SAND2016-7415

Printed July 2016
Unlimited Release
SAND2015-8720 TR

Microgrid Design Toolkit (MDT) Simple Use Case Example for Islanded Mode Optimization

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.

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
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
Online order: http://www.ntis.gov/search

Printed July 2016
Unlimited Release
SAND2015-8720 TR

Microgrid Design Toolkit (MDT) Simple Use Case Example for Islanded Mode Optimization

Software v1.1

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

Abstract

This simple Microgrid Design Toolkit (MDT) use case will provide you an example of a basic microgrid design. It will introduce basic principles of using the MDT islanded mode optimization by modifying a baseline microgrid design and performing an analysis of the results. Please reference the MDT User Guide (SAND2015-8593O) for detailed instructions on how to use the tool.

Contents

1. Introduction 5

2. Modify and Analyze a Simple Microgrid Design.. 7

2.1. Make Simple Changes to a Microgrid Design 7

2.2. Review the Complex Design Element 8

2.3. Review the Optimization Metrics 9

2.4. Analyze Results 10

3. Add Failure Modes to the Microgrid Design 13

3.1. Add Failure Modes to Equipment Specifications 13

3.2. Compare Two Analysis Results 14

3.3. Add Failure Modes to a Subsection of the Microgrid 14

3.4. Analyze “Hot Spot” Results 16

Figures

Figure 1. Selecting specifications for a diesel generator. 7

Figure 2. Elements of the Complex Design Option page. Bus Options (highlighted in green) have additional sub options (highlighted in purple).. 9

Figure 3. Pareto frontier for use case. The bottom of the plot displays the number of feasible and infeasible solutions (highlighted in green).. 10

Figure 4. Point labels can be displayed on the Pareto frontier. They are accessed from the Controls tab (highlighted in purple). 11

Figure 5. Selecting two plots from two different result sets. 14

Figure 6. Area of the microgrid that is an unreliable "hot spot".. 15

Figure 7. Multiple solutions selected (using "box select") on the Pareto Frontier for the B2 Hot Spot run. 16

Figure 8. Response Function Filters for B2 Hot Spot run.. 17

1. Introduction

The current version of the Microgrid Design Toolkit (MDT) includes two main capabilities. Each capability has its own input screens and underlying model. 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).

These two capabilities are functionally separate in MDT. Purchases recommended by MSC are not directly transferable to the islanded mode optimization. MSC is used in the early stages of the design process to determine the initial size of a microgrid design with a focus on operating in grid-connected mode. Before the islanded mode optimization can be used, the topology (fixed and variable) and other details of the microgrid design must be determined. Once these intermediate steps have been completed, the islanded mode optimization can be used to refine the microgrid design to improve performance in islanded mode operation.

The simple MDT use case described in this document focuses on the second capability, microgrid operation in islanded mode. It will introduce basic principles of using the MDT Islanded Mode by modifying a baseline microgrid design and performing an analysis of the results. The actions taken on a pre-existing model will be:

- Adding simple decision variables to the design
- Adding complex design options
- Adding failure modes to equipment specifications
- Adding failure modes to equipment in the microgrid design

A separate example and document will address the MSC capability.

This use case example comes with three files:

1. IEEE9Bus_UseCase1.mbf
2. SpecificationDB.mdf
3. SpecificationDB_log.ldf

Please reference these additional documents for more information on the MDT:

- Detailed instructions on how to use the tool
    - *Microgrid Design Toolkit (MDT) User Guide (SAND2015-8593O).* Sandia National Laboratories (2015).
- Description of the underlying algorithms and models
    - *Microgrid Design Toolkit (MDT) Technical Documentation and Component Summaries (SAND2015-8849).* Sandia National Laboratories (2015).
- Example input file for the MSC capability
    - Available as part of the MDT distribution

2. Modify and Analyze a Simple Microgrid Design

2.1. Make Simple Changes to a Microgrid Design

First, you will need to use the example equipment specifications files before starting the MDT system.

1. Browse to directory: *C:\users\public\public documents*
2. You will see folders for each version of the MDT that you have installed (if applicable).
3. Find the current version of MDT.
4. You will see your specifications database files (*SpecificationDB.mdf* and *SpecificationDB_log.ldf*) in the folder. Do not rename these files. Copy them into another folder for later retrieval.
5. Copy the use case example *SpecificationDB.mdf* and *SpecificationDB_log.ldf* files into the folder of the current version of MDT.
6. When you have completed this use case example, restore the database files from step 3 into the folder of the current version of MDT.

A simple, baseline microgrid design has been created for you.

1. Open the MDT.
2. Open the IEEE9Bus_UseCase1.mbf file.
3. Under Microgrids, click on "Listing".
4. Click on "Microgrid 1" in the grid at the top. The diagram of "Microgrid 1" will be displayed.

⚠	Be sure to save your work frequently by pressing Ctrl-S or by pressing the save button on the toolbar of any window (💾).

Looking at the Properties tab on the right, we see that the microgrid has an aggregate load of 1100 kW. The microgrid also has three diesel generators (B1 Diesel, B2 Diesel, B3 Diesel), but each one only generates 100kW. This is clearly not enough power to support the system load. Let's modify the microgrid to include appropriate power generation.

5. Locate "B1 Diesel" on the diagram. Double-click on it and a window will appear.
6. In the window that appears, click on the Allowable Specifications field and open the menu (Figure 1).
7. You will now see a list of several diesel generators. We can select a specific generator to use for Bus 1, or we can let the optimization model select a generator. Let's let the model choose the generator.
    a. Unselect "No Generator".
    b. Select Diesel Generator Specifications 1-5.

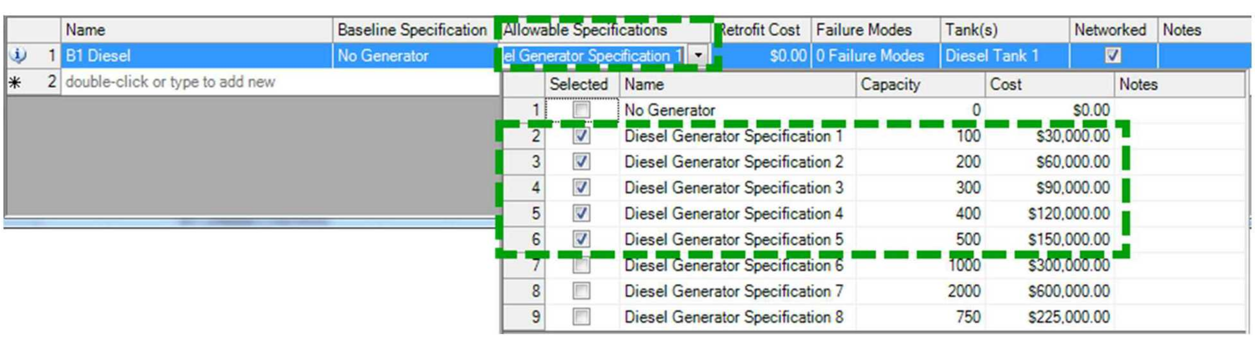

Figure 1. Selecting specifications for a diesel generator.

8. Dismiss the window using the “X” in the upper right.
9. Repeat the above steps for “B2 Diesel” and “B3 Diesel”, selecting specifications 1-5 for each.

2.2. Review the Complex Design Element

Return to the Diagram to view the complex design element. We will investigate the complex design option that has already been built in this model.

1. Select the Complex Options tab on the right.
2. Click the Design Option 1 dropdown menu. There are three different choices for this complex design option.
    a. Design Option 1 Empty Realization: This is the “do not add anything” option.
    b. Design Option 1 Realization 0: This option adds a switch, 2 lines, and 100kW diesel generator to Bus 6.
    c. Design Option 1 Realization 1: This option adds a switch and 2 lines only (no diesel generator) to Bus 6.

   Note: The order of realization 0 and 1 may be swapped in your tool.

Realization 1 makes no sense: there is no point in adding a switch and lines to a bus when there is no generator. This realization needs to be removed as an option.

3. In the grid listing at the top of the form, click in the name column for “Microgrid 1”.
4. A button will appear on the right in the cell. Click the button and a new form will appear.
5. In the new form, under Complex Design Elements, select Design Options.
6. The Enumerated Size field for Design Option 1 should contain the value 3. This means that there are 3 enumerations/permutations for this design option.
7. Click the “View/Edit” button next to Design Option 1.
8. You will see the three possible permutations of the complex design option.
9. Uncheck the “Included” field of Realization 1 (*or whichever realization doesn’t include the generator*).
10. Click “Finish” at the bottom of the window.
11. The Enumerated Size field for Design Option 1 should now contain the value 2.
12. Return to the diagram and go to the Complex Options tab.
13. The Design Option 1 dropdown should only include the Empty Realization and 1 other (0 or 1 depending on the order as described above).

This example illustrates the usefulness of complex design options. Complex design options allow you to define a set of equipment that should be treated as a unit. In this scenario, you either want all of the equipment in the unit, or you don’t want to use the unit at all. In the example above, there is no point in adding the switch if there will be no diesel generator. Simple decision variables can still be included in a complex design option.

1. Under Complex Design Elements, select Design Options.
2. In the window below Design Option 1, select the Bus Options tab at the bottom of the screen (highlighted in green in Figure 2).
3. Select the Diesel Generators tab in the row above Bus Options (highlighted in purple in Figure 2).
4. Select the Specifications dropdown for Diesel Generator 1. You will see that two items are selected. This is a simple decision variable.

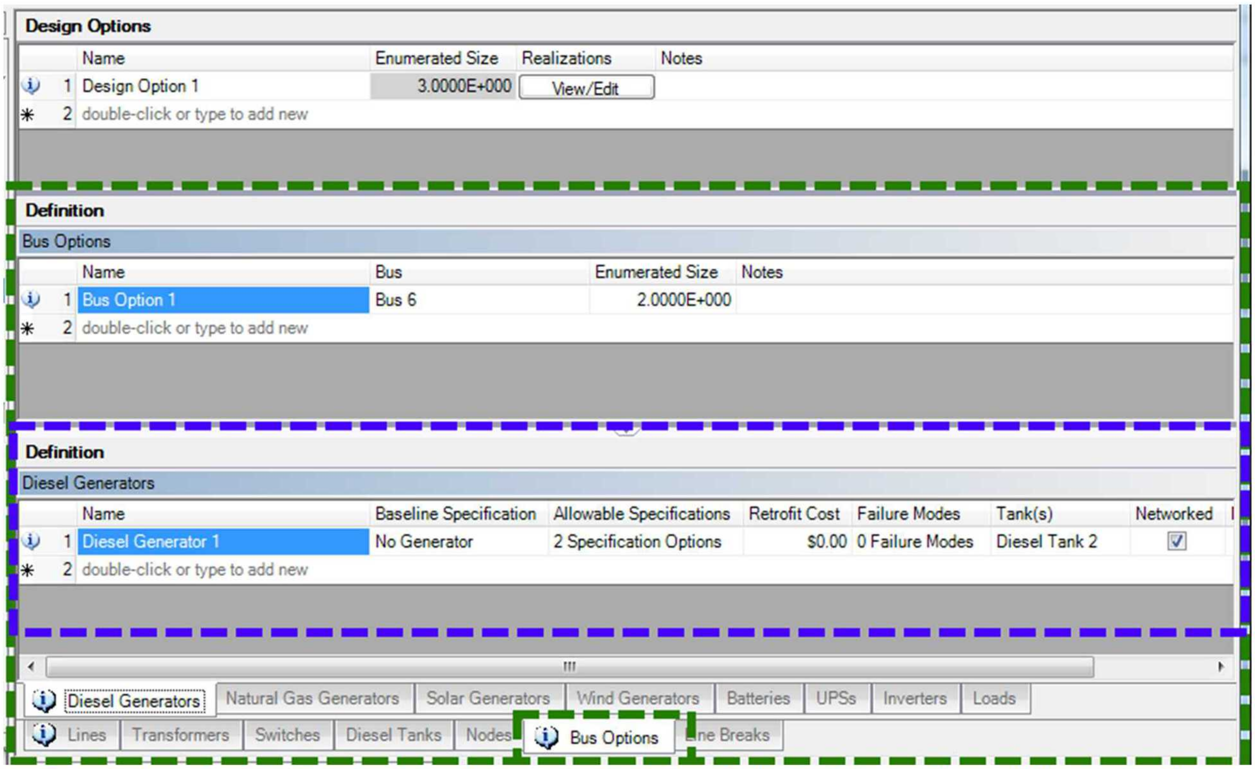

Figure 2. Elements of the Complex Design Option page. Bus Options (highlighted in green) have additional sub options (highlighted in purple).

2.3. Review the Optimization Metrics

Let's look at the Microgrid Metrics to understand the model constraints that will be applied to the optimization.

1. Under Optimization Objectives, click on "Microgrid Metrics".
2. Under Cost Metrics, the maximum total purchase cost is $1,200,000. The objective is to limit the total purchase cost to $900,000. Since the most expensive diesel generator is the 500kW at $150,000, and we only need three generators, cost should not be an issue.
3. Under Load Metrics, the minimum energy availability goal is 98%, with an objective to meet 99.999% if possible.
4. Under Fuel Metrics, the maximum average diesel fuel use rate is 100 gallons/hour of the outage, with an objective to obtain a fuel use rate of 50 gallons/hour if possible.
5. Under Efficiency Metrics, the minimum diesel efficiency is 30%, with an objective to have an efficiency of 37% if possible.
6. Click "Finish" at the bottom of the window.

Please see *Microgrid Design Toolkit (MDT) User Guide* Section 3.4.7 (SAND2015-8593O) for descriptions of all of the optimization objectives.

2.4. Analyze Results

Next, run the model.

1. Click the green play arrow in the toolbar.
2. You can ignore the warnings presented.
3. When the model has finished running, the Results Viewer page will open with the Pareto Frontier (Figure 3).

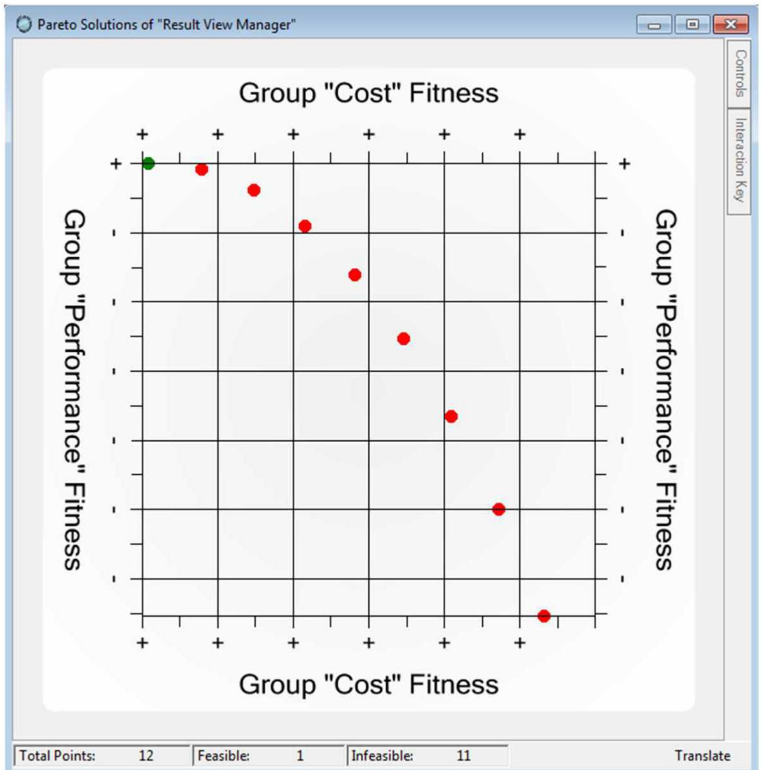

Figure 3. Pareto frontier for use case. The bottom of the plot displays the number of feasible and infeasible solutions (highlighted in green).

The Pareto frontier above shows 10 solutions, with one feasible solution (the green dot) and nine infeasible solutions (the red dots). Feasible in this context means that all metric limits have been satisfied. This summary information is displayed at the bottom of the plot (highlighted in green in Figure 3). You may obtain slightly different results when you run the model.

Click on the green dot to select the solution. To view the ID number of all solutions, click on the Controls tab and select "Show Point Labels" (Figure 4).

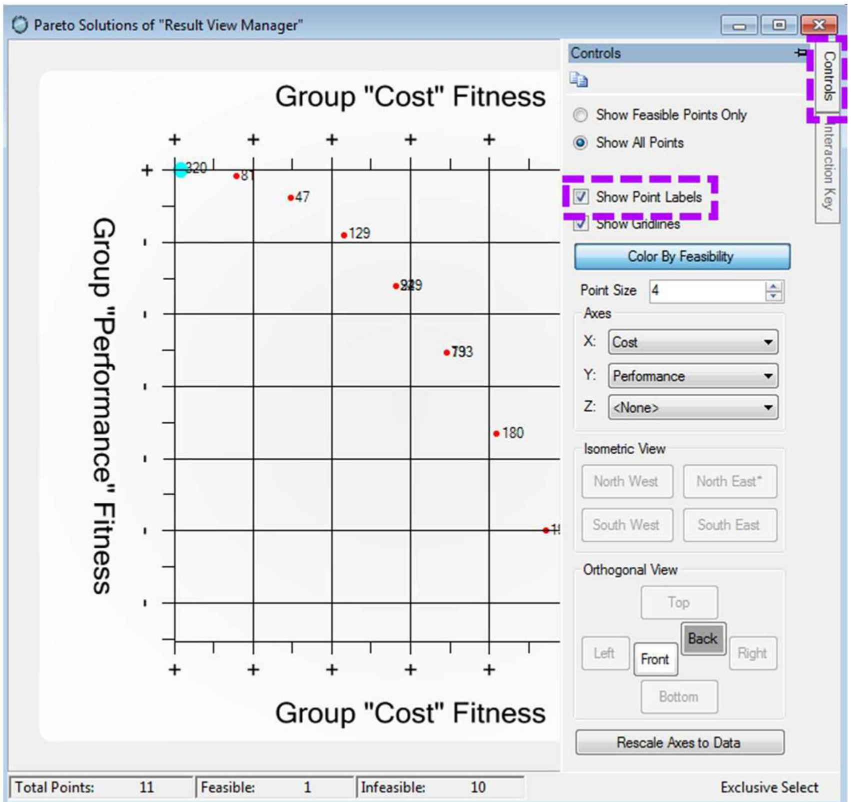

Figure 4. Point labels can be displayed on the Pareto frontier. They are accessed from the Controls tab (highlighted in purple).

The diesel generators were decision variables in our microgrid design. To see which generators were selected, select Diagram in the Results Viewer.

To see how the solution performed with respect to the other three performance metrics, open Solution Text and scroll all the way to the bottom.

- Purchase cost: $330,000
  - Limit was <= $1,200,000
  - Met the objective of <= $900,000
- Diesel Fuel Used: 81 gal/hour of outage
  - Limit was <= 100 gal/hour of outage
  - Did not meet objective of <= 50 gal/hour of outage
- Diesel Efficiency: 0.36
  - Limit was >= 0.3
  - Almost met the objective of >= 0.37
- Energy Availability: 100%
  - Limit was >= 98%
  - Met the objective of >= 99.999%

We can see from the Pareto frontier that the next closest solution (#124 in Figure 4, but the solution may have a different ID in your results) is a cheaper solution, but did not meet all of the performance requirements. At the top of the Solution Text window, select the solution ID from the Configuration dropdown menu and scroll all the way to the bottom. This solution met all metrics except for Energy Availability.

To view the performance values for all of the solutions, open Response Function Filters. This will display the performance values for the optimization metrics on a parallel coordinates plot. Each horizontal line represents a solution and each axis represents a metric. Clicking on the line will make the solution ID appear in the configuration dropdown menu at the top of the page.

To view which equipment specifications were selected across all solutions, open Usage Frequency. This plot provides a histogram of how many times each equipment specification was selected per decision variable. This plot is helpful in understanding if certain equipment specifications are more useful than others for your microgrid design.

Let's rename this result set since we will be performing additional model runs.

1. Under Available Results Plots, locate Result View Manager, which should be the top of the hierarchy.
2. Right click on it.
3. Select Rename.
4. Enter "Baseline Run".

Please see *Microgrid Design Toolkit (MDT) User Guide* Section 3.8 (SAND2015-8593O) for descriptions of all of the results plots.

3. Add Failure Modes to the Microgrid Design

3.1. Add Failure Modes to Equipment Specifications

None of the equipment is assigned failure modes, which means none of it can fail in the model. Scrolling through the Solution Text, you will see for each piece of equipment, at the end of its performance data, the line, “The item could not fail.”

Let’s modify the microgrid design to introduce some failure modes to equipment. Failure modes define the ways that each equipment type can break. Failure modes can be defined for equipment specifications and in the microgrid design. The current dummy equipment specifications do not have failure modes defined.

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.

Let’s first add failure modes to the equipment specifications for the diesel generators.

1. On the menu, select Edit -> All Specifications.
2. Select Diesel Generator Specifications from the navigation menu.
3. For Diesel Generator Specification 1, click on the Failure Modes field. This will open a window.
4. Enter name FailureMode1 in the table.
5. Click on the mean time between failure (MTBF)[1] field.
6. Select Exponential from the dropdown menu.
    a. Enter Mean: 1250
    b. Leave location as 0.
7. Click on the mean time to repair (MTTR) field.
8. Select Triangular from the dropdown menu.
    a. Enter Lower limit: 0.5
    b. Enter Mode: 8
    c. Enter Upper limit: 24
9. Enter the same failure mode for Diesel Generator Specifications 1-5. MDT supports copy and paste, which will make this process faster.
    a. Click on FailureMode1.
    b. Press CTRL-C to copy the failure mode.
    c. For Diesel Generator Specification 2, click on the Failure Modes field.
    d. Click on the Name field.
    e. Press CTRL-V to paste the failure mode.
    f. Repeat for specification 3-5.
10. Press the Save button when you are done.
11. Click the Finish button at the bottom of the window.

[1]Descriptions of the various failure mode distributions can be found in Appendix B of the *Microgrid Design Toolkit (MDT) User Guide* (SAND2015-8593O).

Since we entered these failure modes at the specifications level, any diesel generators we use in our microgrid design that uses any of these specifications will inherit these failure modes.

Run the model with these updates and see how it affects the results.

3.2. Compare Two Analysis Results

After running the model, you will notice that your prior run, Run 1, is still available in the Results Viewer. Rename your new model run results as "DG Failure Modes".

On the Pareto Frontier for DG Failure Modes, select the one feasible solution. Open the Diagram to view the feasible solution. With the introduction of failure modes, the model may make different selections for the three diesel generators and complex design option.

Open the Solution Text for the feasible solutions in Baseline Run and DG Failure Modes (Figure 5). Resize the windows so that you can view them side-by-side in the tool. You can do this quickly using the menu at the top (*Windows-Tile Vertical*). Scroll all the way to the bottom of both windows to compare results.

Under Local Upgrades, we can compare the different equipment selections and performance metrics. Since our failure modes didn't cause the generators to fail very often, performance metrics should be similar between the two runs.

Scroll back up through Solution Text until you find Diesel Generator B1 Diesel @ Bus Bus 1 in both windows. You can see how the failure mode impacted the generator performance. Since DG Failure Modes allows the generators to fail, it contains additional information about outage durations and operational durations.

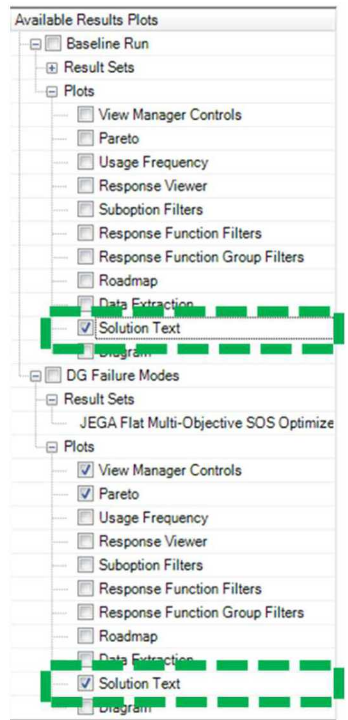

Figure 5. Selecting two plots from two different result sets.

3.3. Add Failure Modes to a Subsection of the Microgrid

Let's now assume that the area around Bus 2 (Figure 6) is an unreliable "hot spot". We will add failure modes to the transformer and the three lines in this area. This time, since the unreliability is due to characteristics of this specific region and not due to the type of equipment, the failure modes will be added to the microgrid design rather than in the equipment specifications. If we added the failure modes at the equipment specification level, then all of the lines and transformers in the microgrid design would inherit them, which is not the behavior we want.

1. Return to the Input navigation tab and visit Microgrids/Listing to view the diagram.
2. Locate Transformer 2-7 on the diagram.
3. Double-click to modify its properties.
4. Click on the Failure Modes field. A button will appear on the right. Click it to open a window.
5. Enter name FailureMode1 in the table.

6. Click on the mean time between failure (MTBF)[2] field.
7. Select Normal from the dropdown menu.
    a. Mean: 2184
    b. Standard Deviation: 500
8. Click on the mean time to repair (MTTR) field.
    a. Select Triangular from the dropdown menu.
        i. Lower Limit: 1.5
        ii. Mode: 4
        iii. Upper Limit: 16
9. Locate Line T2-7-2 (which connects Transformer 2-7 to Bus 2).
10. Double-click it to edit.
11. Add FailureMode1.
12. Click on the MTBF field.
13. Select Normal from the dropdown menu.
    a. Mean: 2160
    b. Standard Deviation: 100
14. Click on the MTTR field.
15. Select Fixed from the dropdown menu.
    a. Fixed Value: 16
16. Enter the same failure mode for Line 2-DG and Line 2-LS.
17. Press the Save button when you are done.
18. Click the Finish button at the bottom of the window.

Run the model with these updates and see how it affects the results.

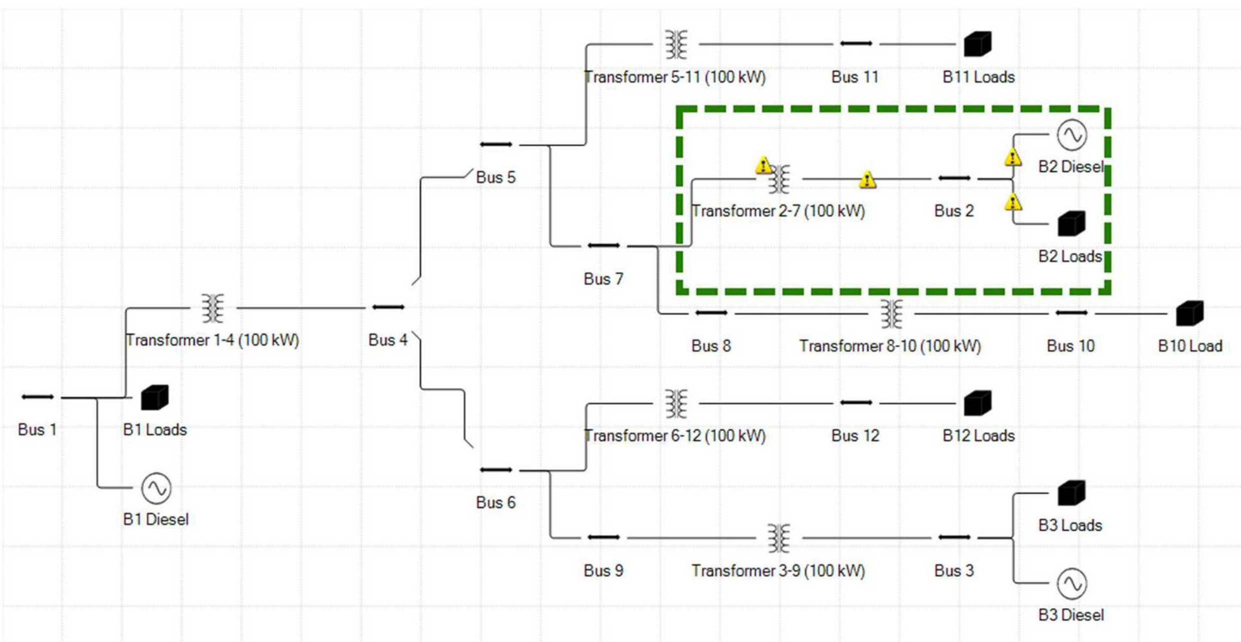

Figure 6. Area of the microgrid that is an unreliable "hot spot".

[2]A more detailed discussion of the various failure mode distributions can be found in Appendix B of the *Microgrid Design Toolkit (MDT) User Guide* (SAND2015-8593O).

3.4. Analyze "Hot Spot" Results

Rename your new model run results as "Bus 2 Hot Spot".

This time on your Pareto frontier, you may see that there are more feasible solutions. If you look into them, you will find that all have lesser energy availability then the feasible solutions of the previous runs. It may seem odd that a greater number of feasible solutions are found with less reliability in the system. Keep in mind that the solver is not explicitly seeking to maximize the number of solutions found that meet all limits but is in fact seeking Pareto optimal solutions. There may be several feasible solutions that exist but that fall below the Pareto frontier and are thus inferior to the alternatives presented.

The number and exact solutions that you get may differ slightly each time you run the model. This is due to the uncertainty around the number and duration of equipment failures that may occur during the run, along with the uncertainty for number of system outages that occur (defined on Site Definition: Settings). Having set the random seed to a fixed value will help minimize this uncertainty but at present cannot completely eliminate it.

Using the example below, there are a few solutions with similar performance results but different costs. Let's explore these solutions. You can select multiple solutions on the Pareto frontier by using "box select" (Figure 7):

1. Click on the plot near the area you want you select.
2. Keeping the mouse pressed down, drag a box around the solutions you want to highlight.
3. Release your mouse.

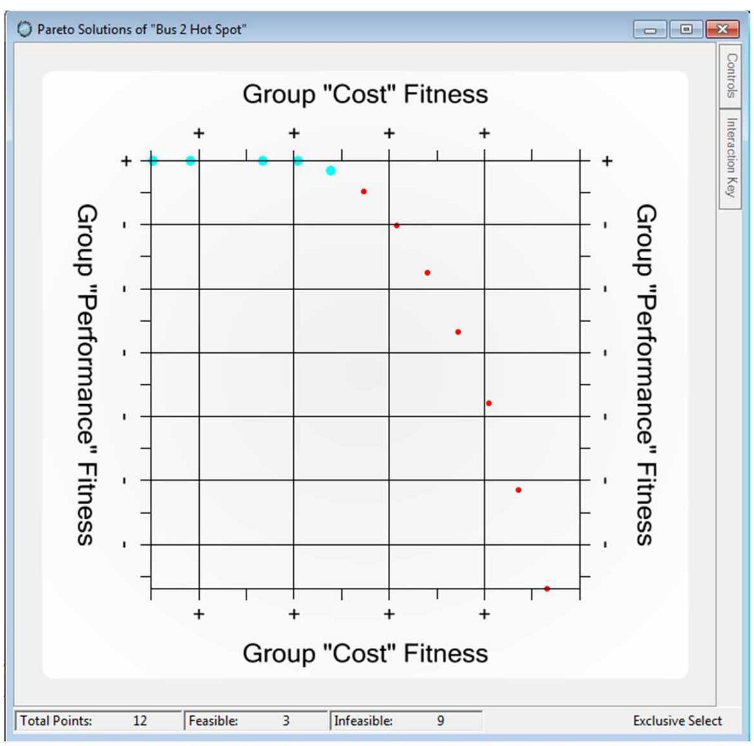

Figure 7. Multiple solutions selected (using "box select") on the Pareto Frontier for the Bus 2 Hot Spot run.

Open the Response Function Filters plot. The highlighted solutions from the Pareto frontier should also be highlighted on this plot (Figure 8). You can easily see how the performance values compare. Aside from cost, the largest variability is in Diesel Efficiency. We can also see from the axis label that the max Energy Availability achieved was approximately 99.3%. Investigation will show that availability decreases with each solution and quickly goes below the minimum energy availability goal of 98%.

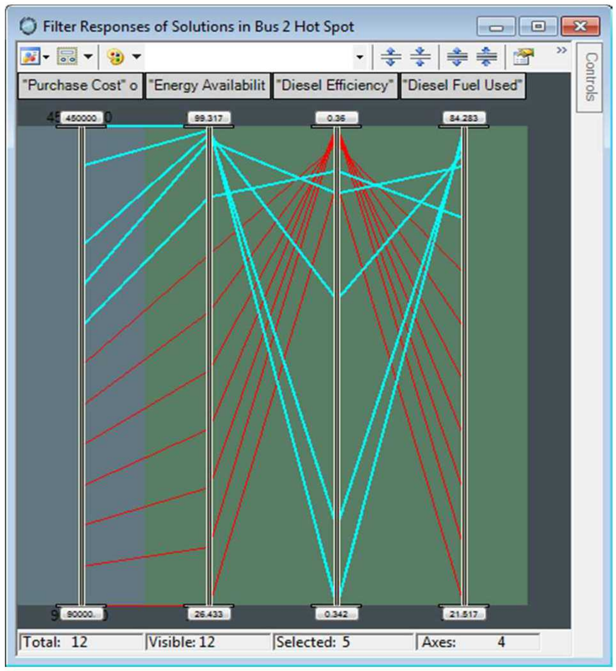

Figure 8. Response Function Filters for Bus 2 Hot Spot run.

Looking at the solutions for this particular run, the solution with the best energy availability assigns two 500kW, one 400kW, and adds the complex design option of a 100kW generator.

. How can we improve energy reliability in this hotspot area? Here are some things to try.

- Add higher capacity diesel generator options (Diesel Generator Specification 6 and 7) for generators B1-B3
- Add higher capacity diesel generator options in the complex Design Option 1
- Add additional diesel generators or other power sources
- Add a redundant path between bus 7 and bus 2 as a complex design option. Perhaps include a normally open switch on this redundant path to tell the MDT that it is secondary.

Try each solution individually. What are the results? What are the pros and cons of each approach? Remember to add the failure modes to Diesel Generator Specification 6 and 7 under Equipment Specifications, otherwise they will never fail during the model run. You can also try 2 or more of the above options simultaneously to investigate the cost-performance trade-offs to help decide which one is best.

Please see *Microgrid Design Toolkit (MDT) User Guide* Section 3.8 for descriptions of all of the results plots.

DISTRIBUTION

1	MS0899	Technical Library, 9536 (electronic copy)

Sandia National Laboratories