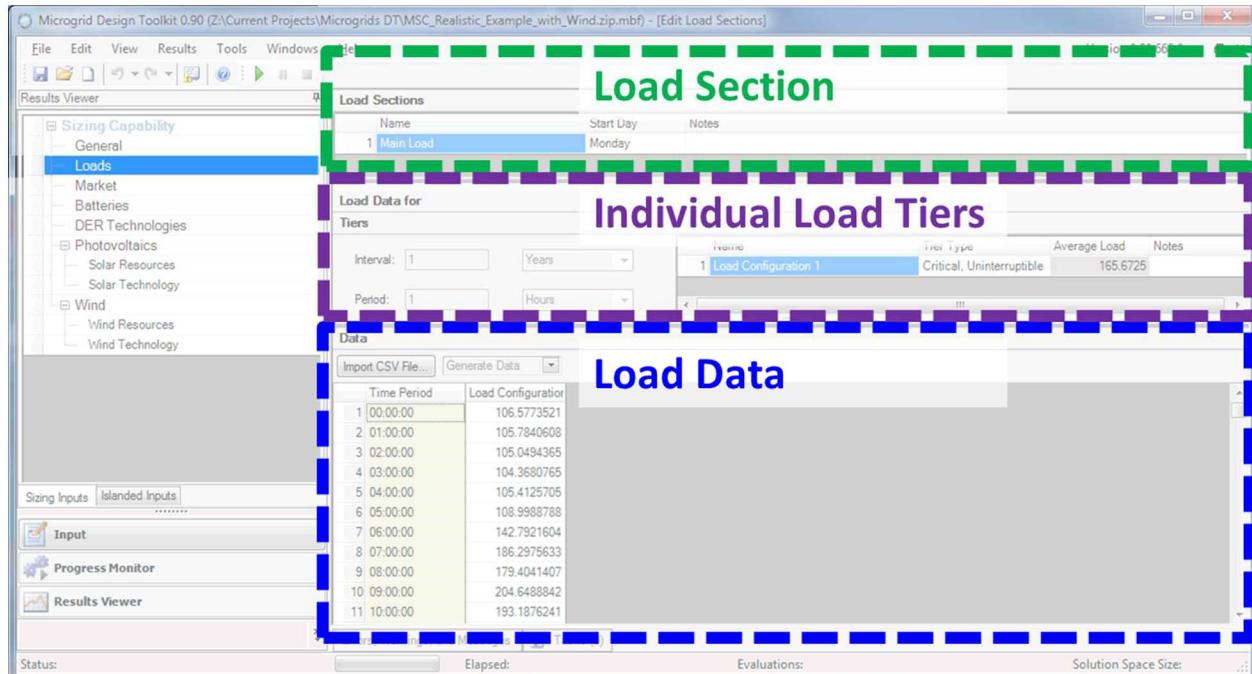


Figure 3. Overview of the Load sizing input page.

## 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.

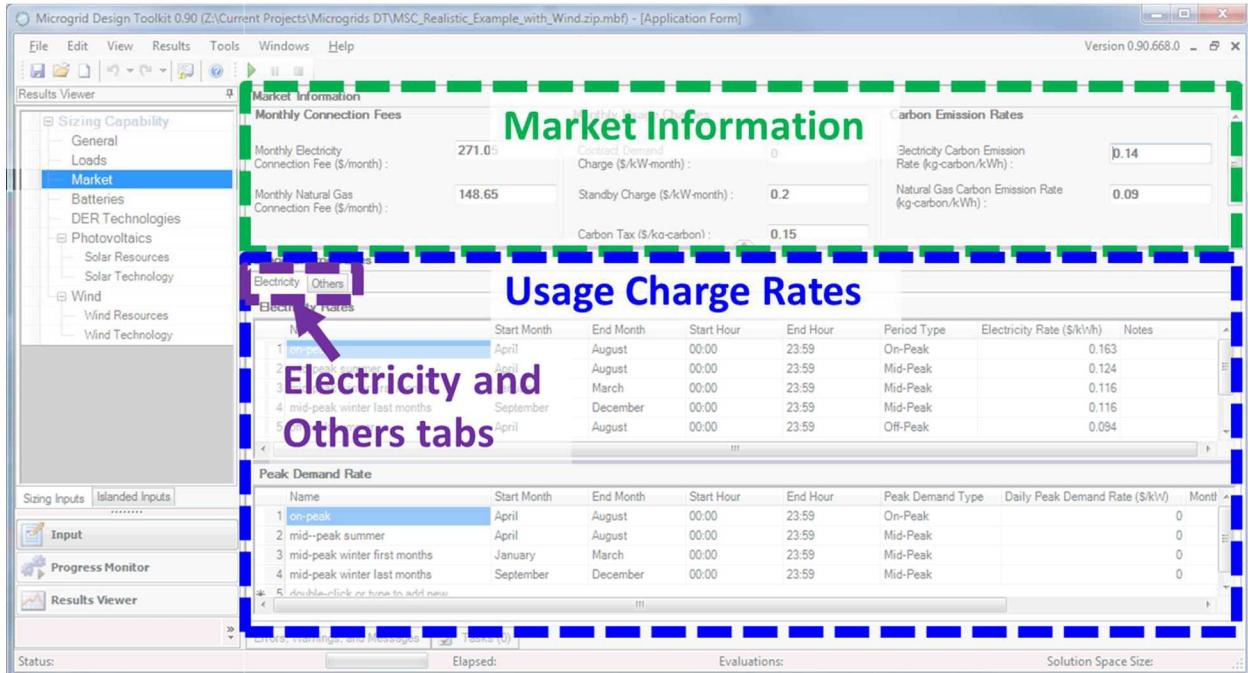


Figure 4. Overview of Market inputs page.

### 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 of 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) – Dollar amount for the natural gas rate.
- **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 is allowed to be purchased 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.
- **Notes** - User supplied notes for this battery power.

### 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 of 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 of the energy coming from the battery will be wasted, and if it is 1, all of 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 in order 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 a DER technology is allowed to be purchased 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** (\$) – The one-time fixed cost for purchasing the DER technology.
  - **Upfront Variable Capital Cost** (\$/kWh) – The one-time cost per kWh of nameplate capacity for purchasing the DER technology.
  - **Annual Maintenance Cost** (\$/kW-year) – Annual maintenance cost charged per year.
- **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, Market section, under Usage Charge Rates on the “Other” tab (see section

- 2.3 Market).
- **Maximum Annual Hours of DER Usage** (hours) – 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.

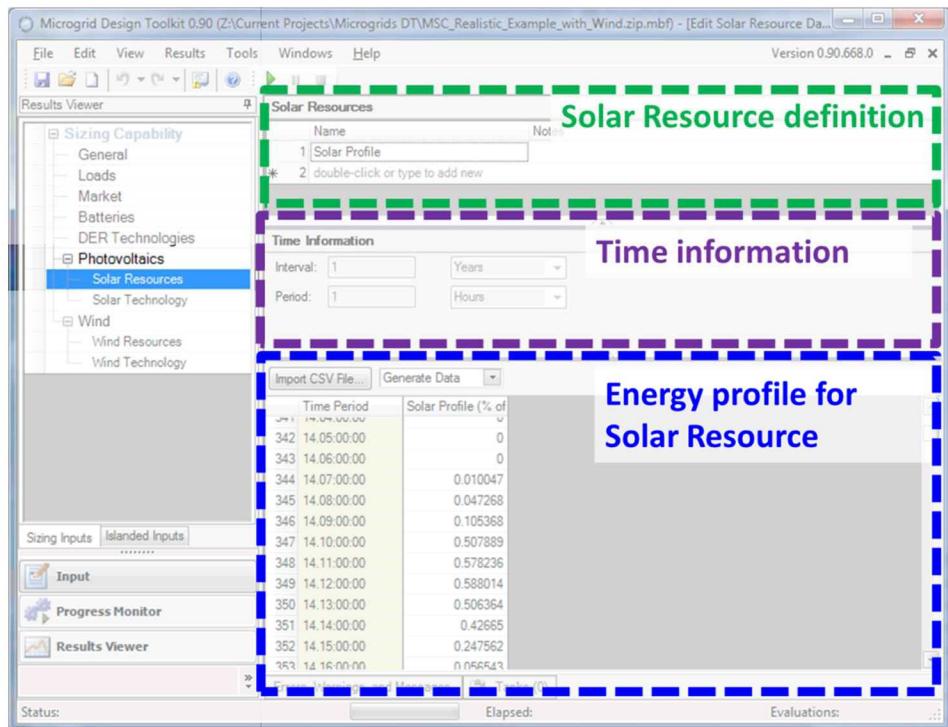


Figure 5. Overview of the Solar Resources page.

## 2.6.2 Solar Technology

The settings in this section characterize the photovoltaic technology to be used in the microgrid. If photovoltaics are allowed to be purchased 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.

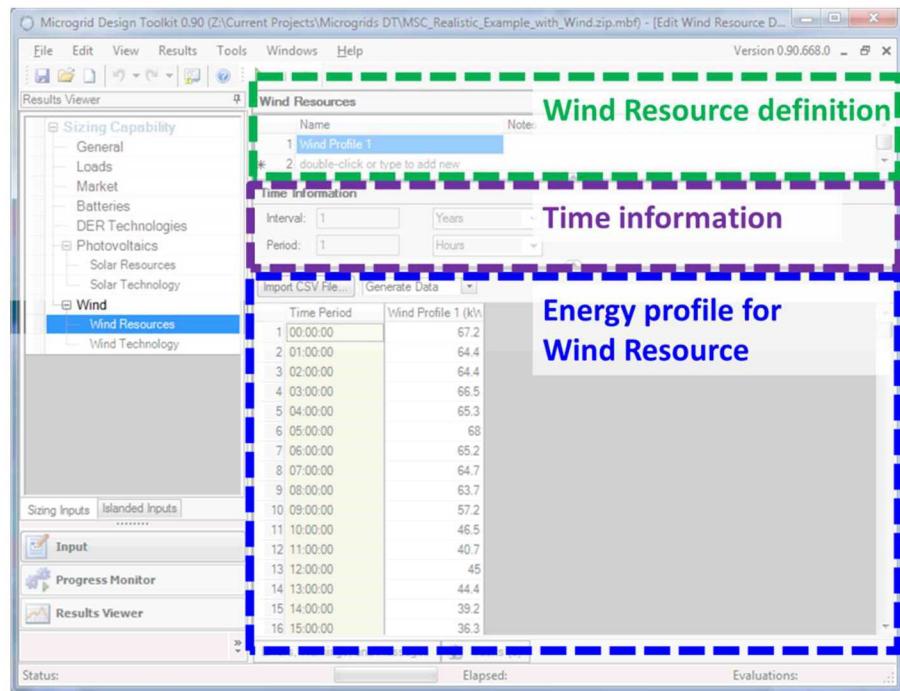


Figure 6. Overview of the Wind Resources page.

## 2.7.2 Wind Technology

The settings in this section characterize the wind technology to be used in the microgrid. If a wind technology is allowed to be purchased 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 Capacity Profile** – The wind capacity profile to be used for the wind technology. Wind capacity 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).

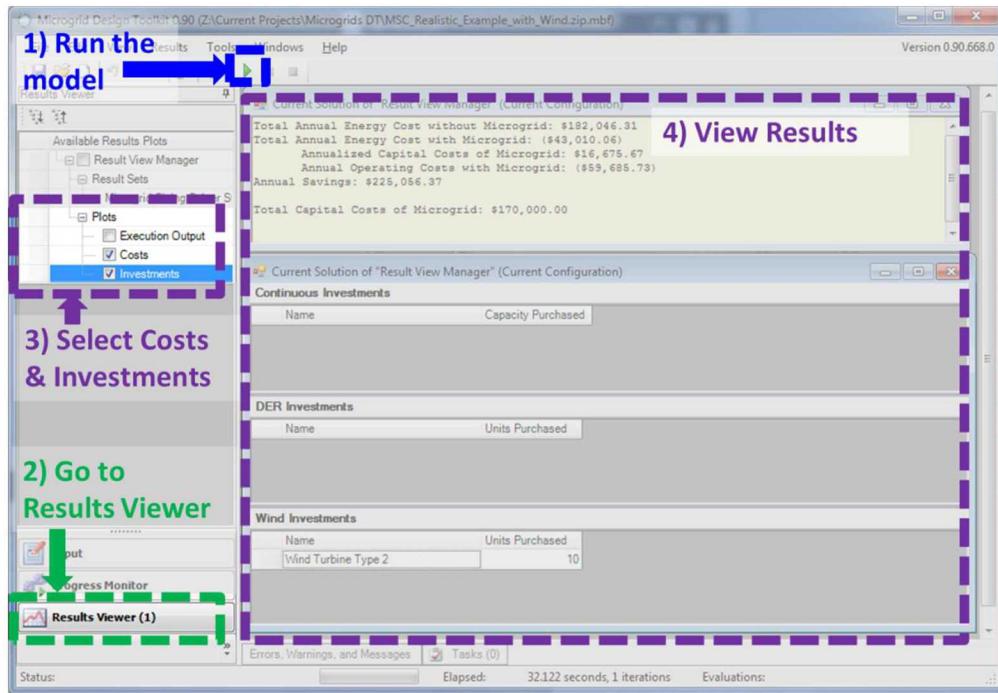


Figure 7. Viewing MSC results.

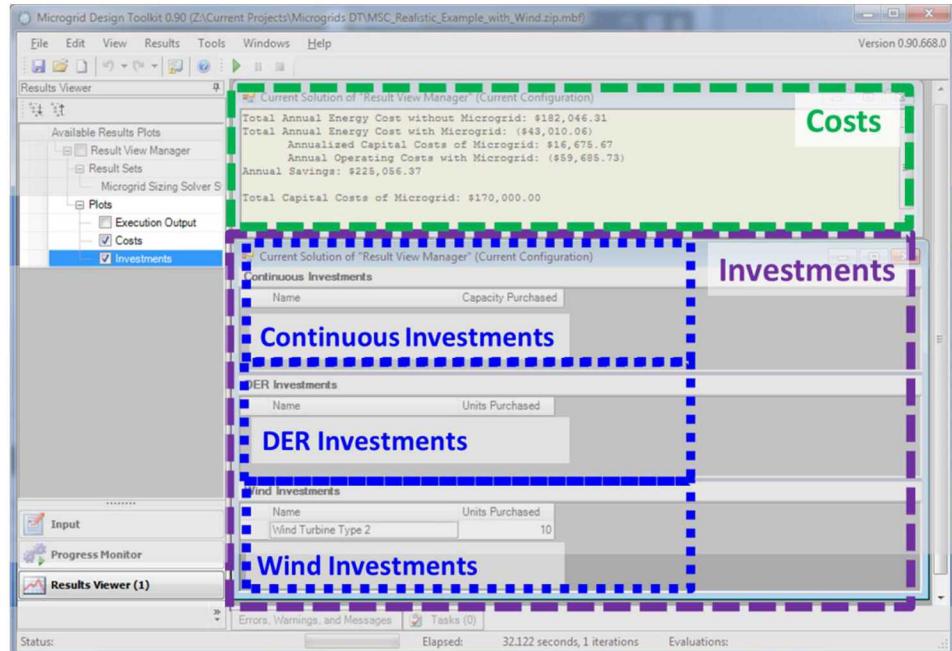


Figure 8. Overview of the MSC Investment results page.

## 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 Savings** (\$) – Difference in operating costs with a microgrid versus no microgrid.
- **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”.

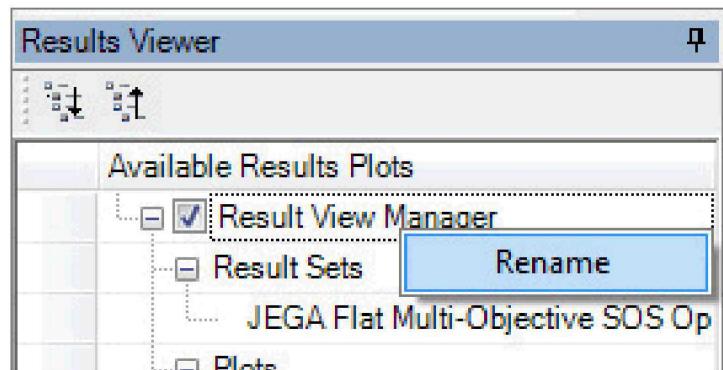


Figure 9. Renaming a result set before saving.

## 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”.

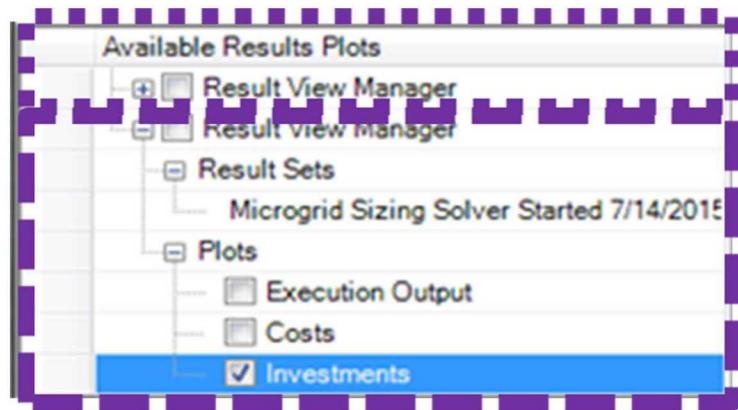


Figure 10. Two different result sets open in the Results Viewer.

## 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.

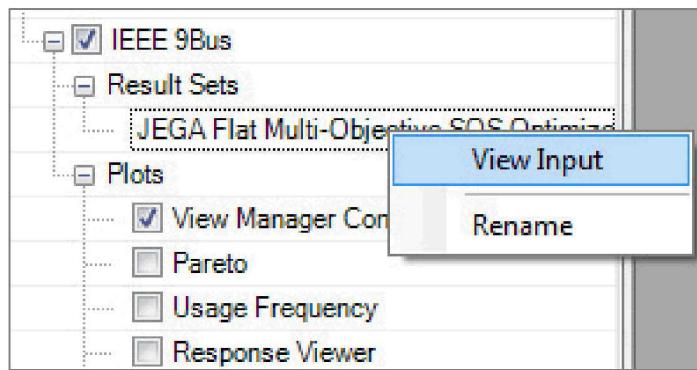


Figure 11. Opening the input set that created this result set.

## 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 refining a microgrid design 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 button (Figure 12). This will provide access to the Islanded Inputs pages.

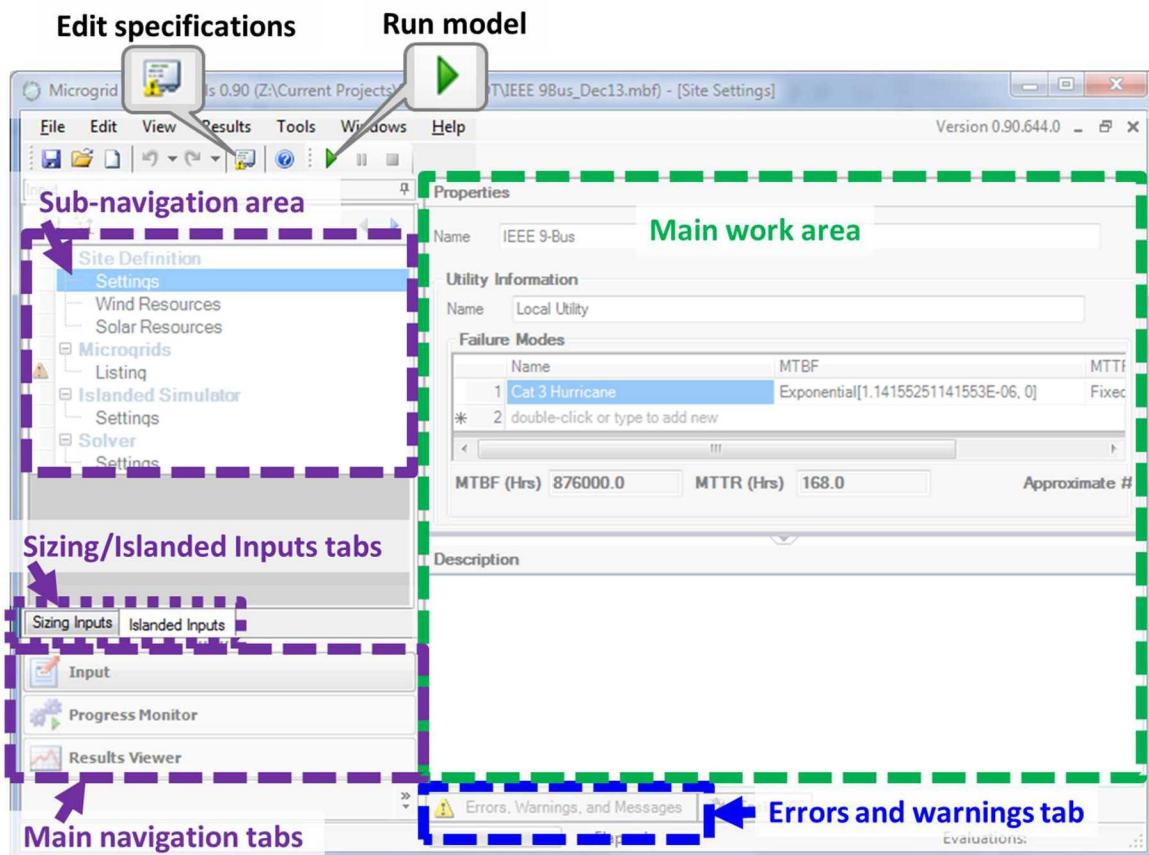


Figure 12. Islanded mode main screen overview.

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) takes up the majority of the screen. This is where elements (components of a microgrid) are added and modified.

### 3.1 Editing Specifications

The equipment specifications are accessed 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 make microgrid creation go much faster. 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. You will have to manually merge the databases 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, and you will be notified when the update is complete. Otherwise, click "Cancel and Use Default Empty DB".

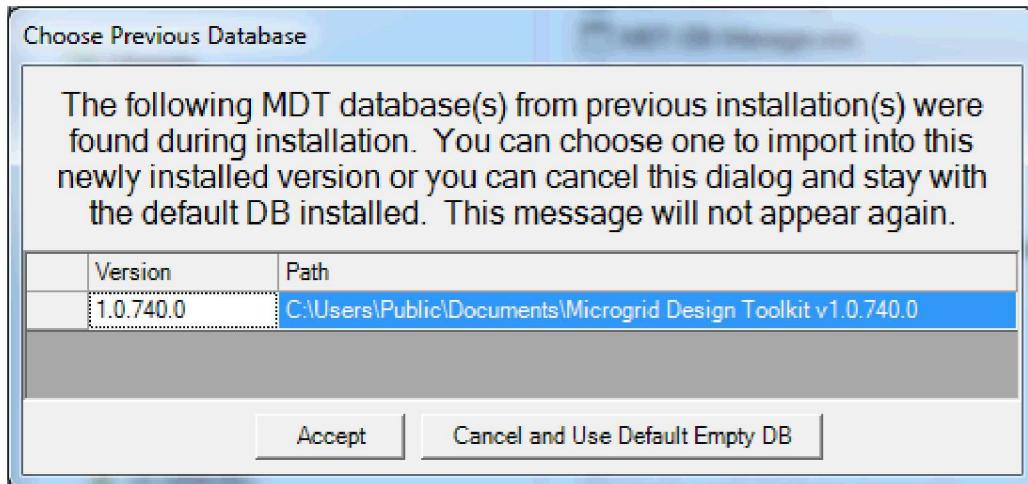


Figure 13. Prompt to include MDT databases from a previous installation.

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, browse to the installation directory of your current version. It will look something like:

C:\Program Files\Sandia National Laboratories\Microgrid Design Toolkit v1.1.839.0

Locate the executable file named MDT-DB-Manager.exe and run it by double-clicking. It will perform the process described above.

#### 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 anywhere a “notes” section is available in MDT is that typing “todo:” followed by user-entered text in the notes section will generate a “Task” in the tab near the errors, warnings, and messages. This makes it easy to create reminders.

**To add a new item,**

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

**To remove an item,**

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

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

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

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

#### Failure Modes

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 is a special failure mode particular to how/where it 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 to failure (MTTF) 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.

- **Name** – Name for the line.
- **Impedance** (Z/unit length) – The impedance of the line, per unit length. Not used in the current version of MDT. The default unit for length is feet.
- **Failure Modes (hours)** – The failure modes intrinsic to lines of this type. If no failure modes are defined, this equipment will never fail.
- **Cost (\$/unit length)** – The purchase cost of the line, per unit length. The default unit for length is feet.
- **Volume (ft<sup>3</sup>/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.
- **Cost (\$)** – The purchase cost of this type and size of switch.
- **Volume (ft<sup>3</sup>)** – The volume of this type and size of switch.
- **Notes** – User supplied notes for this switch generator.

### **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.
- **Failure Modes (hours)** – The failure modes intrinsic to diesel generators of this type. If no failure modes are defined, this equipment will never fail.
- **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 of this type of generator on the first and subsequent attempts.
- **Start Failure MTTR** – The mean time to repair for a generator that fails to start. The default is no MTTR, which results in non-repairable start failures.
- **Cost (\$)** – The purchase cost of this type and size of generator.
- **Volume (ft<sup>3</sup>)** – 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.
- **Volume (ft<sup>3</sup>)** – 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.
- **Failure Modes (hours)** – The failure modes intrinsic to generators of this type. If no failure modes are defined, this equipment will never fail.
- **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 of this type of generator on the first and subsequent attempts.
- **Start Failure MTTR** – The mean time to repair for a generator that fails to start. The default is no MTTR, which results in non-repairable start failures.
- **Cost (\$)** – The purchase cost of this type and size of generator.
- **Volume (ft<sup>3</sup>)** – The volume of this type and size of generator.
- **Notes** – User supplied notes for this natural gas generator.

### **3.1.2.6 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.
- **Failure Modes (hours)** – The failure modes intrinsic to wind generators of this type. If no failure modes are defined, this equipment will never fail.
- **Cost (\$)** – The purchase cost of this type and size of wind generator.
- **Volume (ft<sup>3</sup>)** – The volume of this type and size of generator.
- **Notes** – User supplied notes for this wind generator.

### **3.1.2.7 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.
- **Failure Modes (hours)** – The failure modes intrinsic to solar generators of this type. If no failure modes are defined, this equipment will never fail.
- **Cost (\$)** – The purchase cost of this type and size of solar generator.
- **Volume (ft<sup>3</sup>)** – The volume of this type and size of generator.
- **Notes** – User supplied notes for this solar generator.

### **3.1.2.8 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.
- **Cost (\$)** – The purchase cost of this type and size of battery.
- **Volume (ft<sup>3</sup>)** – The volume of this type and size of battery.
- **Notes** – User supplied notes for this battery.

### **3.1.2.9 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).
- **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.
- **Cost (\$)** – The purchase cost of this type and size of UPS.
- **Volume (ft<sup>3</sup>)** – The volume of this type and size of UPS.
- **Notes** – User supplied notes for this UPS.

### **3.1.2.10 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.
- **Cost (\$)** – The purchase cost of this type and size of inverter.
- **Volume (ft<sup>3</sup>)** – The volume of this type and size of inverter.
- **Notes** – User supplied notes for this inverter.

### **3.1.2.11 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.
- **Cost (\$)** – The purchase cost of this type and size of transformer.
- **Volume (ft<sup>3</sup>)** – 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 displayed 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 and 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. There can be more than one microgrid at a given site. The site itself has attributes which are input by the user.

### 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, and a list of utility failure modes that would cause a utility outage and trigger use of the microgrid in islanded mode.

Properties				
Name	IEEE 9-Bus			
Utility Information				
Name	Local Utility			
Failure Modes				
	Name	MTBF	MTTR	Notes
1	Cat 3 Hurricane	Exponential[1.14155251141553E-06, 0]	Fixed[168]	
*	2	double-click or type to add new		

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 exist (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 mode refers 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 Wind Resources

The Wind Resources section (Figure 15) is intended to provide information about wind that could be made available at that 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.

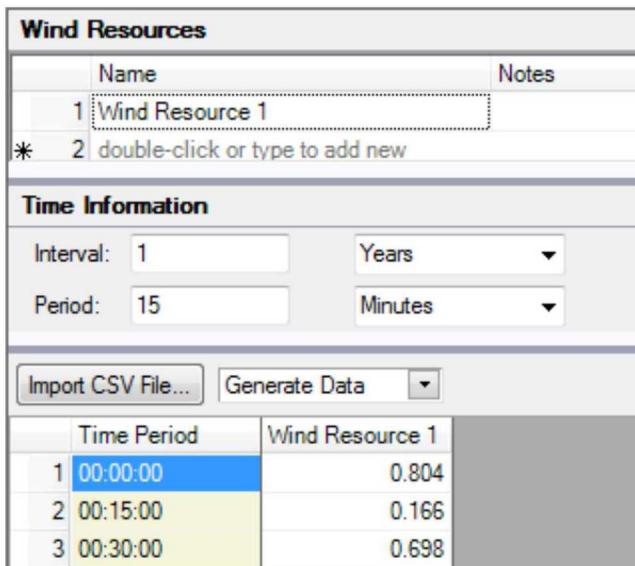


Figure 15. Wind Resources definition screen.

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 (1 <sup>st</sup> 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.
- 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 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, or Hours.
- 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 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 – This will create notional but realistic 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 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 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).

### 3.2.3 Solar Resources

The Solar Resources section (Figure 16) 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.

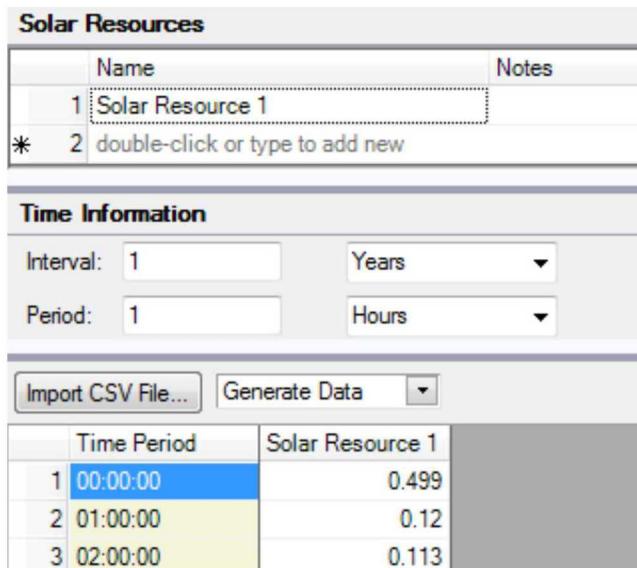


Figure 16. Solar Resources definition screen.

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 (1 <sup>st</sup> 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.
- 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 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, or Hours.
- 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 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 – 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.

### 3.3 Microgrids

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

Enter the following information in the table to define your microgrid options. 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 question. This field is not editable.
- **Average Fixed Load (kW)** – This field is calculated by MDT based on the average loads for all defined buses. This field is not editable.
- **Fixed Volume (ft<sup>3</sup>)** – The volume 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 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.
- **Notes** – User supplied notes for this microgrid option.

Click in the Name field. Click the button with an ellipsis (highlighted in purple in Figure 17) to begin adding elements to your microgrid option. A new window will open with element options. When you have completed entering information about your microgrid option, click the “Finish” button at the bottom of the screen to close the window.

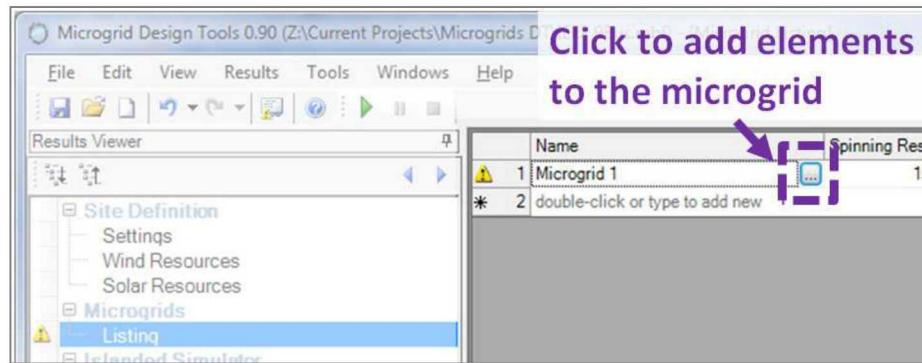


Figure 17. Click the button next to a microgrid name to add elements.

### **3.3.1 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 3.3.2 Element Pages Overview through

3.3.6 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 18). The properties will be displayed on the lower right side of the screen in the Properties window (highlighted in green in Figure 18). Make sure the Properties tab is selected. 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 orange in Figure 18) allows you to add new assets to the diagram.

The menu across the top of the diagram tool (Figure 18) 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 whether or not diesel tanks and their connections are displayed.
- 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).
- 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).

Hovering over an asset type in the asset menu (Figure 19) 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.

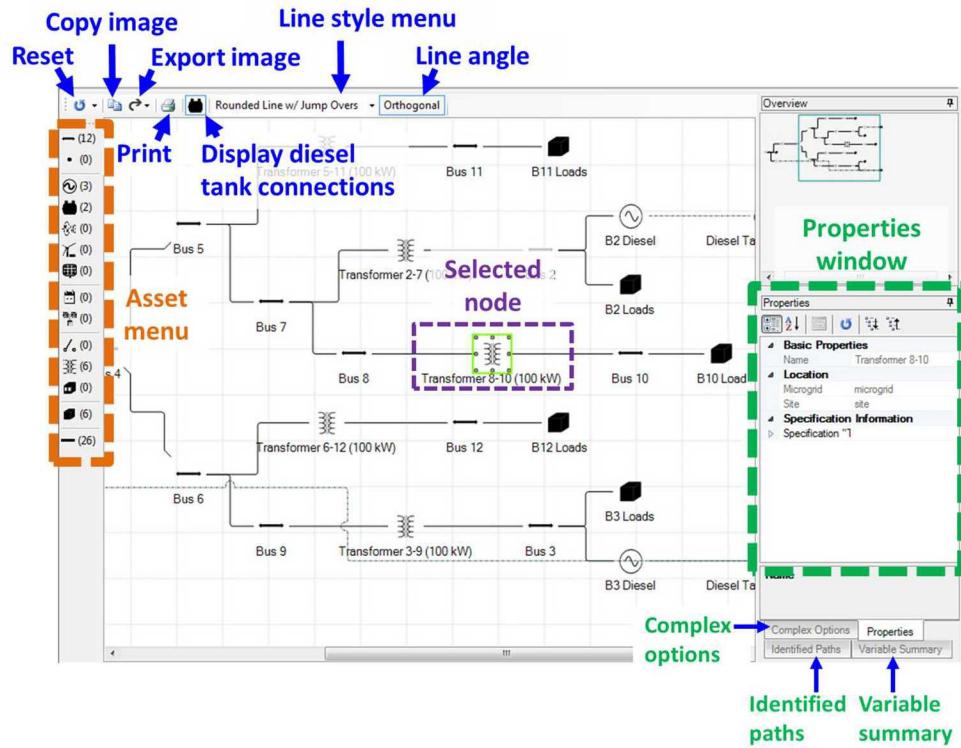


Figure 18. Overview of Diagram page.

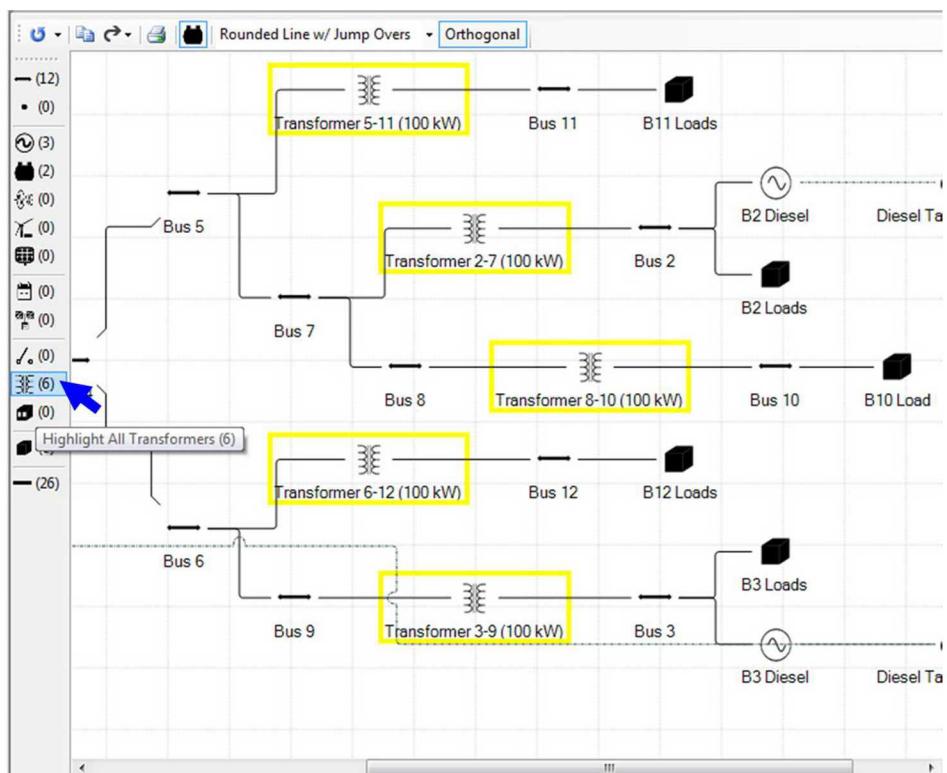


Figure 19. Highlighting assets in the diagram.

### 3.3.1.2 Adding Assets to the Microgrid

Definitions for all assets can be found section 3.3.5 Simple Design Elements. To add an asset to the microgrid, click on an item in the asset menu (Figure 20) and drag the item into the workspace. The following assets can be added directly to the workspace:

- Buses
- Diesel Tanks
- Nodes
- Switches
- Transformers

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

- Batteries
- Diesel Generators
- Inverters
- Load Sections
- Natural Gas Generators
- Solar Generators
- UPSs
- Wind Generators

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.

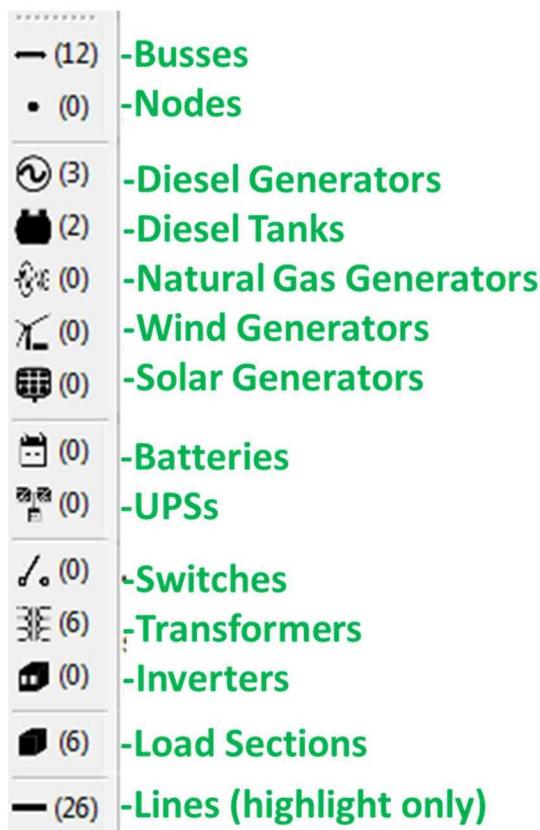


Figure 20. Assets available in the diagram.

There are two 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.
  - b. 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.
  - d. The line connecting the two assets will automatically be added.
  - e. 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.

To remove an asset or a line from the diagram, select the asset or line and then click the “Delete” key.

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 19).

**Table 1. Legal asset connections in the diagram tool.**

	Batteries	Buses	Diesel Generators	Diesel Tanks	Inverters	Load sections	Natural Gas Generators	Nodes	Solar Generators	Switches	Transformers	UPSs	Wind Generators
Batteries	x				x					x	x		
Buses	x	x	x		x	x	x	x	x	x	x	x	x
Diesel Generators		x		x	x					x	x		
Diesel Tanks			x										
Inverters	x	x	x			x	x		x	x	x	x	x
Load Sections		x			x					x	x	x	
Natural Gas Generators		x			x					x	x		
Nodes		x						x		x	x		
Solar Generators		x			x					x	x		
Switches	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
UPSs		x			x	x				x	x		
Wind Generators		x			x					x	x		

### **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 3.3.5 Simple Design Elements.

- 3.3.5.1 Buses
- 3.3.5.2 Loads
- 3.3.5.3 Diesel Generators
- 3.3.5.4 Natural Gas Generators
- 3.3.5.5 Wind Generators
- 3.3.5.6 Solar Generators
- 3.3.5.7 Batteries
- 3.3.5.8 Uninterruptible Power Supplies (UPS)

- 3.3.5.9 Inverters
- 3.3.5.10 Nodes

- 3.3.5.11 Switches
- 3.3.5.12 Transformers

- 3.3.5.13 Lines
- 3.3.5.14 Diesel Tanks

### ***3.3.1.4 Complex Design Elements***

Complex design elements must still be created through tabular entry. See section

### 3.3.6 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. Figure 21 shows a realization with no power plant. Figure 22 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.

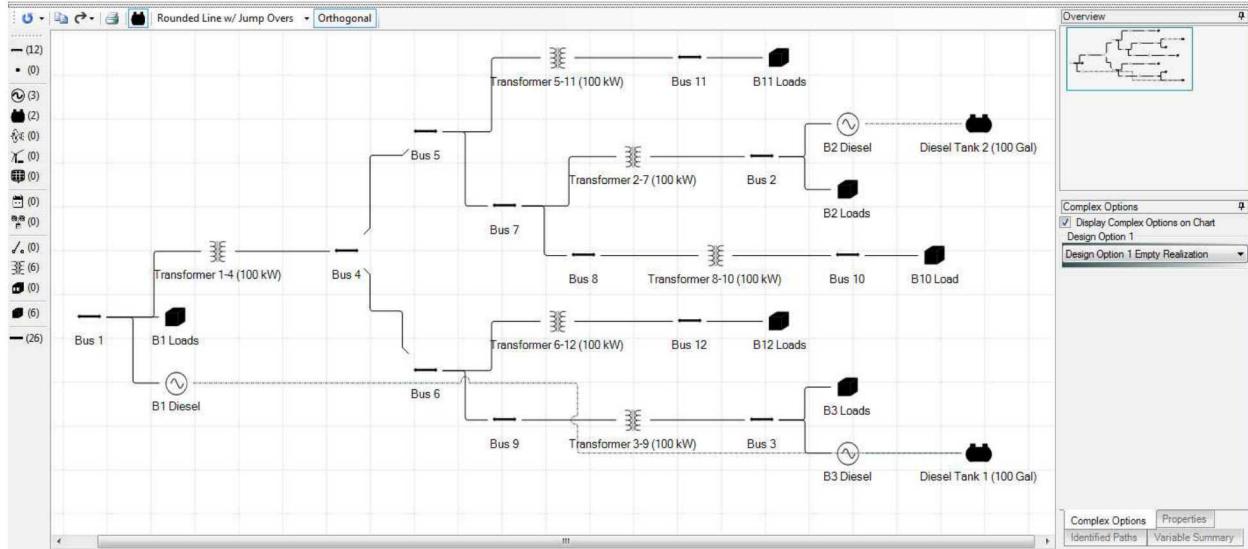


Figure 21. Diagram of the realization with no power plant.

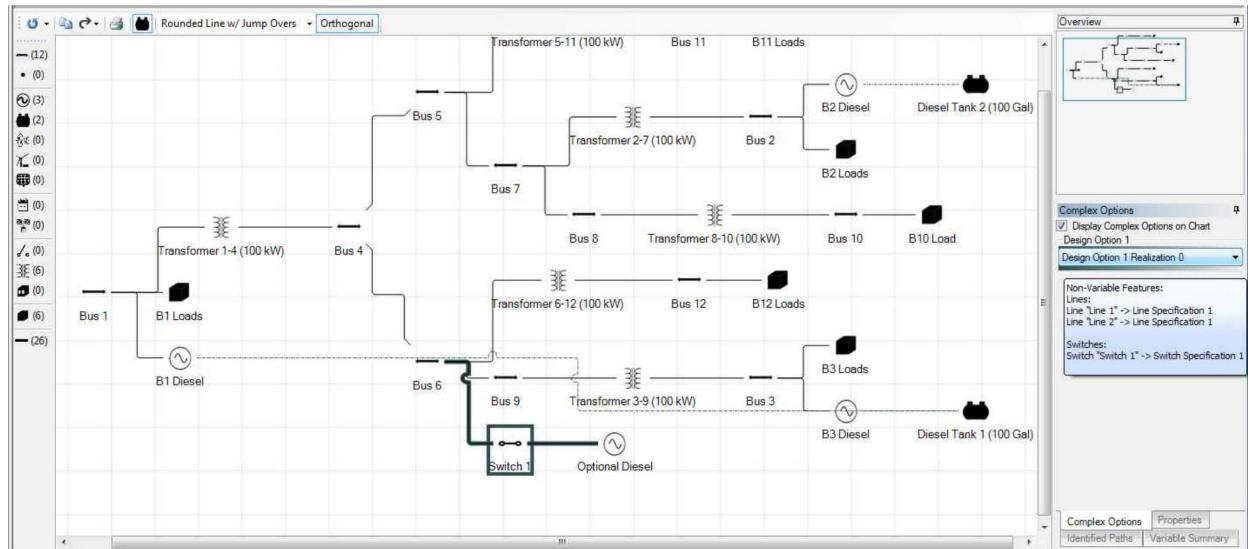


Figure 22. Diagram of a power plant realization option highlighted in green.

Identified Paths is the third tab. It lists all of the paths defined in the microgrid option. Paths are automatically discovered by the application. Hovering over each path in the table highlights the corresponding elements in the diagram (Figure 23).

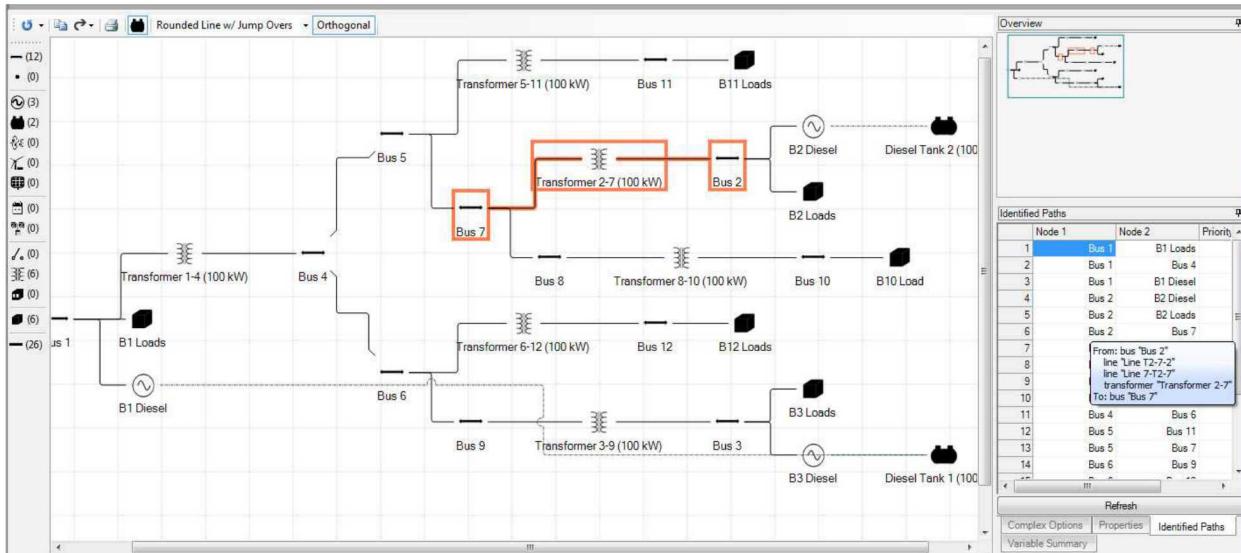


Figure 23. Diagram where a line/path is highlighted in orange.

Variable Summary is the fourth tab (Figure 24). 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.

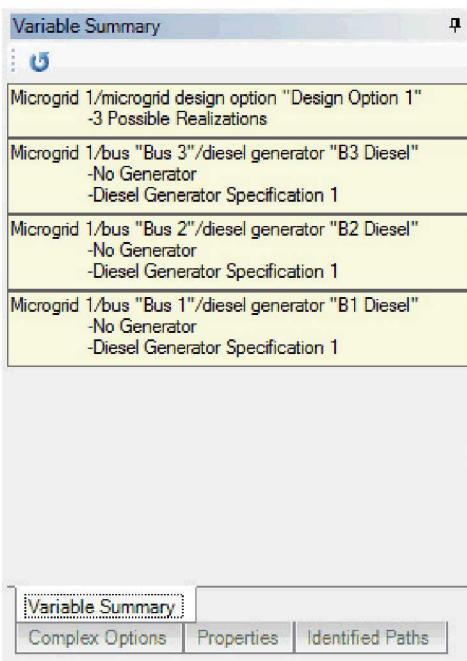


Figure 24. Variable Summary tab for a diagram.

### 3.3.2 Element Pages Overview

Figure 25 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).

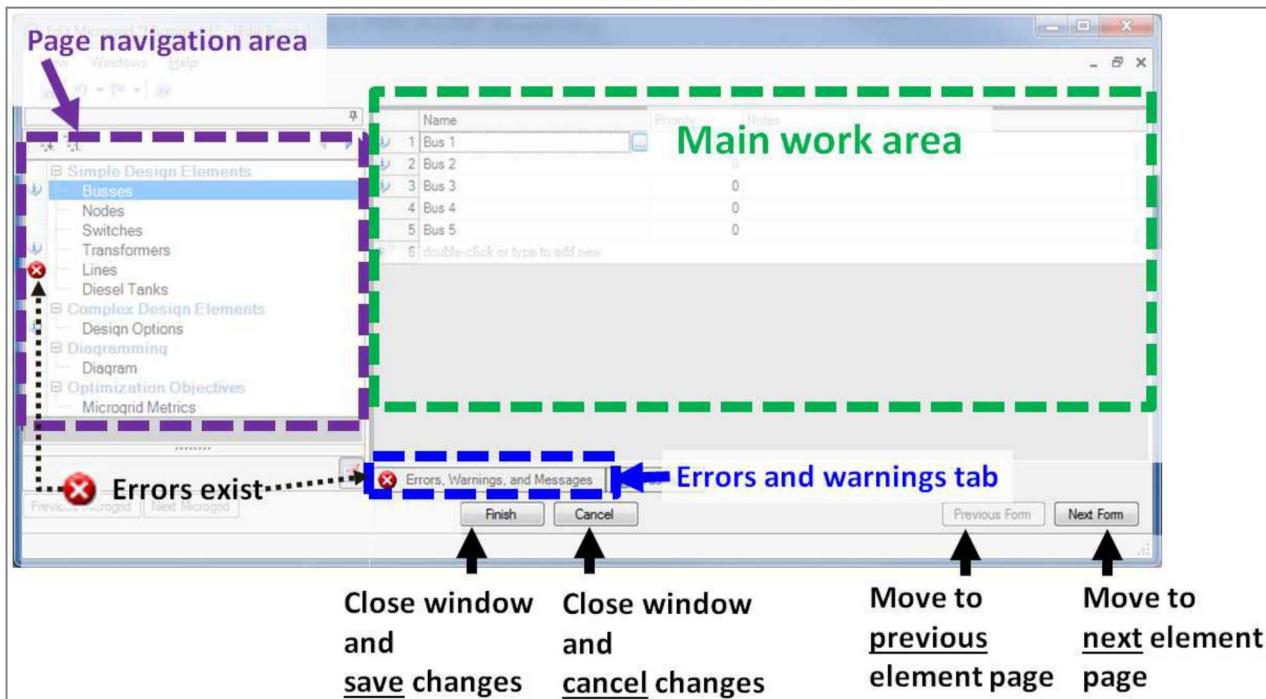


Figure 25. Element pages overview.

### 3.3.3 Editing Elements

Figure 26 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,

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

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

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

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

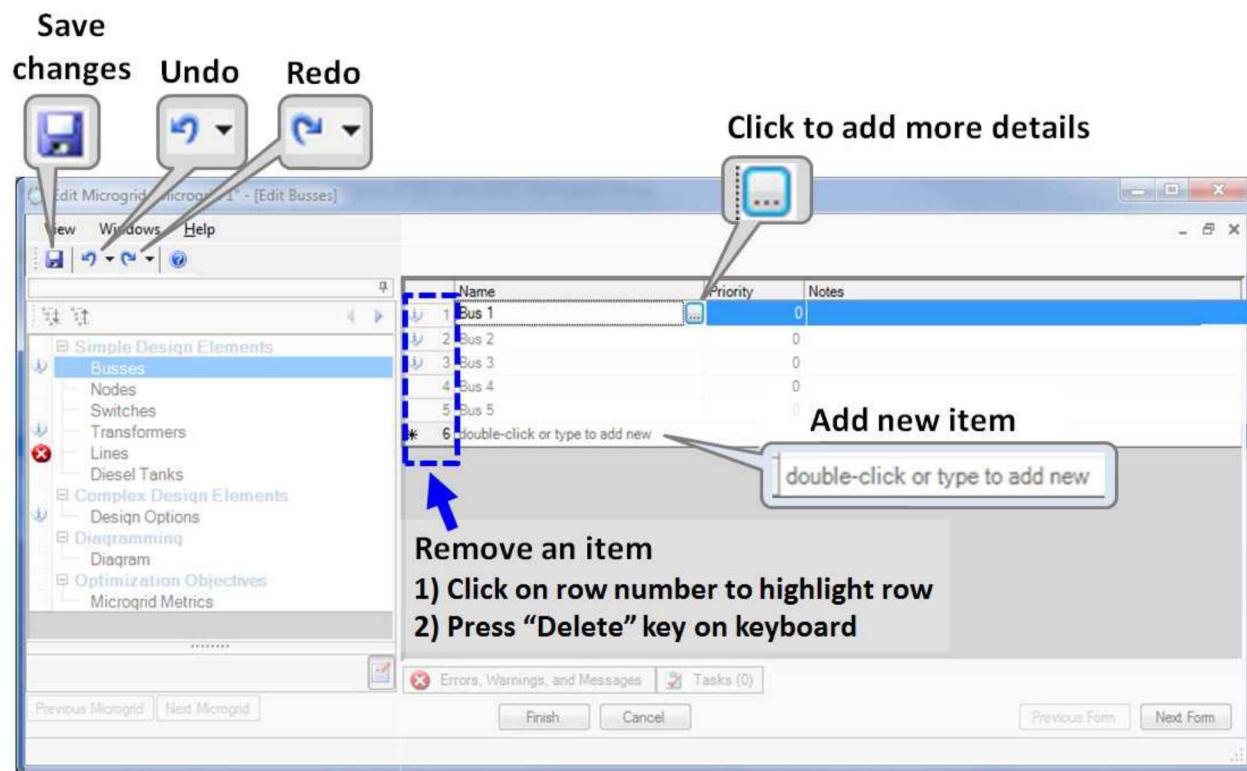
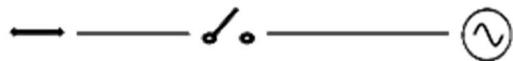


Figure 26. Editing elements.

### 3.3.4 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 27). 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.

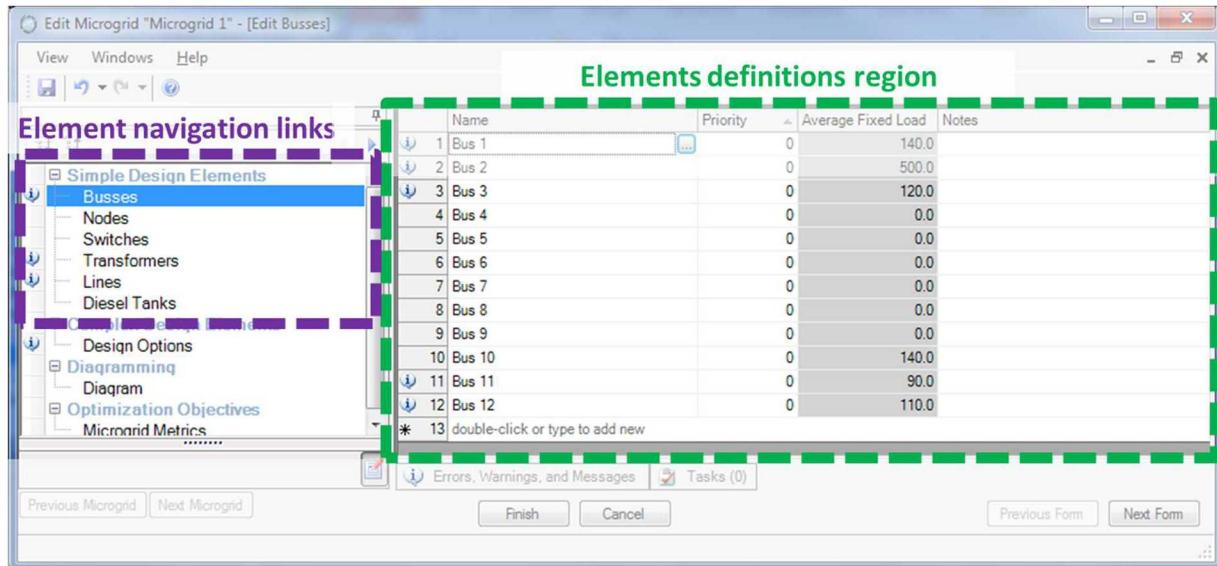


**Figure 27. Example of a complex design option of a switch and diesel generator.**

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.

### 3.3.5 Simple Design Elements

The different element pages (highlighted in green in Figure 28) are accessible via links located beneath the Simple Design Elements header (highlighted in purple in Figure 28).



**Figure 28. Simple Design Elements navigation. Elements are accessed via links below the Simple Design Elements header.**

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. 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 specifications options.

### 3.3.5.1 Buses

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. Default values are provided for all fields, some of which may be empty fields or no value.

- **Name** – Name for the bus.
- **Priority** – The priority of this bus relative to all other buses. 0 (zero) is the highest priority.
- **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).
- **Notes** – User supplied notes for this bus.

Click in the Name field. Click the button with an ellipsis (highlighted in purple in Figure 29) to begin adding elements to your bus. A new window will open with element options.

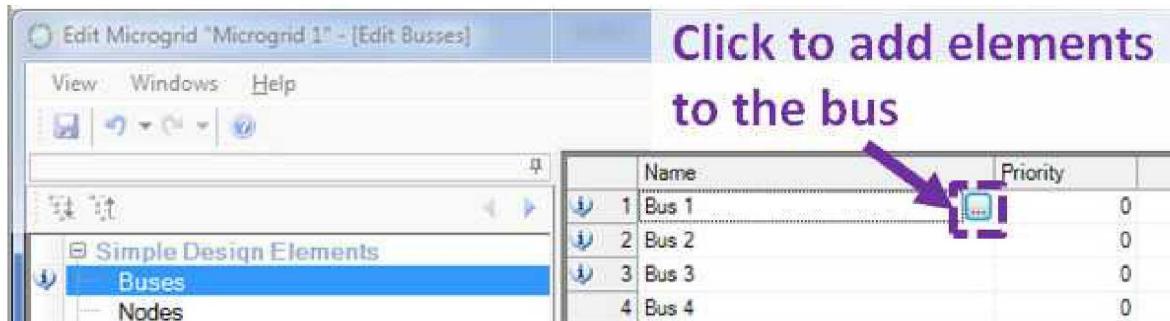


Figure 29. Click the button next to a bus name to add elements.

The different element pages (highlighted in green in Figure 30) are accessible via links located on the left (highlighted in purple in Figure 30). When you have completed entering information about buses, click the “Finish” button at the bottom of the screen to close the window.

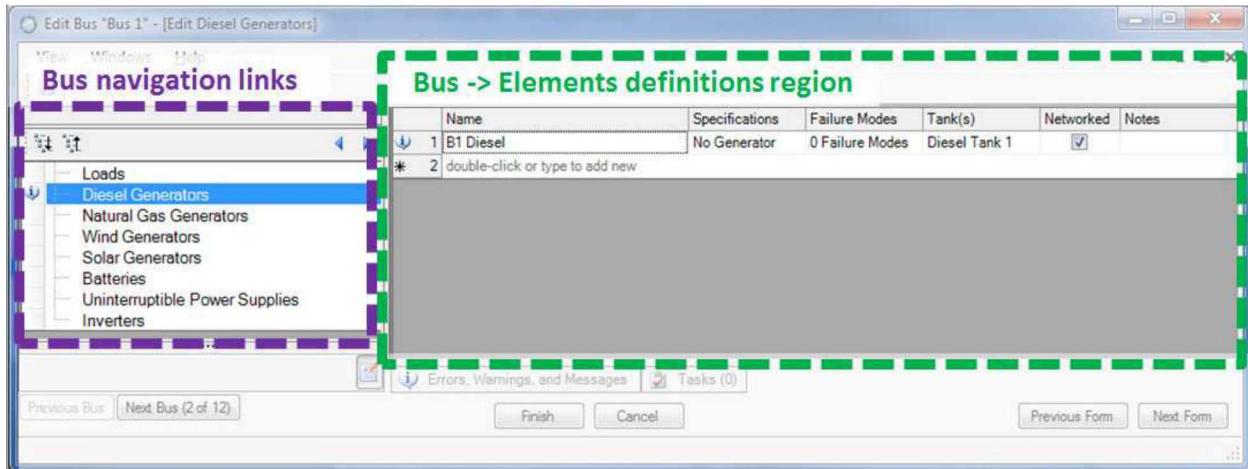


Figure 30. Simple Design Elements -> Bus page overview. Bus elements are accessed via links on the left side of the screen.

### 3.3.5.2 Loads

A load section is a group of 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 31)

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.
- **Priority** – The priority of this load section relative to all other load sections. 0 (zero) is the highest priority.
- **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 31)
  - **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** (highlighted in blue in Figure 31)
    - **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

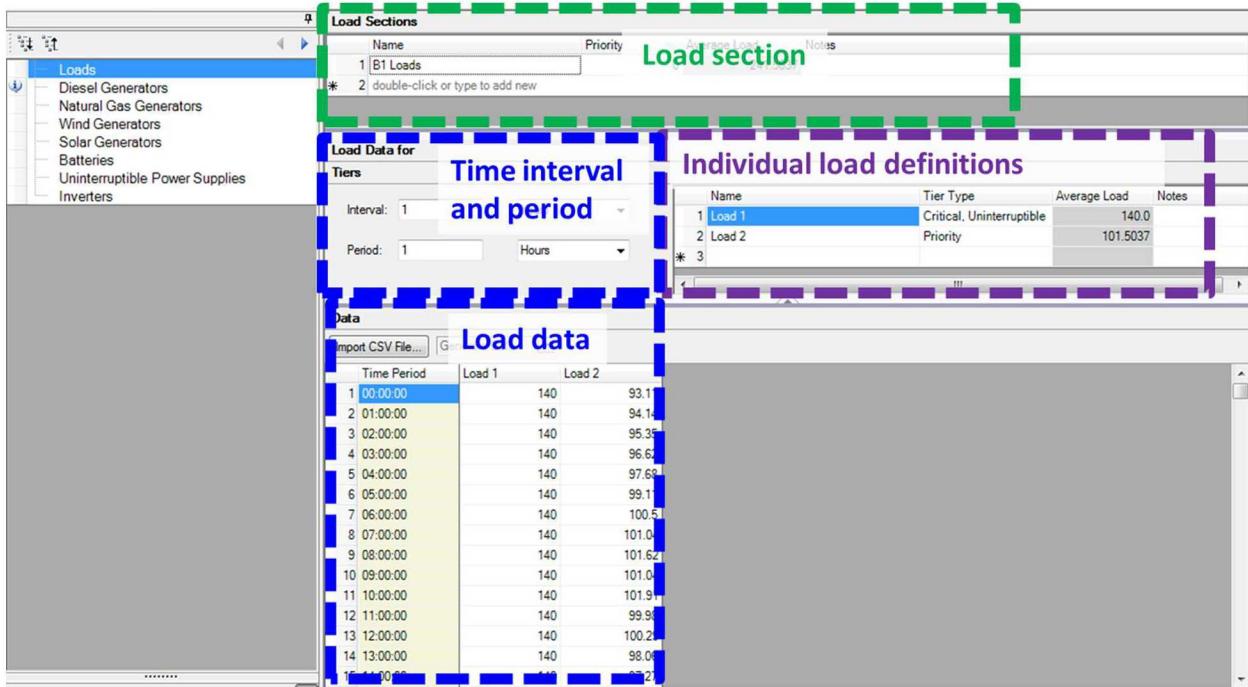


Figure 31. Load section page overview.

- *Data* (highlighted in blue in Figure 31)
  - 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 copy-n-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 32). 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).

Load Data for

Tiers

Interval: 1 Years

Name

1 Load 1

2 Load 2

Period: 1 Click the Generate Data dropdown menu

Data

Import CSV File... Generate Data

Time Period

Time Period	1 00:00:00	2 01:00:00	3 02:00:00	4 03:00:00	5 04:00:00	6 05:00:00	7 06:00:00	8 07:00:00	9 08:00:00	10 09:00:00	11 10:00:00	12 11:00:00	13 12:00:00	14 13:00:00	15 14:00:00	16 15:00:00	17 16:00:00	18 17:00:00	19 18:00:00	20 19:00:00	21 20:00:00
Baseline Magnitude:	100																				
Yearly Sinusoidal Variation																					
Amplitude:	5																				
Phase Shift (Degrees):	-45																				
Daily Sinusoidal Variation																					
Amplitude:	5																				
Phase Shift (Degrees):	-45																				
Gaussian Noise																					
Mean:	0																				
Standard Deviation:	0.5																				
Generate	Cancel																				

140 90.45 140 95.35 140 92.92 140 92.52 140 92.47 140 92.29

Figure 32. Automated generation of data for a load.

### 3.3.5.3 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 this particular generator a decision variable. The model will help you determine which option is better 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 particular to 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 this particular tank a decision variable. The model will help you determine which option is better for your grid design.
- **Networked** – Whether or not 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.

### 3.3.5.4 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 this particular generator a decision variable. The model will help you determine which option is better 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 particular to how/where this generator is used. Failure modes that are generic to all generators should be defined in the Specifications section.
- **Networked** – Whether or not 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.

### 3.3.5.5 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 this particular generator a decision variable. The model will help you determine which option is better 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 particular to how/where this generator is used. Failure modes that are generic to all generators should be defined in the Specifications section.
- **Networked** – Whether or not 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.

### 3.3.5.6 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 this particular generator a decision variable. The model will help you determine which option is better 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 particular to how/where this generator is used. Failure modes that are generic to all generators should be defined in the Specifications section.
- **Networked** – Whether or not 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.

### 3.3.5.7 **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 this particular battery a decision variable. The model will help you determine which option is better 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 particular to 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.

### 3.3.5.8 **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 this particular UPS a decision variable. The model will help you determine which option is better 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 particular to 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.

### 3.3.5.9 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 this particular inverter a decision variable. The model will help you determine which option is better 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 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 particular to how/where this inverter is used. Failure modes that are generic to all inverters should be defined in the Specifications section.
- **Notes** – User supplied notes for this inverter.

### 3.3.5.10 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.

- **Name** – Name for the diesel node.
- **Notes** – User supplied notes for this node.

### 3.3.5.11 Switches

Switches are considered to be 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.

- **Name** – Name for the switch.
- **Default State** – Whether this switch is normally open or closed.
- **Baseline Specification** – The specification describing the current (existing) switch.
- **Allowable Specifications** – Select one or more of the switches defined in the Specifications section. Selecting more than one specification makes this particular switch a decision variable. The model will help you determine which option is better 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 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 particular to 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.
- **Notes** – User supplied notes for this switch.

### 3.3.5.12 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.

- **Name** – Name for the transformer.
- **Baseline Specification** – The specification describing the current (existing) transformer.
- **Allowable Specifications** – Select one or more of the transformers defined in the Specifications section. Selecting more than one specification makes this particular transformer a decision variable. The model will help you determine which option is better 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 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 particular to how/where this transformer is used. Failure modes that are generic to all transformers should be defined in the Specifications section.
- **Notes** – User supplied notes for this generator.

### 3.3.5.13 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.

- **Name** – Name for the line.
- **First Node** – 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.
- **Second Node** – 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.
- **Length (ft)** – The length between the two nodes. Length will be used for power flow calculations once implemented in the MDT. Currently, length is used only to compute the cost of a line which is defined per unit length.
- **Baseline Specification** – The specification describing the current (existing) line.
- **Allowable Specifications** – Select one or more of the lines defined in the Specifications section. Selecting more than one specification makes this particular line a decision variable. The model will help you determine which option is better for your microgrid design.
- **Retrofit Cost (\$)** – The cost associated with using the baseline specification (existing equipment) in a microgrid solution on a per unit length basis.
- **Failure Modes (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 particular to how/where this line is used. Failure modes that are generic to all lines should be defined in the Specifications section.
- **Notes** – User supplied notes for this line.

### 3.3.5.14 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.

- **Name** – Name for the diesel tank.
- **Initial Quantity** (gallons) – The initial amount of fuel in the tank. If the tank is full (regardless of tank size due to specification selection), enter -1.
- **Baseline Specification** – 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 this particular diesel tank a decision variable. The model will help you determine which option is better 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.

### 3.3.6 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.

All elements have a baseline specification, allowable specifications and retrofit costs. A baseline specification is used for existing grid systems. 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. 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 specifications options.

#### 3.3.6.1 Design Option

To create a new complex design option, on the Microgrids window, go to the Complex Design Elements -> Design Options section of the Inputs tab. Enter the following information in the table to define your design option. 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 3.3.6.3 Realizations for more details.
- **Notes** – User supplied notes for this design option.

A complex design option has all of the same element fields as the simple design element section. The different element pages (highlighted in green in Figure 33) are accessible via tabs located at the bottom of the Design Options screen (highlighted in purple in Figure 33). If there is more than one design option listed in the table, click on the row of a design option to view its elements.

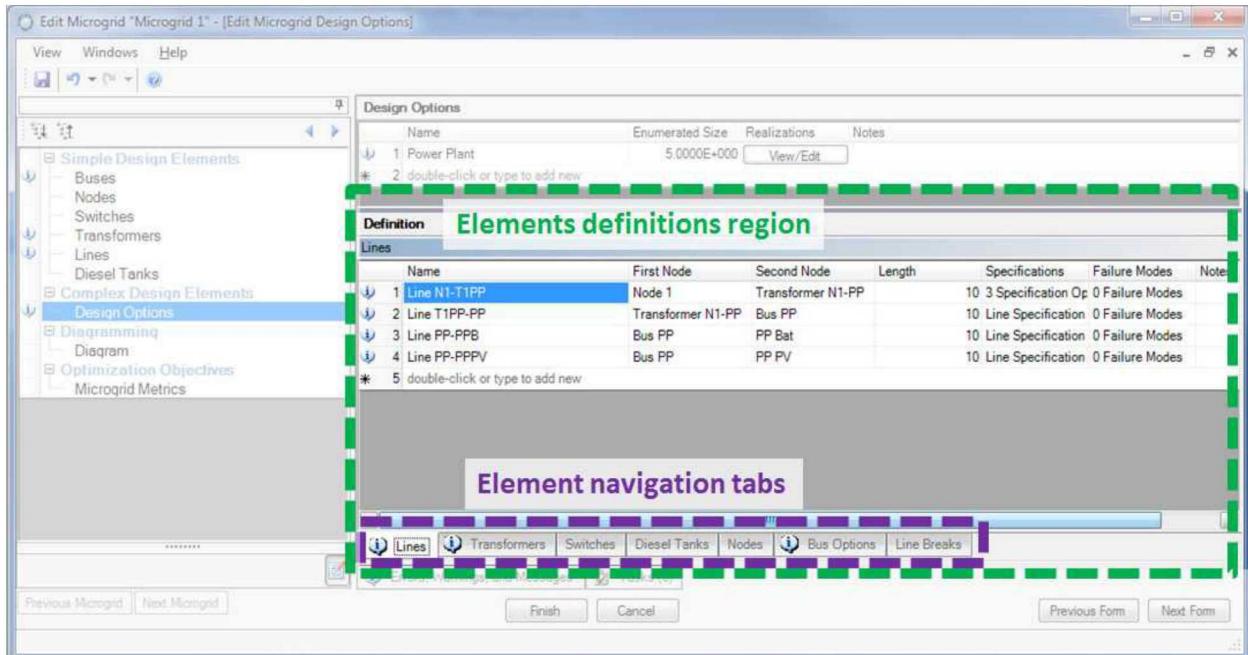


Figure 33. Complex Design Elements navigation. Elements are accessed via tabs along the bottom of the screen.

### 3.3.6.2 **Enumerated Size**

This integer reflects the size of this design option when fully enumerated.

### 3.3.6.3 **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. In some cases, 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.

### 3.3.6.4 **Lines**

Please see the

3.3.5.13 Lines section under 3.3.5 Simple Design Elements for description.

### ***3.3.6.5 Transformers***

Please see the 3.3.5.12 Transformers section under 3.3.5 Simple Design Elements for description.

### ***3.3.6.6 Switches***

Please see the

3.3.5.11 Switches section under 3.3.5 Simple Design Elements for description.

### ***3.3.6.7 Diesel Tanks***

Please see the 3.3.5.14 Diesel Tanks section under 3.3.5 Simple Design Elements for description.

### 3.3.6.8 Nodes

Please see the 3.3.5.10 Nodes section under 3.3.5 Simple Design Elements for description.

### 3.3.6.9 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 34). The different element pages (highlighted in green in Figure 34) are accessible via tabs located on the bottom of the screen (highlighted in purple in Figure 34).

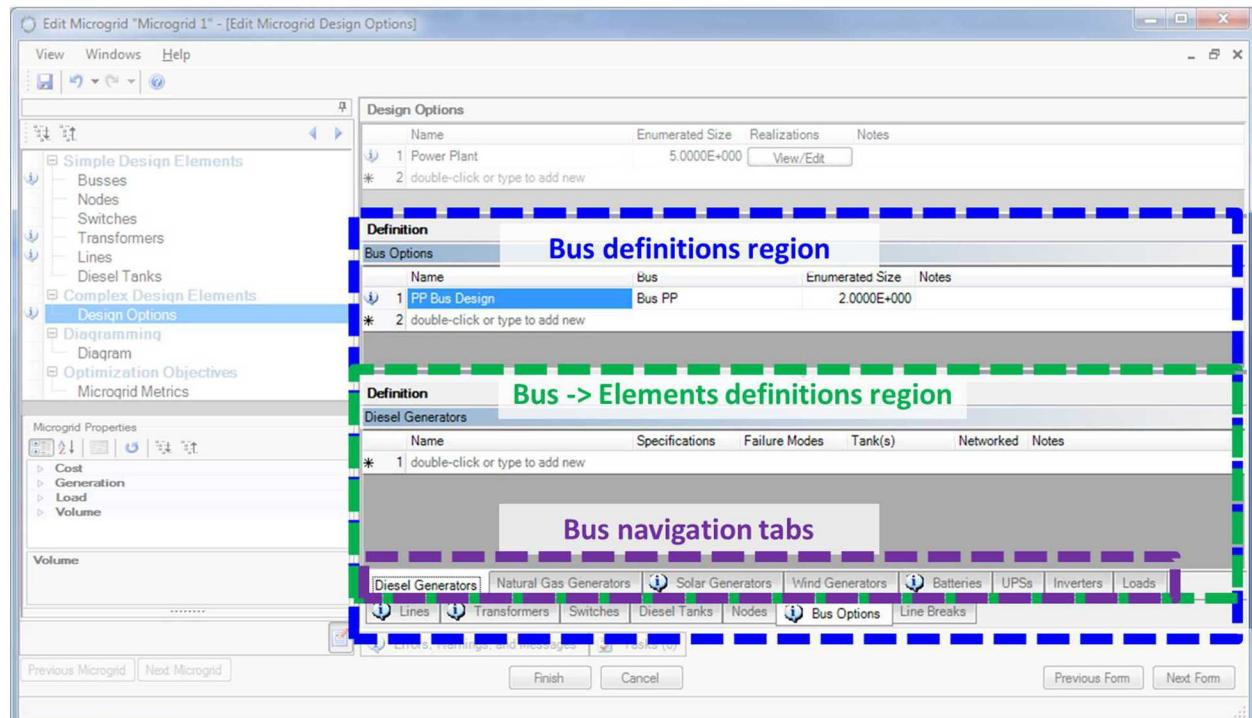


Figure 34. Complex Design Elements -> Bus Options page overview. Bus elements are accessed via tabs near the bottom of the screen.

A bus option has all of the same elements as a Simple Design Element bus. Please see the 3.3.5.1 Buses section under 3.3.5 Simple Design Elements for element descriptions:

- 3.3.5.2 Loads – Click in the Name field. Click the button with three dots (highlighted in purple in Figure 35). A new window will open. Define the loads and add load data to the load section. When you have completed entering information about buses, click the “OK” button at the bottom of the screen to close the window.
- 3.3.5.3 Diesel Generators
- 3.3.5.4 Natural Gas Generators
- 3.3.5.6 Solar Generators
- 3.3.5.7 Batteries
- 3.3.5.8 Uninterruptible Power Supplies (UPS)

- 3.3.5.9 Inverters

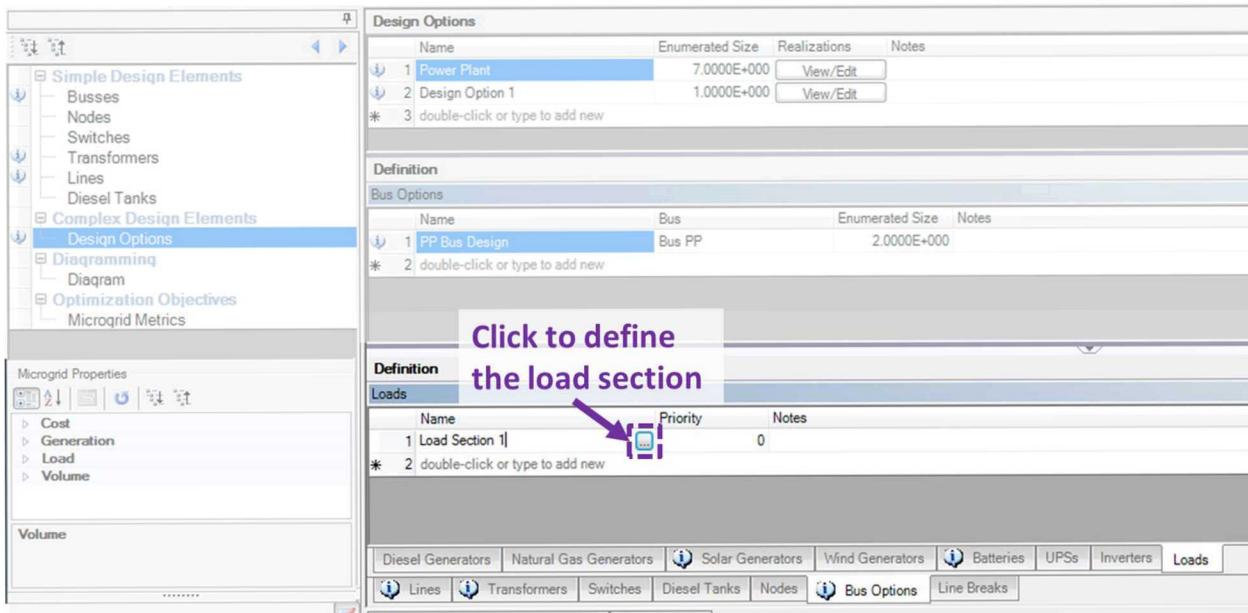


Figure 35. Click the button next to a load section name to define it.

### **3.3.6.10 Line Breaks**

A line break describes where a node may be inserted into an existing part of the microgrid (defined under Simple Design Elements). In order 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 power flow calculations and for computing cost. Power flow is not used in the current version of MDT.
- **Notes** – User supplied notes for this line break.

### **3.3.7 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.

### 3.3.8 Optimization Objectives

#### 3.3.8.1 Microgrid Metrics

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. 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,

- 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 3.5.1 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.

### 3.3.8.2 Cost Metrics

#### 3.3.8.2.1 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 is 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.

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** – Dollars
- **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 at all 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** – By default, Minimize is selected, but you may change it if necessary. MDT is expecting Minimize or Seek Value for this metric. Selecting Maximize will result in a warning.
  - 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.

### 3.3.8.3 Load Metrics

#### 3.3.8.3.1 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).

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).
- **Load Tier** – Select the load tier for this metric. Create a separate metric for each load tier of interest.
- **Units** – kWh/Hour of outage.
- **Limit** – The value that this metric must achieve in the optimization.
- **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 at all 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** – By default, Minimize is selected, but you may change it if necessary. MDT is expecting Minimize or Seek Value for this metric. Selecting Maximize will result in a warning.
  - 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.

### 3.3.8.3.2 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 %.

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).
- **Load Tier** – Select the load tier for this metric. Create a separate metric for each load tier of interest.
- **Units** – % utility outages with LNS.
- **Limit** – The value that this metric must achieve in the optimization.
- **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 at all 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** – By default, Minimize is selected, but you may change it if necessary. MDT is expecting Minimize or Seek Value for this metric. Selecting Maximize will result in a warning.
  - 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.

### 3.3.8.3.3 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 %.

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).
- **Load Tier** – Select the load tier for this metric. Create a separate metric for each load tier of interest.
- **Units** – %
- **Limit** – The value that this metric must achieve in the optimization. Enter a value 0-100.
- **Objective** – The value that would be nice to achieve in the optimization. Values beyond the objective are not as valuable (point of diminishing returns). Enter a value 0-100.
- **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 at all 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** – By default, Maximize is selected, but you may change it if necessary. MDT is expecting Maximize or Seek Value for this metric. Selecting Minimize will result in a warning.
  - 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.

### 3.3.8.4 Fuel Metrics

#### 3.3.8.4.1 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 curves are provided in units of Gallons/kW/hr and consist of four values: the fuel usage rate with the generator loaded at 25%, 50%, 75%, and 100%. Values for utilization rates in between those percentages are interpolated. Values for utilization rates below 25% are extrapolated. So 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). The reason for this is that the PRM will simulate over many outages whose durations may be variable, so to report a value in units of "Gallons/utility outage" would be dubious.

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** – Gallons/Hour of outage.
- **Limit** – The value that this metric must achieve in the optimization.
- **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 at all 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** – By default, Minimize is selected, but you may change it if necessary. MDT is expecting Minimize or Seek Value for this metric. Selecting Maximize will result in a warning.
  - 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.

#### 3.3.8.4.2 Natural Gas Used

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

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** – MBTU/Hour of outage.
- **Limit** – The value that this metric must achieve in the optimization.
- **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 at all 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** – By default, Minimize is selected, but you may change it if necessary. MDT is expecting Minimize or Seek Value for this metric. Selecting Maximize will result in a warning.
  - 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.

### 3.3.8.5 Renewable Metrics

#### 3.3.8.5.1 Average Renewable Penetration

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

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** – %
- **Limit** – The value that this metric must achieve in the optimization. Enter a fraction (0-1).
- **Objective** – The value that would be nice to achieve in the optimization. Values beyond the objective are not as valuable (point of diminishing returns). Enter a fraction (0-1).
- **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 at all 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** – By default, Seek Value is selected, but you may change it if necessary.
  - 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 value 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.

### 3.3.8.6 Efficiency Metrics

#### 3.3.8.6.1 Diesel Efficiency

The instantaneous diesel generator efficiency is a function of the current running rate (utilization rate) of the generator. Each generator's efficiency curves are provided in units of % and consist of four values: the efficiency with the generator loaded at 25%, 50%, 75%, and 100%. Values for utilization rates in between those percentages are interpolated. Values for running rates below 25% are extrapolated. So 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 %.

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** – %
- **Limit** – The value that this metric must achieve in the optimization. Enter a fraction (0-1).
- **Objective** – The value that would be nice to achieve in the optimization. Values beyond the objective are not as valuable (point of diminishing returns). Enter a fraction (0-1).
- **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 at all 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** – By default, Maximize is selected, but you may change it if necessary. MDT is expecting Maximize or Seek Value for this metric. Selecting Minimize will result in a warning.
  - 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.

### 3.3.8.6.2 Natural Gas Efficiency

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

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** – %
- **Limit** – The value that this metric must achieve in the optimization. Enter a fraction (0-1).
- **Objective** – The value that would be nice to achieve in the optimization. Values beyond the objective are not as valuable (point of diminishing returns). Enter a fraction (0-1).
- **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 at all 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** – By default, Maximize is selected, but you may change it if necessary. MDT is expecting Maximize or Seek Value for this metric. Selecting Minimize will result in a warning.
  - 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.

### 3.3.8.7 Fault Metrics

There are currently no fault metrics included in MDT. This section is a placeholder.

### 3.3.8.8 Footprint Metrics

#### 3.3.8.8.1 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 is 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.

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** – ft<sup>3</sup>
- **Limit** – The value that this metric must achieve in the optimization.
- **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 at all 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** – By default, Minimize is selected, but you may change it if necessary. MDT is expecting Minimize or Seek Value for this metric. Selecting Maximize will result in a warning.
  - 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.

### 3.3.8.9 Operational Metrics

There are currently no operational metrics included in MDT. This section is a placeholder.

## 3.4 Islanded Simulator Settings

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

The screenshot shows the 'Islanded Simulator Settings' screen. At the top, 'Simulation Settings' are defined: 'Simulation Years' is set to 1000, and 'Approximate Number of Simulated Outages' is set to 10. Below this, a table lists 'Name' and 'Notes' for 'Microgrid 1'. The next section, 'Settings of Microgrid "Microgrid 1"', includes 'Diesel Tank Settings' for 'Diesel Tank 1' and 'Diesel Tank 2', both of which have the 'Infinite Fuel' checkbox checked. The bottom section, 'Startup Controller Settings', contains a table of properties and their values:

Property	Value	Units
1 Grid Formation Delay - Without Generator Failures	600	Seconds
2 Grid Formation Delay - With Generator Failures	120	Seconds
3 Generator Restart Delay	15	Seconds
4 Generator Synchronization Delay	15	Seconds
5 Bus Synchronization Delay	20	Seconds
6 Renewables Restart Delay	300	Seconds

Figure 36. Islanded Simulator Settings screen.

### 3.4.1 Simulation Settings

The simulation settings (Figure 36) 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**
- **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 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 to attempt 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 generators 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 the user to modify some information that impacts the simulation during islanded mode.
  - **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 to attempt 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 generators 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 this box is unchecked, then the failure modes are ignored during periods of grid-tied operation. 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 sufficient 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

At this time, use of the default solver settings is recommended.

### 3.5.1 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 3.3.8.1 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 3.3.8.1 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 37).
  - e. The metric should now appear in the Response Functions list.
  - f. Add additional metrics to the group, if applicable.

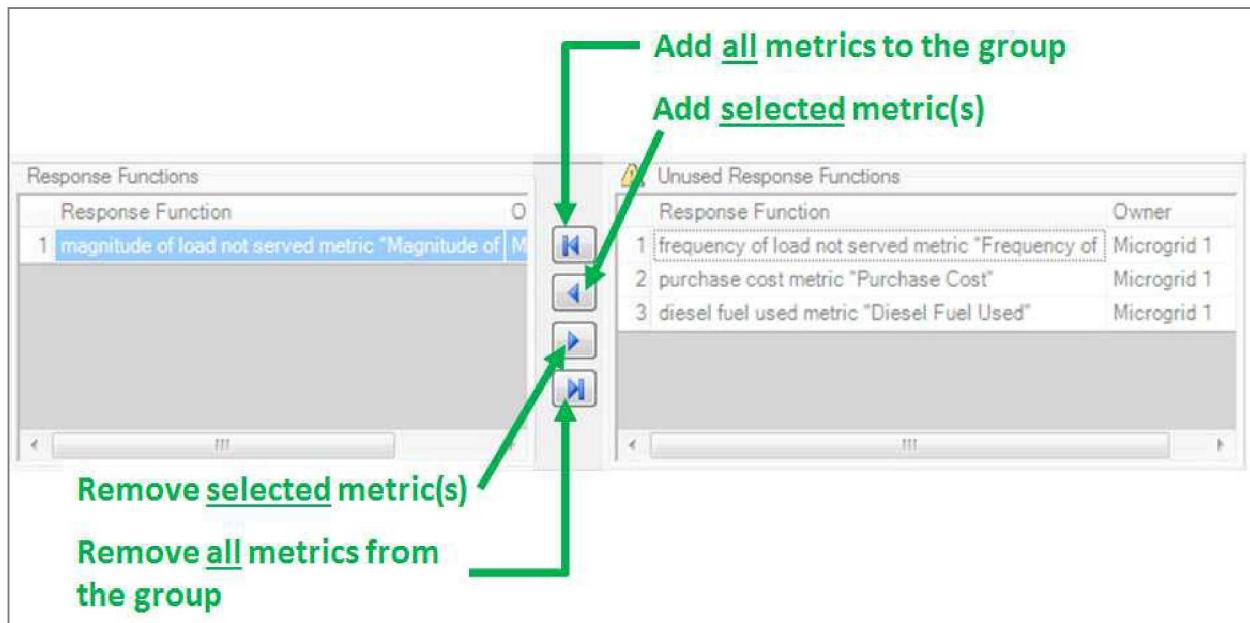


Figure 37. Adding and removing metrics from Response Function Groups.

3. Review the metrics in each group (Figure 38, Figure 39).
  - 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.

Response Groups	
Response Function Groups	
Name	Notes
1 Cost	
2 Performance	
*	3

Response Functions	
Response Function	0

Unused Response Functions	
Response Function	Owner
1 magnitude of load not served metric "Magnitude of Microgrid 1"	Microgrid 1
2 frequency of load not served metric "Frequency of Microgrid 1"	Microgrid 1
3 purchase cost metric "Purchase Cost"	Microgrid 1
4 diesel fuel used metric "Diesel Fuel Used"	Microgrid 1

Figure 38. The "Cost" Response Function Group is empty. It contains no metrics.

Response Groups	
Response Function Groups	
Name	Notes
1 Cost	
2 Performance	
*	3

Response Functions	
Response Function	0
1 magnitude of load not served metric "Magnitude of Microgrid 1"	M
2 frequency of load not served metric "Frequency of Microgrid 1"	M
3 diesel fuel used metric "Diesel Fuel Used"	M

Unused Response Functions	
Response Function	Owner
1 purchase cost metric "Purchase Cost"	Microgrid 1

Figure 39. The "Performance" Response Function Group contains three metrics.

### Modifying Response Function Groups

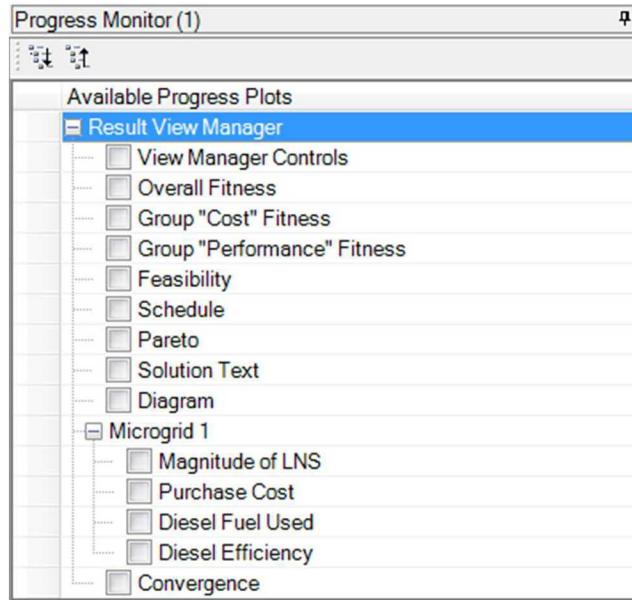
- Remove a metric from a group.
  1. In the Response Function Groups list, click on the row number to select a group.
  2. The Response Functions list displays the metrics in the selected group.
  3. In the Response Functions list, click on the row number of a metric to select it.
  4. Click the right arrow button to remove the metric from the group (Figure 37).
  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 a number of possible runtime progress plots, which include:

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

The available progress plots are shown below (Figure 40).



**Figure 40: 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 of the plots are interactive. This is due to the fact that MDT does not tell you the “right” answer for your microgrid design. Rather, it helps you to explore all of the efficient configurations found and understand the design tradeoffs, allowing you to make an informed decision.

All available plots are listed in the Results Viewer (highlighted in purple in Figure 41). Check the checkboxes of the plots in the Results Viewer to open the plots. You can resize and move the plot windows to view multiple plots at once (highlighted in green in Figure 41).

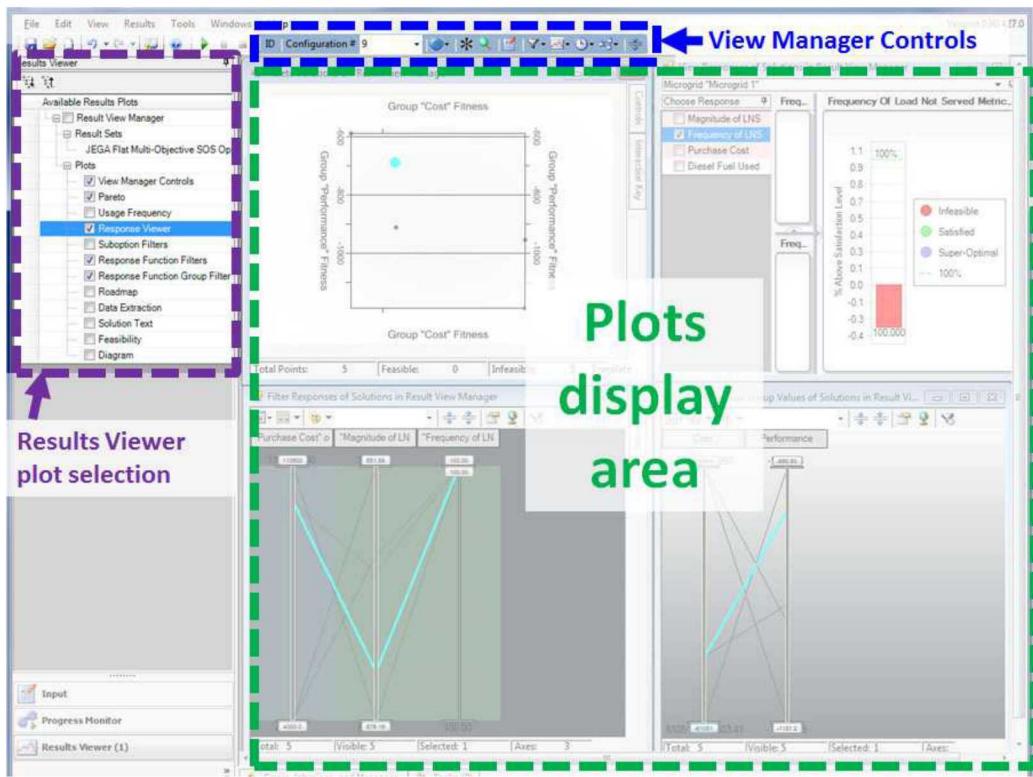


Figure 41. Results Viewer overview.

The plots are also 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 41, you will see a bright blue dot or line in three of the plots, which represent the same configuration.

Most plot images can be copy-and-pasted into other tools. Most plot windows 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 tool of your choice.

For all plots, 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 configuration 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 Suboption Filters plot.

### 3.7.1 Save Results

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

10. Right click on “Result View Manager” in the left navigation (Figure 42).
11. Select “Rename” from the menu.
12. A new window will open. Type in a new name for your result set.
13. Click “OK”.
14. Select the checkbox next to you renamed result set.
15. Go to “Results” in the toolbar.
16. Select “Save Selected”.
17. Enter a name for your results set file.
18. Click “Save”.

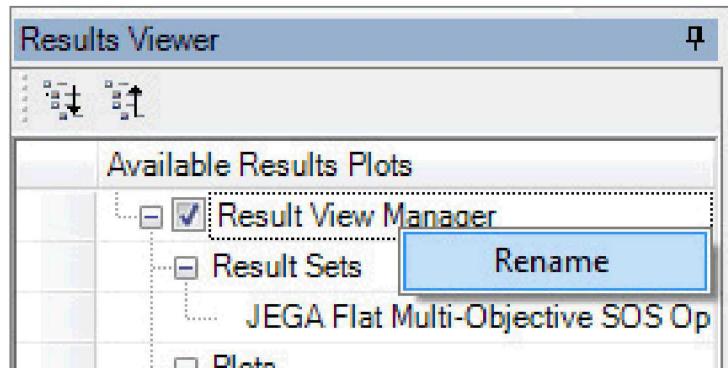


Figure 42. Renaming a result set before saving.

### 3.7.2 Open Results

To open a previously saved result set,

6. Go to “Results” in the toolbar.
7. Select “Load”.
8. Locate your file (which will have file extension \*.mof).
9. Click “Open”.
10. Go to the Results Viewer tab to view your results.

You can open as many result sets as necessary (Figure 43). 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”.

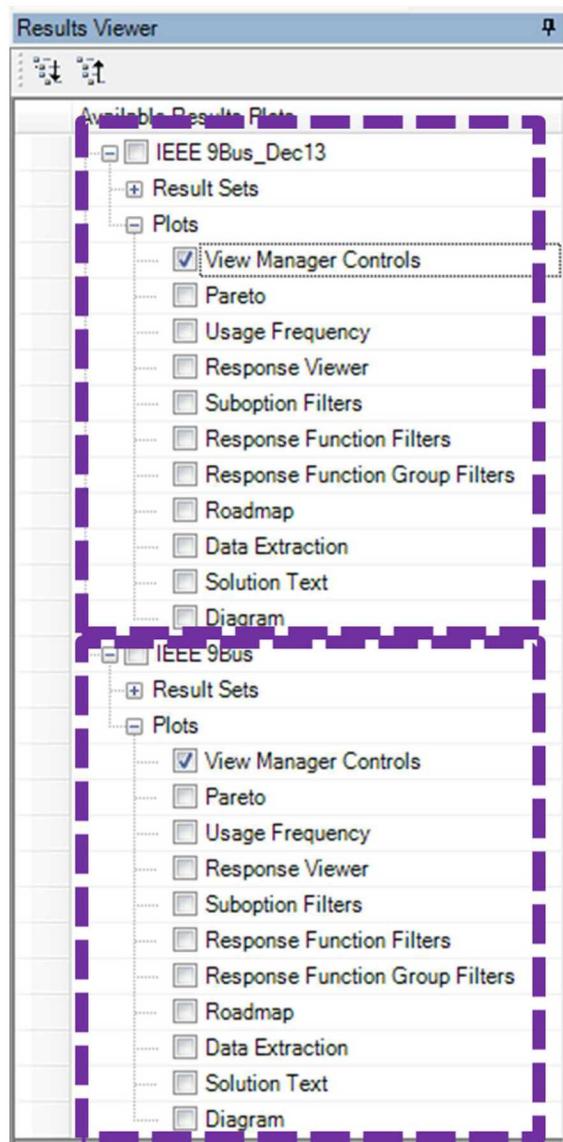


Figure 43. Two different result sets open in the Results Viewer.

### 3.7.3 View Input for a Result Set

To view the input file for a result set,

7. Locate your result set in the Results Viewer navigation.
8. Under the “Result Sets” header, right click on the solution set previously generated by the solver. (Figure 44).
9. Select “View Input”.
10. 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.”
11. Click “OK”.
12. 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.

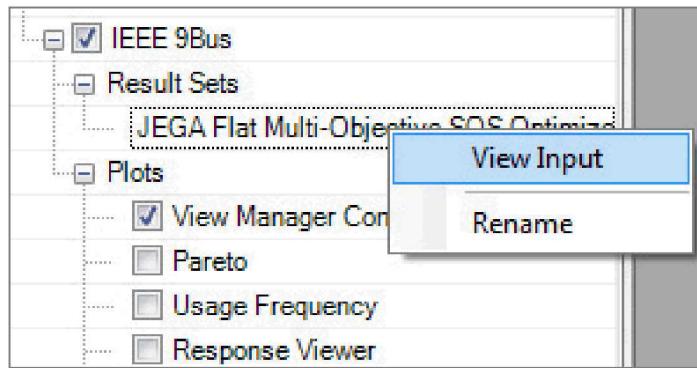


Figure 44. Opening the input set that created this result set.

### 3.7.4 Close a Result Set

To close a result set,

5. Select the checkbox next to your result set name.
6. Go to “Results” in the toolbar.
7. Select “Remove Selected”.
8. The result set should be removed from the Results Viewer navigation.

### 3.7.5 View Manager Controls

The “View Manager Controls” checkbox in the plots navigation opens a toolbar (highlighted in blue in Figure 41) that allows you to see the currently selected configuration and which filters are current applied (Figure 45).

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 of the filters that are currently applied. It also allows you to clear all of 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 Suboption 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

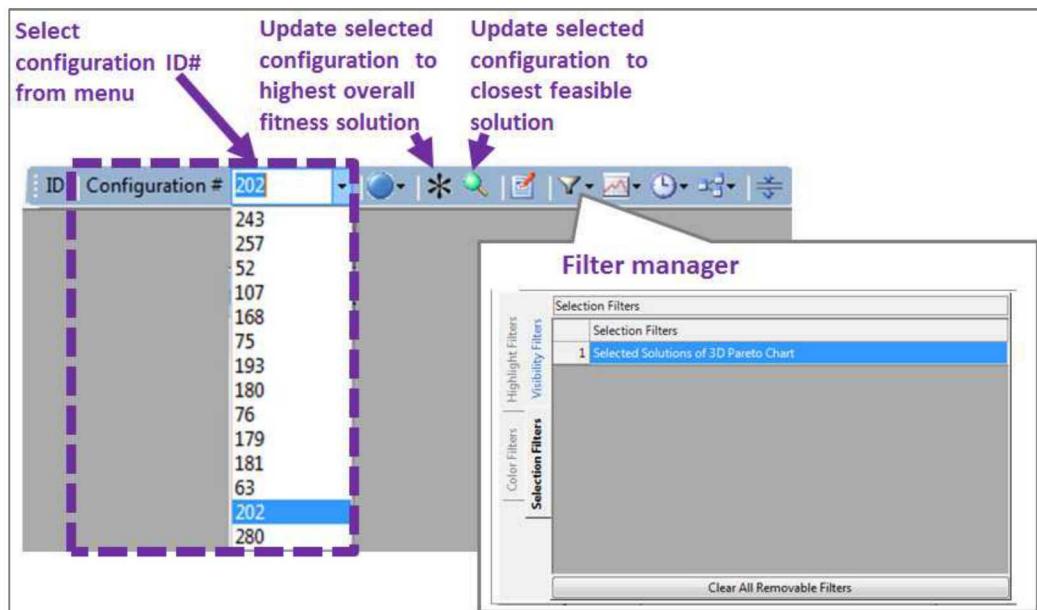


Figure 45. Overview of the View Manager Controls toolbar.

### 3.7.6 Multiple Configuration Plots

The following plots display information about multiple configurations.

#### 3.7.6.1 Pareto

The Pareto frontier shows a set of points that are 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 46 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.

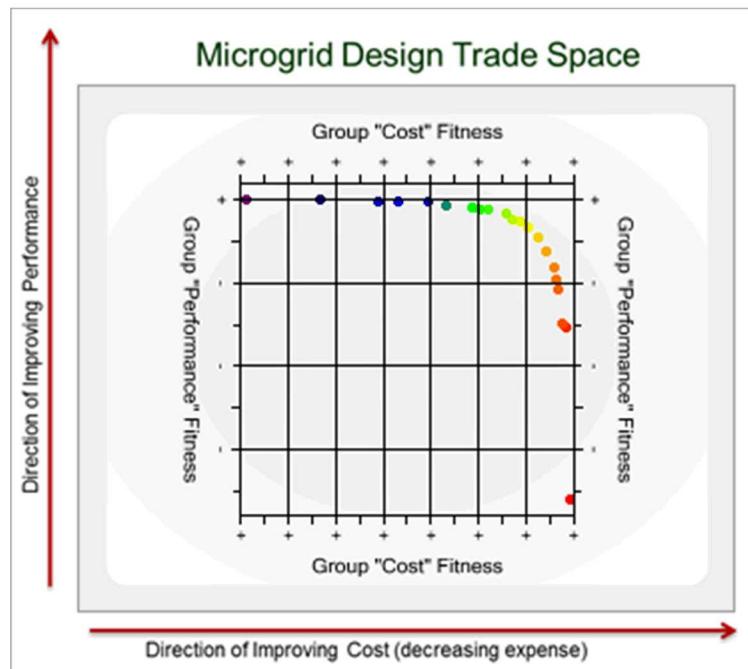


Figure 46. Guide to understanding Pareto frontiers.

To select a single configuration, click on a point (Figure 47). 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.

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 47). 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".

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”.

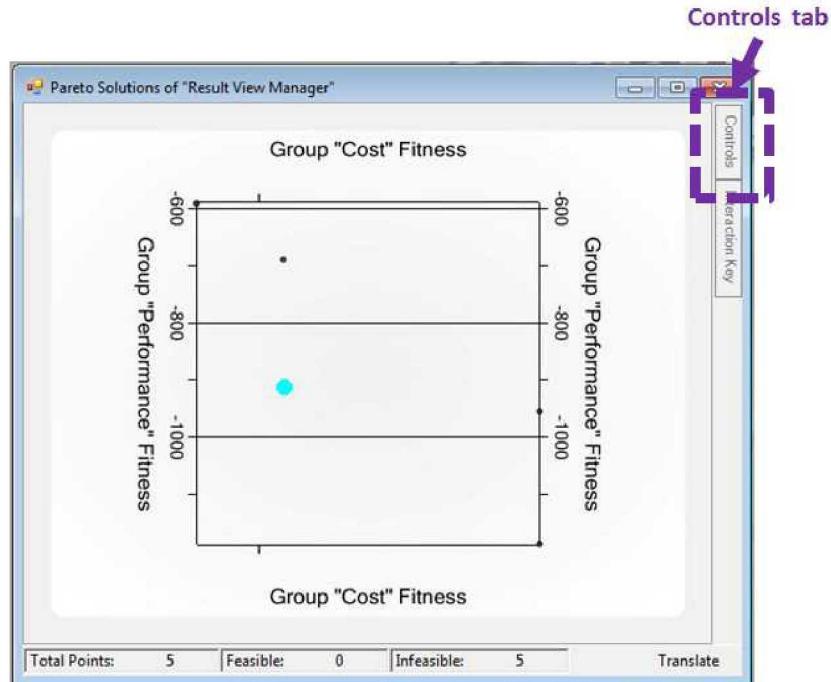


Figure 47. Pareto plot with one configuration selected. The selected configuration is highlighted as a bright blue point.

### 3.7.6.2 Usage Frequency

Usage Frequency displays the frequency of selection of each equipment specification across all configurations (Figure 48). 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 frequency of selection for each specification.

The Controls tab (highlighted in purple in Figure 48) 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.

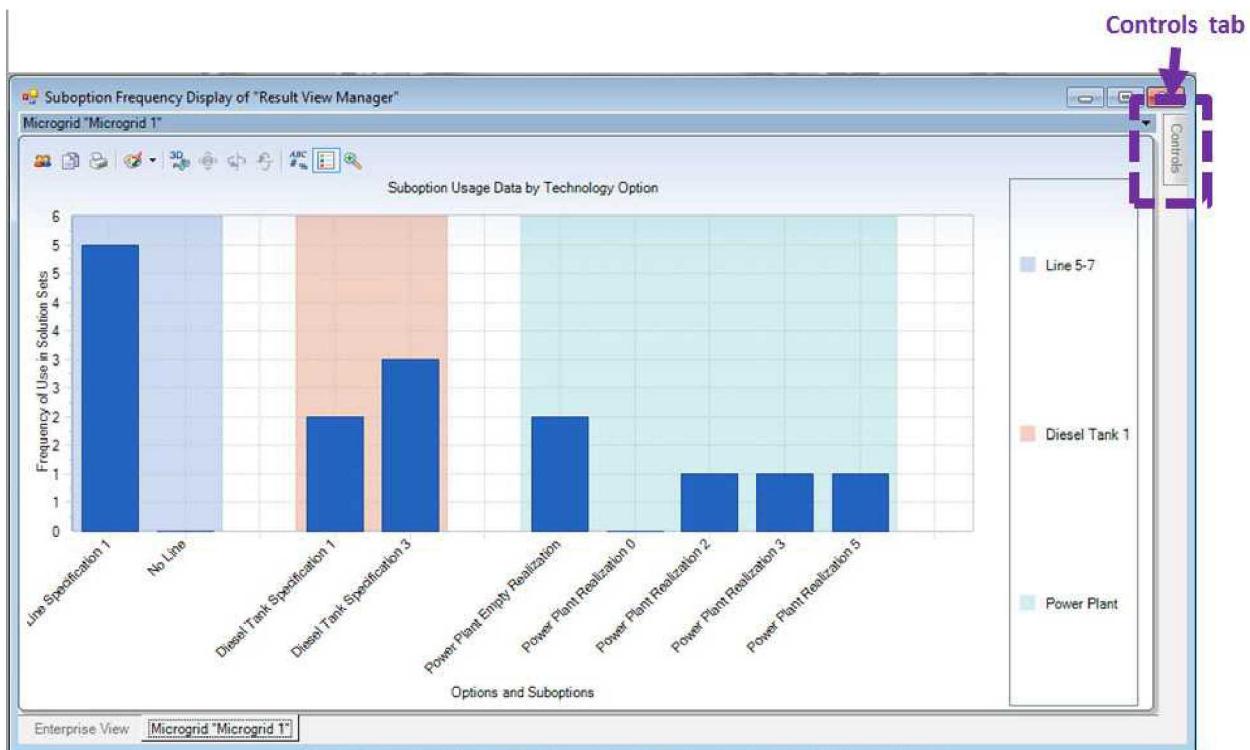


Figure 48. Usage Frequency displays the frequency of selection for each equipment specification.

### 3.7.6.3 Suboption Filters

Suboption 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 49 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 50 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.

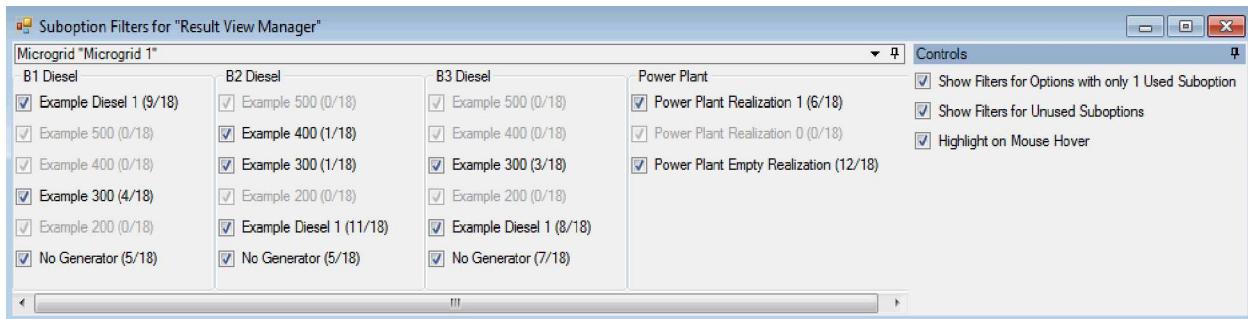


Figure 49. Suboption Filters with all configurations displayed.

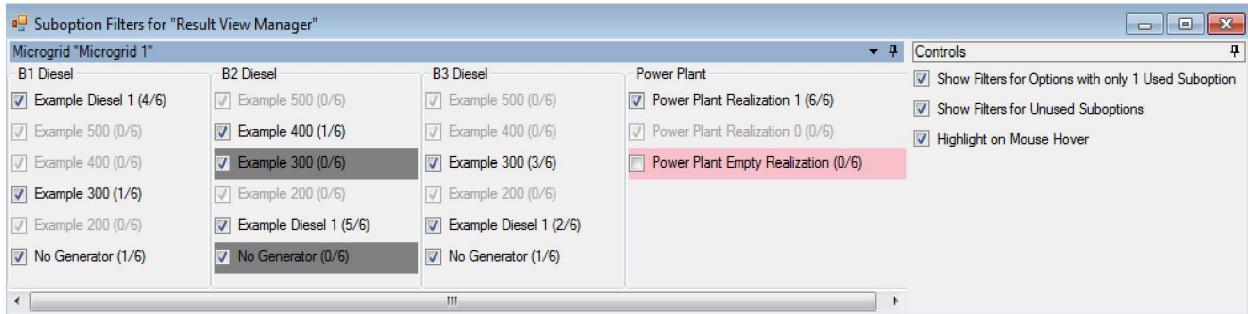


Figure 50. Suboption Filters where only the Power Plant Realization 1 option is selected. Deselected options are highlighted in red.

### 3.7.6.4 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 51).

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 52). 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 axes.

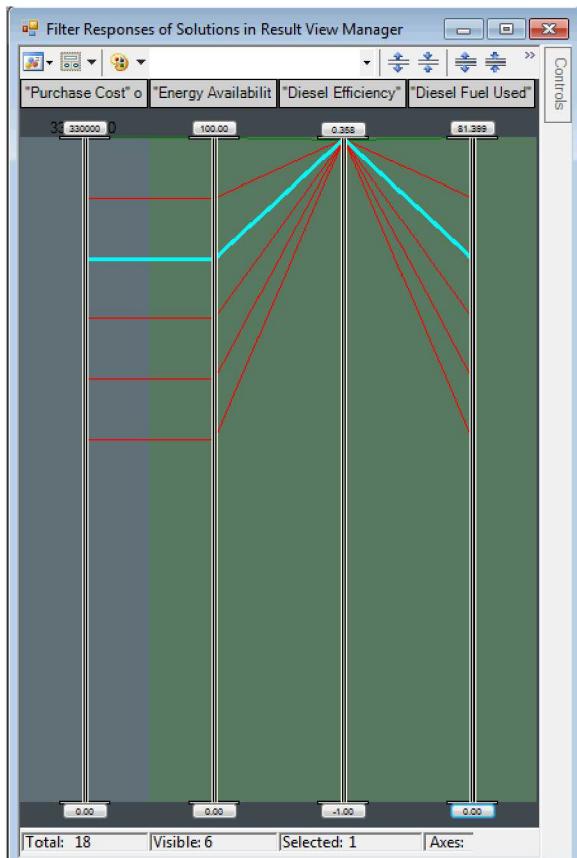


Figure 51. Response Function Filters plot displaying all configurations. One configuration is highlighted.

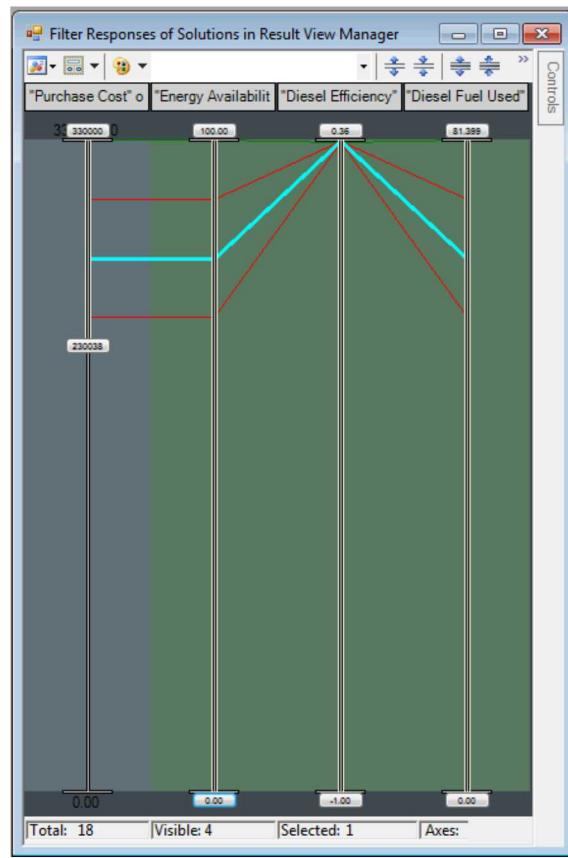


Figure 52. Response Function Filters plot where the minimum value of the "Purchase Cost" metric has been increased. Two configurations are filtered out.

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 53). 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.

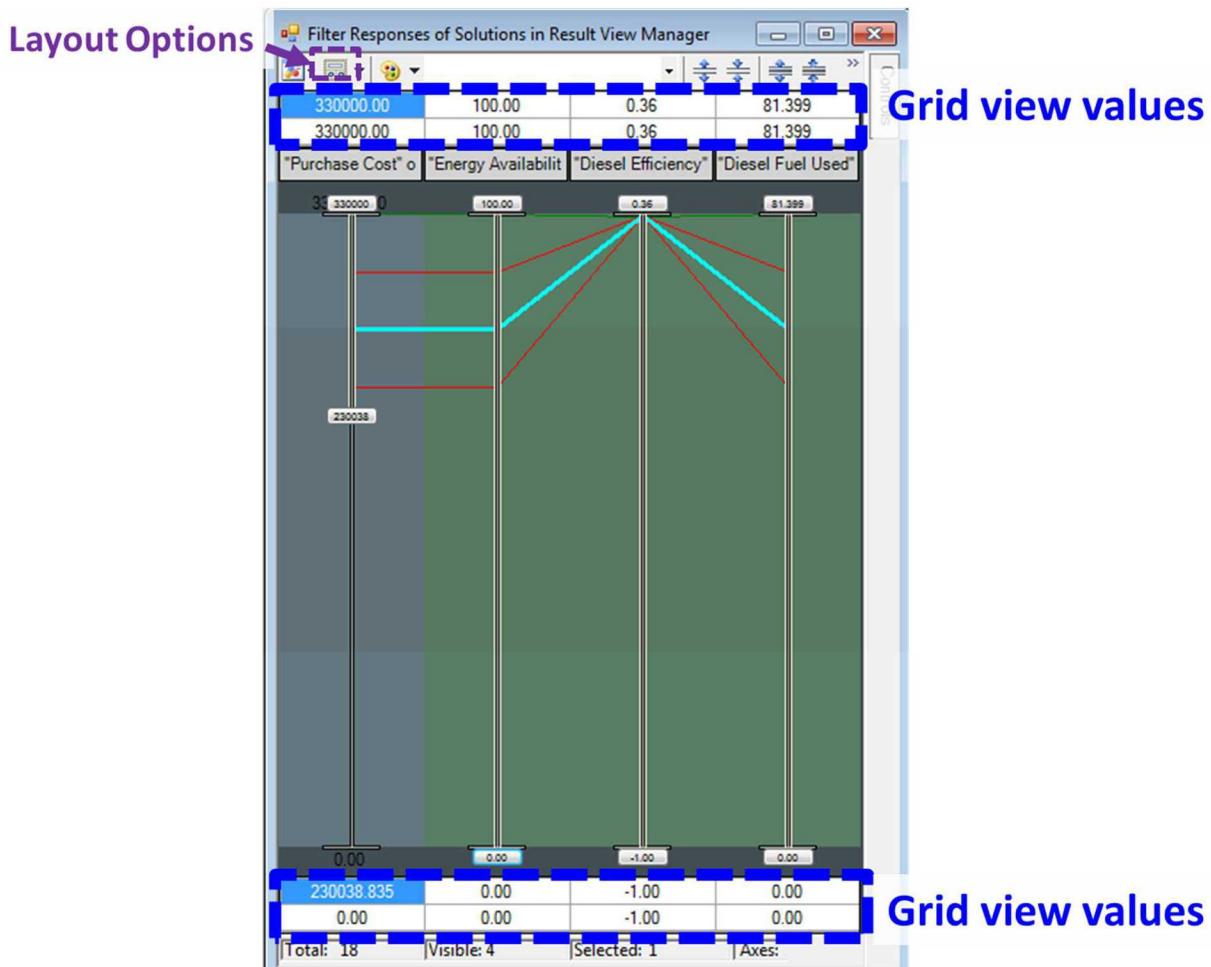


Figure 53: The grids view of Response Function Filters is an alternate method of viewing and filtering.

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 54) 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.

Rescale  
Color>Select  
Line Color  
Scheme

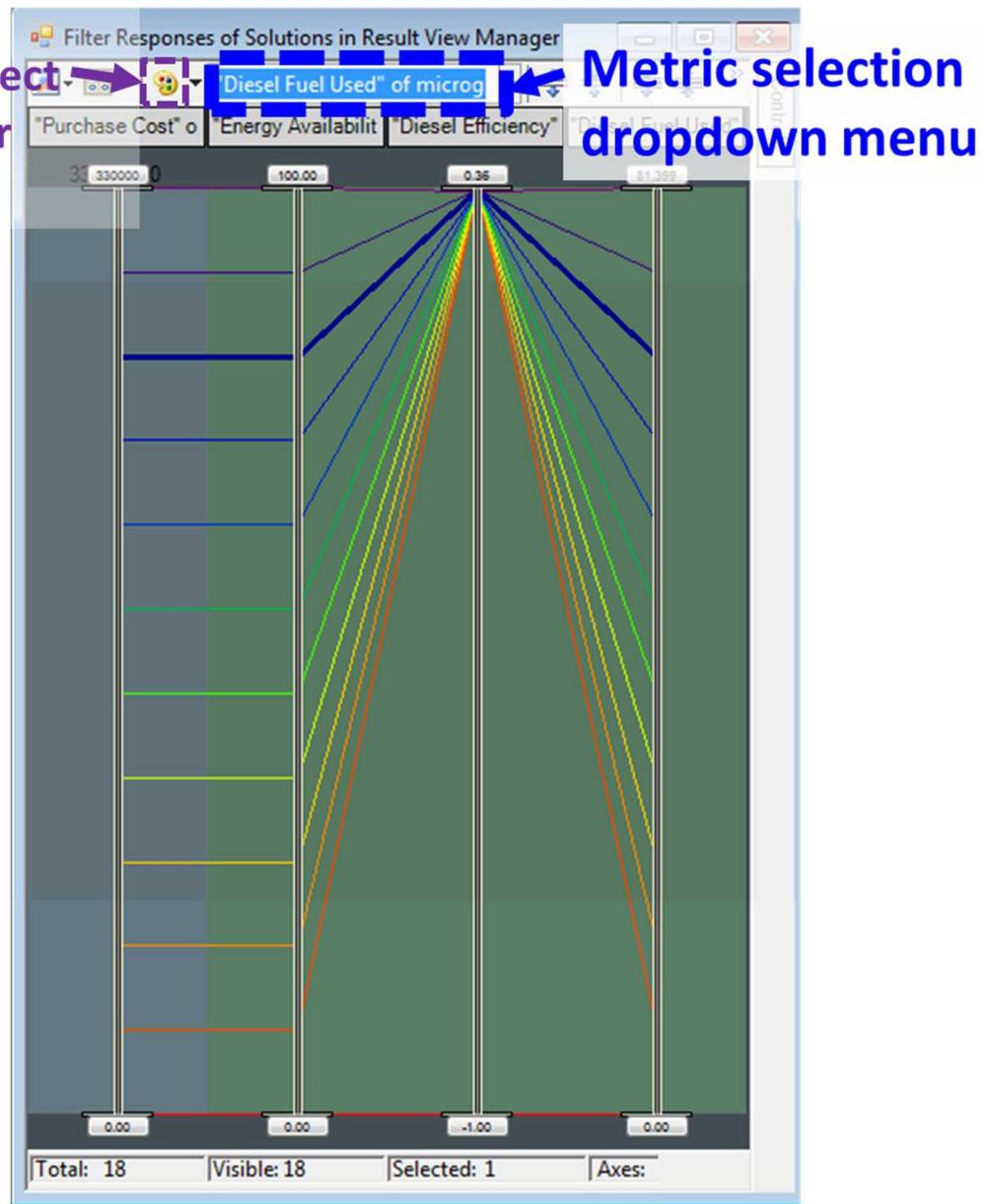


Figure 54: Rainbow view of the Response Function Filter.

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

### 3.7.6.5 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 55).

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 56). Configurations that do not meet this constraint are removed from the plot.

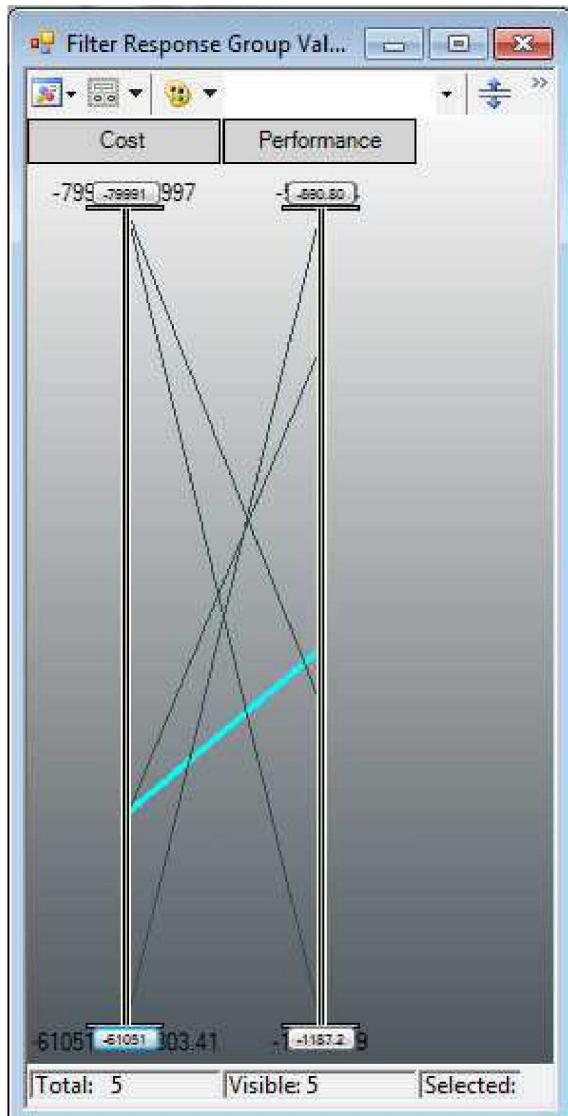


Figure 55. Response Function Group Filters plot displaying all configurations. One configuration is highlighted.

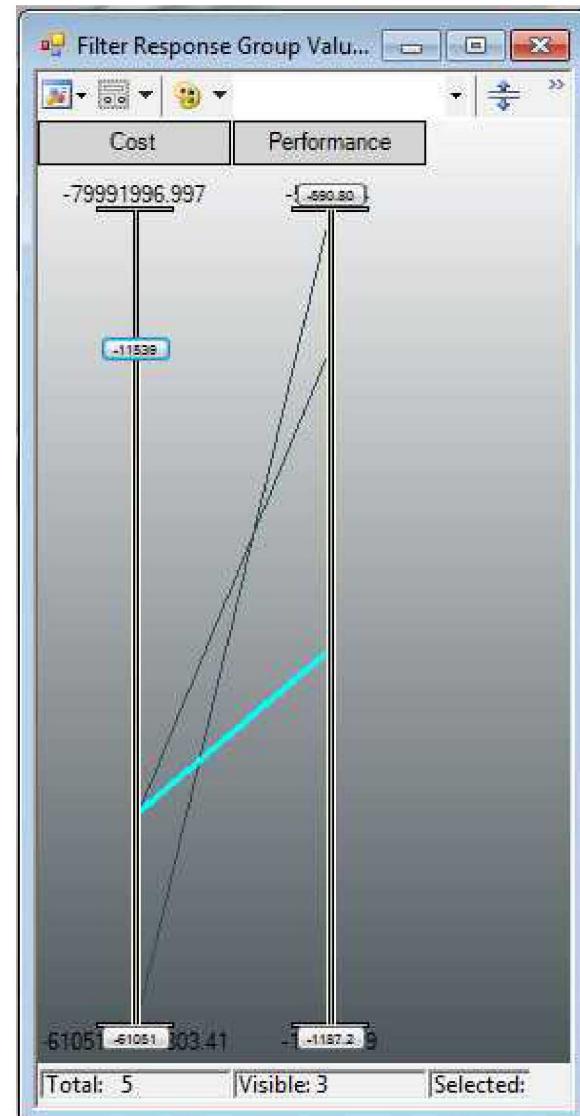


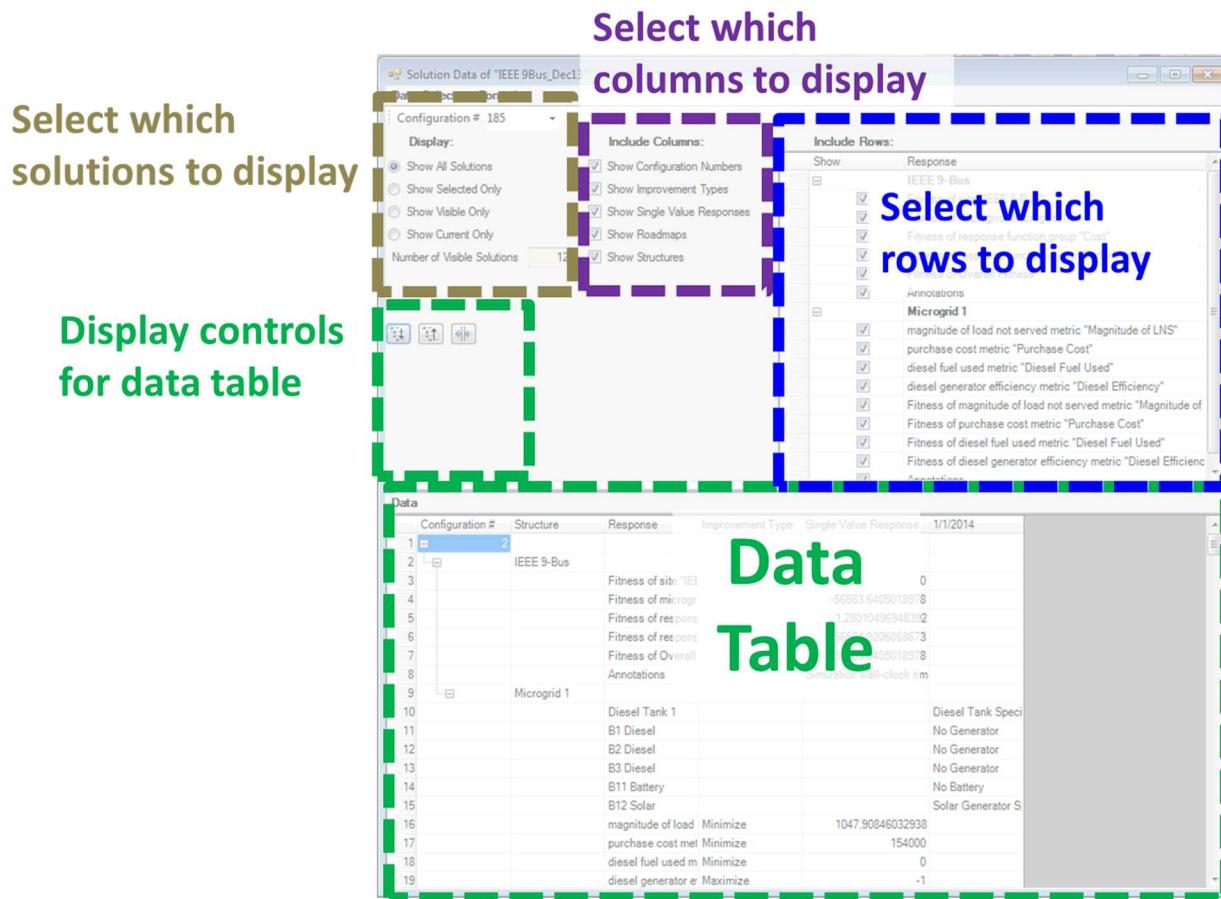
Figure 56. Response Function Group Filters plot where the maximum value of the Cost group has been decreased. Two configurations are filtered out.

### 3.7.6.6 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 57). This data can be copy-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 57).
- The “Show – Response” checkboxes control which rows are displayed (highlighted in blue in Figure 57).
  - 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 57).
  - 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 Suboption 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.



### **3.7.7 Single Configuration Plots**

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.

#### **3.7.7.1 Response Viewer**

The Response Viewer plot (Figure 58) displays how well a single configuration performed against the metrics created under

3.3.8 Optimization Objectives on the Input tab. The configuration must be selected on one of the other plots or by using the View Manager Controls toolbar.

Metrics are displayed on the left under “Choose Response”. All metrics created under 3.3.7 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.

3.3.8 Optimization Objectives are displayed in the list. The metrics highlighted in red have limit violations.

Select a metric to display in the plot by checking its checkbox.

The Controls tab offers four plot options. First, the user must select whether to plot Raw Values or the Satisfaction Level. The distinction is described below.

- Raw Values – This plot shows the raw values of the Response that is selected.
- Satisfaction Level – This plot shows the degree to which the configuration has satisfied the limit and objective. The objective satisfaction level (100%) is displayed as a dotted green line. The metric value is displayed on the bar chart.
  - Infeasible: The metric that violates the limit will have a negative satisfaction level. It will appear as a red bar.
  - Satisfied: The metric that meets but only precisely achieves the limit will have a 0% satisfaction level. Values between the limit and objective will appear as a green bar.
  - Super-Optimal: The metric that achieves the objective will have a 100% satisfaction level. If the metric exceeds the objective, it will have a greater than 100% satisfaction level. It will appear as a purple bar.

Other options include whether to show limits and objectives on the plot and whether to allow multiple Responses on the same plot.

- Show Limits & Objectives – This option will display the values of the limit and objective.
- Allow Multiple – Allows display of multiple Responses on the same chart.

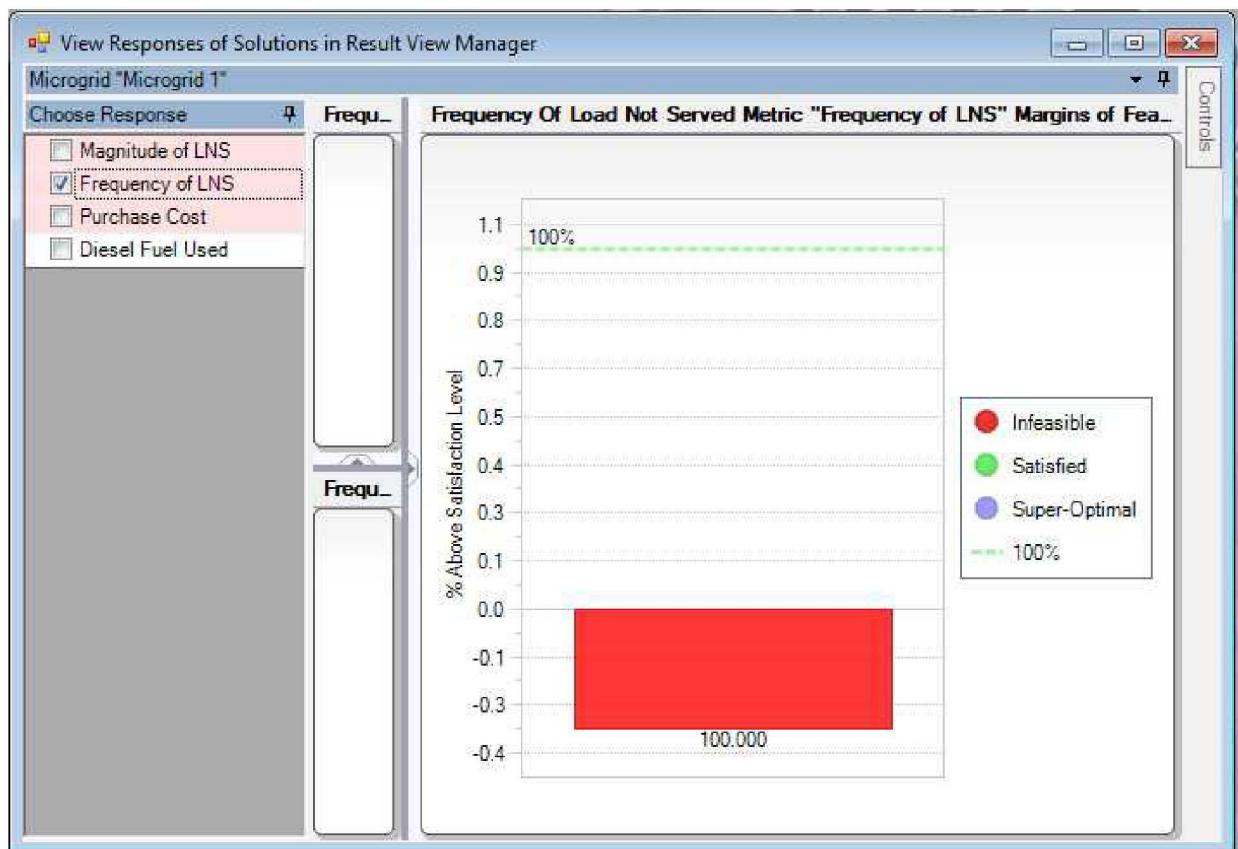


Figure 58. Response Viewer displaying a configuration's performance against the Frequency of LNS metric (shown as satisfaction level).

### 3.7.7.2 Roadmap

The Roadmap shows the equipment specifications selected for decision variables of a single configuration. Only equipment specifications that are part of a decision variable are displayed. The configuration must be selected on one of the other plots or by using the View Manager Controls toolbar.

If the configuration includes a complex design element, hover over that specification with your mouse (Figure 59). A tool tip will appear that shows the non-variable and variable components of the complex design element.

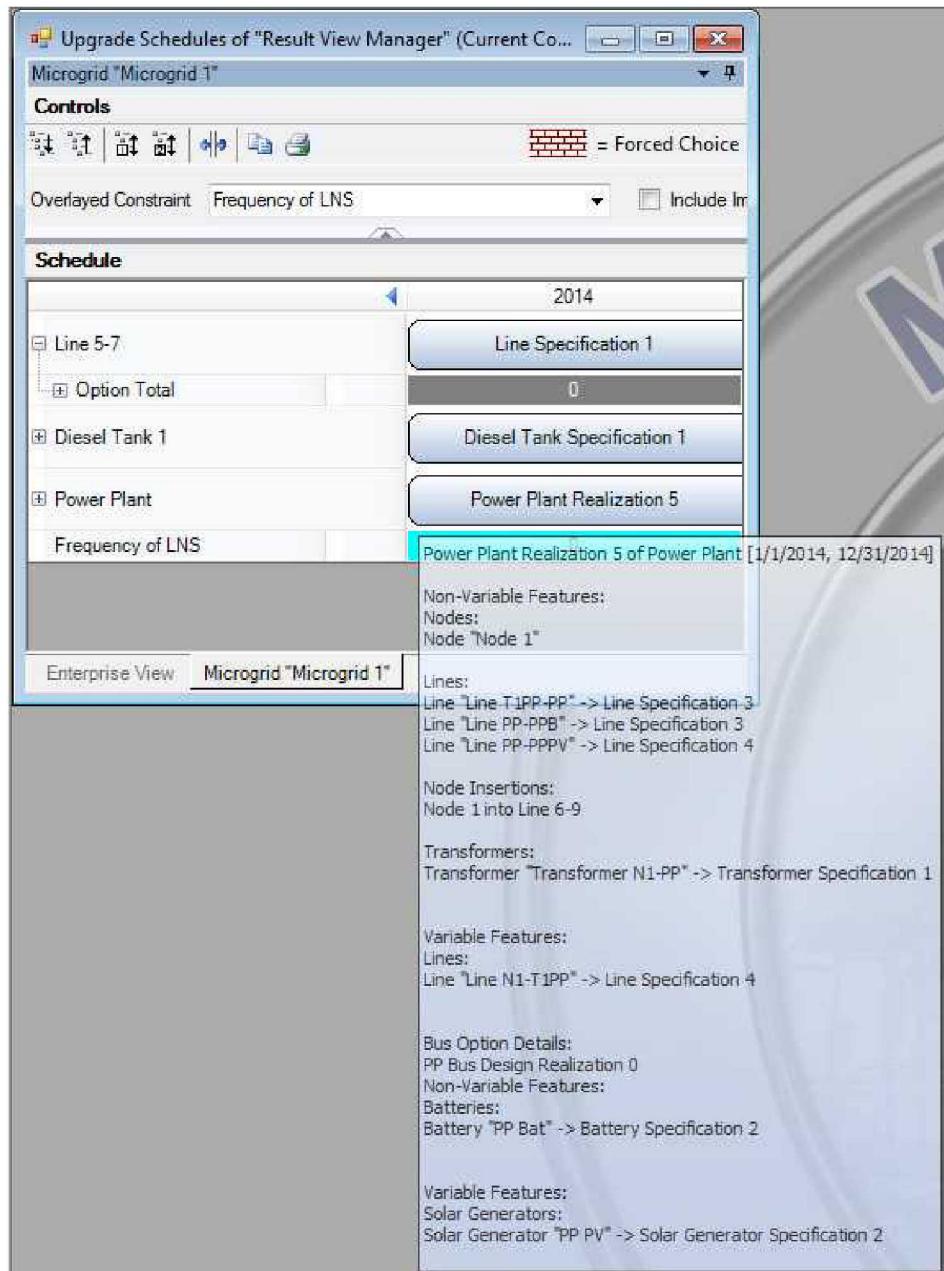


Figure 59. Roadmap for a single configuration that displays the selected equipment specifications.

### **3.7.7.3 Solution Text**

Solution Text displays all of 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's probably 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.

### 3.7.7.4 Diagram

The Diagram allows you to view the topology of a configuration. The configuration must be selected on one of the other plots or by using the View Manager Controls toolbar.

You can click on any icon and move it on the screen. To reset it to the original layout, click the refresh button (highlighted in blue in Figure 60) in the upper left corner. More information about the diagram toolbar controls are in section 3.3.1 Diagramming a Microgrid.

To view equipment properties, select the Node Properties tab in the lower right hand corner (highlighted in green in Figure 60). Click on any node or line. The properties will be displayed in the Properties tab. Equipment can be expanded to view details and specification information. When no equipment is selected in the diagram, properties of the microgrid are displayed.

Equipment that appears in all configurations will be in black font. Equipment that differs among the configurations will be displayed with green, underlined font (highlighted in brown in Figure 60). These are a part of the solution. These are typically decision variables or components of a complex design element. A box with a red X (highlighted in purple) denotes that the specification “no asset” was selected by the model.

Identified Paths is the second tab in the lower right hand corner. It lists all of the lines/paths defined in the microgrid option. Hovering over each path in the table highlights the corresponding elements in the diagram.

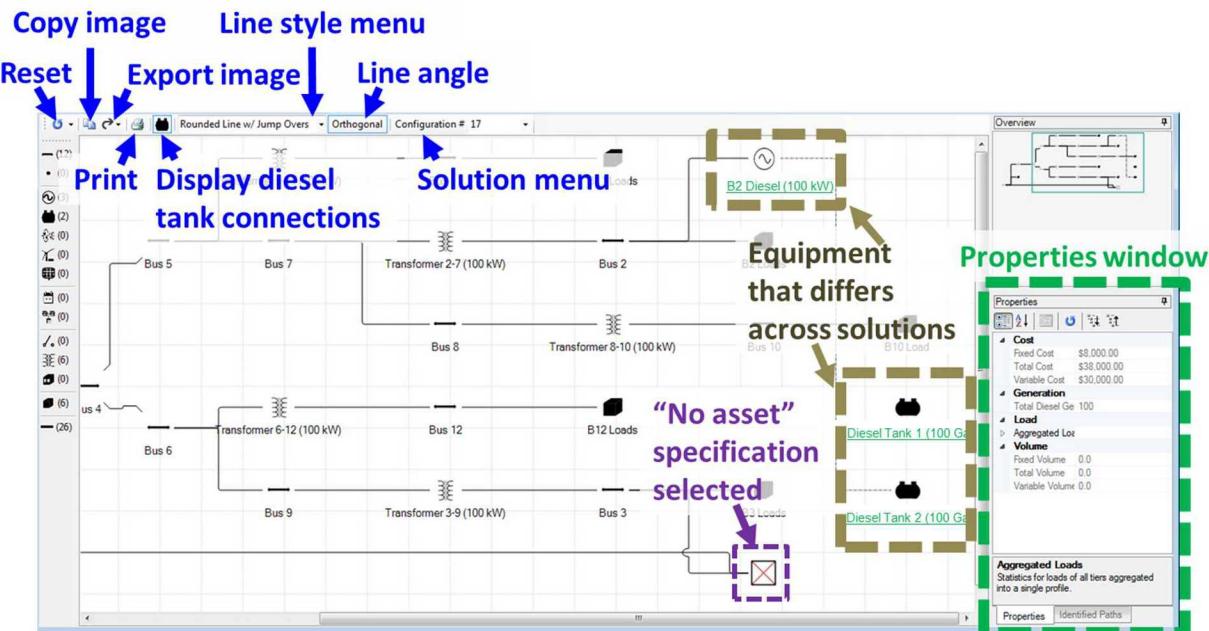


Figure 60. Overview of a Diagram for a single configuration.



## 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 61).

- **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 61). When the Input tab (under *Main navigation tabs* in Figure 61) 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.

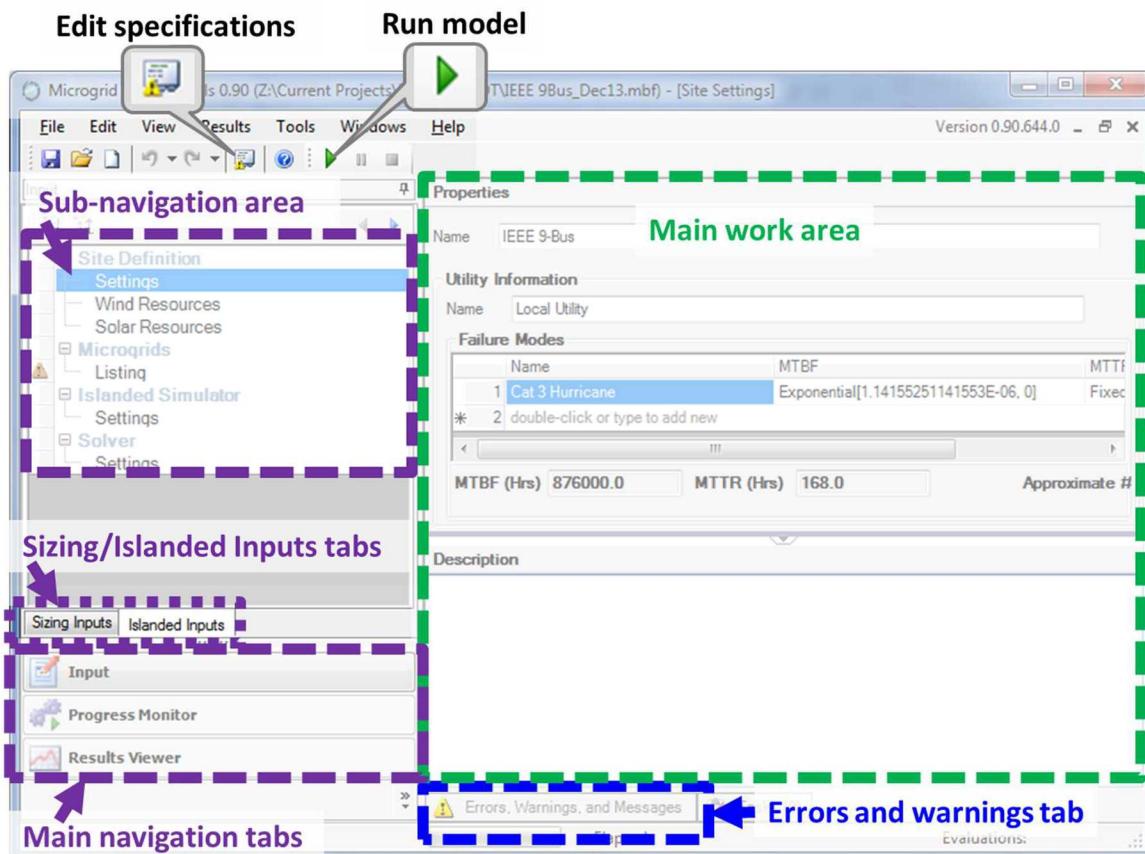


Figure 61. MDT main screen overview.

Pages have two main areas.

- The **page navigation** area is located on the left side of the page (highlighted in purple in Figure 61).
- The **main work area** (highlighted in green in Figure 61) takes up the majority of 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 61). Errors and warnings are also displayed on the element pages 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 62). This will provide access to the Sizing Input Options. The inputs pages are accessed through the left navigation area.

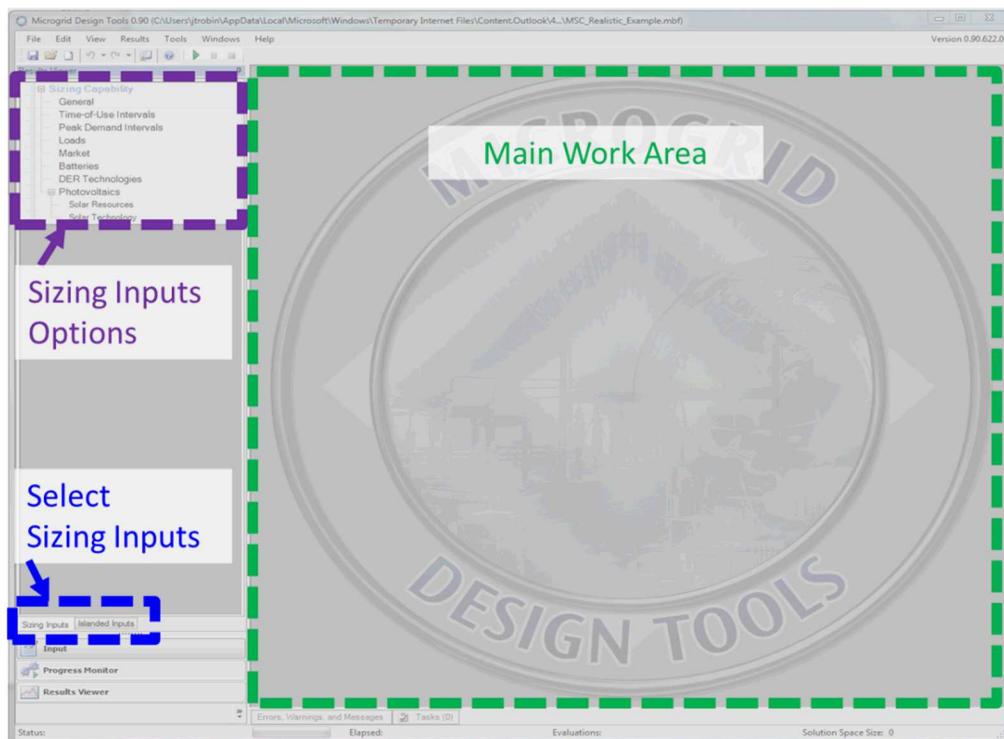


Figure 62. MSC main screen overview.

### 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 63). 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.

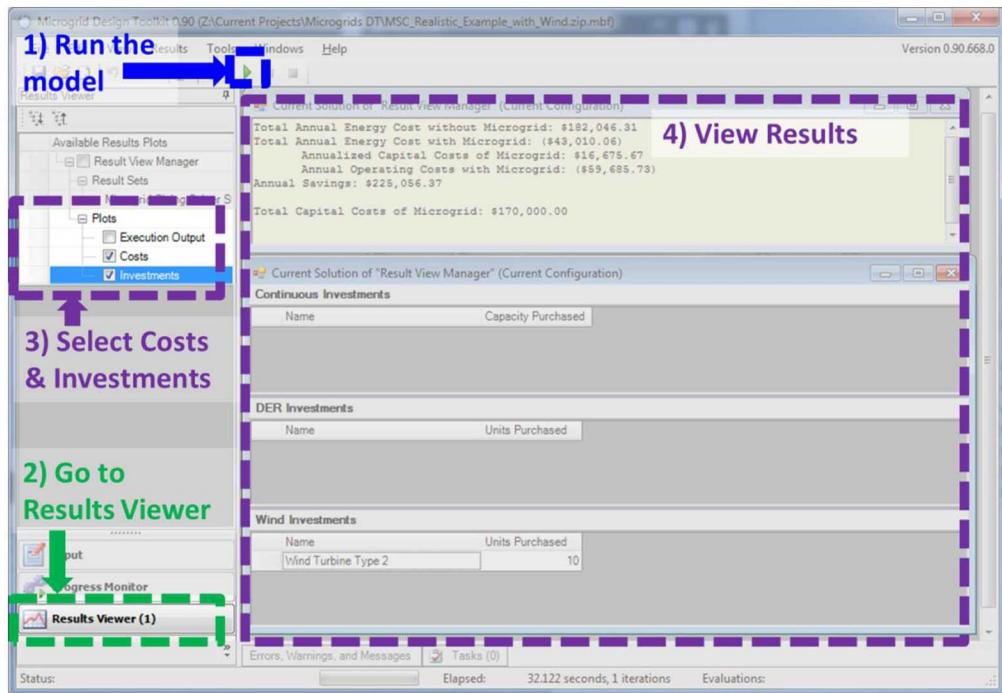


Figure 63. Viewing MSC results.

#### 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,

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

**To open** a results file,

1. 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 64 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).

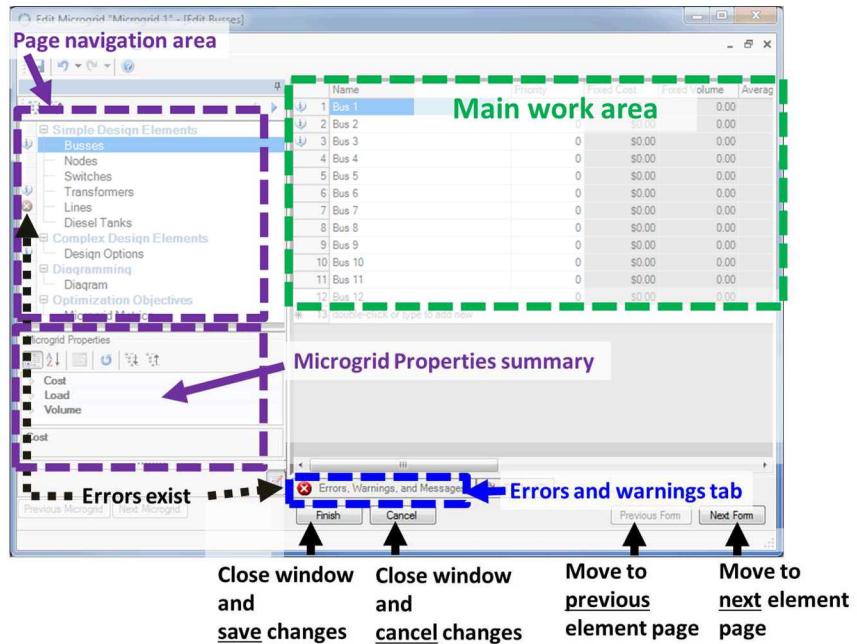


Figure 64. Element pages overview.

#### 4.3.3 Editing Elements: Tabular Entry

Figure 65 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,

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

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

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

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

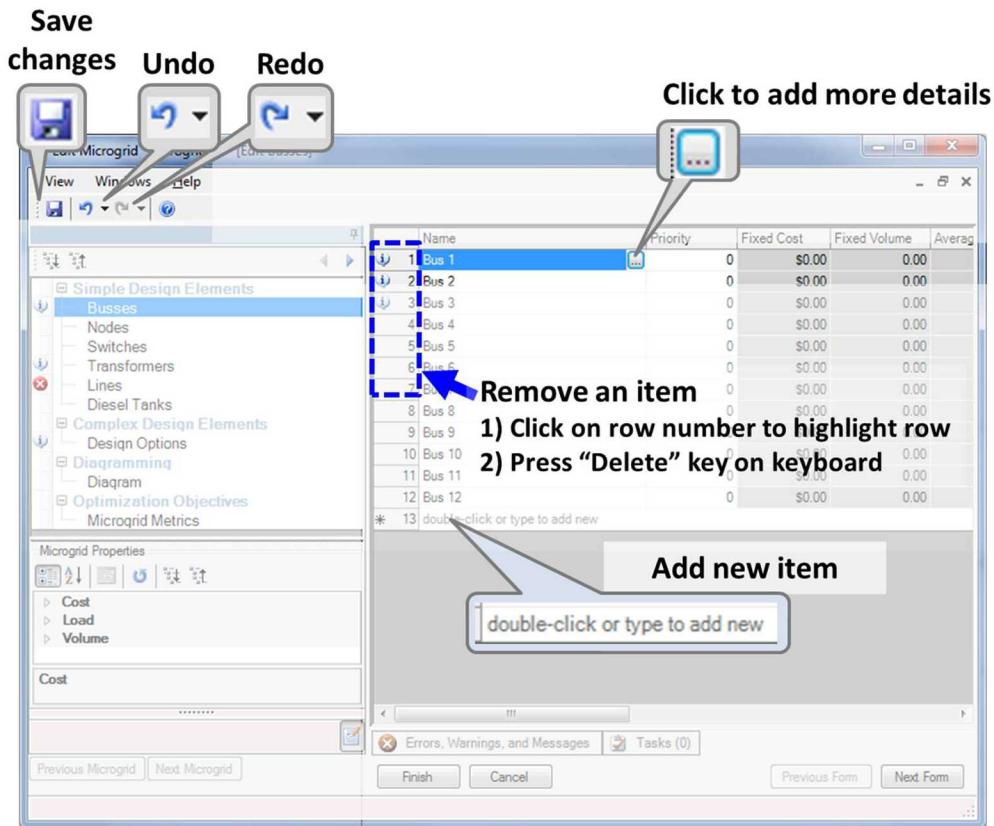


Figure 65. Editing elements.

#### 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 66) allows you to select which plots to display.
- **View Manager Controls** (highlighted in blue in Figure 66) 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 66) can display multiple plots at once. Plot windows can be resized and moved.

All of the 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 66, you will see a bright blue dot or line in three of the plots, which represent the same configuration.

All plot images can be copy-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 66. Results Viewer 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,

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

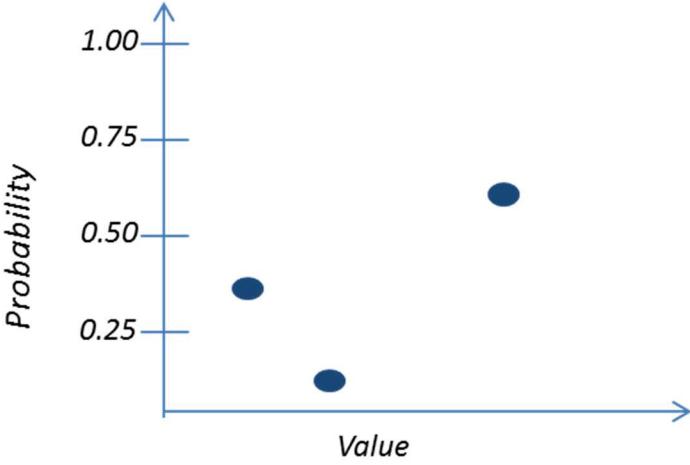
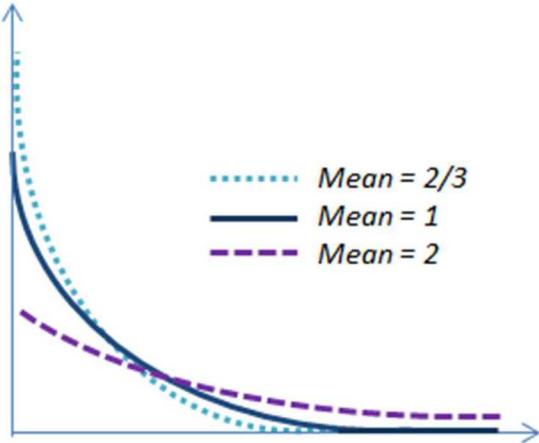
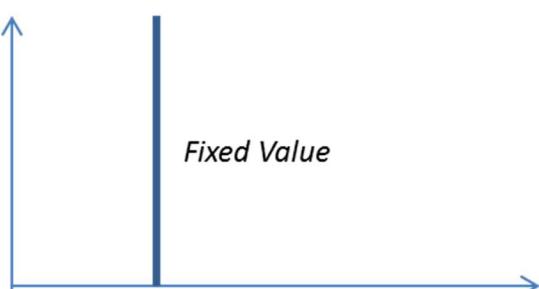
**To open** a results file,

2. 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.

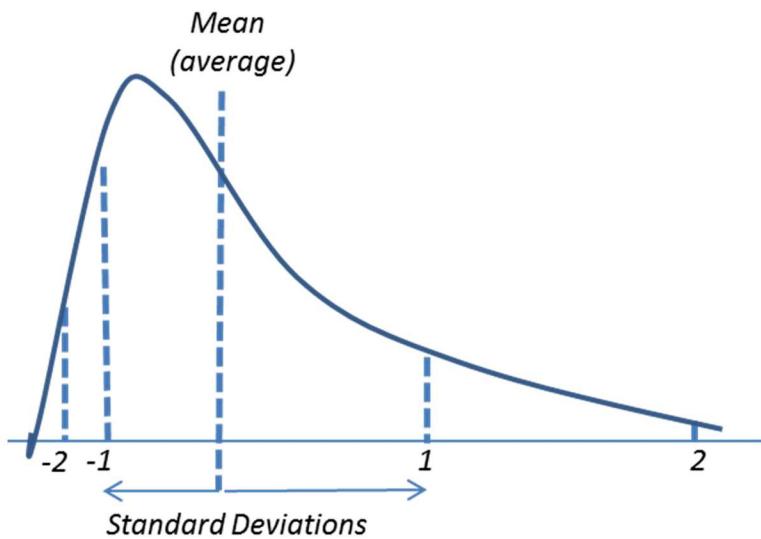
You can define as many failure modes as needed, including the mean time to failure (MTTF) and mean time to repair (MTTR). They are defined in hours. This section provides a description of each distribution and recommendations on when to use each one.

<p><b>Discrete</b></p> <p>Parameters:</p> <ul style="list-style-type: none"> <li>• Values and their Probabilities (1 or more. Probabilities must add up to 100%)</li> </ul>	 <table border="1"> <thead> <tr> <th>Value</th> <th>Probability</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>0.33</td> </tr> <tr> <td>2</td> <td>0.33</td> </tr> <tr> <td>3</td> <td>0.34</td> </tr> </tbody> </table>	Value	Probability	1	0.33	2	0.33	3	0.34
Value	Probability								
1	0.33								
2	0.33								
3	0.34								
<p><b>Exponential</b></p> <p>Parameters:</p> <ul style="list-style-type: none"> <li>• Mean (1/Lambda)</li> <li>• Location</li> </ul>	 <table border="1"> <thead> <tr> <th>Mean</th> <th>Approximate Distribution</th> </tr> </thead> <tbody> <tr> <td><math>2/3</math></td> <td>High Probability at Low Values, Decaying Rapidly</td> </tr> <tr> <td>1</td> <td>Medium Probability at Intermediate Values</td> </tr> <tr> <td>2</td> <td>Low Probability at High Values, Decaying Slowly</td> </tr> </tbody> </table>	Mean	Approximate Distribution	$2/3$	High Probability at Low Values, Decaying Rapidly	1	Medium Probability at Intermediate Values	2	Low Probability at High Values, Decaying Slowly
Mean	Approximate Distribution								
$2/3$	High Probability at Low Values, Decaying Rapidly								
1	Medium Probability at Intermediate Values								
2	Low Probability at High Values, Decaying Slowly								
<p><b>Fixed</b></p> <p>Parameters:</p> <ul style="list-style-type: none"> <li>• Fixed Value</li> </ul>	 <p>Fixed Value</p>								

### Log Normal

Parameters:

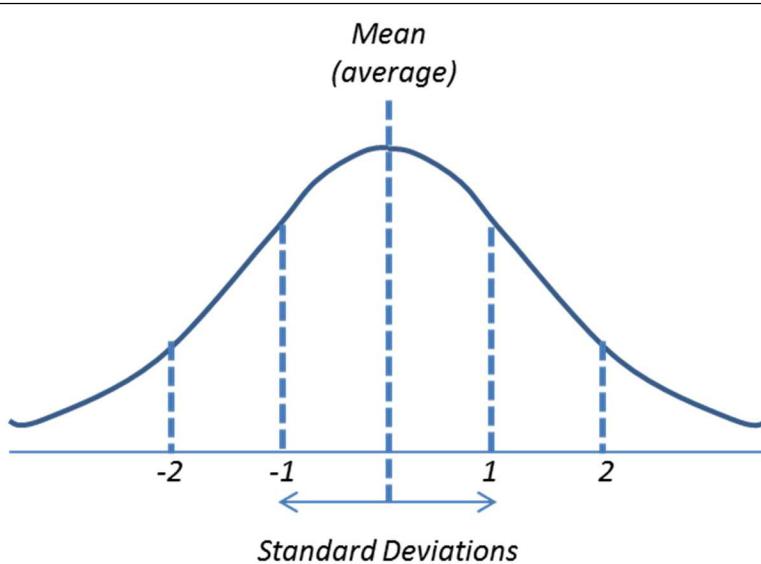
- Mean
- Standard Deviation



### Normal

Parameters:

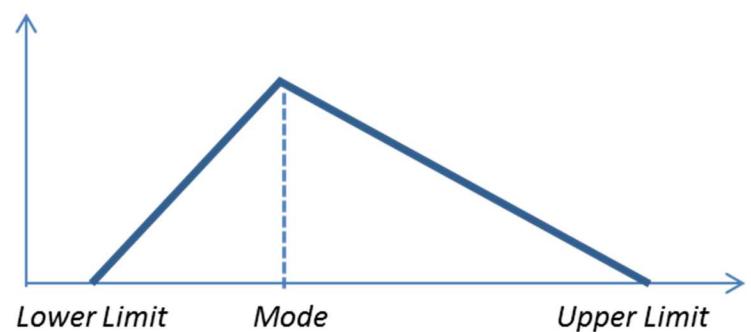
- Mean
- Standard Deviation



### Triangular

Parameters:

- Lower Limit
- Mode
- Upper Limit

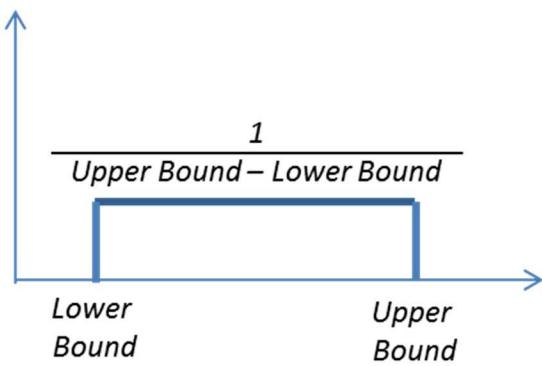


**Uniform**  
(aka rectangular distribution)

Parameters:

- Lower Bound
- Upper Bound

When to use:



**DISTRIBUTION**

1      MS0899      Technical Library, 9536 (electronic copy)



**Sandia National Laboratories**