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Grid Integrated Distributed PV (GridPV)

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Grid Integrated Distributed PV (GridPV)

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Abstract

This manual provides the documentation of the MATLAB toolbox of functions for using OpenDSS to simulate the impact of solar energy on the distribution system. The majority of the functions are useful for interfacing OpenDSS and MATLAB, and they are of generic use for commanding OpenDSS from MATLAB and retrieving information from simulations. A set of functions is also included for modeling PV plant output and setting up the PV plant in the OpenDSS simulation. The toolbox contains functions for modeling the OpenDSS distribution feeder on satellite images with GPS coordinates. Finally, example simulations functions are included to show potential uses of the toolbox functions. Each function in the toolbox is documented with the function use syntax, full description, function input list, function output list, example use, and example output.

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TABLES

Table 1. Summary of EPRI Test Ckt24. 45

NOMENCLATURE

COM	Component Object Model
DG	Distributed Generation
DOE	Department of Energy
EPRI	Electric Power Research Institute
GUI	Graphical user interface
IEEE	Institute of Electrical and Electronics Engineers
LDC	Line Drop Compensation
LTC	Load Tap Changer
MW	Megawatts (AC)
OpenDSS	Open Distribution System Simulator™
PCC	Point of Common Coupling
pu	per unit
PV	Photovoltaic
UTM	Universal Transverse Mercator
VBA	Visual Basic for Applications
WVM	Wavelet Variability Model

1. INTRODUCTION

The power industry is beginning to see a change to larger amounts of generation on the distribution system. This presents a new set of issues, especially for renewable generation with variable intermittent power output. It is important to precisely model the impact of solar energy on the grid and to help distribution planners perform the necessary interconnection impact studies. The variability in the load, throughout the day and year, and the variability of solar, throughout the year and because of clouds, makes the analysis increasingly complex. Both accurate data and timeseries simulations are required to fully understand these variations.

This manual describes the functionality and use of a MATLAB toolbox for using OpenDSS to model the variable nature of the distribution system load and solar energy. OpenDSS is an electric power distribution system simulator that is open source software from the Electric Power Research Institute (EPRI) [1]. OpenDSS is used to model the distribution system with MATLAB providing the frontend user interface through a COM interface. OpenDSS is designed for distribution system analysis and is very good at timeseries analysis with changing variables and dynamic control. OpenDSS is command based and has limited visualization capabilities. By bringing control of OpenDSS to MATLAB, the functionality of OpenDSS is utilized while adding the looping, advanced analysis, and visualization abilities of MATLAB.

The functions in the toolbox are categorized into five main sections in the manual: OpenDSS functions, Solar Modeling functions, Plotting functions, Geographic Mapping functions, and Example Simulations. Each function is documented with the function use syntax, full description, function input list, function output list, and an example use. The function example also includes an example output of the function.

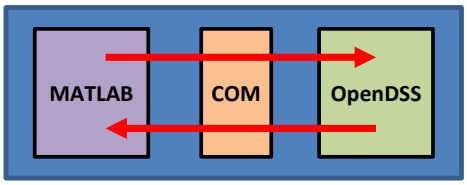
1.1. Objectives

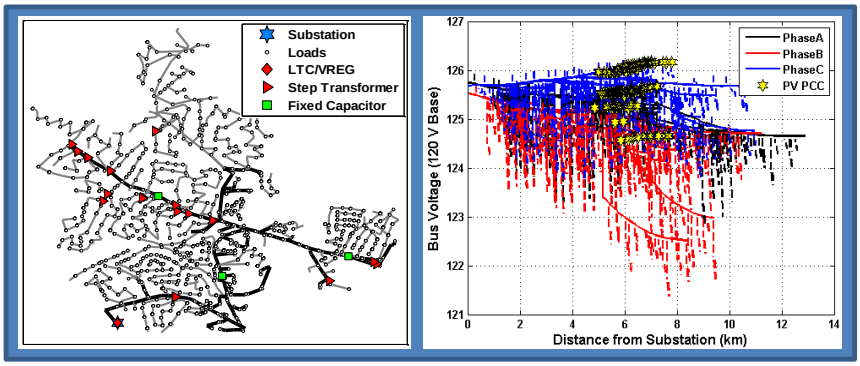
The GridPV Toolbox for MATLAB provides a set of well-documented functions for simulating the performance of photovoltaic energy systems. Version 1 contains functions, example scripts, and sample data files.

The toolbox was developed at Sandia National Laboratories and it implements many of the models and methods developed at the Labs. Future versions are planned that will add more functions and capability.

1.2. Overview of GridPV Features

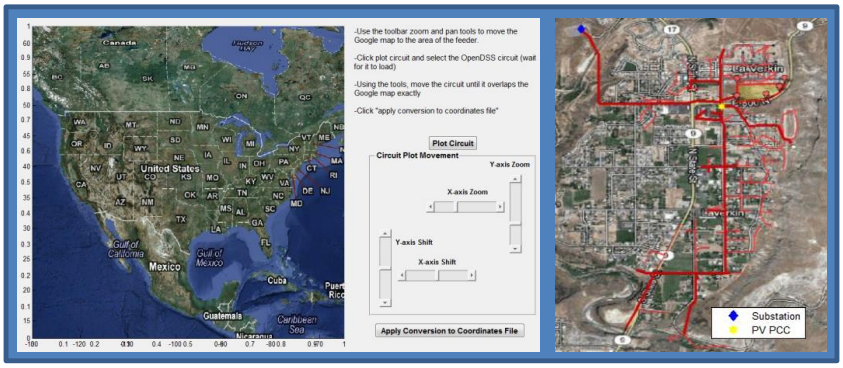
Standardizes interface between MATLAB and OpenDSS for easy parameter queries

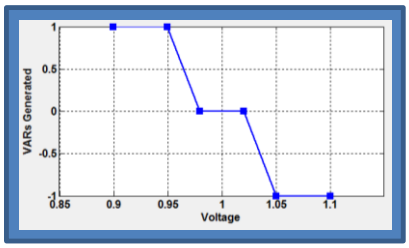




Validates OpenDSS feeders and checks for errors

Integrates GIS functionality through Google Maps and includes functions to convert between coordinate systems

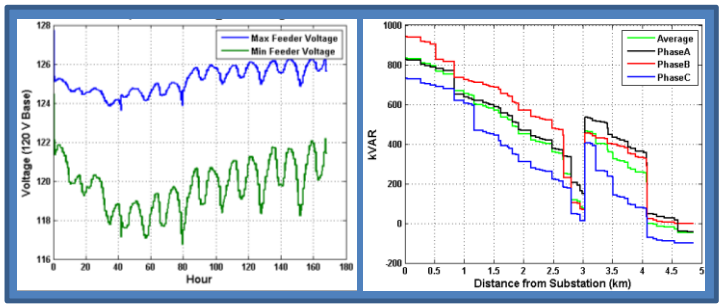


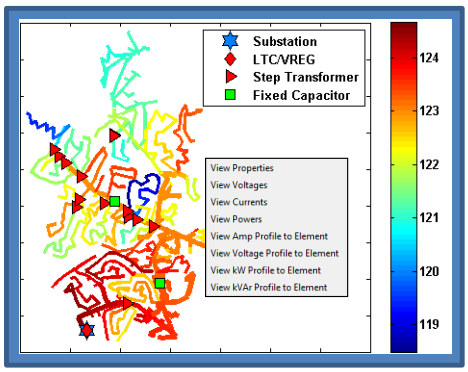


Models solar power easily and accurately

- **GUI for setting up PV plants**
- **Model solar variability for size and dispersion of PV**
- **Power factor and reactive power control for PV plants**
- **Central and distributed plants**

Performs time-series and steady-state simulations





Plots and visualizes results

- **Clean and interactive plots with numerous options**
- **Integrated plotting options such as feeder circuit diagram and voltage, current, and power profiles**

2. DOWNLOAD AND INSTALLATION

2.1. OpenDSS Installation

Before using the GridPV toolbox, the current version of OpenDSS must be installed. To install OpenDSS, go to http://sourceforge.net/projects/electricdss/ [1]. No settings need to be changed from the default installation choices.

2.2. Download GridPV

To download the GridPV toolbox, go to www.gridintegration.org and download the GridPV zip file. You will have to sign in before you can download the toolbox. Please review the license agreement before downloading the GridPV toolbox.

2.3. GridPV Installation Instructions

Once you have download the GridPV zip file, follow these steps:

1. Extract the zip file to the desired location
2. Open MATLAB
3. Go to the FILE menu -> SET PATH. (For MATLAB 2013, "Set Path" button under the HOME toolbar ribbon.
4. Push "Add with Subfolders" and select GridPV folder and press OK (this will add the GridPV Toolbox to your path file)
5. Click "Save"
6. **Important** Make sure you remove previous versions of the GridPV Toolbox from your path.
7. Go to MATLAB's help and you should see GridPV Toolbox listed with your other toolboxes. (For MATLAB 2013, in the MATLAB help click "Supplemental Software" at the bottom left.)

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Sandia Corporation ("SANDIA"), under its Contract No. DE-AC04-94AL85000 with the United States Department of Energy for the management and operation of the Sandia National Laboratories, Livermore, California and Albuquerque, New Mexico, has developed the MATLAB GridPV Toolbox, herein called "GridPV Toolbox". By downloading this software, the licensee ("YOU") agree to the following terms:

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Attachment A

1. GridPV Toolbox:
   GridPV Toolbox is a Sandia Corporation copyrighted software, SCR 1507.0, that provides a collection of MATLAB routines for that can be used to model photovoltaic power systems.
2. License Fees:
   GridPV Toolbox is being offered at no cost under this agreement. Commercial distribution licenses for GridPV Toolbox are available from Sandia at reasonable rates.

2.5. GridPV Uninstall Instructions

1. Open MATLAB
2. Go to the FILE menu -> SET PATH. (For MATLAB 2013, "Set Path" button under the HOME toolbar ribbon.
3. Select the main folder and all sub-folders where you previously installed the GridPV toolbox.
4. Click "Remove"
5. Click "Save"
6. You can now navigate to the location of the toolbox files and delete them.

3. OPENDSS

OpenDSS is an open source electric power distribution system simulator from the Electric Power Research Institute (EPRI) [1]. It is a 3-phase distribution system analysis power flow solver that can handle unbalanced phases. OpenDSS is commonly used to model solar on the grid because of its high-resolution time series analysis capabilities [3-7]. Currently available utility-standard simulation tools are not generally well suited for sequential or dynamic simulations needed to fully characterize the effects of PV output variability on distribution feeders. The program was designed to help distribution planners analyze various issues with distributed generation integration and future smart grid applications.

The GridPV toolbox uses OpenDSS to run all electrical simulations and to solve the power flows. Each electrical component in the circuit is modeled in OpenDSS. To perform analysis, the feeder must be setup and compiled into OpenDSS memory. This can be done through MATLAB, but the easiest way is to setup a circuit is through the OpenDSS program and file structure independently. One example feeder is seen in the toolbox documentation folder (Section 5), and other feeders can also be downloaded from the OpenDSS website [1]. These other feeders are included in the OpenDSS installation in two folders: one for the EPRI feeders, and another for the IEEE feeders. Existing feeder models can be converted from other software into the OpenDSS format. OpenDSS is very flexible with respect to scenario analysis; however, it has a basic interface that supports a manual, script-based study process. To facilitate analysis in OpenDSS, this toolbox provides supplemental tools for research and customized analysis through MATLAB.

3.1. OpenDSS Resources

There are many online sources for help and documentation on OpenDSS, so this manual provides very little material or training on using OpenDSS. A few references have been included here for assistance in getting started with OpenDSS or learning more details. The OpenDSS Help Menu is also a very good reference for DSS commands and properties. Specific details about using the OpenDSS COM interface are discussed in Section 4, but for more information on the details, models, or syntax of OpenDSS, see the references below.

3.1.1. Websites

Main OpenDSS Sourceforge

- http://sourceforge.net/projects/electricdss/

Help Forum

- http://sourceforge.net/p/electricdss/discussion/

OpenDSS Wiki

- http://sourceforge.net/apps/mediawiki/electricdss/index.php?title=Main_Page

OpenDSS Getting Started Wiki

- http://sourceforge.net/apps/mediawiki/electricdss/index.php?title=Getting_Started

OpenDSS Training Materials from Dr. Luis Ochoa

- https://sites.google.com/site/luisfochoa/research/opendss-training

3.1.2. Documents

OpenDSS Manual

- http://sourceforge.net/p/electricdss/code/HEAD/tree/trunk/Distrib/Doc/OpenDSSManual.pdf

OpenDSS New User Primer

- http://sourceforge.net/p/electricdss/code/HEAD/tree/trunk/Distrib/Doc/OpenDSSPrimer.pdf

Introduction to OpenDSS

- http://sourceforge.net/p/electricdss/code/HEAD/tree/trunk/Distrib/Doc/Introduction%20to%20the%20OpenDSS.pdf

Training Presentation

- http://sourceforge.net/p/electricdss/code/HEAD/tree/trunk/Distrib/Training/AtlantaWorkshop.pdf

4. GETTING STARTED WITH THE TOOLBOX

This guide will demonstrate how to initiate the COM interface within MATLAB, load and compile a circuit, check the distribution circuit for any errors, generate the coordinate conversion for the circuit, add PV to the existing circuit, and produce plots with the analysis results.

Each toolbox function has its own example contained in the header file, as well as in Section 7. These examples will run on their own using the example circuit and may be useful for becoming familiar with the toolbox.

The basic process for getting started with the toolbox is:

```
% 1. Start the OpenDSS COM. Needs to be done each time MATLAB is opened
    [DSSCircObj, DSSText, gridpvPath] = DSSStartup;
% 2. Compiling the circuit
    DSSText.command = ['Compile "' gridpvPath
      'ExampleCircuit\master_Ckt24.dss"'];
% 3. Solve the circuit. Call anytime you want the circuit to resolve
    DSSText.command = 'solve';
% 4. Run circuitCheck function to double-check for any errors in the circuit
      before using the toolbox
    warnSt = circuitCheck(DSSCircObj);
```

There is much documentation for each toolbox function contained within the toolbox in the form of standard MATLAB help. These help files can be accessed via the typical help browser or by querying the help via the command line.

```
      help getBusInfo
```

The help files are also included online at www.gridintegration.org as well as in Section 7 of the manual. For OpenDSS help, see the references in Section 3 on OpenDSS resources.

Section 4 is organized as follows:

4.1. OpenDSS COM Object Interface – Overview of the OpenDSS COM object and interactions with OpenDSS

4.2. Circuit Information Retrieval Using GridPV – Use of the toolbox functions for pulling OpenDSS parameters from the COM object

4.3. Circuit Check Function – Description of the OpenDSS circuit validation process

4.4. Plotting Tutorial – Introduction to the GridPV plotting tools

4.5. Coordinate Conversion Tutorial – Converting the circuit coordinates into latitude/longitude coordinates

4.6. Solar Tutorial – Overview of the process and functions for setting up PV on the distribution system model

4.7. Example Analyses – Description of the analysis example provided in the toolbox

4.1. OpenDSS COM Object Interface

This section provides an overview of the interaction between MATLAB and OpenDSS through the COM server object. The features and methods described in Section 4.1 are built in to the OpenDSS COM server and can be accessed from other programs such as VBA in Excel. The purpose is to give the reader a basic understanding of the OpenDSS COM, and further information about the OpenDSS COM server can be found in the OpenDSS resources in Section 3.

4.1.1. Initiating the COM Interface

The first step is to initiate the COM interface. A MATLAB function in the toolbox does this for the user by calling DSSStartup:

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
```

DSSStartup starts up OpenDSS in the background and returns the handle pointer to MATLAB for interface. DSSStartup returns three outputs:

- `DSSCircObj`, which is the pointer to the COM interface. This contains the active circuit (`DSSCircObj.ActiveCircuit`), which is not yet compiled, and the text interface to OpenDSS (`DSSCircObj.Text`). `DSSCircObj` will be empty until a circuit is compiled, as discussed in Section 4.1.2 Compiling the Circuit.
- `DSSText` is the text interface contained within `DSSCircObj`. It has been redefined in this manner for easier use within the MATLAB command window. `DSSCircObj.Text.Command` and `Text.command` point to the same text interface, except the latter requires less typing.
- `gridpvPath` is a string containing the toolbox path location on your computer.

DSSStartup will return an error if MATLAB was unable to create a link to OpenDSS. The most common reasons for this error are if OpenDSS is not installed on the computer or if an older version of OpenDSS was installed.

Note that the OpenDSS program that MATLAB interfaces with via the COM server is different than the graphical interface window of the OpenDSS executable. Any information, circuits, solutions, or parameters set in the graphical interface window of OpenDSS will not show up in the COM server version of OpenDSS, and vice versa.

4.1.2. Compiling the Circuit

To open a circuit in OpenDSS, use the text interface to pass the 'compile' command into OpenDSS.

```
DSSText.command = 'Compile C:\GridPV\ExampleCircuit\Run_Ckt24.dss';
```

Relative file paths can be used in the compile command, but the OpenDSS directory will change to the folder that contains the .dss file during the compile command. To ensure that the compile command works every time, it is recommended to use the full file path.

When working with the example circuit in the toolbox, the `gridpvPath` returned from DSSStartup can be used to link to the circuit. For example, use

```
DSSText.command = ['Compile "', gridpvPath,
    'ExampleCircuit\master_Ckt24.dss"'];
```

IMPORTANT NOTE: At this point you have opened an instance of OpenDSS *in the background* and compiled a circuit. This instance of OpenDSS is entirely unassociated with any visible instance of OpenDSS (the GUI) that you may already have open. Changes to a circuit in the OpenDSS GUI will not be reflected in the MATLAB OpenDSS circuit.

To make changes to the circuit, use either the `DSSText` interface inside MATLAB. Alternatively, manually edit the .dss files, save them, and recompile the circuit in MATLAB.

4.1.3. Getting Data into MATLAB from OpenDSS

Now that the COM interface has been started and the circuit has been solved, you can begin to use the Command Window to interact with the COM interface structure.

Call `DSSCircObj.methods` to view the available methods with which you can use to interact with the interface. Use the `DSSCircObj.get` method to view the main interface. For information on the rest of the methods, refer to OpenDSS documentation and resources in Section 3.

In the return for `DSSCircObj.get`, notice that there are several other pointers to OpenDSS interface COM objects. One such sub-pointer is the ActiveCircuit interface. The ActiveCircuit refers to the compiled circuit in OpenDSS and contains all parameters and power flow solutions. Since the ActiveCircuit pointer will be used regularly, redefining the active circuit interface as its own, separate handle can save on the amount of typing in the future:

```
DSSCircuit = DSSCircObj.ActiveCircuit;
```

Now call `DSSCircuit.methods` to view the methods pertaining to the solved circuit. Again, use the `DSSCircuit.get` method to view all the different fields and interfaces present in the circuit interface:

```
DSSCircuit.methods
DSSCircuit.get
```

In the return after calling `DSSCircuit.get`, you will notice several more OpenDSS COM interface pointers, each referring to specific elements in the circuit. You can also view the methods of any of these interfaces that appear as fields of `DSSCircuit`. Notice the fields that

show up in the return. Now that you are aware of what the lines interface contains, you can query a specific field.

```
DSSCircuit.Lines.methods

DSSCircuit.Lines.get
DSSCircuit.Lines.LineCode

DSSCircuit.Capacitors.get
DSSCircuit.Capacitors.Name
```

However, you should also notice that most of these fields in these interfaces are populated with information about an individual line. The fields refer to data about the element that you are currently viewing, which is initially the first element by default.

This is an important observation to understanding how iteration is used to retrieve all the data about a circuit. The `.first` and `.next` methods that were present in the return for `DSSCircuit.Lines.get` are used to change the index of the object. Use the `.first` method to be certain that you have reset the current line, capacitor, etc. to the first one in the list. Then, use the `.next` method while iterating to step through the list. This is true for each type of circuit element present in the OpenDSS COM, such as Lines, Capacitors, Transformers, etc.

```
% Set transformer element to beginning
DSSCircuit.Transformers.first;
% Get total number of transformers
numXfmr = DSSCircuit.Transformers.count;
% Preallocate
xfmrNames = cell(numXfmr, 1);
% Iterate
for ii = 1:numXfmr
    %Get current transformer name
    xfmrNames{ii} = DSSCircuit.Transformers.Name;
    % Advance to next transformer
    DSSCircuit.Transformers.Next;
end
```

Notice the use of the `numXfmr` variable. Initially, it may seem useful to save this line of code and just use `DSSCircuit.Transformers.count` in the two locations that `numXfmr` appears. However, `DSSCircuit.Transformers.count` has to go through the COM server and takes more time; therefore, it is most efficient to call this just once and then use the workspace variable going forward.

The above transformer example is solely for demonstration of using iteration with the interfaces. It is not the easiest way to obtain all of the transformer names. This highlights another point about these element interfaces: even though many of the fields will be specific to a single element, there are several methods and fields that return or contain global information. Be sure to look over what methods and fields are available, as they can save resources by avoiding iteration. Notice that the following method is effectively the same as the above loop:

```
xfmrNames = DSSCircuit.Transformers.AllNames;
```

4.1.4. Active Elements

When interacting with the COM server, there are two main locations from which you can get data about a particular circuit element. The first location was just shown in the previous section and involves using the interface specific to the type of element (e.g. the line interface or the capacitor interface).

Another interface, the active element interface, can also be used to find data about any element type. If you call `DSSCircuit.ActiveCktElement.get` you will see a list of fields that, individually, may or may not apply to each type of circuit element. You will also see that there is some data that will be pertinent to a particular type of element but was not present in that element's interface. This is why the active element interface is so useful: it contains relevant data that cannot be found elsewhere. In general, the class interfaces (lines, transformers, etc.) contain the information about the circuit element (ratings, connections, impedances, etc.) and the active element interface contains the power flow solution values for that element.

After calling `DSSCircuit.ActiveCktElement.methods`, you may notice that there are no `.first` or `.next` methods. This is because the active element interface requires that you set the active element manually. This can be done with the `DSSCircuit.SetActiveElement` method. See the below example to see how to effectively use the active element interface:

```
%Get line names and set up structure
lineNames = DSSCircuit.Lines.AllNames;
Lines = struct('name',lineNames);
% Iterate and retrieve line buses
for ii=1:length(Lines)
    % Set the active element as the current line
    DSSCircuit.SetActiveElement(['line.' Lines(ii).name]);
    % Get the bus names, a cell array of length 2
    lineBusNames = DSSCircuit.ActiveElement.BusNames;
    Lines(ii).bus1 = lineBusNames{1};
    Lines(ii).bus2 = lineBusNames{2};
end
```

4.1.5. Running Commands

Apart from the circuit interface, the other primary tool for interacting with the COM server is the text interface. The text interface can be used to pass command strings to OpenDSS, as shown before when the example circuit was compiled. The text interface allows string commands to be passed to OpenDSS and run directly in OpenDSS. For example:

```
DSSText.command = 'Set controlmode=static';
DSSText.command = 'Set mode=snapshot number=1 hour=0 h=1 sec=0';
DSSText.command = 'solve';
```

Here, the text interface was used to solve the circuit after setting the particular control mode, the time, and the time step h. The command string is compiled in OpenDSS, so the text interface can be used to do anything that can be done via scripting in OpenDSS.

An important aside about solutions: when solving the circuit, OpenDSS solves for the current time and then steps to the next timestep. After setting `h=1` (h is the timestep in seconds), passing the solve command again without resetting the hour and second would yield results for the next second in time.

4.1.6. Adding/Editing Elements

One of the most common uses of the text interface within the toolbox is to add and edit circuit elements. Using the OpenDSS commands "new" and "edit", different elements can be added, moved, and changed via MATLAB as shown in the following example:

```
% Note that there are currently no generators
DSSCircuit.Generators.get;

% Add PV in the form of a generator object
DSSText.command = 'new generator.PV bus1= n292757 phases=3   kv=34.5
   kw=500 pf=1 enabled=true';

% You can now see the generator that was added
DSSCircuit.Generators.get;

% Set it as the active element and view its bus information
DSSCircuit.SetActiveElement('generator.pv');
DSSCircuit.ActiveElement.BusNames

% Now change it to another bus and observe the change
DSSText.command = 'edit generator.PV bus1=n1325391 kv=13.2';
DSSCircuit.ActiveElement.BusNames
```

4.2. Circuit Information Retrieval Using GridPV

Much of the most useful COM server interaction described in Section 4.1 has already been incorporated into the toolbox in the form of seven "get-functions" (e.g. `getLineInfo`, `getCapacitorInfo`, etc.). They use the iteration mentioned in the previous section to obtain all of the circuit element data from OpenDSS and return it as an organized structure. Some of the information is also formatted during entry in the structure, for example phase power flows, so that it is consistent between object types and individual elements. These get-functions can save new users a significant amount of time in learning how to interact with OpenDSS, as all information can be queried and loaded into MATLAB using the GridPV toolbox.

4.2.1. Using the GridPV Get Functions

The get-functions are useful toolbox functions that automate some of the most tedious aspects of interacting with the COM-server. When calling them, pass the pointer to the COM-object and optionally, a cell array of element names. If you do not include the element names, all of the enabled elements will be returned by default. If you include element names, each element will be in the output, even if the element is disabled.

```
% Calling it without specifying names to return all buses
Buses = getBusInfo(DSSCircObj);
% Calling it with specifying names (don't forget braces)
Buses = getBusInfo(DSSCircObj,{'N1311915'});
% Calling it with a cell array of names
Buses = getBusInfo(DSSCircObj,{'N1311915', 'N312536'});
% Calling it with specifying all names via the COM-server
Buses = getBusInfo(DSSCircObj, DSSCircObj.ActiveCircuit.AllBusNames);
```

If you include element names in the input, there will be some parameters in the structure that are not returned. This is due to how OpenDSS uses both the active element interface as well as the object-specific interface to return data. The object-specific interfaces do not include disabled elements in their stack. Because the toolbox functions return any disabled elements that are requested when element names are provided by the user, there would be a potential mismatch between the data obtained from the active element interface and the data from the object-specific interface. Not only does the object-specific interface solely return enabled elements, but the only way to query a specific element in the object is to iterate through every object. Therefore, to optimize the speed of the specific element calls for a few objects, the object-specific properties will not be returned.

The get-functions have been designed to return all possible parameters for each object. This presents a comprehensive list of object properties, but the result is that the get-functions can take significant time to pull every parameter for every element in a large circuit. For applications where the user will be doing numerous repetitive calls to get-functions for large datasets, it is recommended that the user optimize the get-functions for their application. There are two ways to improve the speed of the get-functions. The first method was previously discussed of sending only the names of the required elements. This limits the looping necessary to get through all objects. The other method is to customize the get-function for specific applications to only query the parameters that are needed. For example, the getLineInfo function could be saved as getLineCurrents and all COM property queries other than obtaining the line currents could be commented out. Reducing the number of properties pulled does not have significant impact to the time for a single call, but this can have substantial advantages for repetitive calls during an extended simulation.

Important Note: The get-functions *do not* return pointers to any objects. They are structures containing *static* data from the most recent power flow solution of the circuit. Any time the circuit is modified or there is a new power flow solution, the get-functions will have to be called again to populate the structures with the most recent data.

4.2.2. Working with Structures from the Toolbox

In order to most effectively use the structures that are obtained by using the toolbox's get-functions it is necessary to recall some MATLAB syntax for working with structures. The value of each field in the structure is accessed by placing the fieldname after a period. The fieldnames for a given structure can be found by calling the MATLAB function `fieldnames()`. The results of the get-functions are returned in a structure array, for example `Buses`, where each bus is in a structure in `Buses` and the values of that bus are found by indexing the correct bus in `Buses`.

```
% Find all field names in the Buses structure
fields = fieldnames(Buses);
% Return the name of the first bus
Buses(1).name
% Return the number of phases of the second bus
Buses(2).numPhases
% Return how many buses are in the structure
length(Buses)
```

When trying to access data from multiple elements in the structure, be sure to include the call inside of brackets (or braces for cells) to obtain an array result.

```
Loads = getLoadInfo(DSSCircObj);
% Calling it without brackets returns each kW separately
Loads.kW
% Versus calling it with brackets, which returns all kW in an array
[Loads.kW]
% The same holds true for cell arrays
{Loads.name}
```

This use of the MATLAB syntax is useful for filtering for certain criteria. For example, you can filter the loads structure to contain only three-phase loads or loads below a specific voltage rating.

```
% Filter for three-phase loads
ThreePhaseLoads = Loads([Loads.numPhases]==3);
% Filter for low voltage secondary system loads
SecondaryLoads = Loads([Loads.kV]<=0.24);
```

4.3. Circuit Check Function

One particularly useful tool at the outset of any analysis for a particular circuit is the `circuitCheck` function. This function will examine the OpenDSS circuit for any potential typos or inconsistencies that may yield a rather curious solution from OpenDSS. It is helpful for troubleshooting actual MATLAB errors returned by toolbox functions. It is also useful for tracking down anomalies visible in the plots from typos that are creating apparent errors in the circuit but are still allowing it to compile. It is recommended that you run this `circuitCheck` function on any OpenDSS circuit before using it with the toolbox. The `circuitCheck` function

has been run on the example circuit included in the toolbox, but the function should be run on all other circuits, including the example circuits mentioned in Section 5.

The `circuitCheck` function checks for numerous issues with the circuit model. One example is incorrectly entering a load size causing it to be too large. You will obtain a solution that works with the toolbox, but your transformer would be impractically overloaded. The circuit checker function would provide you with the name of the overloaded transformer so you can edit your circuit accordingly. Another example may be having a b-phase line beginning at a bus with only phases a and c. This particular OpenDSS solution would generate an error in the data parsing of the toolbox function `getLineInfo`. All of the get-functions are contained in a try-catch block that will automatically run the circuit checker algorithm in the event of a failure. After reaching this error, the toolbox would identify the cause and return the original error along with the circuit checker result, which would contain the offending line name.

4.3.1. Running Circuit Check Function

To run `circuitCheck` manually, first compile and solve the circuit. Then, include the pointer to the COM-object as well as the warning option in a call to `circuitCheck`. The warnings field is optional, and the default value is to have warnings on.

```
warnSt = circuitCheck(DSSCircObj, 'Warnings', 'off');
warnSt = circuitCheck(DSSCircObj);
```

If warnings are on, the `warnSt.str` will be printed to the Command Window after completing the check. Regardless of the warnings setting, the `warnSt.offenders` will always have to be accessed via the workspace. Open the `warnSt` variable from the MATLAB workspace by double clicking on it and browsing the errors found in the circuit.

The `circuitCheck` function is automatically called in any of the get-functions if an error is encountered.

4.3.2. Interpreting Circuit Check Output

With warnings turned on, any issues with the circuit will show as a warning in the Command Window. Regardless of whether or not warnings are on, `circuitCheck` will always output a warning structure. By checking this structure you can view any of warnings caught by the function. Each element of the structure corresponds to a single warning and will contain a string describing the warning as well as a list of elements that violate that error-check. After receiving warnings, you should always check this structure to begin troubleshooting your circuit (or if warnings are set to off, always check to see whether the output structure is empty).

The default thresholds for each check can be changed by editing the thresholds towards the top of the `circuitCheck.m` file.

The purpose of `circuitCheck` is to identify potential issues. Not every warning returned by `circuitCheck` is necessarily something that is wrong with the circuit. The user will have to inspect the output to determine which of the warnings are actually errors in the circuit that should be corrected.

The warnings that may be shown are listed below:

`warnSt.NoBusCoords`

Purpose:	To check for the presence of bus coordinates
Threshold:	n/a
`warnSt.str`:	" `There are no bus coordinates with this compiled circuit. Toolbox functionality will be severely limited.` "
Reasoning:	The toolbox relies on bus coordinates to do the circuit line plots as well as for any solar integration.
`warnSt.offenders`:	n/a

`warnSt.InvalidLineBusName`

Purpose:	To check that bus naming conventions for specifying lines' buses match the designated phases of that line
Threshold:	n/a
`warnSt.str`:	" `One or more line has a bus name that does not match the number of phases of the line. (e.g. A 2-phase line should have both bus 1 and 2 with names similar to 'BUSNAME.2.3' with 2 phases indicated in the decimal notation.` "
Reasoning:	The toolbox uses this naming convention to help determine the phases present on a particular line. The number of phases on the line should match the number of phases on the bus that it is connected to.
`warnSt.offenders`:	Each row of the table includes the LineName, the NumPhases of that line, and the names of each bus. From this, it should be obvious which part of the lines definition is causing issues.

`warnSt.LineLength`

Purpose:	To check for incorrectly entered lines with nonsensically long lengths
Threshold:	5 km
`warnSt.str`:	" *n* `of the lines exceed 5 km.` "
Reasoning:	Accidental input of large lengths may fail to be an obvious issue and may cause power flow irregularities
`warnSt.offenders`:	Line name and length

`warnSt.LineOverLoading`

Purpose:	To check for thermal violations on lines
Threshold:	100%

warnSt.str: "*n* Lines are load more than 100%. Visualize using plotCircuitLines(DSSCircObj,'Coloring','lineLoading')"

Reasoning: Notifies you of line loading violations that may be a result of incorrect parameters in the circuit such as line ratings

warnSt.offenders: Line names and their loading percentages

warnSt.BusDistance

Purpose: To check for incorrectly entered lines causing nonsensically far buses

Threshold: 25 km

warnSt.str: " n of the bus distances exceeds 25 km from the substation. "

Reasoning: Accidental incorrect input of circuit parameters, such as a line length, may cause a bus to be unintentionally far from the substation.

warnSt.offenders: Bus name and distance

warnSt.BusVoltage

Purpose: To check for over/under voltage violations

Threshold: 1 +/- 0.05 pu

warnSt.str: "*n* of the enabled bus voltages are outside of the range 1+/- 0.05 pu. Visualize using plotVoltageProfile(DSSCircObj)"

Reasoning: Notifies you of voltage violations that may be a result of incorrect parameters in the circuit causing large voltage changes

warnSt.offenders: Bus name and voltage (both pu and kV) along with rated kV

warnSt.CapacitorRatingMismatch

Purpose: To check for elements that may have accidentally had incorrectly entered kV ratings

Threshold: 5%

warnSt.str: "*n* of the capacitor kV ratings differs from its bus kV rating by more than 5%. "

Reasoning: Incorrectly entered ratings may cause irregularities in the solution without immediately giving an error or drawing attention to the problem. Most likely this is an issue where single-phase values were not entered line to neutral or two/three-phase values were not entered line to line.

warnSt.offenders: Each element name and its line-line kV ratings as well as each bus's name and its line-line kV rating

warnSt.LoadRatingMismatch

Purpose: To check for elements that may have accidentally had incorrectly entered kV ratings

Threshold: 5%

warnSt.str: "*n* of the load kV ratings differs from its bus kV rating by more than 5%. "

Reasoning:	Incorrectly entered ratings may cause irregularities in the solution without immediately giving an error or drawing attention to the problem. Most likely this is an issue where single-phase values were not entered line to neutral or two/three-phase values were not entered line to line.
`warnSt.offenders`:	Each element name and its line-line kV ratings as well as each bus's name and its line-line kV rating

`warnSt.PVRatingMismatch`

Purpose:	To check for elements that may have accidentally had incorrectly entered kV ratings
Threshold:	5%
`warnSt.str`:	" *n* `of the PV kV ratings differs from its bus kV rating by more than 5%.` "
Reasoning:	Incorrectly entered ratings may cause irregularities in the solution without immediately giving an error or drawing attention to the problem. Most likely this is an issue where single-phase values were not entered line to neutral or two/three-phase values were not entered line to line.
`warnSt.offenders`:	Each element name and its line-line kV ratings as well as each bus's name and its line-line kV rating

`warnSt.TransformerRatingMismatch`

Purpose:	To check for elements that may have accidentally had incorrectly entered kV ratings on either side of the transformer
Threshold:	5%
`warnSt.str`:	" *n* `of the transformer kV ratings differs from its bus kV rating by more than 5%.` "
Reasoning:	Incorrectly entered ratings may cause irregularities in the solution without immediately giving an error or drawing attention to the problem. Most likely this is an issue where single-phase values were not entered line to neutral or two/three-phase values were not entered line to line.
`warnSt.offenders`:	Each element name and its line-line kV ratings as well as each bus's name and its line-line kV rating

`warnSt.TransformerOverloaded`

Purpose:	To check for thermal violations on the transformers
Threshold:	5%
`warnSt.str`:	" *n* `of the transformer kVA ratings differs from its bus1 power by more than %. Check that the loads on the transformer are entered correctly.` "
Reasoning:	Notifies you of transformer loading violations that may be a result of incorrect parameters in the circuit
`warnSt.offenders`:	Transformer names and their loading percentages

`warnSt.LineRatingMismatch`

Purpose:	To check for elements that may have accidentally had incorrectly entered line codes
Threshold:	150%
`warnSt.str`:	"*n* `of the line ratings are 150% the size of the immediately upstream line. Visualize using plotCircuitLines(DSSCircObj,'Thickness','lineRating')`"
Reasoning:	Line ratings that increase downstream *may* be indicative of incorrectly entered linecodes (or may be by design)
`warnSt.offenders`:	The upstream line name (smaller line) and the downstream line name (larger line), followed by each line respective line rating as well as each lines respective line code.

4.4. Plotting Tutorial

This section includes an overview of the plotting features in the GridPV toolbox. Many of the examples are shown for `plotCircuitLines`, but the descriptions apply to all plotting function from section 7.3.

It is important to recall the fact that the OpenDSS COM server in MATLAB is an entirely separate entity from the OpenDSS GUI that you are able to use independently apart from MATLAB. This means that any circuit that you may have solved and plotted in your OpenDSS program outside of MATLAB is irrelevant. Furthermore, any changes to a circuit file will only take affect once the circuit is recompiled.

4.4.1. Plotting Circuits

Generating the plots is relatively straight forward and is fully demonstrated in section 7.3; however, there are some particularities that are worth mentioning when generating and using the toolbox plots.

Firstly, the plots that are generated are representative of the most recent time step power flow solution. When in doubt, reset the time step to the specific time of interest:

```
DSSText.command = 'Set mode=duty number=10 hour=13 h=1 sec=1800';
DSSText.command = 'Set controlmode = static';
DSSText.command = 'solve';
figure; plotCircuitLines(DSSCircObj);
```

As stated in section 7, calling `plotCircuitLines` in this manner without assigning any property values will default to opening the GUI by calling `plotCircuitLinesOptions`. `plotCircuitLinesOptions` is the function associated with the GUI and can also be called on its own in the same manner; however, it does not accept and other parameters.

```
figure; plotCircuitLinesOptions(DSSCircObj);
```

It is also possible to call `plotCircuitLines` with any number of possible parameters described in Section 7.3.2.

```
figure;
plotCircuitLines(DSSCircObj,'Coloring','PerPhase','Thickness',3,'Mappin
gBackground','on');
```

The plotting functions use the MATLAB parameter name and value argument pair notation for all input options after the handle to the `DSSCircObj`. If you are unfamiliar with this method of passing parameters into a MATLAB function, note that while the order of specific options does not matter, each option requires a pair of inputs: the string denoting which option you are about to define as well as the corresponding specification for that option. For example, in the line above, the `'Coloring'` parameter is being set to `'PerPhase'` and the `'Thickness'` parameter will equal 3.

4.4.2. Circuit Interaction

Once the circuit is plotted, there are some user interactions available that make accessing and viewing the OpenDSS power flow data extremely simple. Any line, transformer, capacitor, load, or PV system is capable of being left and right clicked.

A left click selects the element, displaying its name, as shown in Figure 1. A right click displays the menu shown in Figure 2, which has options to display properties, voltages, currents, and powers for that element. (Note that the right click menu is only available if the right click is precisely over the circuit element. It is often easier to right click a circuit element that is not already selected)

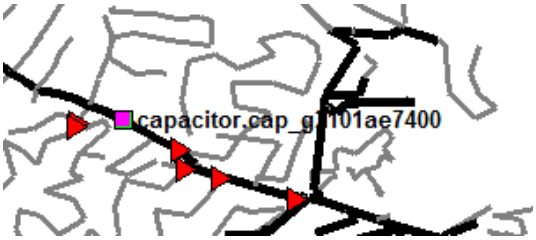


Figure 1. Selecting an Element with Left Click.

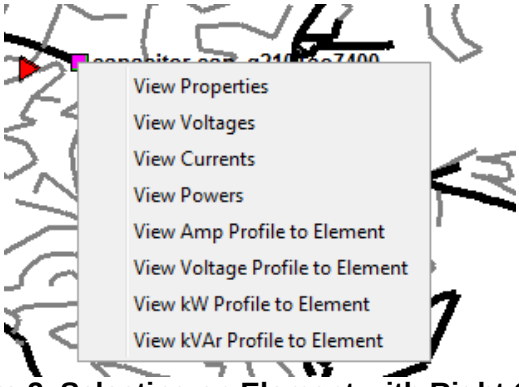


Figure 2. Selecting an Element with Right Click.

Clicking any of the menu options after right-clicking will display the associated OpenDSS window with that information. These view windows (properties, voltages, currents, and powers) are OpenDSS popup windows, so OpenDSS must be allowing forms. This means the `DSSCircObj.AllowForms` must be 1, which is the default value. Currently, OpenDSS 7.6.3 (the current version as of this writing) does not allow for setting the AllowForms field back to 1 after setting it to 0 (thereby requiring a restart of the COM server to view these windows).

The abilities to left and right click exist in all of the profile plots as well.

4.4.3. Plot Editing

After plotting, you may need to edit the plots. Some users who are more experienced with MATLAB and its plots may be used to using the "show plot tools" toggle shown in Figure 3. By default, this will switch to "Plot Browser View" (as shown in the "View" drop-down). In our case, **this is ill-advised.**

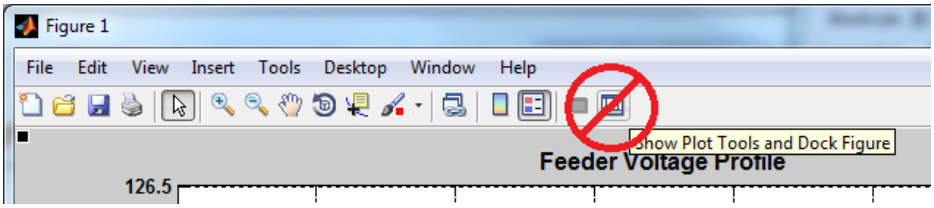


Figure 3. Avoid Using Plot Tools.

The plots generated by the toolbox often contain a very large number of lines plotted in the figure. It is strongly advised, unless your circuit is quite small (less than 150 nodes), that you do not use this route to edit your plot. Opting to "show plot tools" may cause MATLAB to freeze as it populates the long list of plotted items in the Plot Browser. Depending on your computer specifications, and because MATLAB defaults to using a single processor core, you may be forced to kill the MATLAB process and restart it in order to continue working.

Therefore, the best way to edit is to use the "Property Editor" view shown in Figure 4.

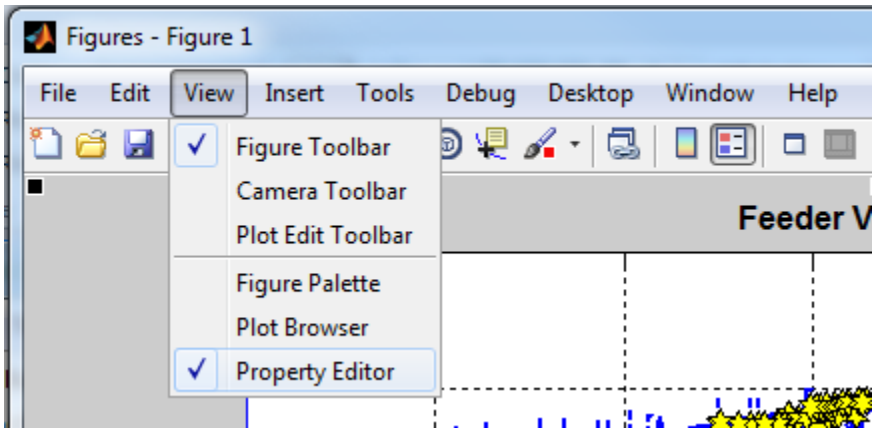


Figure 4. Use Property Editor to Modify.

After selecting this view, you will be able to select various objects around the plot to edit. The Property Editor mode can be used to edit objects in the plot (line colors and thicknesses) and axes titles and labels.

To return to the standard view, just select the "Hide Plot Tools" toggle shown in Figure 5.

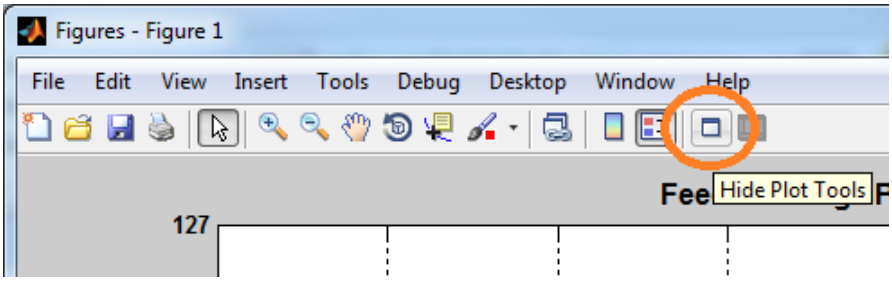


Figure 5. Returning to the Default View.

4.5. Coordinate Conversion Tutorial

If your circuit is not currently using latitude and longitude values for the coordinate system, the coordinate conversion functions can be used to transfer the coordinates to lat/lon values. The toolbox generally assumes that the coordinate system is in lat/lon, and some functions will not work otherwise. Latitude and longitude values allow the toolbox to plot the Google map background with the circuit. The lat/lon coordinates are also required for some of the solar analysis functions that require calculations of the land area of pieces of the circuit. To convert from one coordinate system into latitude/longitude values, start by using the initializer:

```
initCoordConversion();
```

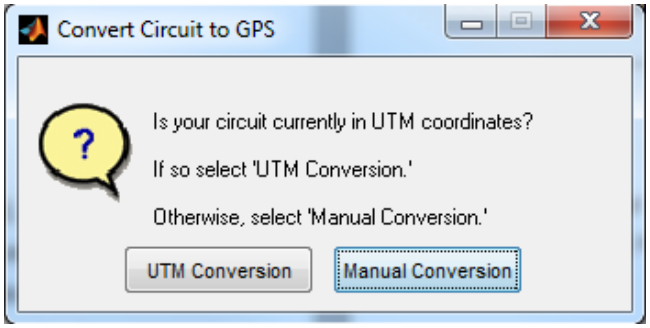


Figure 6. Coordinate Conversion Initializer.

If your circuit is in UTM coordinates, choose that option. If it is not, choose the manual conversion.

4.5.1. Manual Conversion

If you chose the manual conversion option, you should see the following GUI:

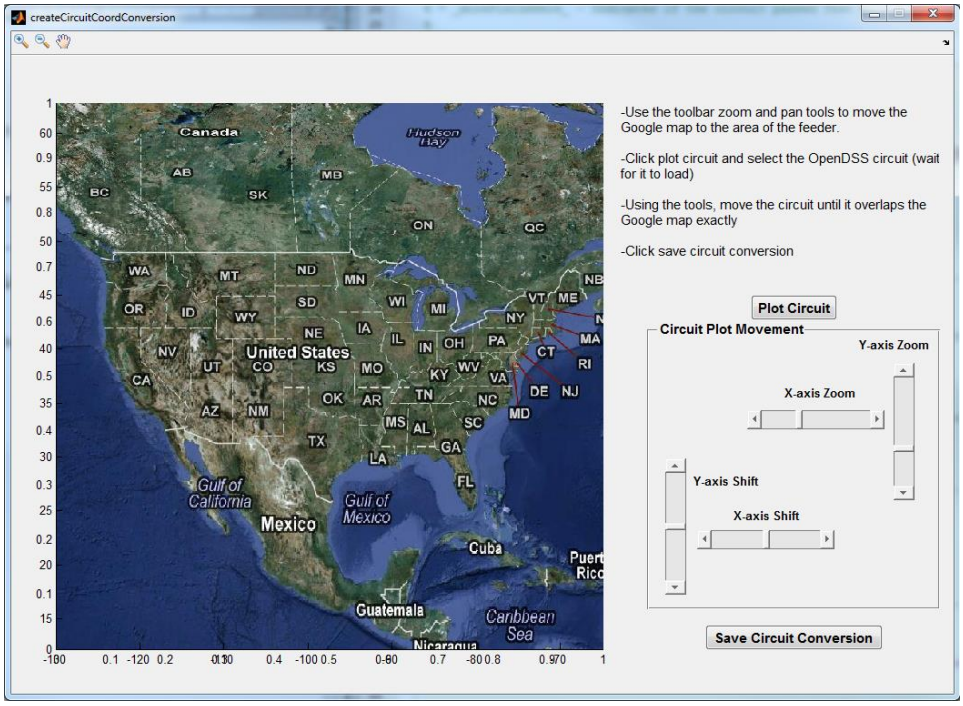


Figure 7. Manual Coordinate Conversion GUI.

Use the zoom and pan tools, shown in Figure 8, in the upper left corner to situate the map approximately where the feeder is.

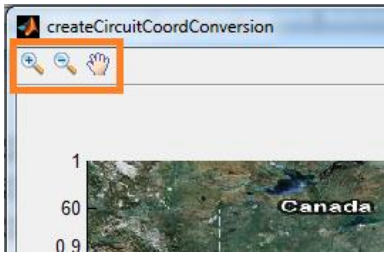


Figure 8. Satellite Image Map Tools.

Once you have the map zoomed in on the correct area, click the "plot circuit" button to the left to open the .dss file for the feeder. After selecting the main .dss file for the feeder, the GUI will load its topography onto your current map. It may take a while to load the circuit, depending on its size.

Note that after loading a circuit, you can no longer use the tools in Figure 8 to reposition the satellite image.

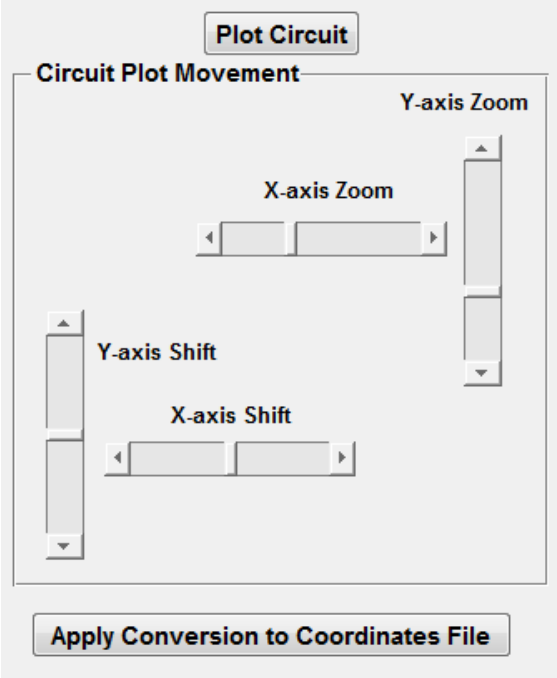


Figure 9. Feeder Map Tools.

Once the circuit is loaded, you can position it over the satellite image, attempting to line up the circuit's lines with the roadways or any other visual cues. To slide the circuit, use the "y-axis shift" and "x-axis shift" sliders. To resize the circuit relative to the satellite image, use the "y-axis zoom" and "x-axis zoom" sliders.

After positioning the circuit to the appropriate location, click "Apply Conversion to Coordinates File" to commit the changes to your circuit's coordinates file.

When prompted to "Select bus coordinates file," use the window to navigate to the file containing your coordinates. The GUI will now make a back-up of your old coordinates file. If you see the warning dialog shown in Figure 10, the backup was not successfully created. If this happens, you should manually make a backup copy of your coordinates file *before* pressing "OK."

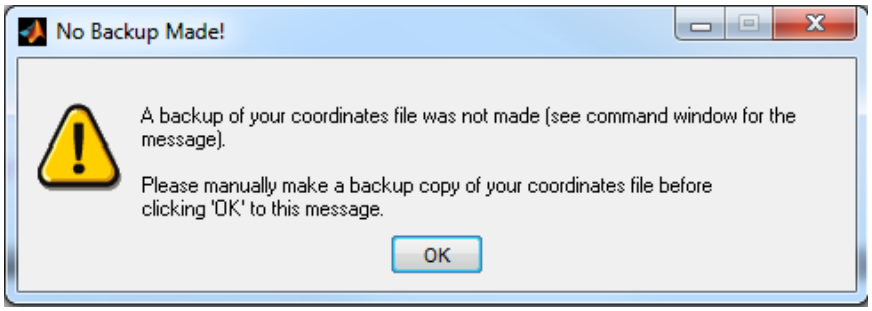


Figure 10. Coordinate File Backup Warning.

Once the old coordinates file has been backed up, a new coordinates file will be saved with the bus coordinates now in latitude and longitude. When you see the success dialog shown in Figure 11, your coordinates file has been updated to contain lat/lon coordinates.

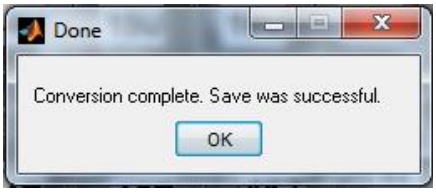


Figure 11. Coordinate Conversion Successful.

4.5.2. UTM Conversion

If you chose the UTM conversion from the options shown in Figure 6, you should see the following GUI:

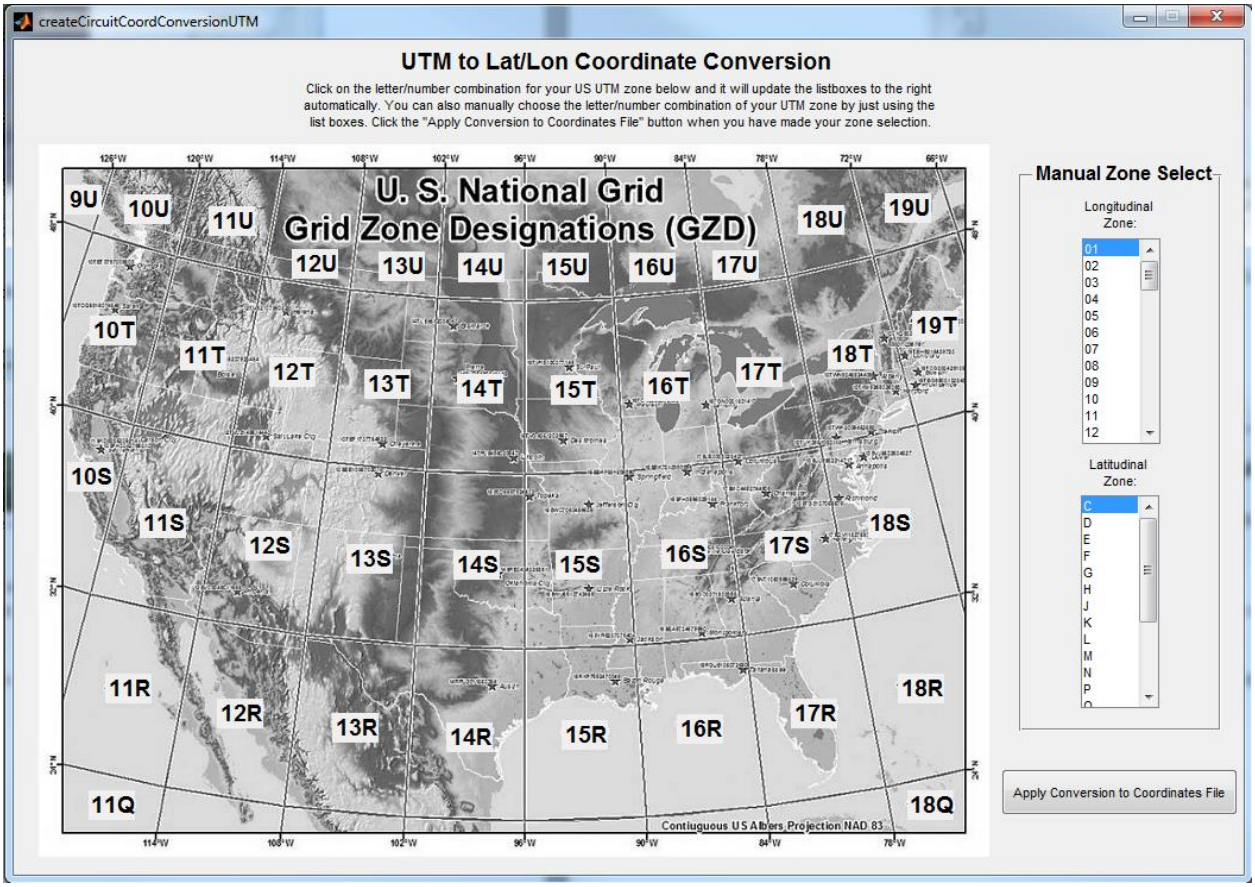


Figure 12. UTM Coordinate Conversion GUI.

If your feeder is in the United States, you can click the number/letter combination corresponding to its UTM zone, which will automatically update the list box selections on the right. Otherwise, manually select the letter/number pair from the list boxes on the right.

Once you have selected the appropriate letter/number combination for your circuit's UTM zone, select "Apply Conversion to Coordinate File."

When prompted to "Select the OpenDSS file with the circuit," use the window to navigate to the master file for your circuit.

Then, when prompted to "Select bus coordinates file," use the window to navigate to the file containing your coordinates.

The GUI will now make a back-up of your coordinates file. If you see the warning dialog shown in Figure 10, the backup was not successfully created. In your file explorer, you should manually make a backup copy of your coordinates file *before* pressing "OK."

Once the old coordinates file has been backed up, a new coordinates file will be saved with the bus coordinates now in latitude and longitude. When you see the success dialog shown in Figure 11, you coordinates file has been updated to contain lat/lon coordinates.

4.6. Solar Tutorial

This section provides a tutorial for setting up PV on the distribution system. Most of the toolbox is useful for any type of analyses or studies using OpenDSS, but this section discusses the functions that directly apply to solar. The toolbox functions provide an easier method for setting up solar interconnection studies with PV on the distribution system. GridPV applies the Wavelet Variability Model (WVM) to convert measured irradiance to power plant output using the physical layout of the PV plant to smooth the variability accounting for the plant size and density. Section 4.6 walks you through setting up the PV plant, with all necessary OpenDSS code produced by the end.

4.6.1. Placing PV on the Circuit

You can add PV to any circuit by calling:

```
placePVplant();
```

A dialog box will appear asking for the .dss basecase file. Navigate to the .dss master file for your circuit and click open.

The toolbox will then load the circuit, bringing up the GUI. This may take a while depending on the size of your circuit. Make sure that the circuit bus coordinates are in latitude/longitude before using `placePVplant`. If the coordinates are not in latitude/longitude, see section 4.5 on coordinate conversion.

The satellite image for the example circuit, EPRI Ckt 24, is the ocean, as shown in Figure 13, because the true location of the feeder is not public.

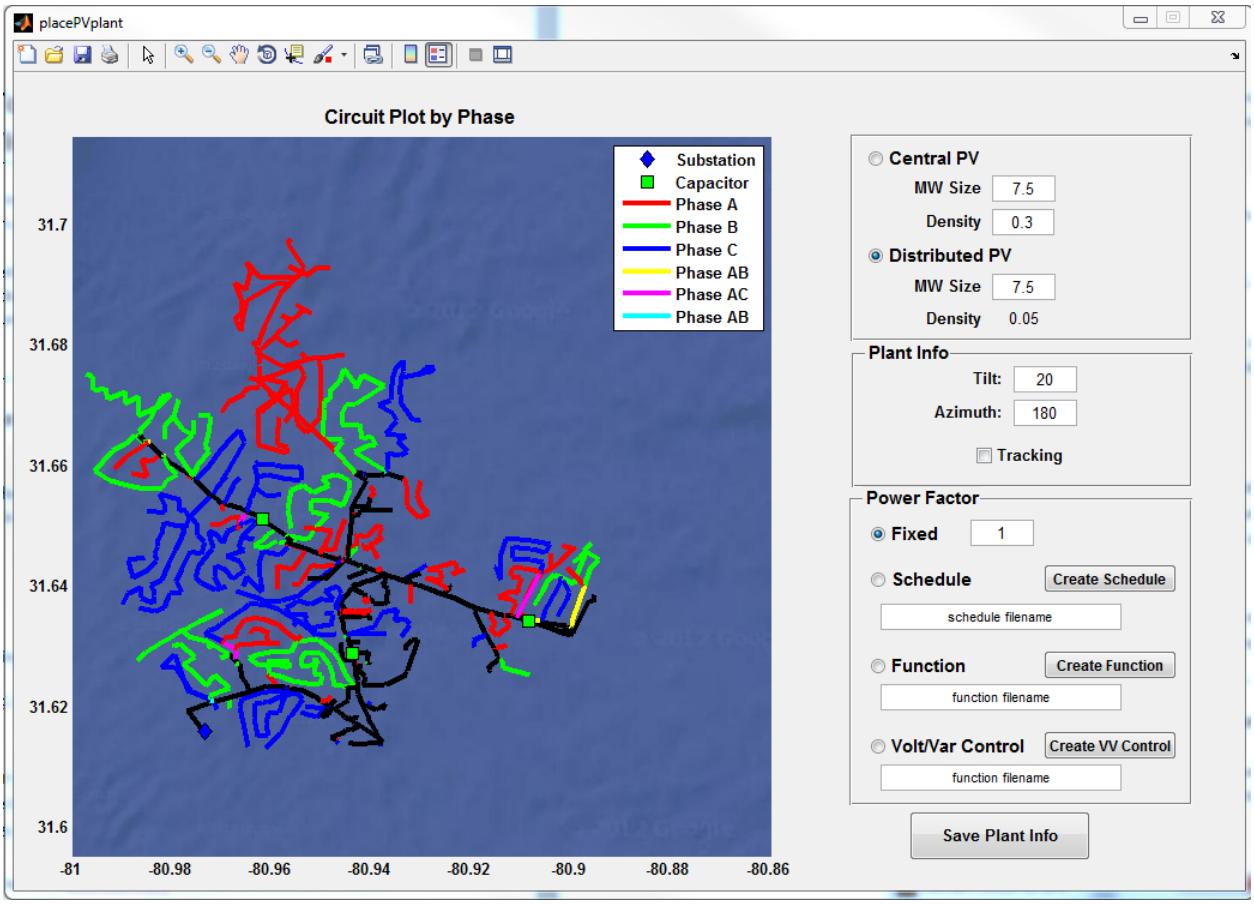


Figure 13. GUI of placePVPlant.

To add PV select between the two radio buttons labeled "Central PV" and "Distributed PV."

4.6.2. Adding Central PV

After selecting the "Central PV" radio button, a dialog will appear:

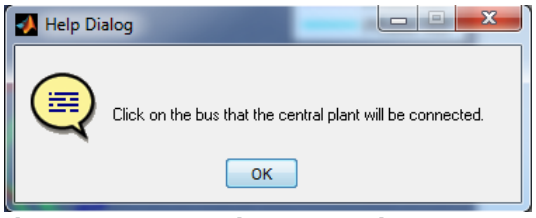


Figure 14. Central PV Location Prompt.

As the message says, click near the bus on which the plant should be connected. Note that central plants are three phase, so be sure to choose a location on a three phase line (represented by black lines). Regardless of where you click, any central plant will be added to the three-phase bus geometrically nearest the coordinates of your click.

Be sure to edit the "MW Size" and "Density" text boxes to be the appropriate values. The density value represents the amount of land area filled with panels. A value of approximately 0.3 is around the correct value for a central PV plant that has land filled with panels with typical spacing between module string rows. A smaller density value will assume a larger land area for the same MW size, thus slightly decreasing the variability of the plant.

4.6.3. Adding Distributed PV

After selecting the "Distributed PV" radio button, a dialog will appear:

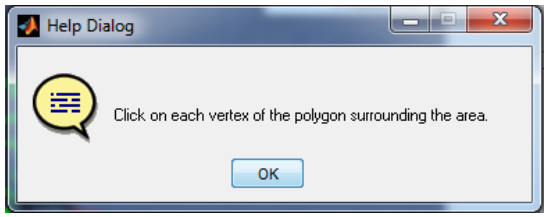


Figure 15. Distributed PV Location Prompt.

As the message says, create a polygon surrounding the area that the distributed PV should be placed by clicking to create each vertex. (You will know you have closed the shape when the cursor turns from a cross to a circle, depicting that you are about to complete the polygon.)

If you have the Image Processing toolbox, you will be able to edit the shape after closing, including: shifting the area, adding/removing vertices, moving vertices, etc. Without this toolbox, if you wish to edit your area, you will have to reselect the "distribute PV" radio button, which will then delete your current area and allow you to redefine a new one.

Be sure to edit the "MW Size" text box to be the appropriate value and the density will change accordingly. The density value represents the amount of land area filled with panels. A value of approximately 0.05 is around the correct value for distributed rooftop PV in a residential neighborhood with PV on each house. The density value can be changed by modifying the MW size of the plant or adjusting the drawn polygon to contain more land area.

The GUI distributes the total PV proportionally by transformer size over all of the transformers contained within the area indicted. If your feeder does not contain transformer objects, the GUI will distribute the PV evenly over all load buses in the area irrespective of load size.

4.6.4. Editing Plant Info

Use the plant info text to indicate the tilt and azimuth of the PV panels. There is a check box to toggle PV tracking on and off.

4.6.5. Editing Power Factor

Choose between a fixed power factor, a scheduled power factor, using a power factor function, and using volt/var control by selecting the appropriate radio button.

If you choose fixed, you can edit the fixed value in the text box. A negative power factor represents absorbing Vars, and positive power factor represents producing Vars.

If you choose any of the other three types of power factor control, you need to load in the .mat file pertaining to that PF control by clicking "function filename." This will open a standard file navigation GUI. When the PV scenarios are created, the file path to the .mat file is used for the power factor control. If you do not already have a file corresponding to your desired power factor control, you can click the button directly next to your selection (labeled "Create Schedule," "Create Function," or "Create VV Control") to create such a .mat file. These buttons load a specific GUI allowing you to create the corresponding power factor control. The three GUIs are shown below:

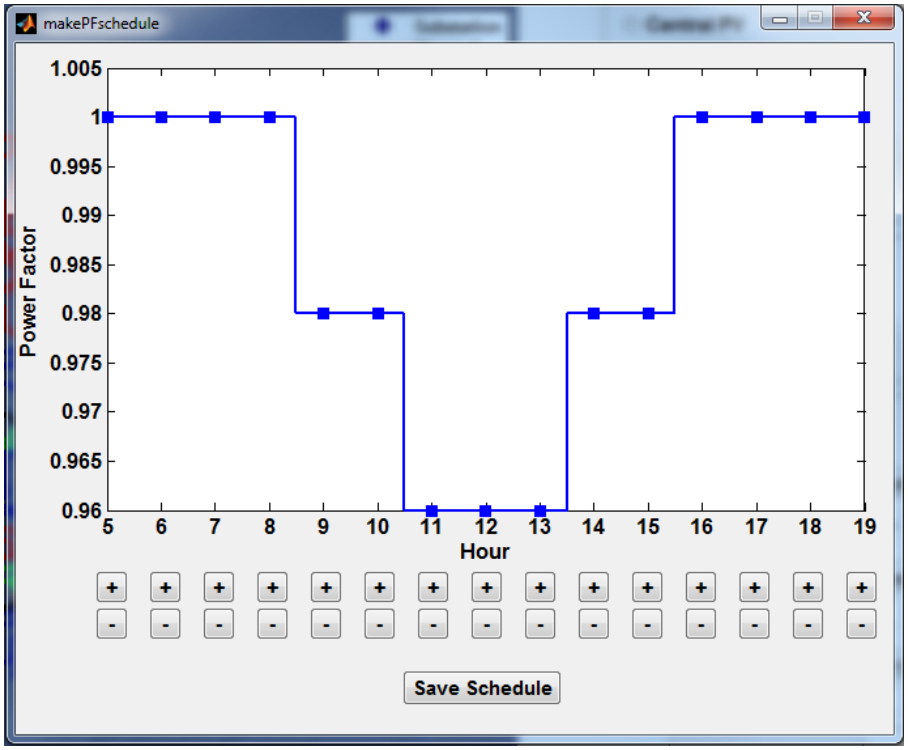


Figure 16. Create Schedule GUI.

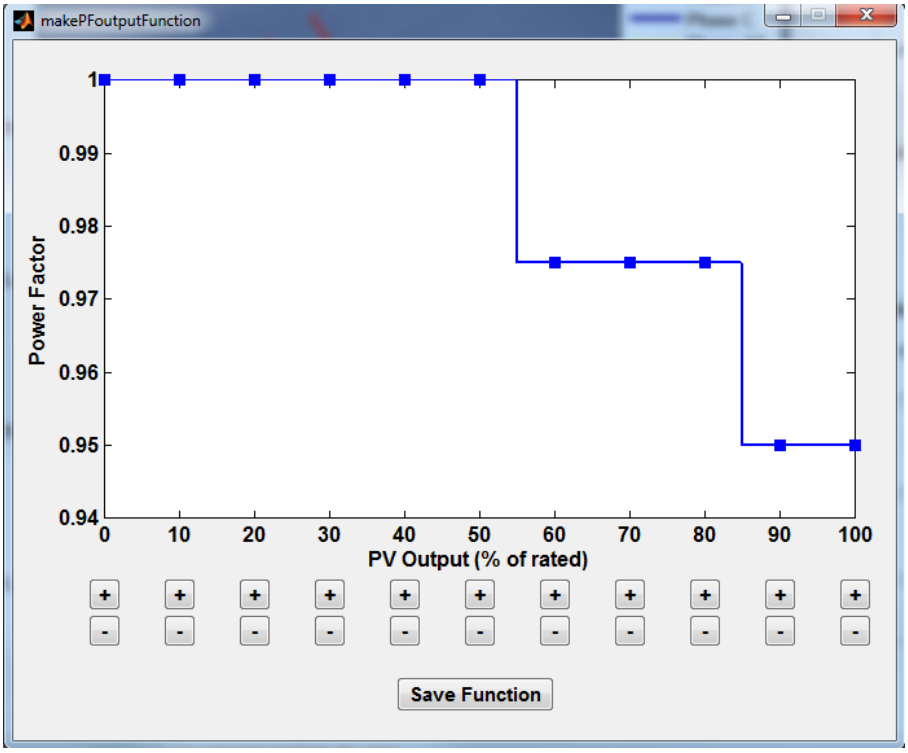


Figure 17. Create Function GUI.

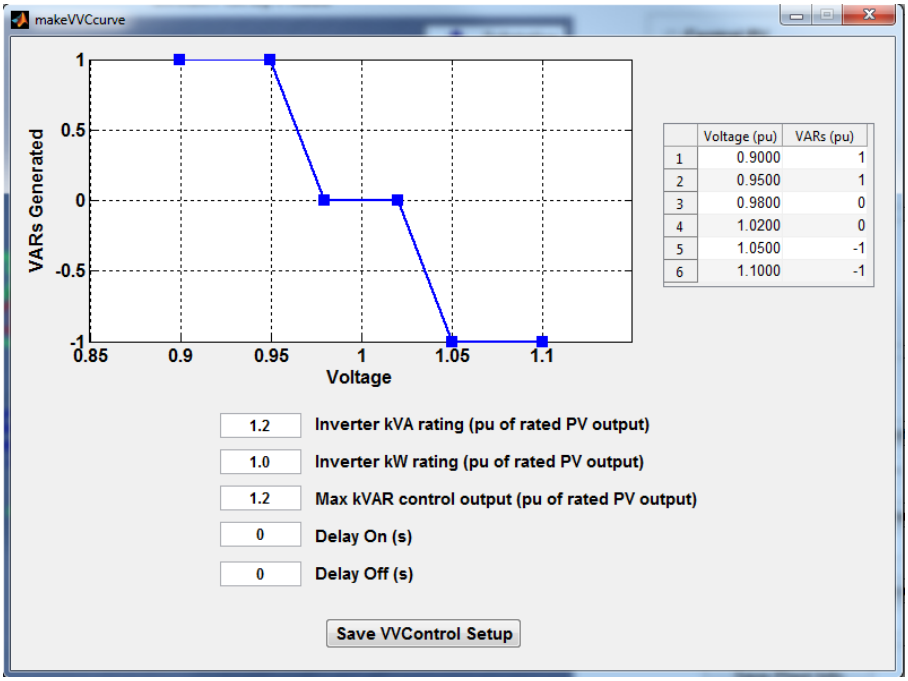


Figure 18. Create VV Control GUI.

For the GUIs in Figure 16 and Figure 17, use the + and – buttons at the bottom to edit the graph. For the GUI in Figure 18, the table on the right is editable and will change the graph accordingly. You can manually set the parameters at the bottom as well.

For all three GUIs, use the save button at the bottom to save the information to a .mat file.

After saving, you still need to point the placePVPlant GUI to the .mat file you just created by clicking in the appropriate "function filename" text box, opening the file browser.

When you have chosen the location and prepared all relevant information, click "Save Plant Info," and choose the correct location and name for your file. This will save a .mat file of all the information pertaining to your plant.

In the following step, you will use this plant info file to create the necessary OpenDSS files.

4.6.6. Creating the PV DSS Files

Now that you have successfully created a .mat file containing all of your desired PV plant parameters, it is necessary to add it to the OpenDSS circuit. To do this, the toolbox can create a .dss file pertaining to the specific PV scenario you just created:

```
createPVscenarioFiles();
```

(If you refer to the documentation, you will notice that it is possible to give this function inputs; however, it is also possible to call the function without inputs and use the GUI file chooser.)

If you opt to call it without inputs you will first do the following as they appear:

- When prompted to "Select the file with the PV plant info", direct the file browser to the .mat file you previously created in section 4.6.5.Next, navigate to and select the .mat file containing the irradiance data when prompted to "Select the file the sensor info." The contents of the sensor info file are described in the header help information for WVM. There is an example sensor info file: .\Subfunctions\WVM_subfunctions\Example_Alamosa_2011_8_21_IrradSensor.mat.
- Then, you will be asked to "Insert an A value." Do so and click "OK."

Important Note: If you receive an error indicated that there is a reference to a "non-existent field," it is likely that an incorrect file was accidentally selected during the above process, resulting in loading the wrong structure. Please, restart the GUI and double check your file selections.

Now that all the inputs are determined, you will see a few more dialogs necessary to create and save the OpenDSS files.

- First, a save dialog will appear asking you to "Save the PV Loadshape file" that was created. Choose a filename and location and then click "save."
- After saving the PV loadshape, a prompt will ask you to "Select the OpenDSS Circuit File of Your Circuit." Navigate to and select the master file for the OpenDSS circuit to which you are adding PV.

- Lastly, you will be asked to "Save the OpenDSS Solar Scenario." This is the .dss file for your PV generators. Choose a filename and location and then click "save."

Now you are finished. You have successfully created the PV loadshape .txt file as well as the .dss file, which contains the information for the PV generator objects in OpenDSS. The .dss file contains a link to the loadshape .txt file that will read the PV profile into OpenDSS. The PV .dss file only contains the PV generator information, and it should be compiled after the master circuit file.

To analyze the circuit with the PV that was just added, compile the master .dss file and the PV .dss file that was just created.

```
DSSText.command = 'Compile ExampleCircuit\master_ckt24.dss';
DSSText.command = 'Compile ExampleCircuit\Ckt24_PV_Central_7_5.dss';
cd(location)
DSSText.command = 'Set mode=duty number=10 hour=13  h=1 sec=1800';
DSSText.command = 'Set controlmode = static';
DSSText.command = 'solve';
```

4.7. Example Analyses

There are three example functions included in the toolbox. These functions will run as a demonstration for the example circuit included. However, without slight modification, not all of these will work for other circuits. The three functions are meant to exhibit ways of incorporating the toolbox into your own scripts and only serve as demonstrations of use of the toolbox for some example analyses. They are examples of three general uses: a static analysis, a time-series analysis with MATLAB, and a time-series analysis with OpenDSS.

4.7.1. Static Analysis

An example static analysis is shown by the `examplePeakTimeAnalysis` function. This function may work with another circuit that has been set up with central or distributed PV in a separate file with duty loadshapes. The example function uses `findMaxPenetrationTime` to identify when to do the snapshot static analysis, but the user could also pick a specific period. After solving the analysis at that timestep, a voltage contour and voltage profile plot are created for each solar scenario.

Note that the control mode for a static analysis is set to static. This allows all control like LTC and capacitor switching to act during the power flow solution.

```
%% Run the simulation in static mode for the peak time
DSSText.command = sprintf('Set mode=duty number=1  hour=%i  h=1.0
    sec=%i',floor((maxTimeIndex)/3600),round(mod(maxTimeIndex,3600)));
DSSText.Command = 'Set Controlmode=Static'; %take control actions
    immediately without delays
DSSText.command = 'solve';
```

After the solve command, `DSSCircObj` is passed into `plotCircuitLines`. All of the data in `DSSCircObj` is from the last solution, which corresponds to the peak penetration time. Ultimately, this function is retrieving the voltage contour and the voltage profile at the time of peak penetration.

4.7.2. Time-Series Analysis in OpenDSS

Time-series simulations are very important to understand the impact of the variability of solar and to characterize the time-dependent aspects of the system [8, 9]. To perform a time-series analysis there are two options. The first method uses MATLAB to iterate and is discussed in the next section. The second, discussed here, uses OpenDSS to iterate.

Unlike the method above that only solved for a single time step, this method will solve for several time steps by using a `number` greater than 1. The control mode should also be set to time. OpenDSS monitors are placed in the circuit and record the time-series data.

Open `exampleTimeseriesAnalyses` to begin tracing through it. The OpenDSS time series solve starts at line 79:

```
%% Run OpenDSS simulation for 1-week at 1-minute resolution
    DSSText.command = 'Set mode=duty number=10080 hour=0  h=60 sec=0';
    DSSText.Command = 'Set Controlmode=TIME';
    DSSText.command = 'solve';
```

All data from the time series simulation is stored in the monitors that are in the circuit. The call to `plotMonitor` in line 86 uses the COM interface to access the monitor data using the export command. The export command and parsing of the monitor data is also done explicitly in this example function as shown in line 93:

```
    %% Feeder Power Factor
    DSSText.Command = 'export mon fdr_05410_Mon_PQ';
    monitorFile = DSSText.Result;
    MyCSV = importdata(monitorFile);
    delete(monitorFile);
    Hour = MyCSV.data(:,1); Second = MyCSV.data(:,2);
    feederPower = MyCSV.data(:,[3,5,7]);
    feederReactivePower = MyCSV.data(:,[4,6,8]);
```

In order for this example to run with another circuit, the circuit must have monitors in place and the monitor names in the example must be changed to reflect the monitor names in the OpenDSS file. For an example of how to insert monitors into an OpenDSS circuit, refer to the example circuit's `Monitors_ckt24.dss` file. Also, refer to the OpenDSS documentation for help regarding the various monitor fields.

4.7.3. Time-Series Analysis in MATLAB

A time-series analysis with MATLAB involves using the COM interface to solve each time step within MATLAB and retrieve the data you are interested in at each time-step. Open `exampleVoltageAnalysis` to view an example of this process. View the set-up for the time-series iteration at line 79:

```
%% Run simulations every 1-minute and find max/min voltages
    simulationResolution = 60; %in seconds
    simulationSteps = 24*60*7;

    DSSText.Command = sprintf('Set mode=duty number=1  hour=0  h=%i
        sec=0',simulationResolution);
    DSSText.Command = 'Set Controlmode=TIME';
```

You can see in line 96 where the time-series iteration begins. Recall that OpenDSS automatically steps to the next time step after each solve command. Therefore, the code at line 99 is automatically populating the `DSSCircuit` interface with data for the next time step. Because the control mode is set to time, OpenDSS automatically remembers previous solution states and handles any delays on the controls correctly. The remainder of the for-loop example is retrieving particular data about this time step. The result is a time-series analysis without the need for placing monitors. This form of solving time series simulations is slower because MATLAB is stopping OpenDSS and processing data after each solution, but it allows for any custom processing such as finding the maximum voltage of all buses. This form of time series analysis can also be useful when MATLAB will take control actions at each solution time step, such as a custom battery controller or demand response setup. An example of using this type of solutions for MATLAB to create custom voltage regulator control algorithms can be seen in [10].

5. DISTRIBUTION SYSTEM MODELS

5.1. Example Circuit

The example circuit included in the GridPV toolbox is EPRI Test Circuit Ckt24. All .dss files for the example circuit can be found in the ExampleCircuit folder in the GridPV installation folder. From running the circuitCheck function, a few parameters in the example circuit were modified and are slightly different than EPRI Ckt24. The loadshapes in the example circuit were also changed from yearly to duty loadshapes in order to demonstrate the duty simulation mode. The summary of Ckt24 provided by EPRI is shown in Table 1. The circuit diagram is shown in Figure 19.

Table 1. Summary of EPRI Test Ckt24.

Circuit Alias	Ckt24
System voltage (kV)	34.5
Number of customers	3885
Service xfmr connected kVA	69373
Total feeder kvar	3300
Subtransmission Voltage (kV)	230
3-Ph SCC at Sub Sec. (MVA)	422
Primary circuit miles total	74
Percent residential by load	87
No. of feeders on the Sub bus	2

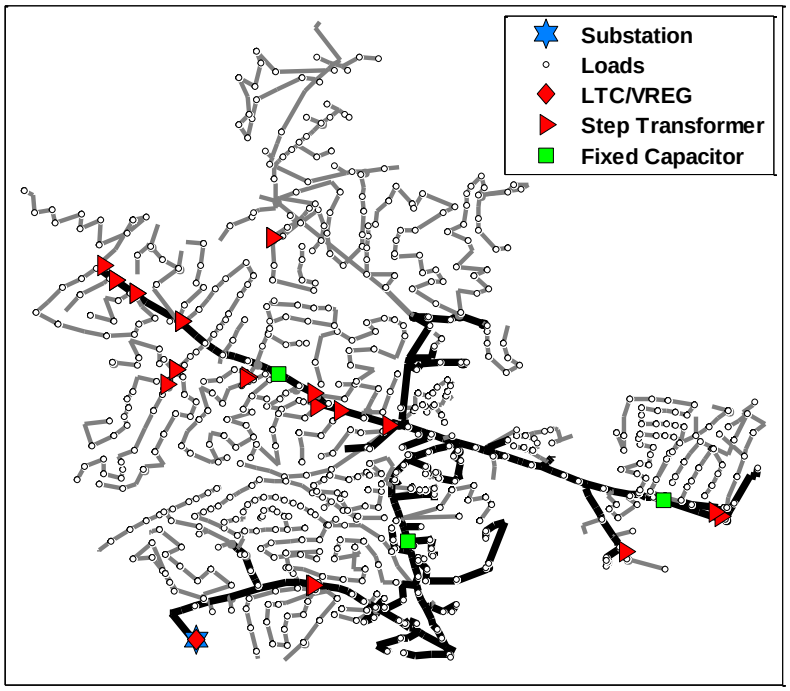


Figure 19. Circuit diagram for GridPV example circuit (EPRI Test Ckt24).

5.2. Links to Other Circuits

Creating the distribution system model in OpenDSS, debugging, and validation can be very time consuming. As a starting point, EPRI has provided three test circuits of actual electric power distribution systems. The example circuit in the GridPV toolbox is based on one of these test circuits. The three distribution system models can be found in the folder EPRITestCircuits inside the OpenDSS program folder where it was installed on the hard drive.

There are a few other OpenDSS circuit models included in the OpenDSS installation, such as the various IEEE test cases. These models are in the IEEETestCases folder inside the OpenDSS program folder. These circuits are commonly used for research purposes to test and simulation ideas.

6. FEEDBACK AND HELP

User feedback can be submitted at www.gridintegration.org. When submitting a request, please classify the feedback as reporting a bug, new feature request, or help and assistance.

7. FUNCTION HELP FILES

The function help files are group by categories of their use. While all function help header information is included here, this content can also be found directly in MATLAB. These help files can be accessed via the typical help browser or by querying the help via the command line.

```
help getBusInfo
```

The help files are also included online at www.gridintegration.org. For OpenDSS help, see the references in Section 3 on OpenDSS resources.

The functions by category are:

7.1. OpenDSS Functions 50

7.2. Circuit Analysis Functions 70

7.3. Plotting Functions 77

7.4. Geographic Mapping Functions 98

7.5. Solar Modeling Functions 105

7.6. Example Simulations 117

7.1. OPENDSS FUNCTIONS

The distribution system electrical modeling is done in the open source software OpenDSS from the Electric Power Research Institute (EPRI) [1]. All power flows are solved with OpenDSS and the results can be transferred to MATLAB through a COM interface. MATLAB runs and commands OpenDSS to do actions, with the results being available to MATLAB through the COM server structure. These functions provide a standardized way to obtain information from OpenDSS. Each "get"-function returns a structure to MATLAB with all OpenDSS circuit elements of that type. Note that the returned structure represents the variables at the most recent power flow solution in OpenDSS and needs to be called each time the circuit or solution has changed.

Function List

DSSStartup - Function for starting up OpenDSS and linking to MATLAB

getBusCoordinatesArray - Gets the coordinates for all buses that have a location in OpenDSS

getBusInfo - Gets the information for all Bus in busNames

getCapacitorInfo - Gets the information for all capacitors in the circuit

getCoordinates - Gets the coordinates for the buses in busNames

getLineInfo - Gets the information for all lines in the circuit

getLoadInfo - Gets the information for all loads in the circuit

getPVInfo - Gets the information for all PV plants in the circuit

getTransformerInfo - Gets the information for all transformers in the circuit

isinterfaceOpenDSS - Used to check for a valid interface input.

7.1.1. DSSStartup

Function for starting up OpenDSS and linking to MATLAB

Syntax

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
```

Description

Function to start up OpenDSS in the background and bring the program handle into MATLAB to allow control of OpenDSS from MATLAB through the COM interface. This function only needs to be executed once per MATLAB session. The same handle to OpenDSS can be used the rest of the session. Note: the OpenDSS session started through the COM interface is separate from the executable program, so the active circuits and parameters can be different between the COM and visual executable.

Inputs

- **none**

Outputs

- `CircuitObj` is the handle to the object in the OpenDSS program containing the circuit object as well as the text object used to the send commands to OpenDSS. Note: CircuitObj will be empty until Text.command = 'compile example.dss' is done to load in an active circuit into the OpenDSS workspace.
- `Text` can be used to send commands to OpenDSS through Text.command; it can also be called with CircuitObj.Text.command.
- `gridpvPath` is a string containing the toolbox location

Example

Intiating OpenDSS from MATLAB:

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup
```

```
DSSCircObj =
        COM.OpenDSSEngine_DSS

DSSText =
        Interface.OpenDSS_Engine.IText

gridpvPath =
C:\OpenDSS_ToolBox\GridPV\
```

7.1.2. getBusCoordinatesArray

Gets the coordinates for all buses that have a location in OpenDSS

Syntax

```
[busCoordNames busCoordArray] = getBusCoordinatesArray(DSSCircObj);
```

Description

Function to get the buses and their coordinates for all buses that have a location in OpenDSS.

Inputs

- **DSSCircObj** - link to OpenDSS active circuit and command text (from DSSStartup)

Outputs

- **busCoordNames** is the array of the bus names
- **busCoordArray** is the matrix of bus coordinates (X,Y) corresponding to the bus name in busCoordNames.

Example

Returns the bus names and coordinates for the active circuit in OpenDSS

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
[busCoordNames busCoordArray] = getBusCoordinatesArray(DSSCircObj);
size(busCoordArray)
```

```
ans =

        1347           2
```

7.1.3. getBusInfo

Gets the information for all Bus in busNames

Syntax

```
Buses = getBusInfo(DSSCircObj);
Buses = getBusInfo(DSSCircObj,busNames);
Buses = getBusInfo(DSSCircObj,busNames,forceFindCoords);
```

Description

Function to get the information for buses in the OpenDSS circuit. If optional input busNames contains a cell array, the function will return a structure for each busName, otherwise Buses will contain all buses in the circuit.

Inputs

- `DSSCircObj` - link to OpenDSS active circuit and command text (from DSSStartup)
- `busNames` - optional cell array of bus names to get information for
- `forceFindCoords` - optional input to force the function to try to find the coordinates for the busNames by searching for other connected buses that do have coordinates

Outputs

`Buses` is a structure with all the parameters for the buses in busNames. Fields are:

- *name* - The busname acquired from the busNames input.
- *numPhases* - Returns the number of nodes on the bus.
- *phaseVoltages* - Value of voltage magnitudes calculated from. the complex voltage returned by OpenDSS. Length is always 3, returning 0 for phases not on the bus.
- *phaseVoltagesPU* - Per-unit value of voltage magnitudes calculated from the complex per-unit voltage returned by OpenDSS. Length is always 3, returning 0 for phases not on the bus.
- *voltage* - Mean of the phastVoltages.
- *voltagePU* - Mean of the phaseVoltagesPU.
- *coordinates* - Returns coordinates stored in OpenDSS for the active bus. If coordinates do not exist and forceFindCoords is 1, it returns coordinates of the coordinates of the nearest upstream element.
- *distance* - Line distance from the bus to the substation.
- *kVBase* - The bus's base voltage in kV.
- Miscellaneous parameters being pulled from OpenDSS but are currently unused within the toolbox (May return null if undefined in OpenDSS): *seqVoltages, cplxSeqVoltages, Voc, Isc, ZscMatrix, Zsc1, Zsc0, YscMatrix*

Example

Returns bus information

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
Buses = getBusInfo(DSSCircObj) %Get information for all buses
Buses = getBusInfo(DSSCircObj,{'N1311915'}) %Get information for one bus
```

```
Buses =

6058x1 struct array with fields:

    name
    numPhases
    voltageAngle
    voltage
    voltagePU
    phaseVoltages
    phaseVoltagesPU
    distance
    kVBase
    seqVoltages
    cplxSeqVoltages
    Voc
    Isc
    ZscMatrix
    Zsc1
    Zsc0
    YscMatrix
    coordinates


Buses =

              name: 'N1311915'
         numPhases: 1
      voltageAngle: 0.6602
           voltage: 2.0486e+04
         voltagePU: 1.0285
    phaseVoltages: [2.0486e+04 0 0]
  phaseVoltagesPU: [1.0285 0 0]
          distance: 2.3813
             kVBase: 19.9186
       seqVoltages: [-1 -1 -1]
  cplxSeqVoltages: [-1 -1 -1 -1 -1 -1]
              Voc: [0 0]
              Isc: [0 0]
        ZscMatrix: 0
             Zsc1: [0 0]
             Zsc0: [0 0]
        YscMatrix: 0
      coordinates: [31.6145 -80.9461]
```

7.1.4. getCapacitorInfo

Gets the information for all capacitors in the circuit

Syntax

```
Capacitors = getCapacitorInfo(DSSCircObj);
Capacitors = getCapacitorInfo(DSSCircObj, capacitorNames);
```

Description

Function to get the information about the capacitors in the circuit and return a structure with the information. If the optional input of capacitorNames is filled, the function returns information for the specified subset of capacitors, excluding the miscellaneous parameters mentioned in the outputs below.

Inputs

- `DSSCircObj` - link to OpenDSS active circuit and command text (from DSSStartup)
- `capacitorNames` - optional cell array of capacitor names to get information for

Outputs

`Capacitors` is a structure with all the parameters for the capacitors in the active circuit. Fields are:

- *name* - The capacitor name.
- *busName* - Name of the associated bus.
- *numPhases* - Number of phases associated with the capacitor bank.
- *enabled* - {1|0} indicates whether this element is enabled in the simulation.
- *phaseVoltages* - Value of voltage magnitudes calculated from the complex voltage returned by OpenDSS. Length is always 3, returning 0 for phases not on the bus
- *phaseVoltagesPU* - Per-unit value of voltage magnitudes calculated from the complex per-unit voltage returned by OpenDSS. Length is always 3, returning 0 for phases not on the bus.
- *voltage* - Mean of the phaseVoltages.
- *voltagePU* - Mean of the phaseVoltagesPU.
- *current* - average phase current
- *coordinates* - Coordinates for the capacitor's bus, obtained from getBusInfo.
- *distance* - Line distance from the capacitor's bus to the substation, obtained from getBusInfo.
- *isDelta* - {1|0} 1 is it connected via delta connection, 0 otherwise.
- *kvar* - Total kvar, if one step, or ARRAY of kvar ratings for each step. Evenly divided among phases.
- *kV* - For 2, 3-phase, kV phase-phase. Otherwise specify actual cap rating.
- *switching* - {1|0} 1 if CapControl lists the capacitor as one of its elements, 0 otherwise.
- *capControl* - Name of the CapControl element controlling the capacitor if the capacitor is being controlled.
- *controlMode* - Mode of control if the capacitor is being controlled.

- Miscellaneous parameters being pulled from OpenDSS but are currently unused within the toolbox (May return null if undefined in OpenDSS): *seqVoltages*, *cplxVoltages*, *seqCurrents*, *cplxSeqCurrents*, *powers*, *seqPowers*, *losses*, *phaseLosses*, *hasSwitchControl*, *hasVoltControl*
- Additional parameters regarding the control object for capacitors on which one is present are also retrieved: *monitoredObj*, *monitoredTerm*, *CTratio*, *PTratio*, *onSetting*, *offSetting*, *Vmax*, *Vmin*, *useVoltOverride*, *delay*, *delayOff*, *deadTime*

Example

Returns capacitor information in the circuit

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
Capacitors = getCapacitorInfo(DSSCircObj) %Get information for all capacitors
Capacitors = getCapacitorInfo(DSSCircObj, {'cap_g2101ae7400'}) %Get information for one
capacitor
Capacitors = getCapacitorInfo(DSSCircObj, [{'cap_g2100pl6500'};{'cap_g2100fk7800'}]); %Get
information for two capacitors
```

```
Capacitors =

3x1 struct array with fields:
    name
    busName
    numPhases
    enabled
    coordinates
    distance
    voltage
    phaseVoltages
    current
    voltagePU
    phaseVoltagesPU
    switching
    seqVoltages
    cplxSeqVoltages
    seqCurrents
    cplxSeqCurrents
    powers
    seqPowers
    losses
    phaseLosses
    hasSwitchControl
    hasVoltControl
    kvar
    isDelta
    kV

Capacitors =
                name: 'cap_g2101ae7400'
             busName: 'n284062'
           numPhases: 3
             enabled: 1
         coordinates: [31.6512 -80.9620]
            distance: 5.4491
             voltage: 2.0413e+04
       phaseVoltages: [2.0328e+04 2.0405e+04 2.0508e+04]
             current: 20.5807
           voltagePU: 1.0248
     phaseVoltagesPU: [1.0206 1.0244 1.0296]
           switching: 0
         seqVoltages: [53.6077 2.0413e+04 66.9674 0 0 0]
      cplxSeqVoltages: [1x12 double]
         seqCurrents: [1x12 double]
      cplxSeqCurrents: [1x12 double]
              powers: [1x12 double]
           seqPowers: [1x12 double]
              losses: [7.2760e-12 -1.2604e+06]
        phaseLosses: [0 -416.6194 0 -419.7602 7.2760e-15 -424.0095]
    hasSwitchControl: 0
      hasVoltControl: 0
                kvar: 900
             isDelta: 0
                  kV: 34.5000
```

7.1.5. getCoordinates

Gets the coordinates for the buses in busNames

Syntax

```
coordinates = getCoordinates(DSSCircObj);
coordinates = getCoordinates(DSSCircObj,busNames);
```

Description

Function to get coordinates for the buses in busNames. If optional input busNames contains a cell array, the function will return a structure for each busName, otherwise coordinates will contain all buses in the circuit.

Inputs

- **DSSCircObj** - link to OpenDSS active circuit and command text (from DSSStartup)
- **busNames** - optional cell array of bus names to find locations for

Outputs

- **coordinates** is the array of bus coordinates corresponding to busNames. The first column is the y values, and second column is x values

Example

Returns the coordinates for buses

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
coordinates = getCoordinates(DSSCircObj); %Get all bus coordinates
coordinates = getCoordinates(DSSCircObj,{'N1311915'}) %Get coordinates for bus N1311915
coordinates = getCoordinates(DSSCircObj,[{'N1311915'}; {'n284022'}]) %Get coordinates for two
buses
```

```
coordinates =

   31.6145  -80.9461


coordinates =

   31.6145  -80.9461
   31.6493  -80.9596
```

7.1.6. getLineInfo

Gets the information for all lines in the circuit

Syntax

```
Lines = getLineInfo(DSSCircObj);
Lines = getLineInfo(DSSCircObj, lineNames);
```

Description

Function to get the information about the lines in the circuit and return a structure with the information. If the optional input of lineNames is filled, the function returns information for the specified subset of lines, excluding the miscellaneous parameters mentioned in the outputs below.

Inputs

- `DSSCircObj` - link to OpenDSS active circuit and command text (from DSSStartup)
- `lineNames` - optional cell array of line names to get information for

Outputs

`Lines` is a structure with all the parameters for the lines in the active circuit. Fields are:

- *name* - Name of the line.
- *bus1* - Name of the starting bus.
- *bus2* - Name of the ending bus.
- *enabled* - {1|0} indicates whether this element is enabled in the simulation.
- *bus1Coordinates, bus1Distance, bus1PhaseVoltages*,
- *bus1PhaseVoltagesPU, bus1Voltage, bus1VoltagePU* - Information regarding the starting bus. All obtained from the corresponding fields of the structure returned by getBusInfo when called with 'bus1' as an input.
- *bus2Coordinates*, *bus2Distance*, *bus2PhaseVoltages*,
- *bus2PhaseVoltagesPU, bus2Voltage, bus2VoltagePU* - Information regarding the starting bus. All obtained from the corresponding fields of the structure returned by getBusInfo when called with 'bus2' as an input.
- *numPhases* - Number of phases associated with the line.
- *lineRating* - The line's current rating.
- *bus1Current* - Average current magnitude for all included phases on bus 1.
- *bus2Current* - Average current magnitude for all included phases on bus 2.
- *bus1PhasePowerReal* - 3-element array of the real components of each phase's complex power at bus 1. Phases that are not present will return 0.
- *bus1PhasePowerReactive* - 3-element array of the imaginary components of each phase's complex power at bus 1. Phases that are not present will return 0.
- *bus2PhasePowerReal* - 3-element array of the real components of each phase's complex power at bus 2. Phases that are not present will return 0.
- *bus2PhasePowerReactive* - 3-element array of the imaginary components of each phase's complex power at bus 2. Phases that are not present will return 0.
- *bus1PowerReal* - Total real component at bus 1 of all present phases.

- *bus1PowerReactive* - Total imaginary component at bus 1 of all present phases.
- *bus2PowerReal* - Total real component at bus 2 of all present phases.
- *bus2PowerReactive* - Total imaginary component at bus 2 of all present phases.
- *parentObject* - name of the line or object directly upstream (parent) of the line
- Miscellaneous parameters being retrieved from OpenDSS but are currently unused within the toolbox (May return null if undefined in OpenDSS): *lineCode*, *length*, *R1*, *X1*, *R0*, *X0*, *C1*, *C0*, *Rmatrix*, *Xmatrix*, *Cmatrix*, *emergAmps*, *geometry*, *Rg*, *Xg*, *Rho*, *Yprim*, *numCust*, *totalCust*, *spacing*

Example

Returns line information in the circuit

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
Lines = getLineInfo(DSSCircObj) %Get information for all lines
Lines = getLineInfo(DSSCircObj, {'g2102cg5800_n284428_sec_1'}); %Get information for a single
line
Lines = getLineInfo(DSSCircObj,[{'05410_8168450ug'};{'05410_52308181oh'}]); %Get info for two
lines
```

```
Lines =

5221x1 struct array with fields:

    name
    bus1
    bus2
    enabled
    bus1PhasePowerReal
    bus1PhasePowerReactive
    bus2PhasePowerReal
    bus2PhasePowerReactive
    bus1PowerReal
    bus1PowerReactive
    bus2PowerReal
    bus2PowerReactive
    bus1Current
    bus2Current
    bus1PhaseCurrent
    bus2PhaseCurrent
    numPhases
    lineRating
    losses
    bus1Coordinates
    bus1Distance
    bus1CoordDefined
    bus1VoltageAngle
    bus1Voltage
    bus1VoltagePU
    bus1PhaseVoltages
    bus1PhaseVoltagesPU
    bus2Coordinates
    bus2Distance
    bus2CoordDefined
    bus2VoltageAngle
    bus2Voltage
    bus2VoltagePU
    bus2PhaseVoltages
    bus2PhaseVoltagesPU
    parentObject
    lineCode
    length
    R1
    X1
    R0
    X0
    C1
    C0
    Rmatrix
    Xmatrix
    Cmatrix
    emergAmps
    geometry
    Rg
```

```
Xg
Rho
Yprim
numCust
totalCust
spacing
```

7.1.7. getLoadInfo

Gets the information for all loads in the circuit

Syntax

```
Loads = getLoadInfo(DSSCircObj)
Loads = getLoadInfo(DSSCircObj, loadNames)
```

Description

Function to get the information about the loads in the circuit and return a structure with the information. If the optional input of loadNames is filled, the function returns information for the specified subset of loads, excluding the miscellaneous parameters mentioned in the outputs below.

Inputs

- `DSSCircObj` - link to OpenDSS active circuit and command text (from DSSStartup)
- `loadNames` - optional cell array of line names to get information for

Outputs

`Loads` is a structure with all the parameters for the loads in the active circuit. Fields are:

- *name* - Name of the load.
- *voltage* - Average magnitude of the phase voltages.
- *busName* - Name of the associated bus.
- *numPhases* - Number of phases associated with the load.
- *xfkVA* - The kVA rating of the associated transoformer.
- *kW*, *kvar*, *kva* - Rated power of the load.
- *kV* - Rated voltage.
- *PF* - Rate power factor of the load.
- Miscellaneous parameters retrieved from OpenDSS but are currently unused within the toolbox (May return null if undefined in OpenDSS): *currents*, *powers*, *losses*, *phaseLosses*, *seqVoltages*, *cplxSeqVotlages*, *seqCurrents*, *cplxSeqCurrents*, *seqPowers*, *hasSwitchControl*, *hasVoltControl*, *energyMeter*, *Idx*, *pctMean*, *pctStdDev*, *allocationFactor*, *Cfactor*, *class*, *isDelta*, *CVRcurve*, CVRwarrs_, *daily*, *duty*, *kwhdays*, *model*, *numCust*, *Rneut*, *spectrum*, *VmaxPU*, *VminEmerg*, *VminNorm*, *VminPU*, *Xneut*, *yearly*, *status*, *growth*

Example

Returns load information in the circuit

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
Loads = getLoadInfo(DSSCircObj) %Get information for all loads
Loads = getLoadInfo(DSSCircObj, {'360667000'}) %Get information for one load
Loads = getLoadInfo(DSSCircObj, [{'530877691_1'};{'331431200'}]); %Get information for two
loads
```

```
Loads =

3891x1 struct array with fields:

    name
    enabled
    voltage
    busName
    numPhases
    currents
    powers
    losses
    phaseLosses
    seqVoltages
    cplxSeqVoltages
    seqCurrents
    cplxSeqCurrents
    seqPowers
    hasSwitchControl
    hasVoltControl
    energyMeter
    xfkVA
    kW
    kvar
    kva
    kV
    PF
    Idx
    pctMean
    pctStdDev
    allocationFactor
    Cfactor
    class
    isDelta
    CVRcurve
    CVRwatts
    CVRvars
    daily
    duty
    kwhdays
    model
    numCust
    Rneut
    spectrum
    VmaxPU
    VminEmerg
    VminNorm
    VminPU
    Xneut
    yearly
    status
    growth


Loads =

               name: '360667000'
            enabled: 1
            voltage: 241.6734
            busName: 'g2101ra0900_n300678_sec_2.1'
          numPhases: 1
           currents: [0.0302 -0.0385 -0.0302 0.0385]
             powers: [0.0116 0.0024 0 0]
             losses: [11.5782 2.3873]
        phaseLosses: [0.0116 0.0024]
        seqVoltages: [1 1 1]
     cplxSeqVoltages: [-1 0 -1 0 -1 0]
        seqCurrents: [1 1 1]
     cplxSeqCurrents: [-1 0 -1 0 -1 0]
          seqPowers: [-1 -1 -1 -1 -1 -1]
    hasSwitchControl: 0
      hasVoltControl: 0
          energyMeter: ''
                xfkVA: 3.2512
                   kW: 2.5812
                 kvar: 0.5241
                  kva: 1.4597
                   kV: 0.2400
                   PF: 0.9800
                  Idx: 1
            pctMean: 50
          pctStdDev: 10
    allocationFactor: 0.8101
             Cfactor: 4
               class: 1
             isDelta: 0
            CVRcurve: ''
            CVRwatts: 0.8000
             CVRvars: 3
               daily: ''
```

```
    duty: ''
  kwhdays: 30
    model: 'dssLoadCVR'
  numCust: 1
    Rneut: -1
 spectrum: 'defaultload'
   VmaxPU: 1.0500
VminEmerg: 0
 VminNorm: 0
   VminPU: 0.7000
    Xneut: 0
   yearly: ''
   status: 'dssLoadVariable'
   growth: ''
```

7.1.8. getPVInfo

Gets the information for all PV plants in the circuit

Syntax

```
PV = getPVInfo(DSSCircObj);
PV = getPVInfo(DSSCircObj, pvNames);
```

Description

Function to get the information about the PV plants in the circuit and return a structure with the information. If the optional input of pvNames is filled, the function returns information for the specified subset of PV installations, excluding the miscellaneous parameters mentioned in the outputs below.

Inputs

- `DSSCircObj` - link to OpenDSS active circuit and command text (from DSSStartup)
- `pvNames` - optional cell array of PV names to get information for

Outputs

`PV` is a structure with all the parameters for the PV plants in the active circuit. Fields are:

- *name* - Name of the PV source.
- *busName* - Name of the associated bus.
- *numPhases* - Number of phases associated with the PV.
- *phaseVoltages* - Value of voltage magnitudes calculated from the complex voltage returned by OpenDSS. Length is always 3, returning 0 for phases not on the bus
- *phaseVoltagesPU* - Per-unit value of voltage magnitudes calculated from the complex per-unit voltage returned by OpenDSS. Length is always 3, returning 0 for phases not on the bus.
- *current* - average phase current output
- *coordinates* - Coordinates for the PV bus
- *distance* - Line distance from the PV bus to the substation, obtained from getBusInfo.
- *phasePowerReal* - 3-element array of the real components of each phase's complex power injected by PV. Phases that are not present will return 0.
- *phasePowerReactive* - 3-element array of the imaginary components of each phase's complex power injected by PV. Phases that are not present will return 0.
- *powerReal* - Total *phasePowerReal*.
- *powerReactive* - Total *phasePowerReactive*.
- Miscellaneous parameters retrieved from OpenDSS but are currently unused within the toolbox (May return null if undefined in OpenDSS): *numTerminals, numPhases, losses, phaseLosses, seqVoltages, cplxSeqVoltages, seqCurrents, cplxSeqCurrents, seqPowers, enabled, hasSwitchControl, hasVoltControl, energyMeter, controller, kW, kvar, PF, numPhases*

Example

Returns PV information in the circuit

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\Ckt24_PV_Distributed_7_5.dss"'];
DSSText.command = 'solve';
PV = getPVInfo(DSSCircObj) %Get information for all PV
PV = getPVInfo(DSSCircObj, {'pvn312429.1.2.3'}) %Get information for one PV
PV = getPVInfo(DSSCircObj, [{'pvn300557.3'};{'pvn300587.2'}]); %Get information for two PV
```

```
PV =

99x1 struct array with fields:

    name
    busName
    numPhases
    voltage
    phaseVoltages
    current
    coordinates
    distance
    voltagePU
    phaseVoltagesPU
    phasePowerReal
    phasePowerReactive
    powerReal
    powerReactive
    numTerminals
    losses
    phasesLosses
    seqVoltages
    cplxSeqVoltages
    seqCurrents
    cplxSeqCurrents
    seqPowers
    enabled
    hasSwitchControl
    hasVoltControl
    energyMeter
    controller
    kV
    kw
    kvar
    PF


PV =

                  name: 'pvn312429.1.2.3'
               busName: 'n312429.1.2.3'
             numPhases: 3
               voltage: 2.0580e+04
         phaseVoltages: [2.0505e+04 2.0547e+04 2.0689e+04]
               current: 5.3306
           coordinates: [31.6376 -80.8964]
              distance: 6.2216
             voltagePU: 1.0332
        phaseVoltagesPU: [1.0294 1.0316 1.0387]
         phasePowerReal: [-109.7031 -109.7033 -109.7031]
    phasePowerReactive: [-0.0014 -0.0012 -7.6144e-04]
             powerReal: -329.1094
          powerReactive: -0.0033
           numTerminals: 1
                 losses: [-3.2911e+05 -3.3314]
          phasesLosses: [1x6 double]
           seqVoltages: [112.0575 2.0580e+04 38.3146]
        cplxSeqVoltages: [1x6 double]
           seqCurrents: [0.0098 5.3305 0.0290]
        cplxSeqCurrents: [0.0095 0.0025 -4.2581 3.2066 -0.0286 0.0048]
             seqPowers: [1x6 double]
               enabled: 1
      hasSwitchControl: 0
        hasVoltControl: 0
           energyMeter: ''
            controller: ''
                    kV: 34.5000
                    kw: 1.0970e+03
                  kvar: 0
                    PF: 1
```

7.1.9. getTransformerInfo

Gets the information for all transformers in the circuit

Syntax

```
Transformers = getTransformerInfo(DSSCircObj)
Transformers = getTransformerInfo(DSSCircObj, transformerNames)
```

Description

Function to get the information about the transformers in the circuit and return a structure with the information. If the optional input of transformerNames is filled, the function returns information for the specified subset of transformers, excluding the miscellaneous and additional parameters mentioned in the outputs below.

Inputs

- `DSSCircObj` - link to OpenDSS active circuit and command text (from DSSStartup)
- `transformerNames` - optional cell array of transformer names to get information for

Outputs

`Transformers` is a structure with all the parameters for the transformers in the active circuit. Fields are:

- *name* - Name of the transformer.
- *bus1* - Primary bus.
- *bus2* - Secondary bus.
- *bus1Voltage*, *bus2Voltage* - Primary and secondary voltage respectively.
- *numPhases* - Number of phases associated with the transformer.
- *bus1Distance*, *bus2Distance* - Distance to the substation from the primary and secondary bus respectively.
- *kva* - Transformer power rating.
- *controlled* - Whether or not the transformer is tap-controlled.
- Miscellaneous parameters being pulled from OpenDSS but are currently unused within the toolbox (May return null if undefined in OpenDSS): *numTerminals*, *currents*, *powers*, *losses*, *phaseLosses*, *seqVoltages*, *cplxSeqVoltages*, *seqCurrents*, *cplxSeqCurrents*, *seqPower*, *enabled*, *normalAmps*, *emergAmps*, *hasSwitchControl*, *hasVoltControl*, *energyMeter*, *controller*, *XfmrCode*, *wdg*, *R*, *tap*, *minTap*, *maxTap*, *numTaps*, *kV*, *Xneut*, *Rneut*, *isDelta*, *Xhl*, *Xht*
- Additional parameters regarding the control object for transformers on which one is present are also retrieved: *controller*, *CTPrimary*, *delay*, *forwardBand*, *forwardR*, *forwardVreg*, *forwardX*, *isInverseTime*, *_isReversible*, *maxTapChange*, *monitoredBus*, *PTratio*, *reverseBand*, *reverseR*, *reverseVreg*, *reverseX*, *tapDelay*, *tapWinding*, *voltageLimit*, *winding*

Example

Returns transformer information in the circuit

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
Transformers = getTransformerInfo(DSSCircObj) %Get information for all transformers
Transformers = getTransformerInfo(DSSCircObj, {'05410_g2101ak7700'}) %Get information for one
transformer
Transformers = getTransformerInfo(DSSCircObj, [{'05410_g2101ah4300'};{'05410_g2101ae2300'}]);
%Get information for two transformers
```

```
Transformers =

843x1 struct array with fields:

    name
    bus1Voltage
    bus2Voltage
    bus1
    bus2
    numPhases
    bus1Distance
    bus2Distance
    controlled
    numTerminals
    currents
    powers
    losses
    phaseLosses
    seqVoltages
    cplxSeqVoltages
    seqCurrents
    cplxSeqCurrents
    seqPower
    enabled
    normalAmps
    emergAmps
    hasSwitchControl
    hasVoltControl
    energyMeter
    inputkva
    kva
    XfmrCode
    wdg
    R
    tap
    minTap
    maxTap
    numTaps
    bus1kV
    Xneut
    Rneut
    isDelta
    Xhl
    Xht
    bus2kV
    controller
    CTPrimary
    delay
    forwardBand
    forwardR
    forwardVreg
    forwardX
    isInverseTime
    isReversible
    maxTapChange
    monitoredBus
    PTratio
    reverseBand
    reverseR
    reverseVreg
    reverseX
    tapDelay
    tapWinding
    voltageLimit
    winding


Transformers =

              name: '05410_g2101ak7700'
       bus1Voltage: 7.6872e+03
       bus2Voltage: 240.8940
              bus1: 'n284223.1'
              bus2: 'g2101ak7700_n284223_sec.1'
        numPhases: 1
      bus1Distance: 7.5266
```

```
    bus2Distance: 7.5266
      controlled: 0
    numTerminals: 2
        currents: [1x8 double]
          powers: [18.8783 4.2165 0 0 -18.7226 -3.8157 0 0]
          losses: [155.6803 400.8587]
     phaseLosses: [0.1557 0.4009]
     seqVoltages: [1 1 1 1 1 1]
 cplxSeqVoltages: [-1 0 -1 0 -1 0 -1 0 -1 0 -1 0]
     seqCurrents: [1 1 1 1 1 1]
 cplxSeqCurrents: [-1 0 -1 0 -1 0 -1 0 -1 0 -1 0]
        seqPower: [-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1]
         enabled: 1
      normalAmps: 7.2169
       emergAmps: 9.8412
hasSwitchControl: 0
  hasVoltControl: 0
     energyMeter: ''
        inputkva: 18.9326
             kva: 45000
        XfmrCode: ''
             wdg: 1
               R: 0.0027
             tap: 1
          minTap: 0.9000
          maxTap: 1.1000
         numTaps: 32
          bus1kV: 34.5000
           Xneut: 0
           Rneut: -1
         isDelta: 0
             Xhl: 0.0605
             Xht: 0.3000
          bus2kV: 13.2000
```

7.1.10. isinterfaceOpenDSS

Used to check for a valid interface input.

Syntax

```
isinterface = isinterfaceOpenDSS(DSSCircObj);
```

Description

Used for input parsing. Checks if the input is an OpenDSS COM interface and that it is compiled. Returns 1 if it is a compiled OpenDSS object, 0 otherwise. If it returns 0, it returns an error indicating whether it failed the interface test or the compiled-circuit test.

Inputs

- **`DSSCircObj`** - link to OpenDSS active circuit and command text (from DSSStartup)

Outputs

- **isinterface** - Returns 1 if it is a compiled OpenDSS object, 0 otherwise

Example

Showing interface check

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
isinterface = isinterfaceOpenDSS(DSSCircObj)
```

```
isinterface =
     1
```

7.2. CIRCUIT ANALYSIS FUNCTIONS

Certain pieces of the circuit analysis can better be performed in MATLAB. OpenDSS solves the power flow and returns the state of the system, but custom queries about features of the circuit can be accomplished in MATLAB.

Function List

circuitCheck - Used to error-check the circuit for any obvious abnormalities

findDownstreamBuses - Finds all buses downstream of the busName

findHighestImpedanceBus - Finds the highest impedance bus for each phase to the source bus

findLongestDistanceBus - Finds the bus for each phase that is farthest distance away

findSubstationLocation - Locates the substation coordinates

findUpstreamBuses - Finds all buses upstream of the busName

7.2.1. circuitCheck

Used to error-check the circuit for any obvious abnormalities.

Syntax

```
warnSt = circuitCheck(DSSCircObj);
warnSt = circuitCheck(DSSCircObj,'Warnings','off');
```

Description

Used for checking OpenDSS circuits for errors or abnormalities that do not prevent OpenDSS from running but will cause errors during analysis (e.g. Phase-a line downstream of a bus with only phases b and c). It is capable of performing a complete circuit check with a warning describing each error found. Warnings can be turned off. A more comprehensive list of elements that cause the errors can be found inside the structure, warnSt, that is outputted at the end of the check.

Inputs

- `DSSCircObj` - link to OpenDSS active circuit and command text (from DSSStartup)
- `'Warnings'` - indicates if the user wants command-prompt warnings on or not `{'on'} | 'off'`

Outputs

- `warnSt` is a structure with parameters relating to the results of various validity check. If the circuit failed a check, an entry for that check appears in this structure with fields for the check name, a string with the description, and a list of offenders that caused the fail.

Example

Example of a circuit test:

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
warnSt = circuitCheck(DSSCircObj)
warnSt = circuitCheck(DSSCircObj, 'Warnings', 'off');
```

```
warnSt =
    LineOverLoading: [1x1 struct]
```

7.2.2. findDownstreamBuses

Finds all buses downstream of the busName

Syntax

```
downstreamBuses = findDownstreamBuses(DSSCircObj,busName);
```

Description

Function to get all the bus names for buses that are downstream of the busName. The downstream buses are defined as buses that are farther from the substation on the electrical path of busName.

Inputs

- **DSSCircObj** - link to OpenDSS active circuit and command text (from DSSStartup)
- **busName** - string of the bus name to start search downstream

Outputs

- **downstreamBuses** is a cell array of the bus names downstream from busName

Example

Returns downstream buses

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
downstreamBuses = findDownstreamBuses(DSSCircObj,'N292792')
```

```
downstreamBuses =

    'n292792'
    'n292783'
    'g2101fk7100_n292792_sec'
    'n292782'
    'g2101fj5700_n292783_sec'
    'g2101fk7100_n292792_sec_1'
    'g2101fk7100_n292792_sec_2'
    'g2101fk7100_n292792_sec_3'
    'g2101fk7100_n292792_sec_4'
    'g2101fk7100_n292792_sec_5'
    'n292769'
    'g2101fj5700_n292783_sec_1'
    'g2101fj5700_n292783_sec_2'
    'g2101fj5700_n292783_sec_3'
    'g2101fj5700_n292783_sec_4'
    'g2101fj5700_n292783_sec_5'
    'g2101fj5700_n292783_sec_6'
    'n292752'
```

7.2.3. findHighestImpedanceBus

Finds the highest impedance bus from the substation

Syntax

```
[highestImpedance highestImpedanceBus] = findHighestImpedanceBus(DSSCircObj, requiredLineRating, threePhase);
```

Description

Function to find highest impedance bus from the substation.

Inputs

- **DSSCircObj** - link to OpenDSS active circuit and command text (from DSSStartup)
- **requiredLineRating** - the minimum allowed conductor size (amps) line rating for PV placement. A larger plant requires a higher required line rating. To not restrict the search algorithm, set this to zero.
- **threePhase** - optional input, logical value for if the bus must be 3 phase. If the input is a logical true, only 3 phase buses will be returned.

Outputs

- **highestImpedance** - impedance rating between fromBus to toBus
- **fromBus** - name of source bus for highest impedance
- **toBus** - name of bus with highest impedance to the source bus (fromBus)

Example

Returns the bus names for the highest impedance bus in the circuit

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
[highestImpedance highestImpedanceBus] = findHighestImpedanceBus(DSSCircObj, 220)
```

```
highestImpedance =
   10.3991

highestImpedanceBus =
    'N284454'
```

7.2.4. findLongestDistanceBus

Finds the bus for each phase that is farthest distance from the source bus

Syntax

```
[longestDistance toBus] = findLongestDistanceBus(DSSCircObj, phaseOption);
```

Description

Function to find the bus for each phase that is farthest distance from the source bus. This can be run to find the farthest bus for each phase (generally single phase) or farthest 3 phase bus.

Inputs

- `DSSCircObj` - link to OpenDSS active circuit and command text (from DSSStartup)
- `phaseOption` - 'perPhase' for the farthest bus on each phase or '3phase' for the farthest 3 phase bus

Outputs

- `longestDistance` - distance between fromBus to toBus
- `toBus` - name of bus with highest impedance to the energy monitor

Example

Returns the bus names and distance for the farthest bus

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
[longestDistance toBus] = findLongestDistanceBus(DSSCircObj, 'perPhase')
```

```
longestDistance =
   12.8993   11.2051   10.9983

toBus =
    'n284397.1'    'n292752.2'    [1x27 char]
```

7.2.5. findSubstationLocation

Locates the substation coordinates

Syntax

```
coordinates = findSubstationLocation(DSSCircObj);
```

Description

Function to find the coordinates of the substation. This is used for plotting the substation on circuit diagrams. The substation is located at the bus coordinate with the shortest "distance".

Inputs

- `DSSCircObj` - link to OpenDSS active circuit and command text (from DSSStartup)

Outputs

- `coordinates` is the [Y X] coordinates for the substation bus location

Example

Returns the substation location

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
coordinates = findSubstationLocation(DSSCircObj)
```

```
coordinates =

   31.6160  -80.9734
```

7.2.6. findUpstreamBuses

Finds all buses upstream of the busName

Syntax

```
upstreamBuses = findUpstreamBuses(DSSCircObj,busName);
```

Description

Function to get all the bus names for buses that are upstream of the busName. The upstream buses are defined as buses that are closer to the substation on the electrical path to busName.

Inputs

- **DSSCircObj** - link to OpenDSS active circuit and command text (from DSSStartup)
- **busName** - string of the bus name to start search upstream

Outputs

- **upstreamBuses** is a cell array of the bus names upstream from busName

Example

Returns upstream buses

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
upstreamBuses = findUpstreamBuses(DSSCircObj,'n292286')
```

```
upstreamBuses =
  Columns 1 through 6
    'n292286'    'n292300'    'n283640'    'n283641'    'n283648'    'n283663'
  Columns 7 through 11
    'n283672'    'n1386726'    'n1386727'    'n283677'    'n283680'
  Columns 12 through 17
    'n283682'    'n283661'    'n283639'    'n283622'    'n283615'    'n283609'
  Columns 18 through 22
    'n283606'    'n283602'    'n283575'    '05410'    'subxfmr_lsb'
```

7.3. PLOTTING FUNCTIONS

These functions create plots in MATLAB from the OpenDSS system. While some of these plots can be created directly in OpenDSS, plotting in MATLAB provides more customization and functionality. These plot functions can be called at any time during an OpenDSS simulation, and they will plot the current state of the OpenDSS feeder. If there are any solar generators in the simulation, the functions will identify the location and mark the PV in the plots.

Function List

plotAmpProfile - Plots the line currents profile and line rating vs. distance

plotCircuitLines - Plots the feeder circuit diagram

plotCircuitLinesOptions - GUI for providing options for how to plot the feeder circuit diagram

plotKVARProfile - Plots the feeder profile for the kVAR power flow on the lines

plotKWProfile - Plots the feeder profile for the kW power flow on the lines

plotMonitor - Plots a monitor from the simulation

plotVoltageProfile - Plots the voltage profile for the feeder (spider plot)

7.3.1. plotAmpProfile

Plots the line currents profile and line rating vs. distance

Syntax

```
plotAmpProfile(DSSCircObj,BusName);
plotAmpProfile(DSSCircObj,BusName, _'PropertyName'_ ,PropertyValue);
```

Description

Function to plot line currents in in each between the selected bus and the substation. The line current and line rating is plotted vs. distance from the substation. Clicking on objects in the figure will display the name of the object, and right clicking will give a menu for viewing properties of the object.

Inputs

- `DSSCircObj` - link to OpenDSS active circuit and command text (from DSSStartup)
- `BusName` - Property for the name of the bus (string) that the current (amp) profile should be plotted to. Only the direct line between the bus and the substation will be plotted
- `Properties` - optional properties as one or more name-value pairs in any order
- -- `'AveragePhase'` - Property for if the average power should be plotted alone or in addition to the phase plots `'on' | {'off'} | 'addition'`

Outputs

- **none** - a figure is displayed with the plot

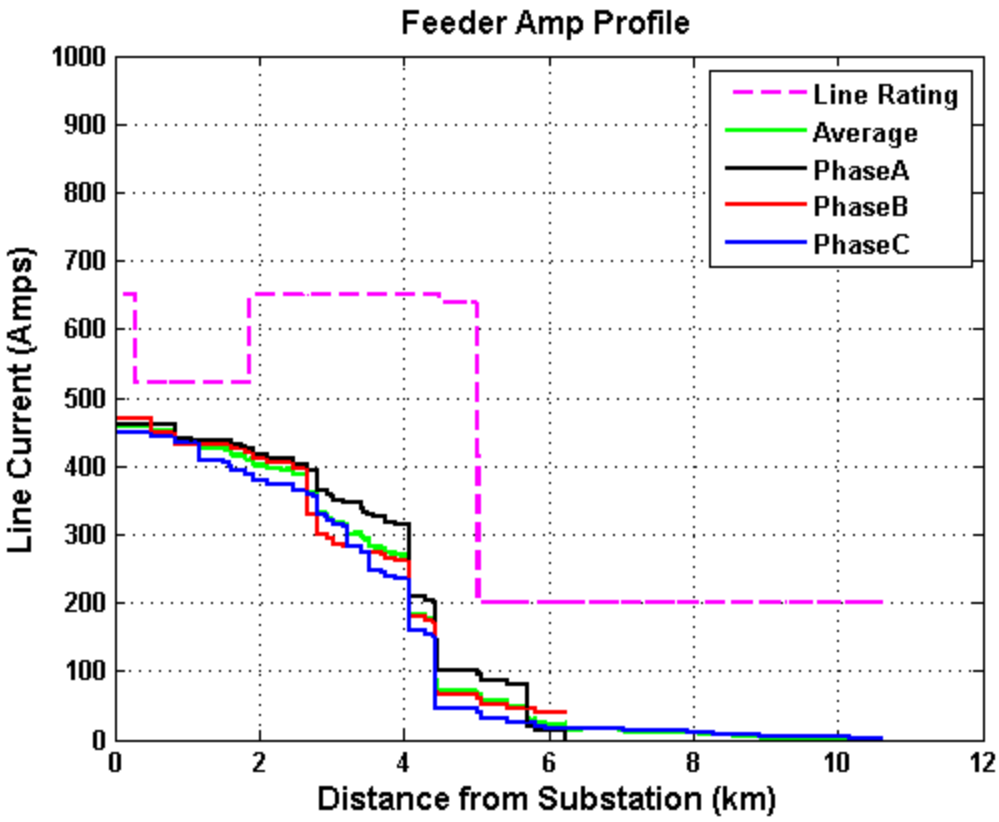
Notes

For the right-click visualizations, the AllowForms field of DSSCircObj must be set to 1, which is the default value. Currently, OpenDSS 7.6.3 (the current version as of this writing) does not allow for setting the AllowForms field back to 1 after setting it to 0.

Example

Example of an Amp profile plot to a bus

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
figure; plotAmpProfile(DSSCircObj, 'G2101JK1400_N300995_sec_1','AveragePhase','addition')
ylim([0 1000])
```


Feeder Amp Profile
Line Rating
Average
PhaseA
PhaseB
PhaseC
Line Current (Amps)
Distance from Substation (km)
0
100
200
300
400
500
600
700
800
900
1000
0
2
4
6
8
10
12

7.3.2. plotCircuitLines

Plots the feeder circuit diagram

Syntax

```
plotCircuitLines(DSSCircObj);
plotCircuitLines(DSSCircObj, _'PropertyName'_ ,PropertyValue);
```

Description

Function to plot the feeder circuit diagram. The coloring and line thickness plotting styles can be customized by the user through the function property inputs. If no properties are selected, the plotCircuitLinesOptions GUI window is displayed to assist the user is selecting plotting options. Clicking on objects in the figure will display the name of the object, and right clicking will give a menu for viewing properties of the object.

Inputs

- `DSSCircObj` - link to OpenDSS active circuit and command text (from DSSStartup)
- `Properties` - optional properties as one or more name-value pairs in any order
- -- `'Coloring'` - Defines how the circuit lines are colored in the figure. `{'numPhases'} | 'PerPhase' | 'voltage' | 'lineLoading' | 'distance' | 'unbalance' | [0,0,0]`
- ------ `ColorSpec` - three-element RGB vector specifying the line color
- ------ `'numPhases'` - black for 3-phase lines and a light gray for 1 or 2 phase lines
- ------ `'PerPhase'` - colors each phase (or combination of phases) a different color in the figure
- ------ `'voltage120'` - contours the line colors according to the voltage on a 120V base
- ------ `'voltagePU'` - contours the line colors according to the per unit voltage
- ------ `'voltage'` - contours the line colors according to the voltage (kV)
- ------ `'lineLoading'` - contours the line colors according to the line loading (current/line rating)
- ------ `'realLosses'` - contours the line colors according to the real power line losses (kW/km)
- ------ `'reactiveLosses'` - contours the line colors according to the reactive power line losses (kVAR/km)
- ------ `'distance'` - contours the line colors according to the distance from the substation
- ------ `'unbalance'` - contours the line colors according to the power (kVA) unbalance between phases
- ------ `'voltageAngle'` - contours the line colors according to the angle of the bus voltage phasor
- ------ `'powerFactor'` - contours the line colors according to the power factor of the power flow
- -- `'ContourScale'` - Defines the minimum and maximum value for contouring or auto scaling `{'auto'} | [0 5]`
- -- `'Thickness'` - Defines how the thickness of the circuit lines is displayed. `{'numPhases'} | 'current' | 'lineRating' | 0 - 10`
- ------ `0 - 10` - numeric value for the fixed line width

- ------ 'numPhases' - thicker lines for 3-phase power lines
- ------ 'current' - thickness is linearly related to the current flowing through the lines relative to the maximum current in any line
- ------ 'lineRating' - thickness is linearly related to the current rating of the line relative to the maximum line rating
- -- **'SubstationMarker'** - Property for if the substation should be marked {'on'} | 'off'
- -- **'PVMarker'** - Property for if the PV PCC should be marked (if it exists) {'on'} | 'off'
- -- **'LoadMarker'** - Property for if loads should be marked {'on'} | 'off'
- -- **'TransformerMarker'** - Property for if controlled transfomer (LTC and VREG) and step transformers (>1000V) should be marked {'on'} | 'off'
- -- **'CapacitorMarker'** - Property for if capacitors should be marked {'on'} | 'off'
- -- **'CustomMarker'** - Property for marking a custom bus by the user specifying a bus name {'off'} | busNameString
- -- **'CustomLegend'** - Text to place in the legend describing the custom bus specified in CustomMarker
- -- **'NumPhases'** - Property for if only lines with the specified number of phases should be plotted [1,2,3] | 1 | [2,3] | [1,2]
- -- **'PhasesToPlot'** - Property for which phases to plot (A,B,C). True/False values for each phase [1,1,1] | [1,0,0]
- -- **'MappingBackground'** - Property for if the satellite image should be displayed in the background. Note, this only works if the coordinates are in latitude/longitude values or if initCoordConversion was performed. 'on' | {'off'}
- -- **'BusName'** - Property for the name of the bus (string) that the circuit should be plotted to. Only the direct line between the bus and the substation will be plotted, unless all buses are selected. {'all'} | busName
- -- **'Downstream'** - If a BusName is given, all buses in the electrical path to the substation (upstream) will be plotted, and if this property is on, all buses in the electrical path downstream of BusName will be plotted too 'on' | {'off'}

Outputs

- **none -** a figure of the circuit is displayed based on the option inputs

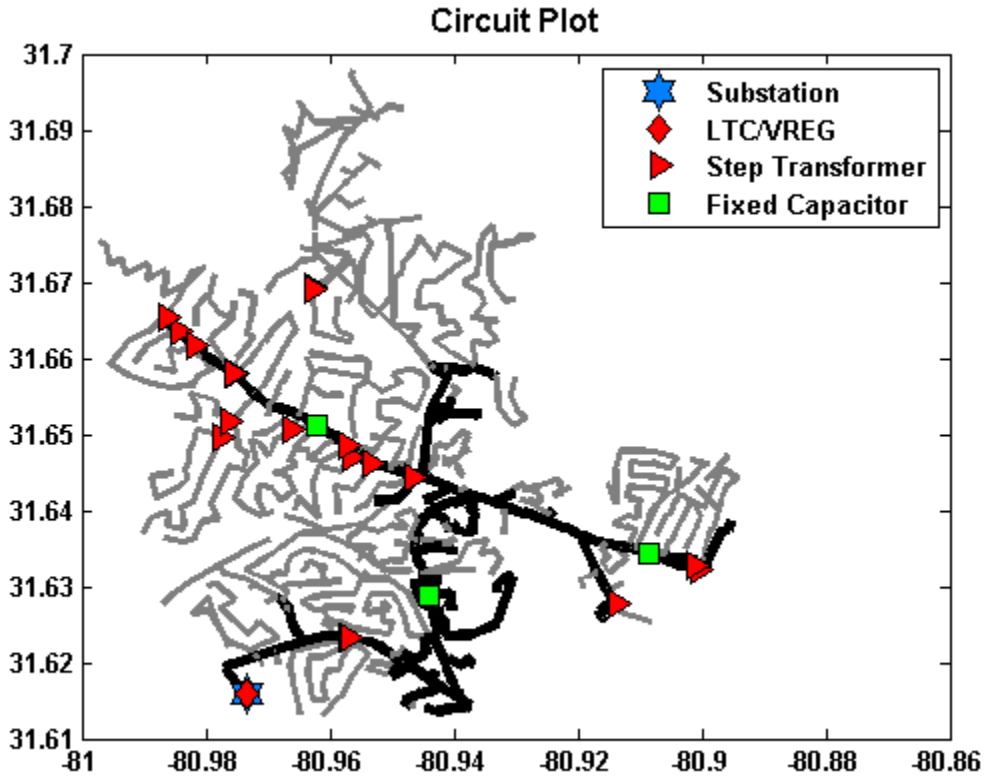
Notes

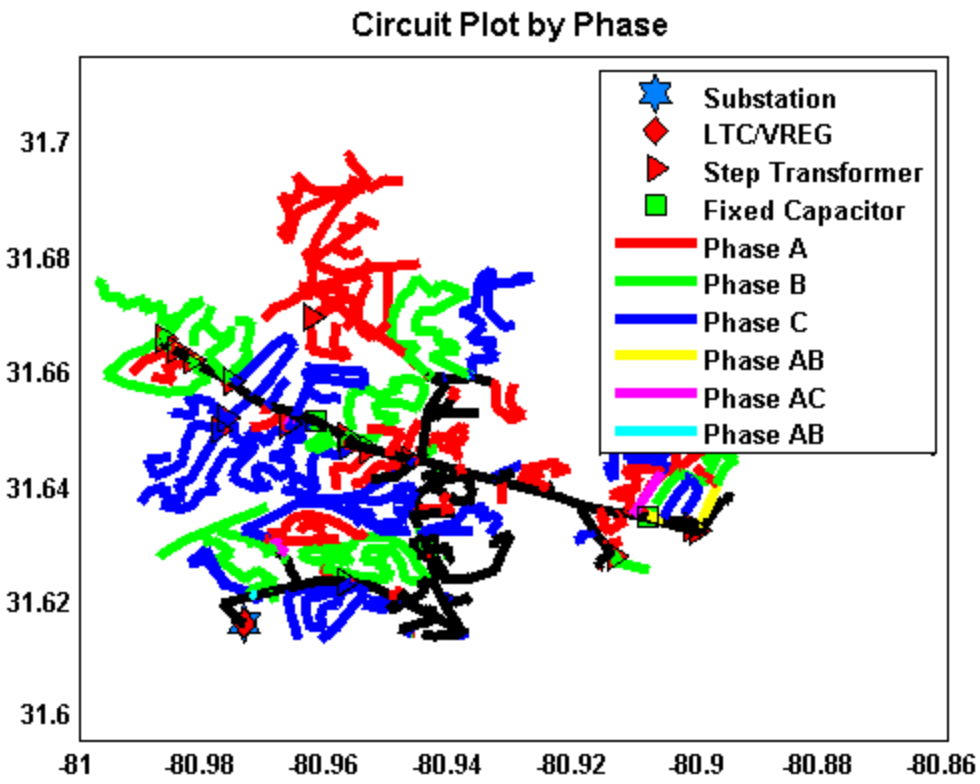
For the right-click visualizations, the AllowForms field of DSSCircObj must be set to 1, which is the default value. Currently, OpenDSS 7.6.3 (the current version as of this writing) does not allow for setting the AllowForms field back to 1 after setting it to 0.

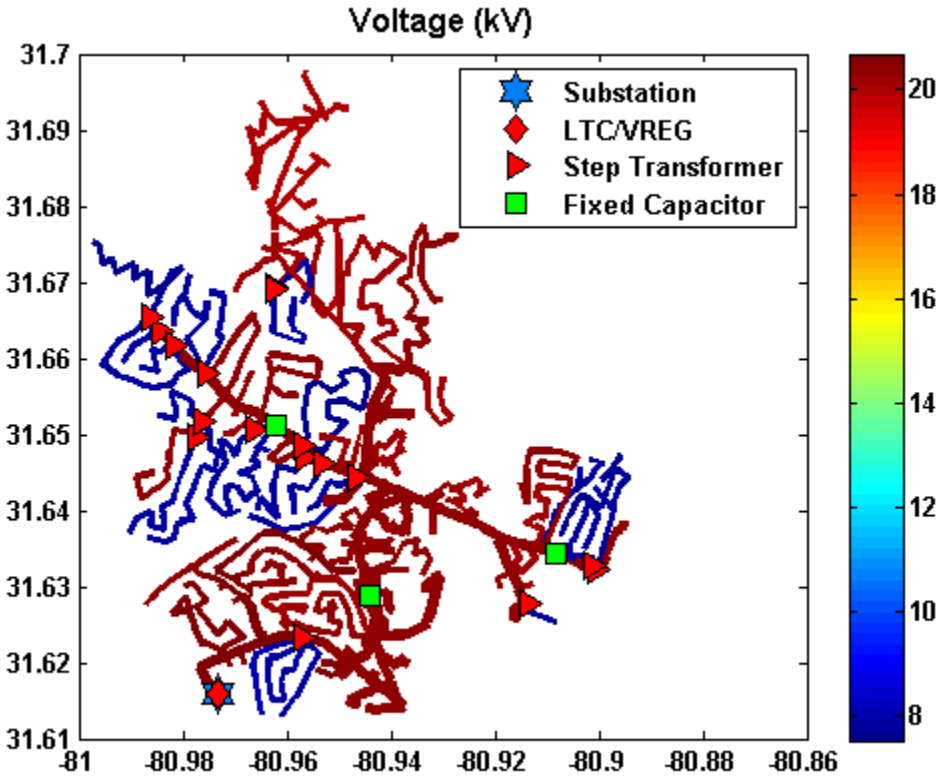
Example

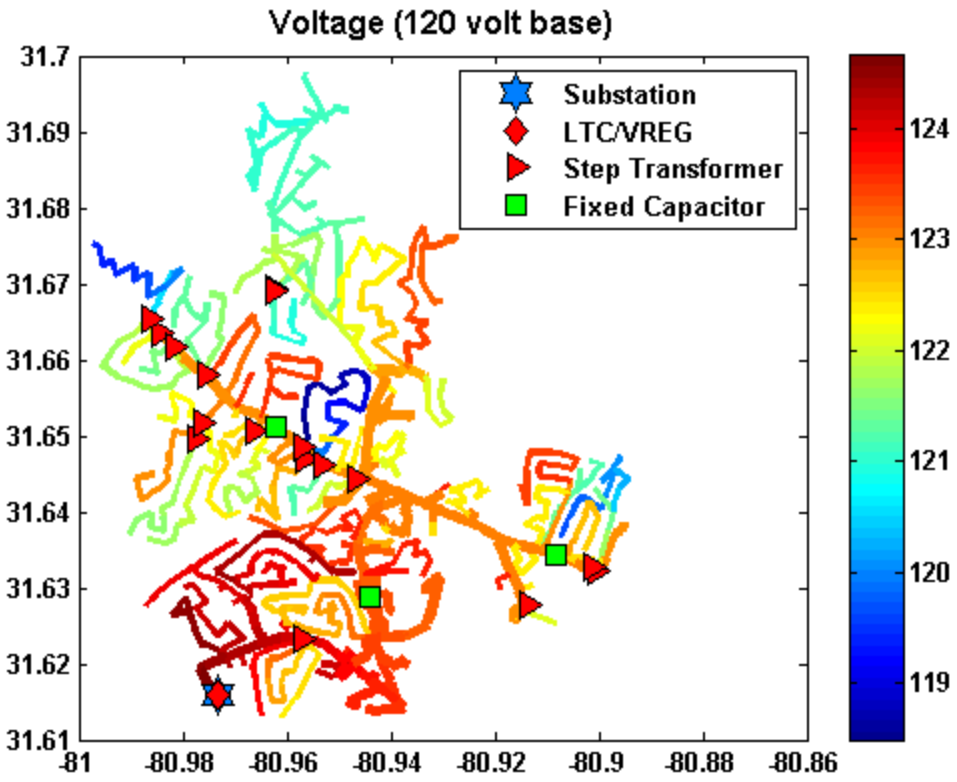
Examples of several different circuit plots that can be created

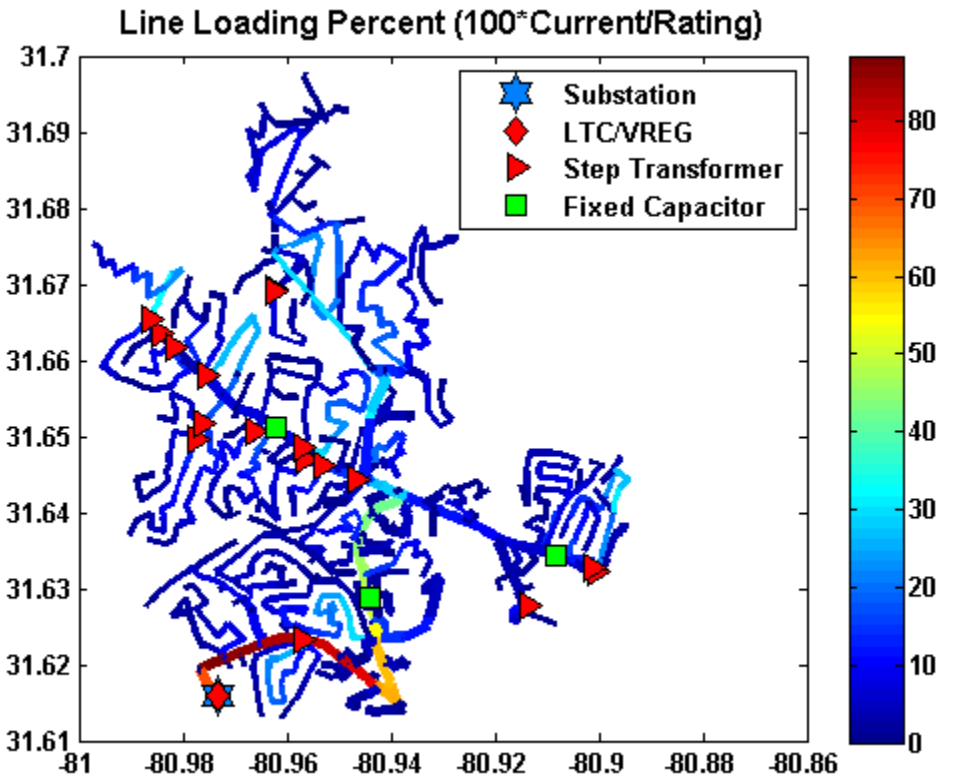
```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
figure; plotCircuitLines(DSSCircObj,'CapacitorMarker','on')
figure;
plotCircuitLines(DSSCircObj,'Coloring','PerPhase','Thickness',3,'MappingBackground','on')
figure; plotCircuitLines(DSSCircObj,'Coloring','voltage')
figure; plotCircuitLines(DSSCircObj,'Coloring','voltage120')
figure; plotCircuitLines(DSSCircObj,'Coloring','lineLoading')
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\Ckt24_PV_Central_7_5.dss"'];
DSSText.command = 'solve';
figure; plotCircuitLines(DSSCircObj,'Coloring','voltage120')
```

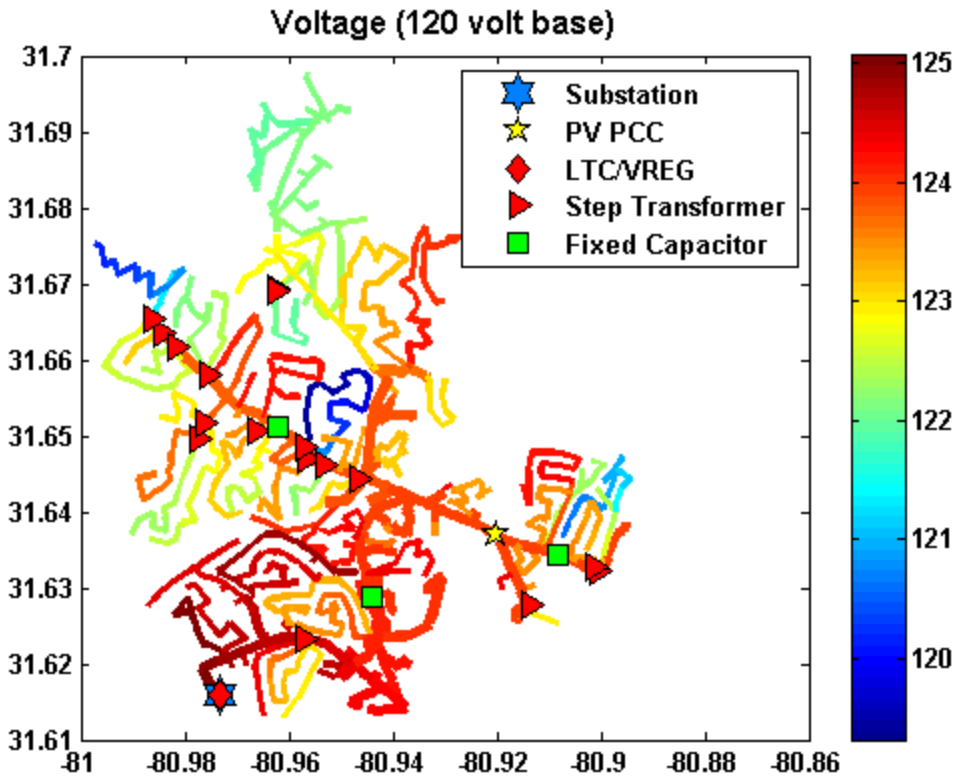



Circuit Plot by Phase
Substation
LTC/VREG
Step Transformer
Fixed Capacitor
Phase A
Phase B
Phase C
Phase AB
Phase AC
Phase AB
31.7
31.68
31.66
31.64
31.62
31.6
-81
-80.98
-80.96
-80.94
-80.92
-80.9
-80.88
-80.86


Voltage (kV)
Substation
LTC/VREG
Step Transformer
Fixed Capacitor
31.7
31.69
31.68
31.67
31.66
31.65
31.64
31.63
31.62
31.61
-81
-80.98
-80.96
-80.94
-80.92
-80.9
-80.88
-80.86
20
18
16
14
12
10
8


Voltage (120 volt base)
Substation
LTC/VREG
Step Transformer
Fixed Capacitor
31.7
31.69
31.68
31.67
31.66
31.65
31.64
31.63
31.62
31.61
-81
-80.98
-80.96
-80.94
-80.92
-80.9
-80.88
-80.86
124
123
122
121
120
119


Line Loading Percent (100*Current/Rating)
Substation
LTC/VREG
Step Transformer
Fixed Capacitor
31.7
31.69
31.68
31.67
31.66
31.65
31.64
31.63
31.62
31.61
-81
-80.98
-80.96
-80.94
-80.92
-80.9
-80.88
-80.86
80
70
60
50
40
30
20
10
0


Voltage (120 volt base)
Substation
PV PCC
LTC/VREG
Step Transformer
Fixed Capacitor
31.7
31.69
31.68
31.67
31.66
31.65
31.64
31.63
31.62
31.61
-81
-80.98
-80.96
-80.94
-80.92
-80.9
-80.88
-80.86
125
124
123
122
121
120

7.3.3. plotCircuitLinesOptions

GUI for providing options for how to plot the feeder circuit diagram

Syntax

```
plotCircuitLinesOptions(DSSCircObj);
```

Description

plotCircuitLines plots the feeder circuit diagram and has many different input argument parameters for changing coloring, line thickness, background, etc. This function provides a GUI for selecting the plotting styles for plotCircuitLines instead of through text arguments. This function can be called directly with the OpenDSS circuit object, or plotCircuitLines.m will call this function if no input arguments were selected.

Inputs

- **`DSSCircObj`** - link to OpenDSS active circuit and command text (from DSSStartup)

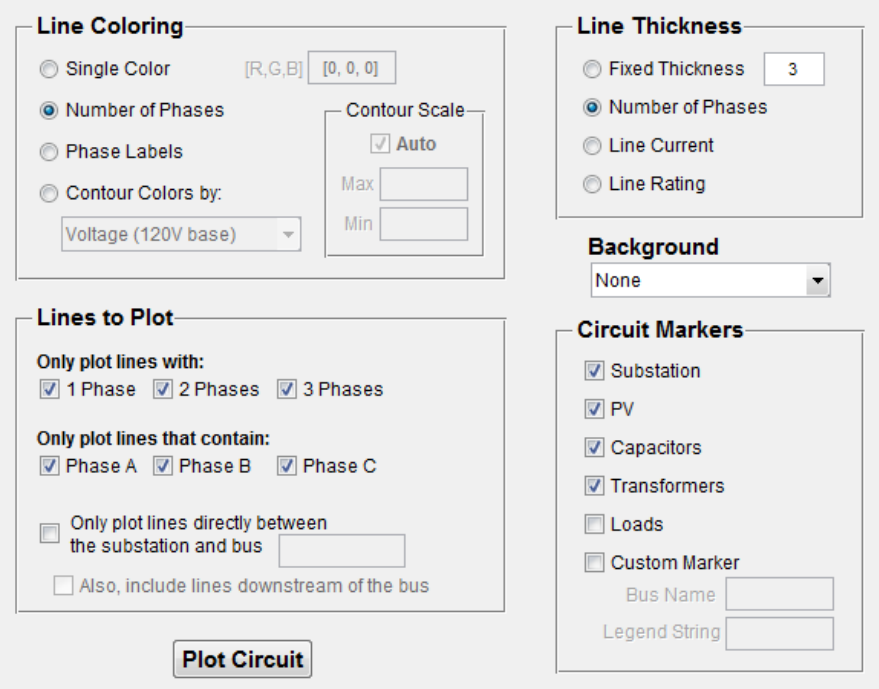
Outputs

- **none** - a figure of the circuit is displayed based on the option inputs

Example

Examples of calling the GUI for plotCircuitLinesOptions

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
figure; plotCircuitLinesOptions(DSSCircObj)
```



7.3.4. plotKVARProfile

Plots the feeder profile for the kVAR power flow on the lines

Syntax

```
plotKVARProfile(DSSCircObj);
plotKVARProfile(DSSCircObj, _'PropertyName'_ ,PropertyValue);
```

Description

Function to plot the feeder profile for the kVAR power flow on the lines. This is the kVAR power vs. distance from the substation graph. Clicking on objects in the figure will display the name of the object, and right clicking will give a menu for viewing properties of the object.

Inputs

- `DSSCircObj` - link to OpenDSS active circuit and command text (from DSSStartup)
- `Properties` - optional properties as one or more name-value pairs in any order
- -- `'Only3Phase'` - Property for if only 3-phase power lines should be plotted `'on' | {'off'}`
- -- `'AveragePhase'` - Property for if the average power should be plotted alone or in addition to the phase plots `'on' | {'off'} | 'addition'`
- -- `'BusName'` - Property for the name of the bus (string) that the kVAR profile should be plotted to. Only the direct line between the bus and the substation will be plotted, unless all buses are selected. `{'all'} | busName`
- -- `'Downstream'` - If a BusName is given, all buses in the electrical path to the substation (upstream) will be plotted, and if this property is on, all buses in the electrical path downstream of BusName will be plotted too `'on' | {'off'}`
- -- `'PVMarker'` - Property for if the PV PCC should be marked (if it exists) `{'on'} | 'off'`

Outputs

- **none** - a figure is displayed with the plot

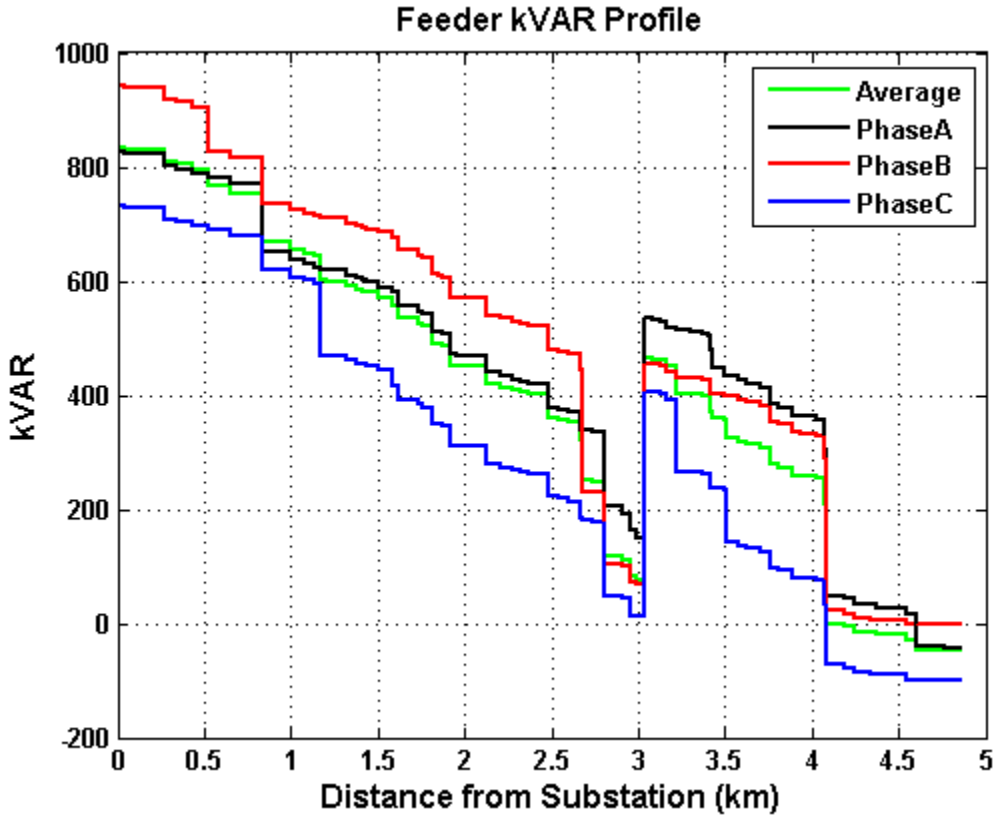
Notes

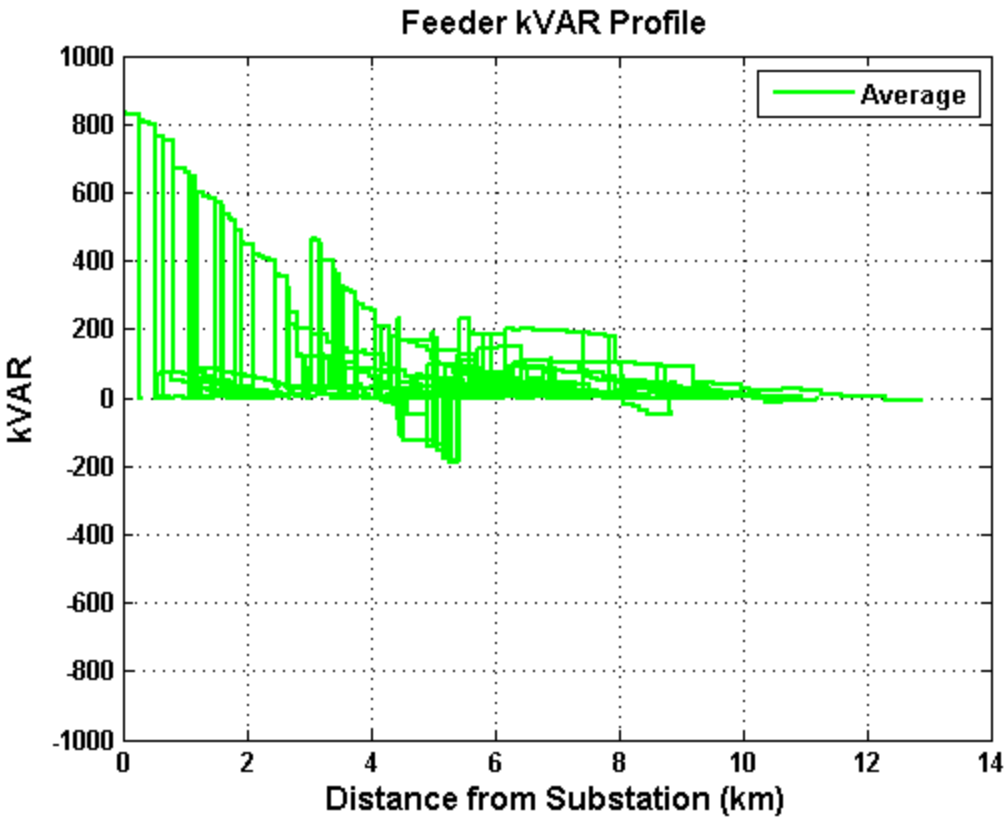
For the right-click visualizations, the AllowForms field of DSSCircObj must be set to 1, which is the default value. Currently, OpenDSS 7.6.3 (the current version as of this writing) does not allow for setting the AllowForms field back to 1 after setting it to 0.

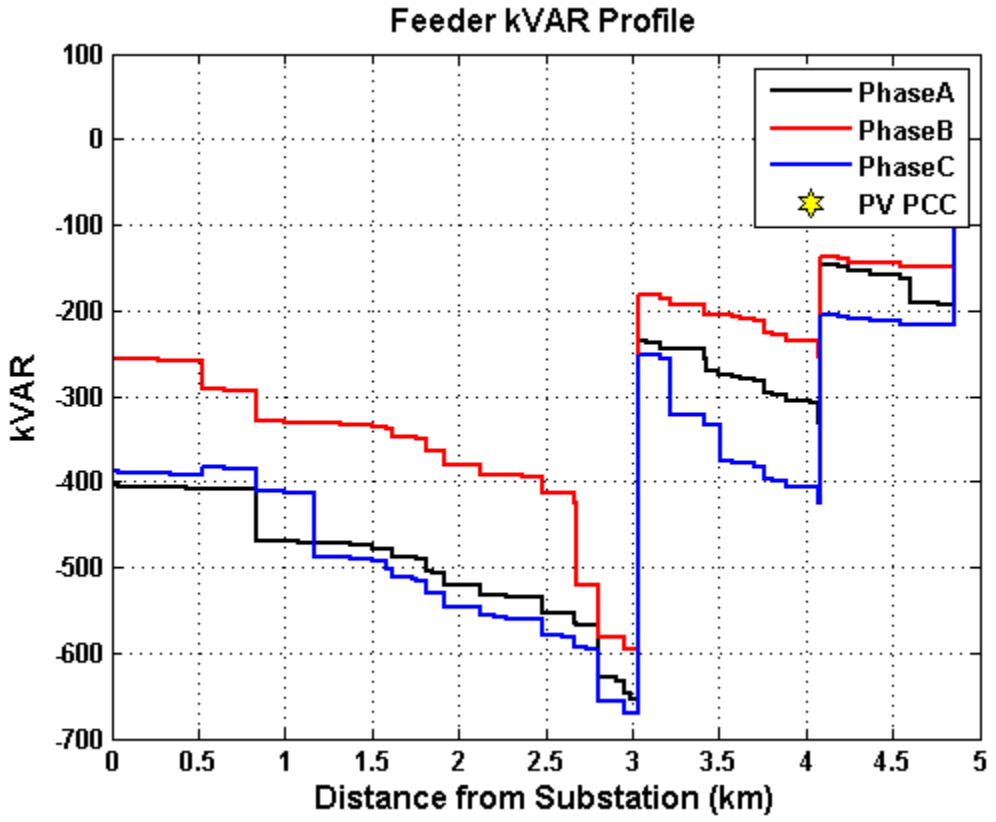
Example

Example of a feeder kVAR profile plot

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
figure; plotKVARProfile(DSSCircObj,'AveragePhase','addition','BusName','N3OO558');
figure; plotKVARProfile(DSSCircObj,'AveragePhase','on');
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\Ckt24_PV_Central_7_5.dss"'];
DSSText.command = 'Set mode=duty number=1  hour=12  h=1 sec=0';
DSSText.command = 'Set controlmode=static';
DSSText.command = 'solve';
figure; plotKVARProfile(DSSCircObj,'BusName','N3OO558')
```




Feeder kVAR Profile
Average
kVAR
Distance from Substation (km)
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
0
2
4
6
8
10
12
14


Feeder kVAR Profile
PhaseA
PhaseB
PhaseC
PV PCC
kVAR
Distance from Substation (km)
100
0
-100
-200
-300
-400
-500
-600
-700
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

7.3.5. plotKWProfile

Plots the feeder profile for the kW power flow on the lines

Syntax

```
plotKWProfile(DSSCircObj);
plotKWProfile(DSSCircObj, _'PropertyName'_ ,PropertyValue);
```

Description

Function to plot the feeder profile for the kW power flow on the lines. This is the kW power vs. distance from the substation graph. Clicking on objects in the figure will display the name of the object, and right clicking will give a menu for viewing properties of the object.

Inputs

- `DSSCircObj` - link to OpenDSS active circuit and command text (from DSSStartup)
- `Properties` - optional properties as one or more name-value pairs in any order
- -- `'Only3Phase'` - Property for if only 3-phase power lines should be plotted `'on' | {'off'}`
- -- `'AveragePhase'` - Property for if the average power should be plotted alone or in addition to the phase plots `'on' | {'off'} | 'addition'`
- -- `'BusName'` - Property for the name of the bus (string) that the kW profile should be plotted to. Only the direct line between the bus and the substation will be plotted, unless all buses are selected. `{'all'} | busName`
- -- `'Downstream'` - If a BusName is given, all buses in the electrical path to the substation (upstream) will be plotted, and if this property is on, all buses in the electrical path downstream of BusName will be plotted too `'on' | {'off'}`
- -- `'PVMarker'` - Property for if the PV PCC should be marked (if it exists) `{'on'} | 'off'`

Outputs

- **none** - a figure is displayed with the plot

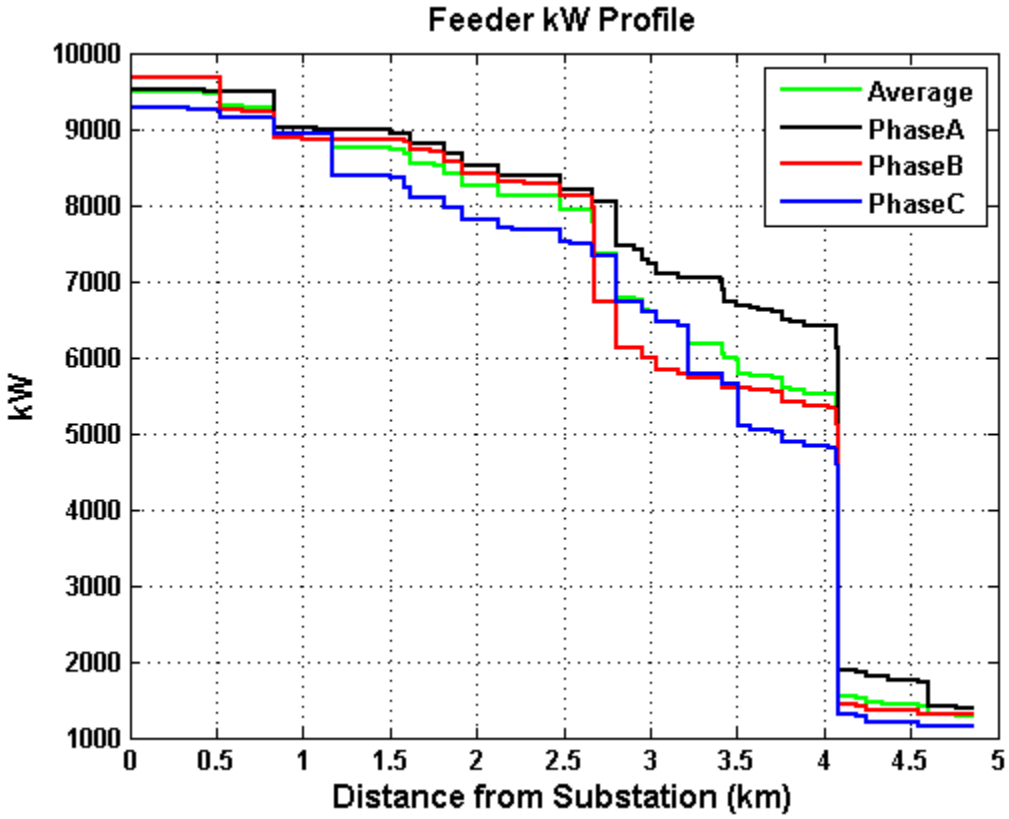
Notes

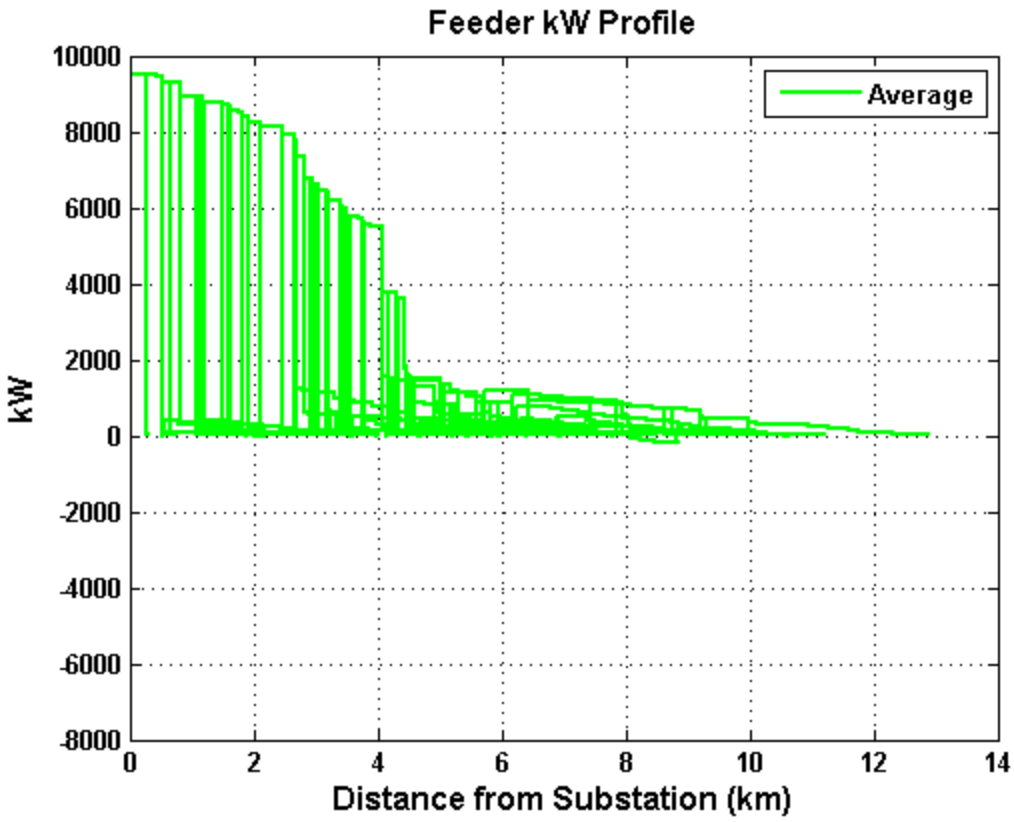
For the right-click visualizations, the AllowForms field of DSSCircObj must be set to 1, which is the default value. Currently, OpenDSS 7.6.3 (the current version as of this writing) does not allow for setting the AllowForms field back to 1 after setting it to 0.

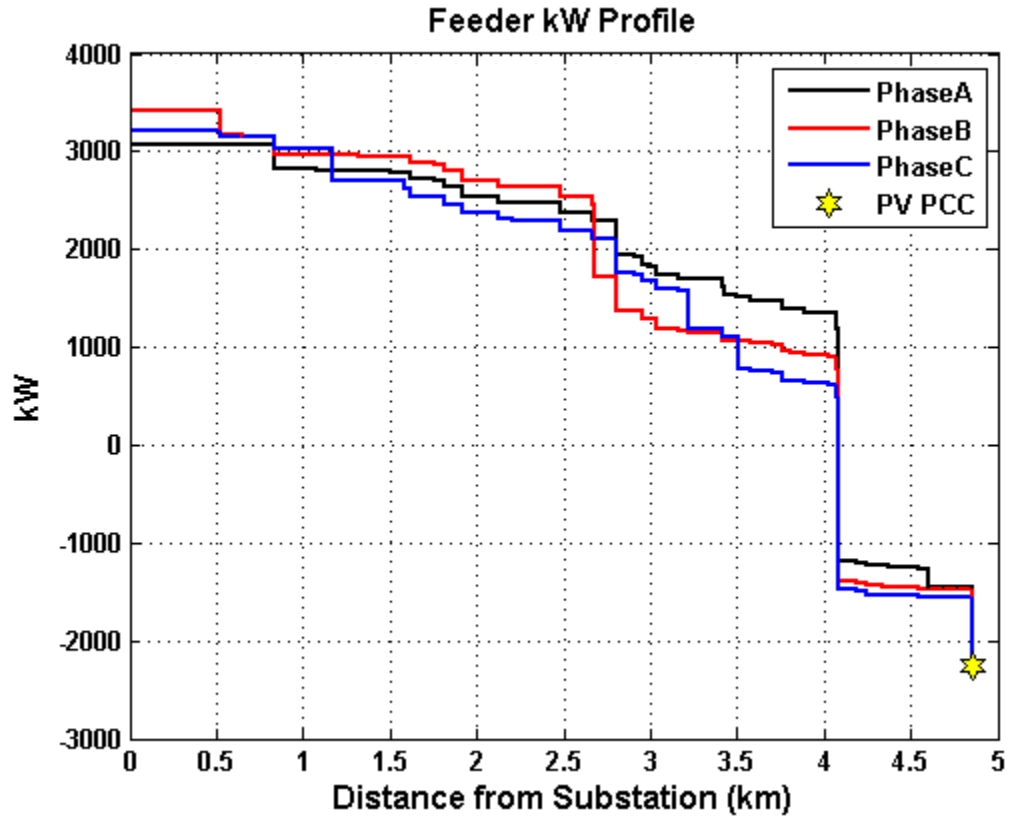
Example

Example of a feeder kW profile plot

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
figure; plotKWProfile(DSSCircObj,'AveragePhase','addition','BusName','N3OO558');
figure; plotKWProfile(DSSCircObj,'AveragePhase','on');
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\Ckt24_PV_Central_7_5.dss"'];
DSSText.command = 'Set mode=duty number=1  hour=12  h=1 sec=0';
DSSText.command = 'Set controlmode=static';
DSSText.command = 'solve';
figure; plotKWProfile(DSSCircObj,'BusName','N3OO558')
```




Feeder kW Profile
Average
kW
Distance from Substation (km)
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
0
2
4
6
8
10
12
14


Feeder kW Profile
PhaseA
PhaseB
PhaseC
PV PCC
kW
Distance from Substation (km)
4000
3000
2000
1000
0
-1000
-2000
-3000
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

7.3.6. plotMonitor

Plots a monitor from the simulation

Syntax

```
plotMonitor(DSSCircObj,monitorName);
```

Description

Function to plot simulation results saved in an OpenDSS monitor

Inputs

- **`DSSCircObj`** - link to OpenDSS active circuit and command text (from DSSStartup)
- **`monitorName`** - string with the name of the OpenDSS monitor

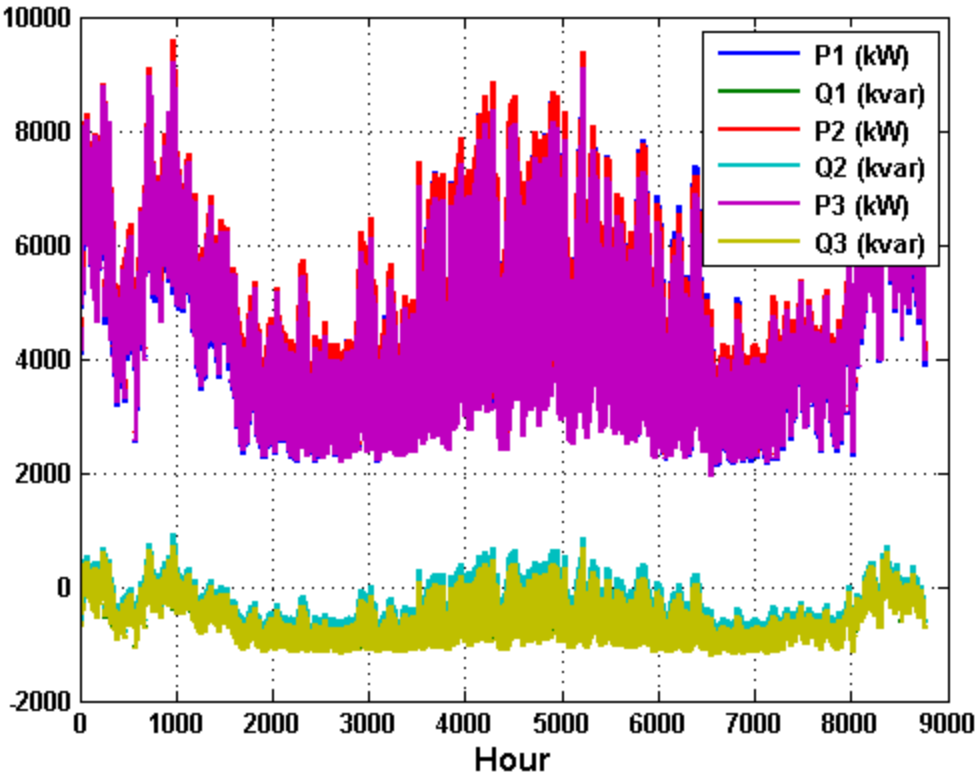
Outputs

- **none** - a figure is displayed with the plot

Example

Example of a feeder power monitor plot

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'Set mode=duty number=8760  hour=0  h=1h sec=0';
DSSText.command = 'Set controlmode = time';
DSSText.command = 'solve';
plotMonitor(DSSCircObj,'fdr_05410_Mon_PQ')
```



7.3.7. plotVoltageProfile

Plots the voltage profile for the feeder (spider plot)

Syntax

```
plotVoltageProfile(DSSCircObj);
plotVoltageProfile(DSSCircObj, _'PropertyName'_ ,PropertyValue);
```

Description

Function to plot the voltage profile for the feeder. This is the bus voltage vs. distance from the substation plot. Also called a spider plot. Clicking on objects in the figure will display the name of the object, and right clicking will give a menu for viewing properties of the object.

Inputs

- `DSSCircObj` - link to OpenDSS active circuit and command text (from DSSStartup)
- `Properties` - optional properties as one or more name-value pairs in any order
- -- `'SecondarySystem'` - Property for if the secondary system should be plotted (if it exists) `{'on'} | 'off'`
- -- `'Only3Phase'` - Property for if only 3-phase power lines should be plotted `'on' | {'off'}`
- -- `'AveragePhase'` - Property for if the average voltage should be plotted alone or in addition to the phase plots `'on' | {'off'} | 'addition'`
- -- `'BusName'` - Property for the name of the bus (string) that the voltage profile should be plotted to. Only the direct line between the bus and the substation will be plotted, unless all buses are selected. `{'all'} | busName`
- -- `'Downstream'` - If a BusName is given, all buses in the electrical path to the substation (upstream) will be plotted, and if this property is on, all buses in the electrical path downstream of BusName will be plotted too `'on' | {'off'}`

Outputs

- **none** - a figure is displayed with the plot

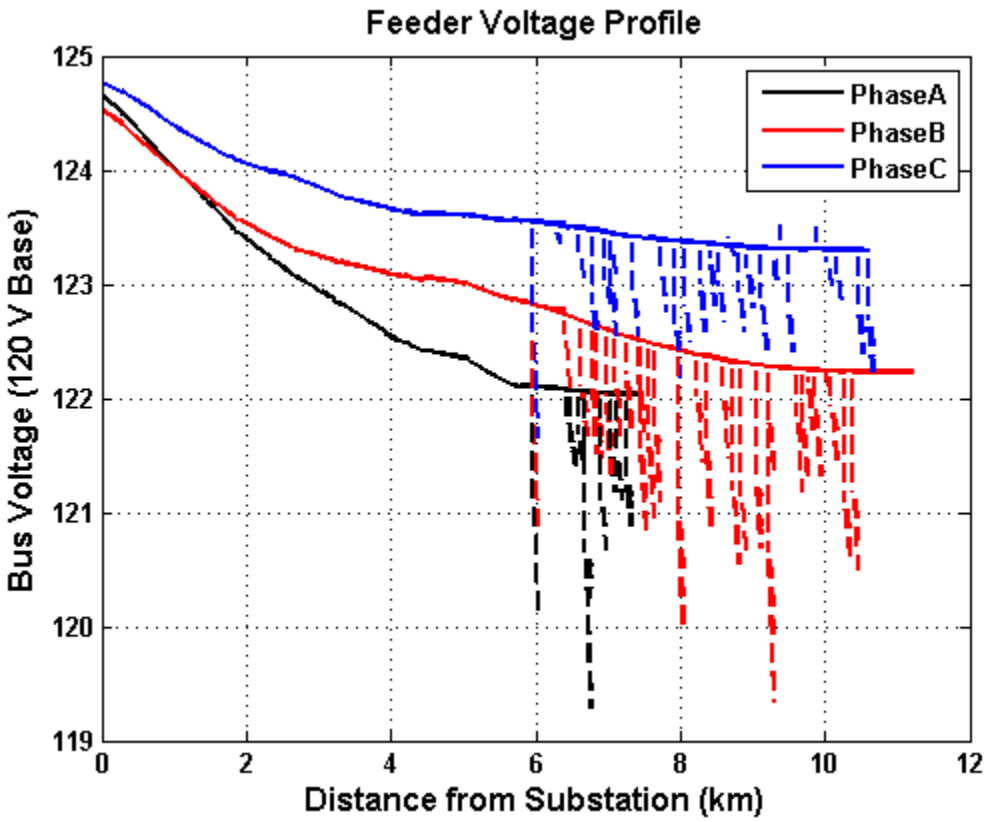
Notes

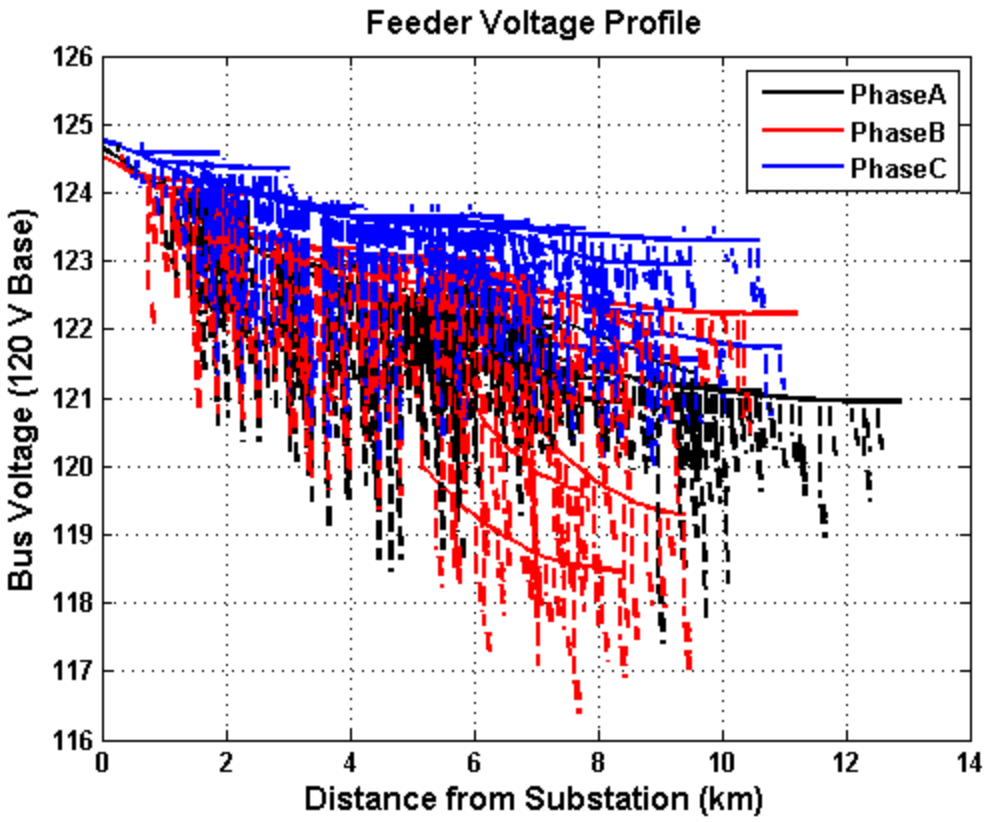
For the right-click visualizations, the AllowForms field of DSSCircObj must be set to 1, which is the default value. Currently, OpenDSS 7.6.3 (the current version as of this writing) does not allow for setting the AllowForms field back to 1 after setting it to 0.

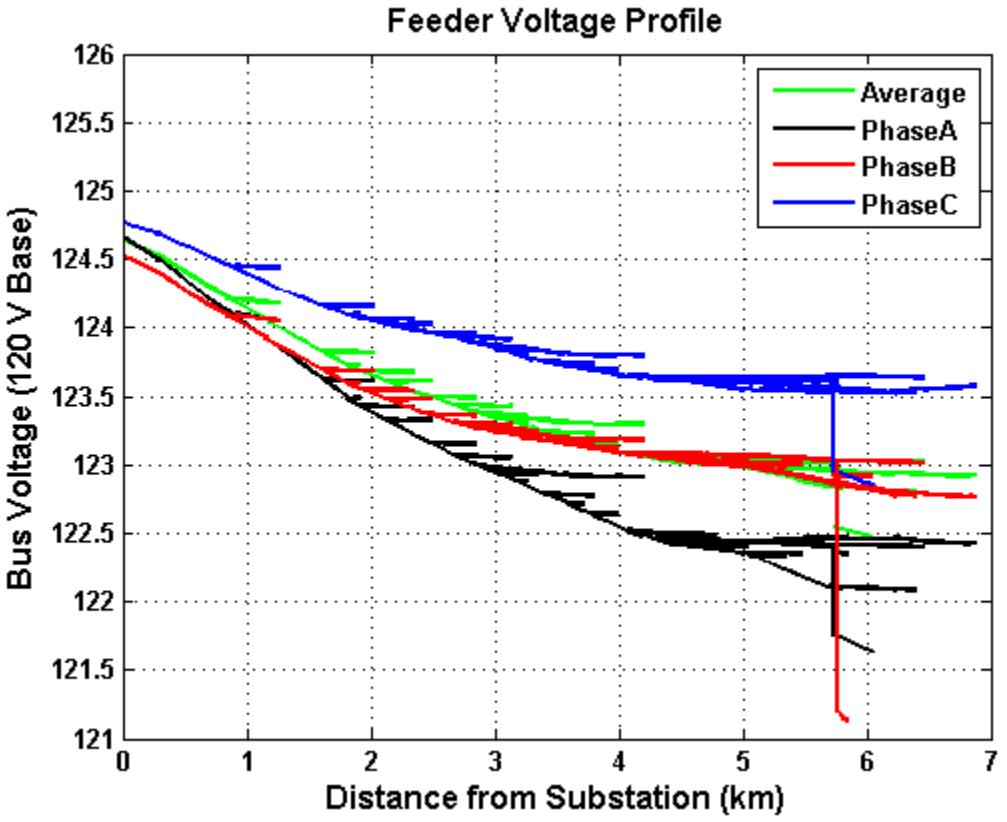
Example

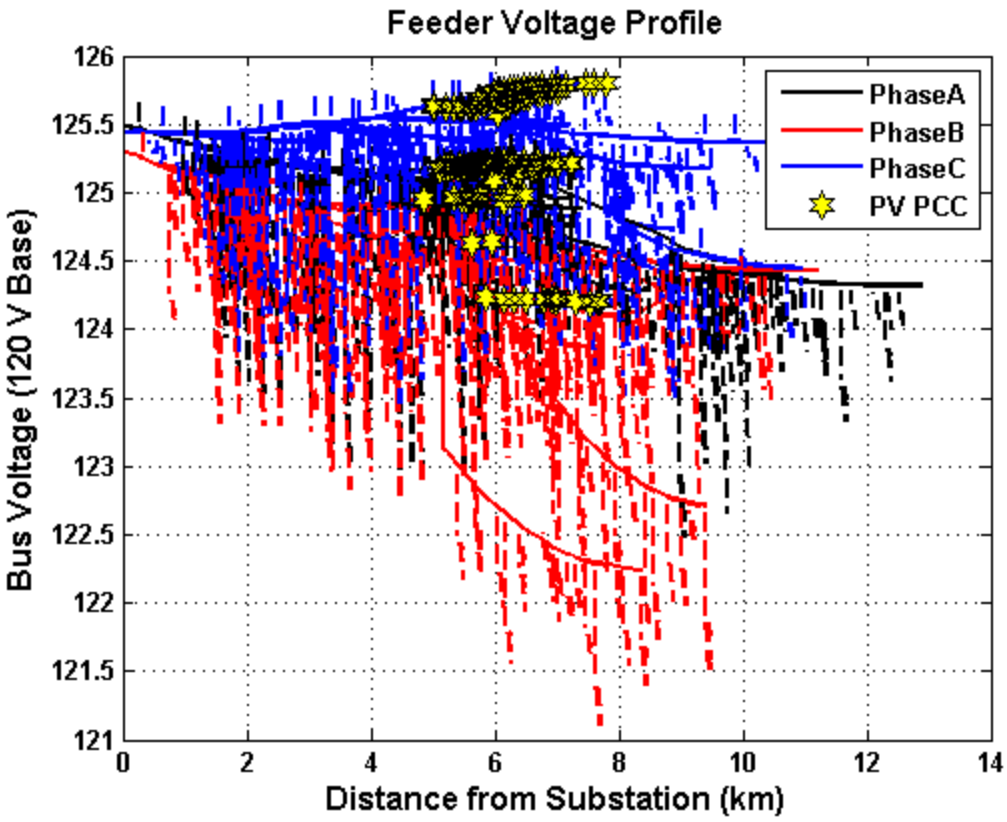
Example of a feeder voltage profile plot

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\master_Ckt24.dss"'];
DSSText.command = 'solve';
figure; plotVoltageProfile(DSSCircObj,'BusName','N292743','Downstream','on');
figure; plotVoltageProfile(DSSCircObj)
figure;
plotVoltageProfile(DSSCircObj,'SecondarySystem','off','AveragePhase','addition','Only3Phase','
on')
DSSText.command = ['Compile "' gridpvPath 'ExampleCircuit\Ckt24_PV_Distributed_7_5.dss"'];
DSSText.command = 'Set mode=duty number=1  hour=12  h=1 sec=0';
DSSText.command = 'Set controlmode=static';
DSSText.command = 'solve';
figure; plotVoltageProfile(DSSCircObj)
```




Feeder Voltage Profile
PhaseA
PhaseB
PhaseC
Bus Voltage (120 V Base)
Distance from Substation (km)
126
125
124
123
122
121
120
119
118
117
116
0
2
4
6
8
10
12
14

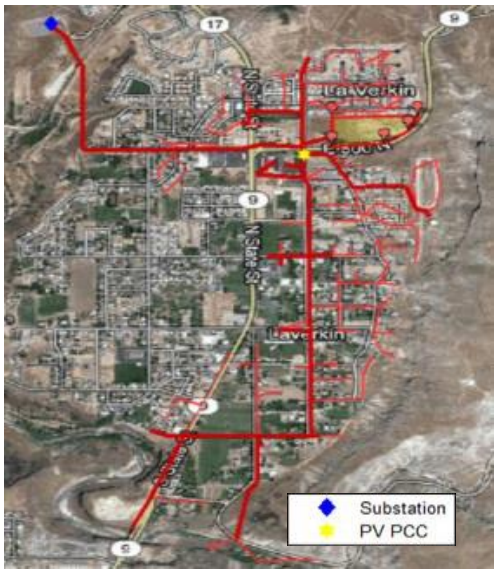

Feeder Voltage Profile
Average
PhaseA
PhaseB
PhaseC
Bus Voltage (120 V Base)
Distance from Substation (km)
126
125.5
125
124.5
124
123.5
123
122.5
122
121.5
121
0
1
2
3
4
5
6
7


Feeder Voltage Profile
Bus Voltage (120 V Base)
Distance from Substation (km)
PhaseA
PhaseB
PhaseC
PV PCC
126
125.5
125
124.5
124
123.5
123
122.5
122
121.5
121
0
2
4
6
8
10
12
14

7.4. GEOGRAPHIC MAPPING FUNCTIONS

If the OpenDSS feeder has geographical information, this can be used to map the feeder to the real world. The OpenDSS feeder coordinates are generally located in a file called "Buscoords.dss" and links each bus to an X and Y coordinate. This information comes from the utility's coordinate system, which can be UTM, a state coordinate system, or their own coordinates. If the conversion from the utility coordinate system is unknown, the createCircuitCoordConversion function tool can be used to visually match the feeder layout to satellite images.

With a known coordinate system, certain GIS or map plotting features are available in the toolbox to visualize the location of the distribution system power lines. Google Maps is used to display streets, location names, and satellite images. The API for Google Maps allows MATLAB to interact and download maps with location specific data, including elevation [11]. The figure displays an example distribution system demonstrating the GIS functionality [6].



Function List

initCoordConversion - Function to initialize the coordinate conversion process

createCircuitCoordConversion - Function to create conversion of circuit coordinates to GPS coordinates

createCircuitCoordConversionUTM - Function to create conversion of circuit coordinates in UTM to GPS coordinates

plot_google_map - Plots a Google map on the current axes using the Google Static Maps API

7.4.1. initCoordConversion

Function to initialize the coordinate conversion process

Syntax

```
initCoordConversion();
```

Description

Function to allow the user to pick between coordinate conversion methods: manual creation or UTM conversion.

Inputs

- **None**

Outputs

- **None**

Example

```
initCoordConversion();
```

7.4.2. createCircuitCoordConversion

Function to create conversion of circuit coordinates to GPS coordinates

Syntax

```
createCircuitCoordConversion();
```

Description

Function is a user interface to map the Google map and the circuit drawing on top of each other. The user aligns the two images and the conversion is created for getting GPS Lat/Lon for the OpenDSS bus coordinates. This is used when the OpenDSS coordinate system is unknown and not any standard coordinate systems like UTM.

Inputs

- **none**

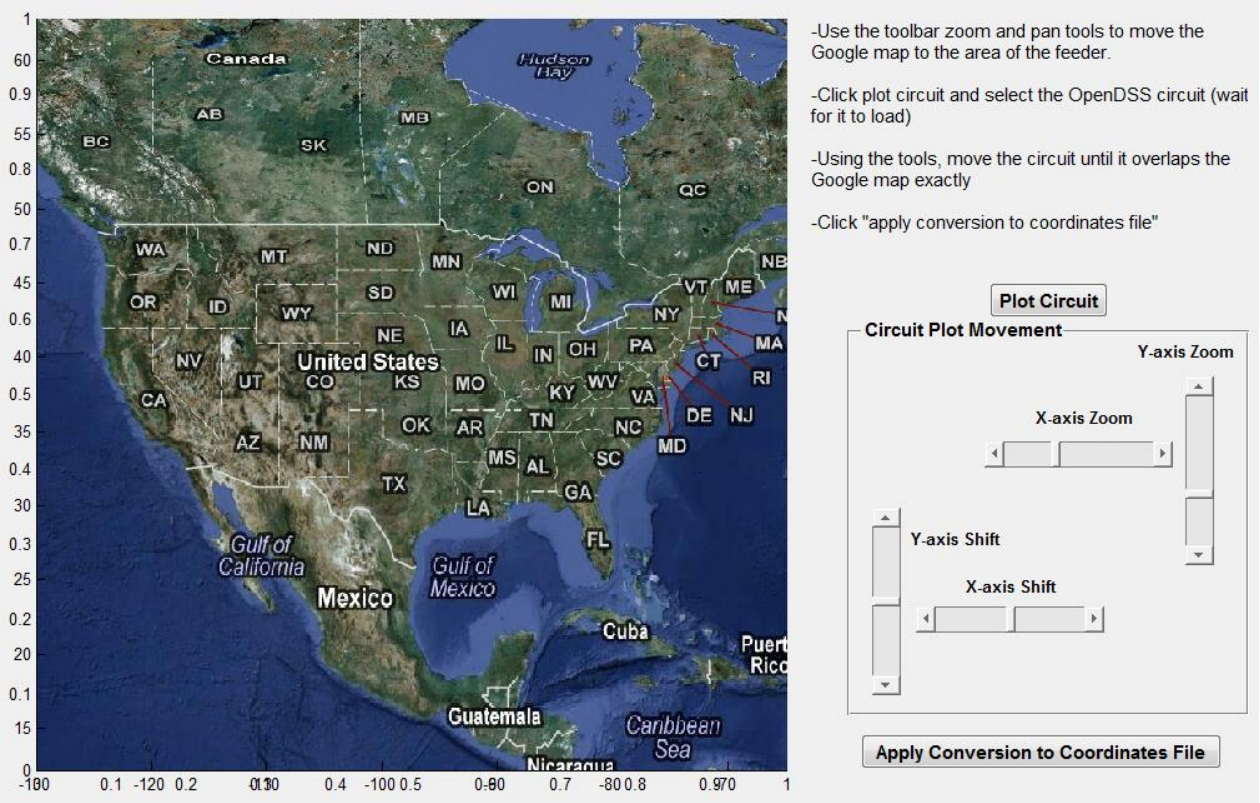
Outputs

- **none** - a Circuit Conversion file is saved for any future plotting

Example

Starts the user interface. Directions are in the interface.

```
createCircuitCoordConversion();
```



7.4.3. createCircuitCoordConversionUTM

Function to create conversion of circuit coordinates in UTM to GPS coordinates

Syntax

```
createCircuitCoordConversionUTM();
```

Description

Function is a user interface that allows the user to select the UTM zone the circuit coordinates are currently in. The conversion is created for getting GPS Lat/Lon for the OpenDSS bus coordinates and the new Lat/Lon OpenDSS buscoords are saved.

Inputs

- **none**

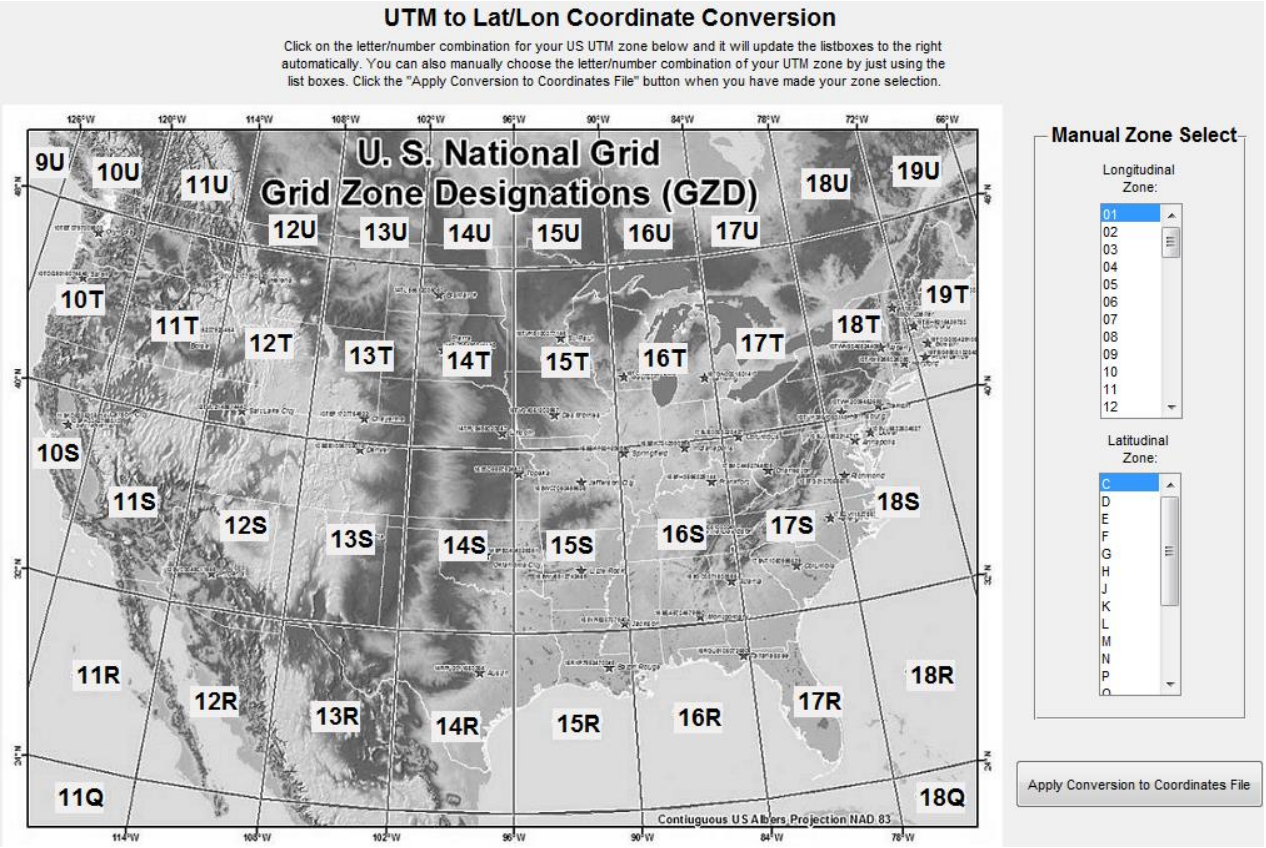
Outputs

- **none** - a Circuit Conversion file is saved for any future plotting

Example

Starts the user interface. Directions are in the interface.

```
createCircuitCoordConversionUTM();
```



7.4.4. plot google map

Plots a google map on the current axes using the Google Static Maps API

Syntax

```
h = plot_google_map(Property, Value,...);
[lonVec latVec imag] = plot_google_map(Property, Value,...);
```

Description

Plots the google map on the current axes given the input properties selected

Inputs

- `Property` - property name from the list below along with the
- `Value` for the property. The default for each porperty is in parenthesis.
- `-- 'Height' (640)` - Height of the image in pixels (max 640)
- `-- 'Width' (640)` - Width of the image in pixels (max 640)
- `-- 'Scale' (2)` - (1/2) Resolution scale factor . using Scale=2 will double the resolution of the downloaded image (up to 1280x1280) and will result in finer rendering, but processing time will be longer.
- `-- 'MapType'` - ('roadmap') Type of map to return. Any of [roadmap, satellite, terrain, hybrid) See the Google Maps API for more information.
- `-- 'Alpha' (1)` - (0-1) Transparency level of the map (0 is fully transparent). While the map is always moved to the bottom of the plot (i.e. will not hide previously drawn items), this can be useful in order to increase readability if many colors are plotted (using SCATTER for example).
- `-- 'Marker'` - The marker argument is a text string with fields conforming to the Google Maps API. The following are valid examples: '43.0738740,-70.713993' (dflt midsize orange marker) '43.0738740,-70.713993,blue' (midsize blue marker) '43.0738740,-70.713993,yellowa' (midsize yellow marker with label "A") '43.0738740,-70.713993,tinyredb' (tiny red marker with label "B")
- `-- 'Refresh' (1)` - (0/1) defines whether to automatically refresh the map upon zoom action on the figure.
- `-- 'AutoAxis' (1)` - (0/1) defines whether to automatically adjust the axis of the plot to avoid the map being stretched. This will adjust the span to be correct only if the figure window is square. If the figure window is rectangular, it will still appear somewhat stretched.
- `-- 'APIKey'` - (string) set your own API key which you obtained from Google: http://developers.google.com/maps/documentation/staticmaps/#api_key This will enable up to 25,000 map requests per day, compared to 400 requests without a key. To set the key, use: plot_google_map('APIKey','SomeLongStringObtaindFromGoogle') To disable the use of a key, use: plot_google_map('APIKey','')

Outputs

- `h` - Handle to the plotted map
- `lonVect` - Vector of Longidute coordinates (WGS84) of the image
- `latVect` - Vector of Latidute coordinates (WGS84) of the image
- `imag` - Image matrix (height,width,3) of the map

References:

http://www.mathworks.com/MATLABcentral/fileexchange/24113
http://www.maptiler.org/google-maps-coordinates-tile-bounds-projection/
http://developers.google.com/maps/documentation/staticmaps/

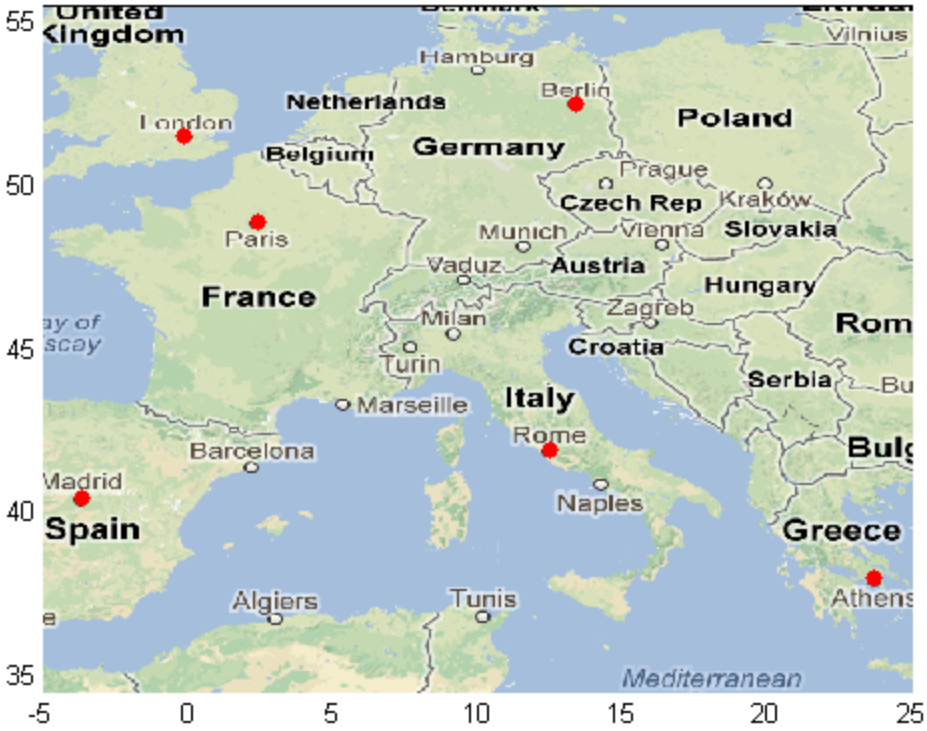
```
Acknowledgement to Val Schmidt for his submission of get_google_map.m
Author: Zohar Bar-Yehuda
```

Copyright

Example

Plot a map showing some capitals in Europe:

```
lat = [48.8708   51.5188   41.9260   40.4312   52.523   37.982];
lon = [2.4131    -0.1300    12.4951   -3.6788    13.415   23.715];
plot(lon,lat,'.r','MarkerSize',20)
plot_google_map
```


55
50
45
40
35
-5
0
5
10
15
20
25
Hamburg
Berlin
Vilnius
Netherlands
London
Poland
Belgium
Germany
Prague
Czech Rep
Kraków
Paris
Munich
Vienna
Slovakia
Vaduz
Austria
Hungary
France
Zagreb
Milan
Croatia
Turin
Serbia
Marseille
Italy
Rome
Barcelona
Madrid
Naples
Spain
Greece
Algiers
Tunis
Athens
Mediterranean

7.5. SOLAR MODELING FUNCTIONS

Simulating the impact of solar on the distribution system requires an accurate timeseries of PV plant power output. The OpenDSS model is used to model the feeder and the loads, but MATLAB is used to setup the PV plant model. The process of modeling solar plant output begins with measured irradiance data. Generally, a specific day or time of year is used for simulation. The IneichenClearSkyModel function can be used to generate a Global Horizontal Irradiance time-series for a clear day for any location and dates to simulate the maximum output from PV on the system each day [12]. Another method would be to identify a highly variable day from measured irradiance data to simulate the impact of PV variability [13].

To simulate a PV plant from irradiance data, the PV plant information is setup using the user interface in the placePVplant function. The interface allows the user to draw the location of a PV plant directly on the Google map and feeder layout. The drawn PV plant is used for smoothing the plant variability using the Wavelet Variability Model (WVM) [14-16]. There are also several options for controlling the power factor of the PV output, such as a power factor schedule, power factor function of output, and volt/var control [17, 18]. The function createPVscenarioFiles will run the WVM model and create the OpenDSS solar scenario case files with the correct loadshape for solar output and PV generators placed on the correct bus locations.

Function List

placePVplant - Draw PV on the circuit diagram and save plant info for WVM input
createPVscenarioFiles - Runs the WVM model and puts out the OpenDSS PV scenario files
distributePV - Allocates PV based off of the load transformer size (kva)
findMaxPenetrationTime - Finds the max penetration time
IneichenClearSkyModel - Generates the clear sky irradiance using Ineichen and Perez model
makePFoutputFunction - GUI for creating power factor as a function of PV power output
makePFprofile - Creates varying Power Factor profile by schedule or PV output
makePFschedule - GUI for creating a power factor daily schedule
makeVVCcurve - GUI for setting up the OpenDSS VVControl function parameters
WVM - WVM Wavelet Variability Model

7.5.1. placePVplant

Draw PV on the circuit diagram and save plant info for WVM input

Syntax
```
placePVplant()
```

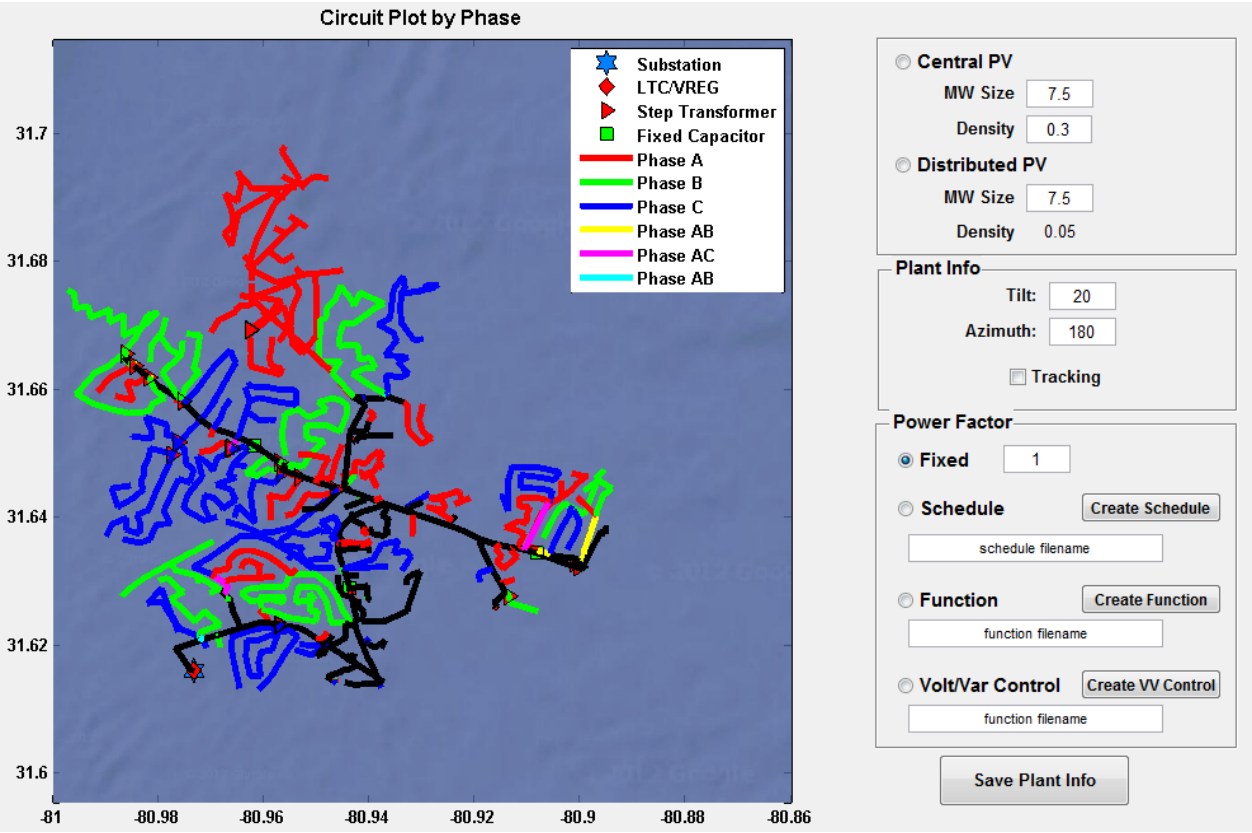
Description
This function is a user interface where the PV plant can be drawn on the circuit diagram. The user will setup all the PV plant info and save it to a file for running WVM.

Inputs
- **none**

Outputs
- **none** saves a *.mat file with the structure plantinfo for input to WVM

Example
Showing the user interface:

```
placePVplant()
```



7.5.2. createPVscenarioFiles

Runs the WVM model and puts out the OpenDSS PV scenario files

Syntax

```
index =
createPVscenarioFiles(plantInfoFile,irradianceFile,A_value,circuitFile);
index = createPVscenarioFiles();
```

Description

Function to load in the inputs to the WVM (plant info and irradiance sensor info), run WVM, create the loadshape file, and the solar scenario OpenDSS file.

Inputs

- `plantInfoFile` - optional input with the link to the MAT file with the require PV plant information structure for WVM (see WVM.m and placePVplant.m)
- `irradianceFile` - optional input with the link to the MAT file with the require irradiance sensor information structure for WVM (see WVM.m)
- `A_value` - optional input with A value for WVM
- `circuitFile` - optional input with the link to the file with the OpenDSS circuit

Outputs

- **none** - outputs both a .txt loadshape file and a .dss solar scenario OpenDSS file

Example

Example run of createPVscenarioFiles

```
createPVscenarioFiles('./ExampleCircuit/Ckt24_PV_Central_7_5.mat','./Subfunctions/WVM_subfunct
ions/Example_Alamosa_2011_8_21_IrradSensor.mat',1.5392,'.\ExampleCircuit\Run_Ckt24.dss');
```

7.5.3. distributePV

Allocates PV based off of the load transformer size (kva)

Syntax

```
distributePV(totalPVSize,area)
```

Description

Allocates distributed PV spread out around a designated area. PV is placed at each transformer in the area based off of the load transformer size (kva)

Inputs

- `totalPVSize` - total size of the distributed PV system in kW
- `area` - matrix of vertices defining the area to distribute the PV inside, 1 row per vertex with [X,Y]

Outputs

- text file allocatedPV.txt with the text to be copy and pasted in an OpenDSS file

Example

Distributes the total PV size around the given area.

```
area = [1.1732e7 3.708e6; 1.1732e6 3.728e6; 1.1748e7 3.708e6; 1.1748e7 3.728e6];
totalPVSize = 2e3;
distributePV(totalPVSize,area);
```

7.5.4. findMaxPenetrationTime

Finds the max penetration time

Syntax

```
index = findMaxPenetrationTime(loadFile,pvFile);
index = findMaxPenetrationTime();
```

Description

Function to calculate when the max penetration (PV output / load) time occurs. User inputs the load file and PV output profile, max time is calculated.

Inputs

- `loadFile` - optional input with the link to the file with the load data
- `pvFile` - optional input with the link to the file with the PV output data

Outputs

- `index` - the index in the array with the maximum penetration

Example

Finds the maximum penetration time for sample files

```
index =
findMaxPenetrationTime('ExampleCircuit\LS_ThreePhase.txt','ExampleCircuit\PVloadshape_7_5MW_Ce
ntral.txt')
```

```
index =

       39125
```

7.5.5. IneichenClearSkyModel

Generates the clear sky irradiance using Ineichen and Perez model 2002

Syntax

```
GHI = IneichenClearSkyModel(times,latitude,longitude,elevation,Lz);
```

Description

Function to generate the clear sky global horizontal irradiance for a given time period and location using the SoDa Linke Turbidity maps

Inputs

- **`times`** - MATLAB datenum (Example: datenum(2011,2,23)), can be an array of times
- **`latitude`** - site latitude (decimal degrees)
- **`longitude`** - site longitude (decimal degrees) (negative for West)
- **`elevation`** - site elevation (meters)
- **`Lz`** - standard times zone meridian (120 for PST, 105 for MST, 90 CST, and 75 for EST). To find the time zone meridian, just take GMT offset and multiply by -15. (e.g. Eastern time is GMT -5hrs, so the meridian is (-5)*(-15) = 75 degrees.
- Linke Turbidity images in a folder ('LinkeTurbidity'), images obtained from (http://www.helioclim.org/linke/linke_helioserve.html)

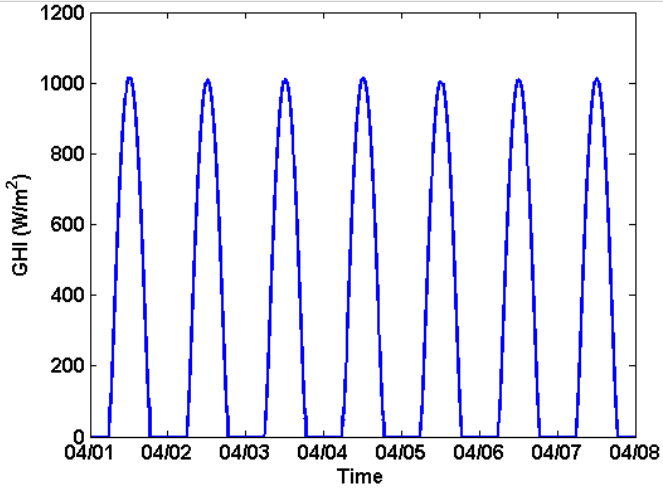
Outputs

- **`GHI`** is an array of GHI values for each time in array times

Example

Generates the 1-minute GHI profile for Albuquerque for the first week in April, 2011.

```
times = datenum(2011,4,1):1/(24*60):datenum(2011,4,8);
GHI=IneichenClearSkyModel(times, 35.04, -106.62, 1617, 105);
plot(times, GHI,'LineWidth',2); datetick('x','mm/dd','keeplimits','keepticks');
set(gca,'FontSize',12,'FontWeight','bold');
ylabel('GHI (W/m^2)','FontSize',12,'FontWeight','bold');
xlabel('Time','FontSize',12,'FontWeight','bold');
```



7.5.6. makePFoutputFunction

GUI for creating power factor as a function of PV power output

Syntax

```
makePFoutputFunction()
```

Description

This function is a user interface to create the Power Factor as a function of PV power output. The user draws the function and then saves it to a .mat file. This function is often called from placePVplant.m when the PV plant power factor control is selected. The saved mat file is used in createPVscenarioFiles.m when the solar scenario OpenDSS generators are created.

Inputs

- **none**

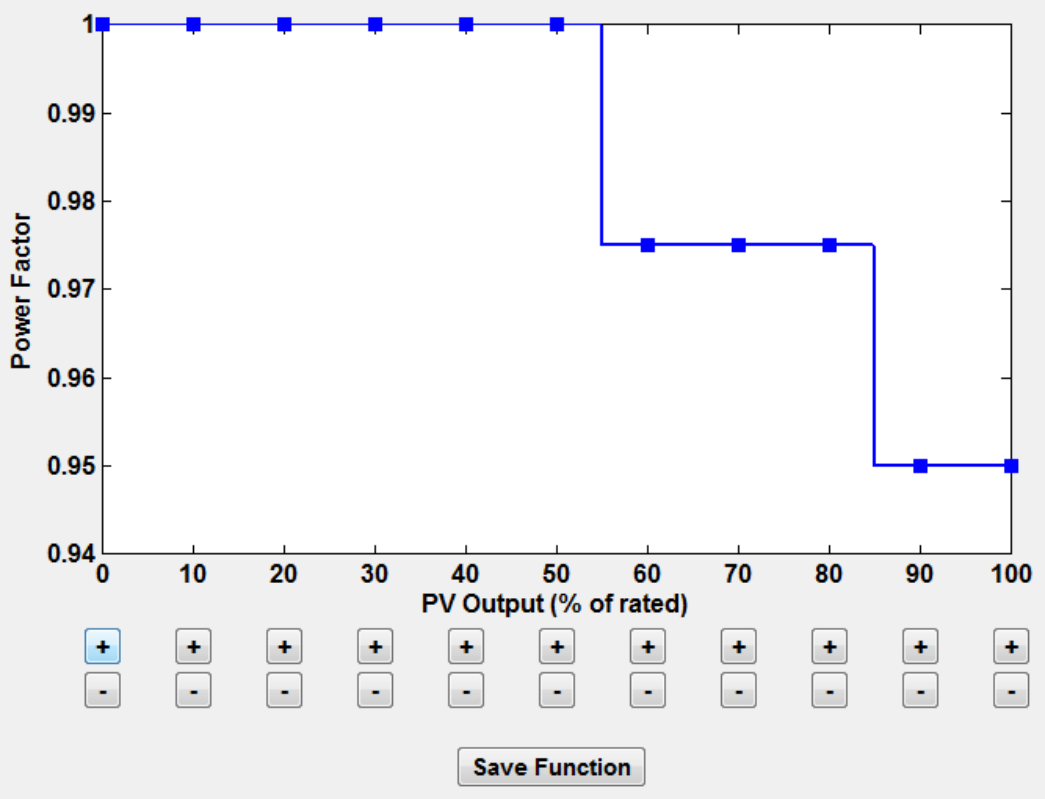
Outputs

- **none** saves a *.mat file with the power factor function of PV power output

Example

Showing the user interface:

```
makePFoutputFunction()
```



7.5.7. makePFprofile

Creates varying Reactive Power output profile from given power factor schedule or function of PV output

Syntax

```
[MW MVar] = makePFprofile(pvTimes,pvOutput,type,filepath,ratedMVA);
```

Description

Function that takes a schedule (makePFschedule.m) or a function of PV output power (makePFoutputFunction.m) and creates the time varying Reactive Power output profile for the system. The input is the pvOutput (MW) and it is converted to MVar using the given power factor. This is called from createPVscenarioFiles to create the reactive power timeseries given the type of power factor profile

Inputs

- `pvTimes` - array of times
- `pvOutput` - array of net power output from the total plant (MVA)
- `type` - type of PF profile ('schedule' or 'function')
- `filepath` - filepath to PF schedule or function. These files are generated by either makePFschedule.m or makePFoutputFunction.m
- `ratedMVA` - ratedMVA of the PV plant

Outputs

- `MVar` - array of MVar output from each timestep

Example

Runs sample irradiance data through WVM and then uses the saved power factor function to calculate MVAR from MW and power factor

```
[DSSCircObj, DSSText, gridpvPath] = DSSStartup;
irr_sensor =
load([gridpvPath,'Subfunctions\WVM_subfunctions\Example_Alamosa_2011_8_21_IrradSensor.mat']);
load([gridpvPath,'ExampleCircuit\ExampleCentralPlantInfoPFfunction.mat']);
A_val = 1.5392;
[timeout,POA_plant,Power_plant,MWs]=WVM(irr_sensor,plantinfo,A_val);
MVar =
makePFprofile(timeout,Power_plant,plantinfo.powerFactor.type,plantinfo.powerFactor.filepath,pl
antinfo.MWs);
plot(timeout,Power_plant,'LineWidth',2); hold all;
plot(timeout,MVar,'LineWidth',2);
legend('Plant Output (MW)','MVAR (Absorbing)');
title('Power Factor as a Function of PV Output','FontWeight','bold','FontSize',12);
set(gca,'FontSize',10,'FontWeight','bold');
xlabel('Time','FontSize',10,'FontWeight','bold');
```

7.5.8. makePFschedule

GUI for creating a power factor daily schedule

Syntax

```
makePFschedule()
```

Description

This function is a user interface to create Power Factor daily schedule. The user draws the schedule and then saves it to a .mat file. This function is often called from placePVplant.m when the PV plant power factor control is selected. The saved mat file is used in createPVscenarioFiles.m when the solar scenario OpenDSS generators are created.

Inputs

- **none**

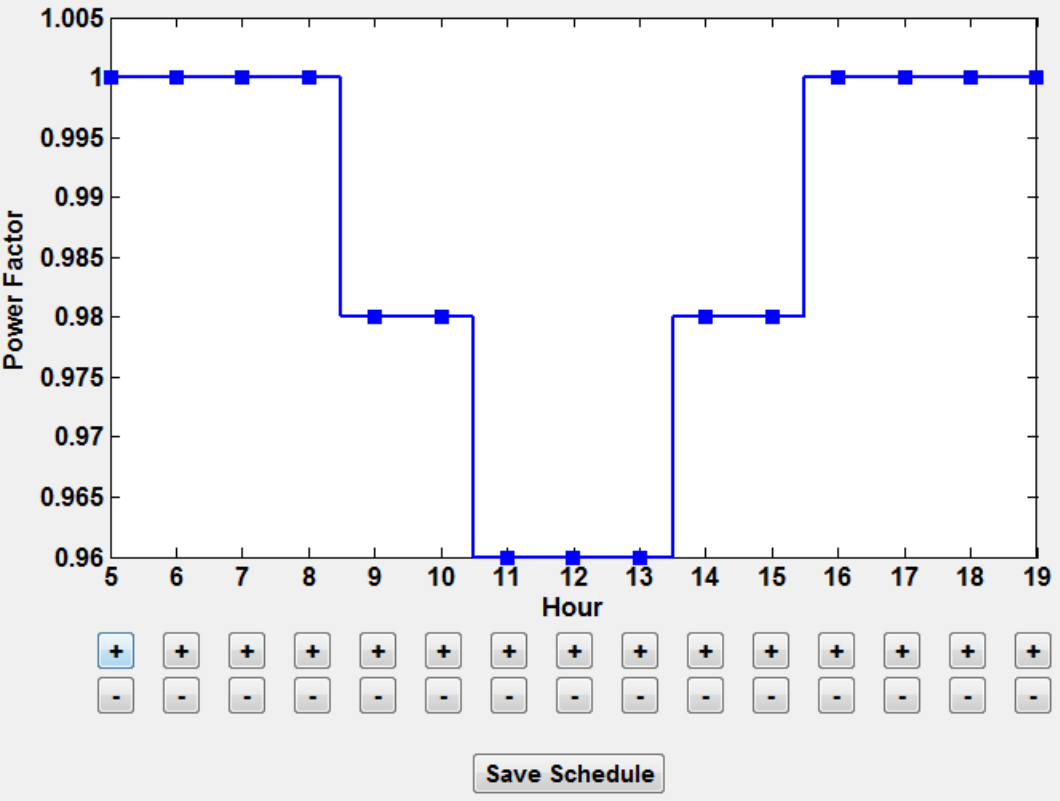
Outputs

- **none** saves a *.mat file with the power factor daily schedule

Example

Showing the user interface:

```
makePFschedule()
```



7.5.9. makeVVCcurve

GUI for setting up the OpenDSS VVControl function parameters

Syntax

```
makeVVCcurve()
```

Description

This function is a user interface to create the Volt/Var control function in OpenDSS. The required parameters are entered into the interface and a mat file is saved with the parameters. This function is often called from placePVplant.m when the PV plant power factor control is selected. The saved mat file is used in createPVscenarioFiles.m when the solar scenario OpenDSS generators are created.

Inputs

- **none**

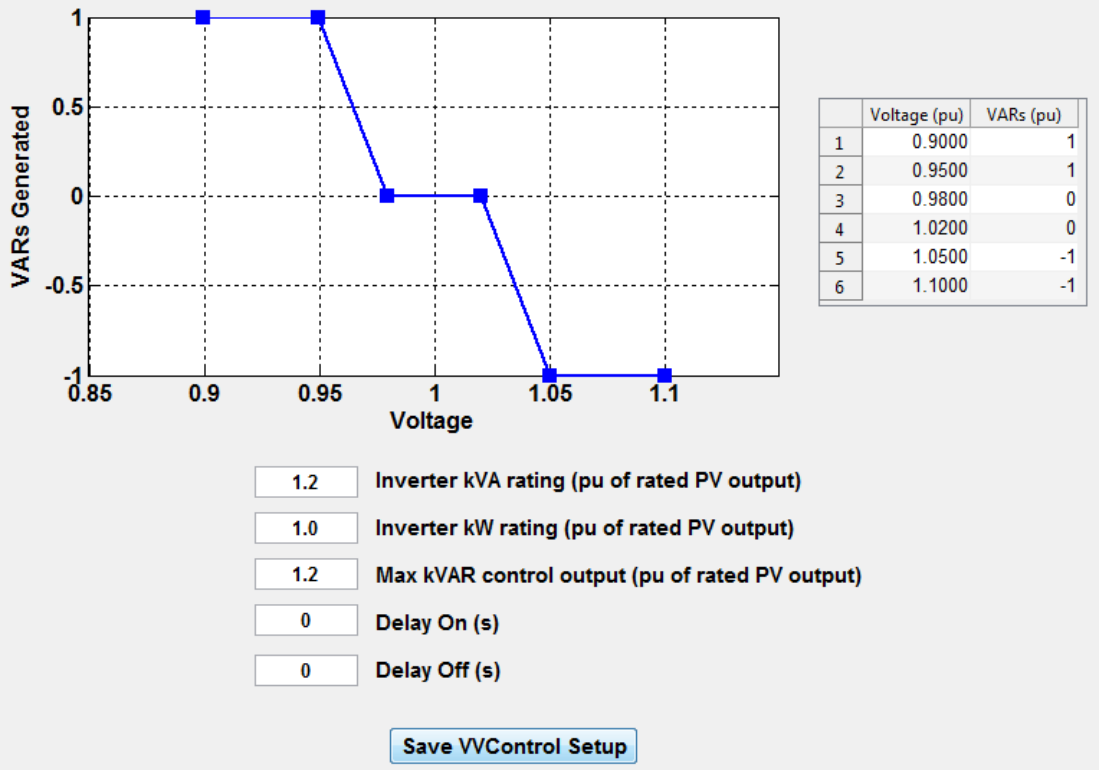
Outputs

- **none** saves a *.mat file with the VVControl parameters

Example

Showing the user interface:

```
makeVVCcurve()
```



7.5.10. WVM

WVM Wavelet Variability Model

Syntax

```
[timeout,POA_plant,Power_plant,MWs]=WVM(irr_sensor,plantinfo,A_val);
```

Description

Function from Matthew Lave for smoothing variability from a point irradiance sensor to represent a larger PV array with decreased ramps. The method uses wavelets at different time scales to provide all cooresponding smoothing.

Inputs

- `irr_sensor` is a struct with variables:
- irr_sensor.irr the irradiance measurement
- irr_sensor.time the time labels for irr_sensor.irr
- irr_sensor.Lat latitude of the sensor
- irr_sensor.Lon longitude of the sensor
- irr_sensor.tilt tilt angle of the sensor, 0 = flat
- irr_sensor.azimuth azimuth angle of the sensor, 180 = due south
- irr_sensor.tracking =1 if single-axis tracking (with tilt irr_sensor.tilt), =0 if not
- irr_sensor.UTCoffset=UTC offset
- `plantinfo` is a struct describing the plant to simulate with variables:
- plantinfo.tilt tilt angle of plant panels
- plantinfo.azimuth azimuth angle of plant panels
- plantinfo.tracking =1 if plant is single axis tracking (with tilt specified by plantinfo.tilt), =0 if not
- plantinfo.square =1 if plant is square shape (i.e., a central plant), =0 if not square
- if plantinfo.square==1
- plantinfo.MWs if plant is square, then specify the plant size in MWs
- plantinfo.density density of PV (i.e., density = 0.25 for central plant)
- else
- plantinfo.polygons cell with polygon vertices. polygons{1}=first polygon vertices, polygons{n}=nth polygon vertices
- plantinfo.densities vector with densities of polygons, corresponding to cells of polygons
- end
- `A_val` is the correlation scaling coefficient (A)

Outputs

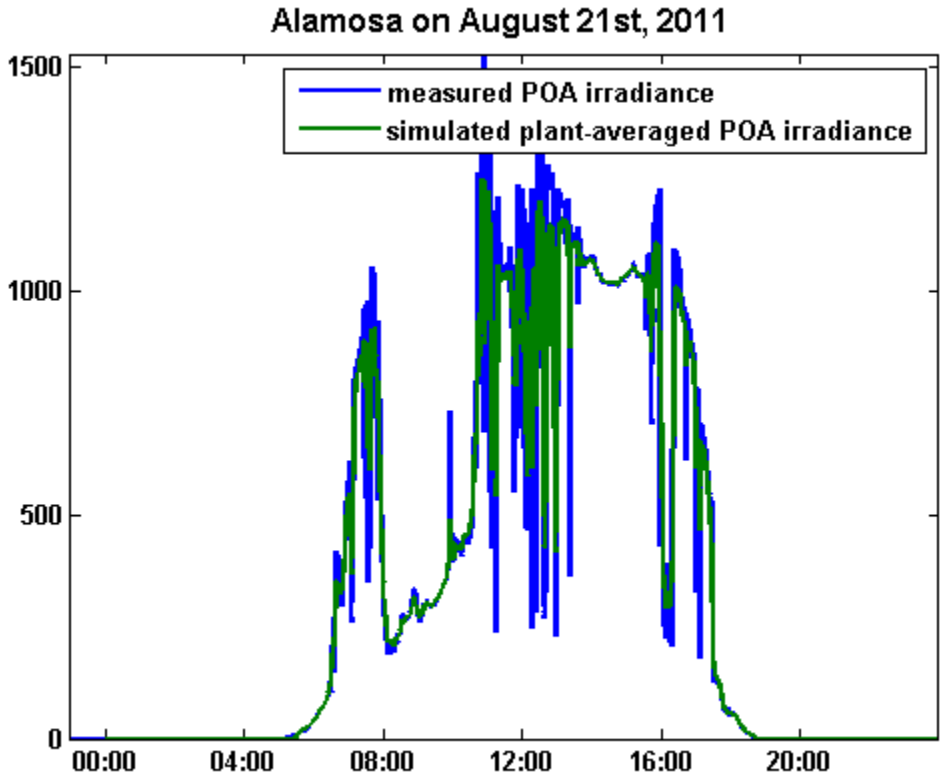
- `timeout` - array of times
- `POA_plant` - array of plane of array irradiance values
- `Power_plant` - array of net power output from the total plant
- `MWs` - plant MW rating

Copyright

Example

Runs the WVM to determine the geographically smoothed output for the specified input irradiance and PV plant to be simulated

```
irr_sensor =
load([gridpvPath,'Subfunctions/WVM_subfunctions/Example_Alamosa_2011_8_21_IrradSensor.mat']);
plantinfo = load([gridpvPath,'Subfunctions/WVM_subfunctions/Example_Alamosa_PlantInfo.mat']);
A_val = 1.5392;
[timeout,POA_plant,Power_plant,MWs]=WVM(irr_sensor,plantinfo,A_val);
plot(irr_sensor.time,irr_sensor.irr,'LineWidth',2); hold all;
plot(timeout,POA_plant,'LineWidth',2);
legend('measured POA irradiance','simulated plant-averaged POA irradiance');
title('Alamosa on August 21st, 2011','FontWeight','bold','FontSize',12); axis tight;
set(gca,'FontSize',10,'FontWeight','bold');
set(gca,'xtick',irr_sensor.time(1)+1/24:4/24:irr_sensor.time(end));
datetick('x','HH:MM','keepticks','keeplimits');
```



7.6. EXAMPLE SIMULATIONS

These functions serve as examples for running simulations and analysis of solar on the distribution system in OpenDSS. Once the feeder is setup in OpenDSS and the solar scenarios are created, these functions can loop through the different predefined cases and perform analysis during the simulations. As examples, these functions can be modified to perform any other research analysis in the same framework with snapshot analyses or timeseries analyses.

Function List

examplePeakTimeAnalysis - Runs simulation during peak penetration time and generates plots

exampleTimeseriesAnalyses - Timeseries analysis and plots monitor values from the simulation

exampleVoltageAnalysis - Example analysis of maximum and minimum feeder voltages through time

7.6.1. examplePeakTimeAnalysis

Runs simulation during peak penetration time and generates plots

Syntax

```
examplePeakTimeAnalysis(basecaseFile,solarScenarioFiles);
examplePeakTimeAnalysis();
```

Description

Function to calculate when the max penetration (PV output / load) time occurs. A snapshot analysis is performed at this peak time, with both a voltage contour plot and voltage profile plot being generated.

Inputs

- **`basecaseFile`** - optional input with the link to the OpenDSS file with the circuit.
- **`solarScenarioFiles`** - optional input with a cell array of links to the OpenDSS files with the solar scenarios to run

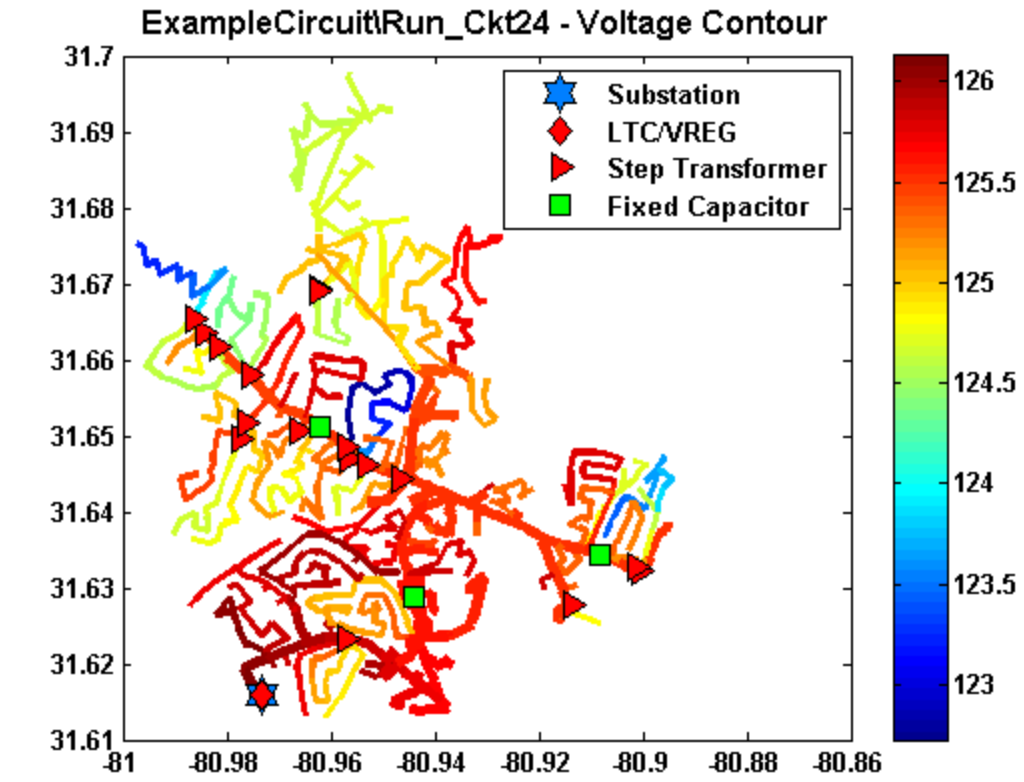
Outputs

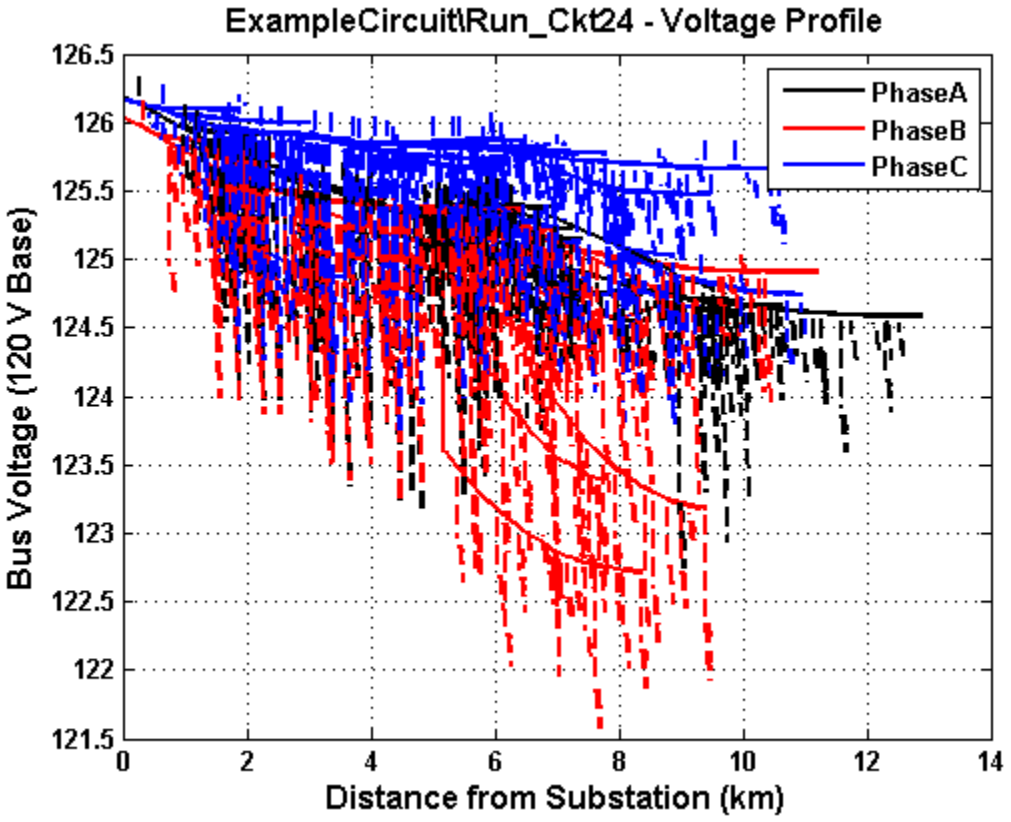
- **none** - generates 2 figures for each analysis scenario and saves them

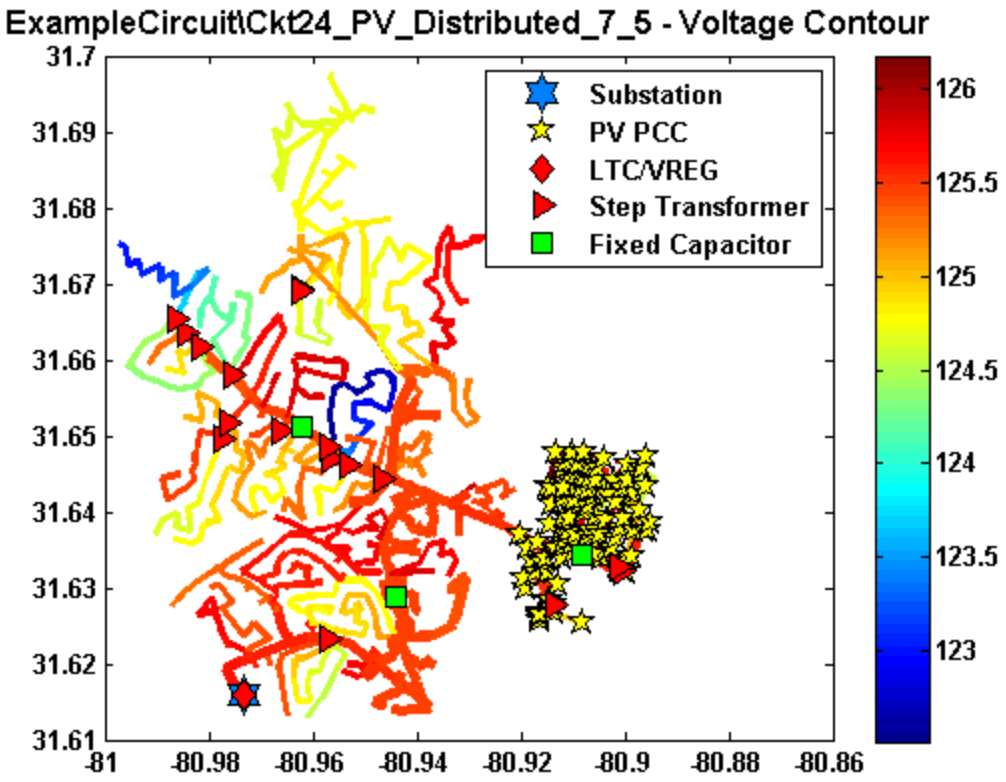
Example

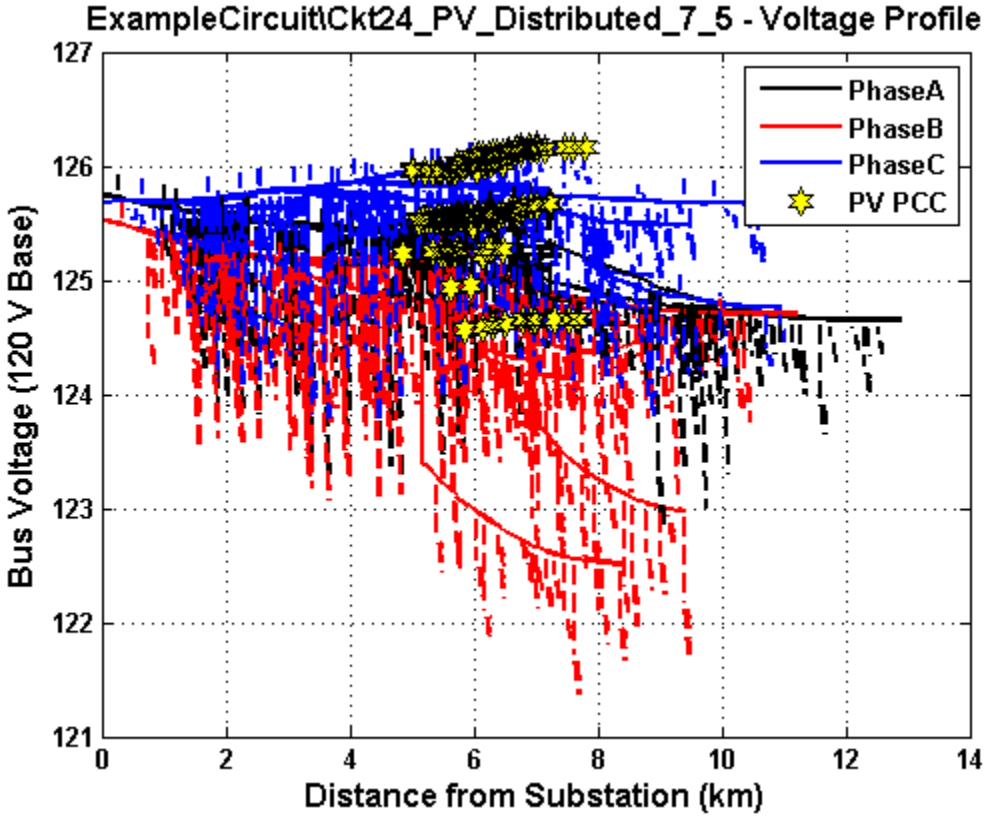
Runs the basecase circuit and the distributed solar case

```
examplePeakTimeAnalysis('ExampleCircuit\Run_Ckt24.dss',{'ExampleCircuit\Ckt24_PV_Distributed_7
_5.dss'})
```


ExampleCircuit\Run_Ckt24 - Voltage Contour
Substation
LTC/VREG
Step Transformer
Fixed Capacitor
31.7
31.69
31.68
31.67
31.66
31.65
31.64
31.63
31.62
31.61
-81
-80.98
-80.96
-80.94
-80.92
-80.9
-80.88
-80.86
126
125.5
125
124.5
124
123.5
123


ExampleCircuit\Run_Ckt24 - Voltage Profile
PhaseA
PhaseB
PhaseC
Bus Voltage (120 V Base)
Distance from Substation (km)
126.5
126
125.5
125
124.5
124
123.5
123
122.5
122
121.5
0
2
4
6
8
10
12
14


ExampleCircuit\Ckt24_PV_Distributed_7_5 - Voltage Contour
Substation
PV PCC
LTC/VREG
Step Transformer
Fixed Capacitor
31.7
31.69
31.68
31.67
31.66
31.65
31.64
31.63
31.62
31.61
-81
-80.98
-80.96
-80.94
-80.92
-80.9
-80.88
-80.86
126
125.5
125
124.5
124
123.5
123


ExampleCircuit\Ckt24_PV_Distributed_7_5 - Voltage Profile
PhaseA
PhaseB
PhaseC
PV PCC
Bus Voltage (120 V Base)
127
126
125
124
123
122
121
0
2
4
6
8
10
12
14
Distance from Substation (km)

7.6.2. exampleTimeseriesAnalyses

Timeseries analysis and plots monitor values from the simulation

Syntax

```
exampleTimeseriesAnalyses(basecaseFile,solarScenarioFiles);
exampleTimeseriesAnalyses();
```

Description

Example function for timeseries analysis and monitor plotting for net feeder power and switching components like LTC and capacitors. Monitors must be setup in the basecaseFile circuit definition. Place monitors in the desired locations, then use the same names in the code in this function.

Inputs

- `basecaseFile` - optional input with the link to the OpenDSS file with the circuit.
- `solarScenarioFiles` - optional input with a cell array of links to the OpenDSS files with the solar scenarios to run

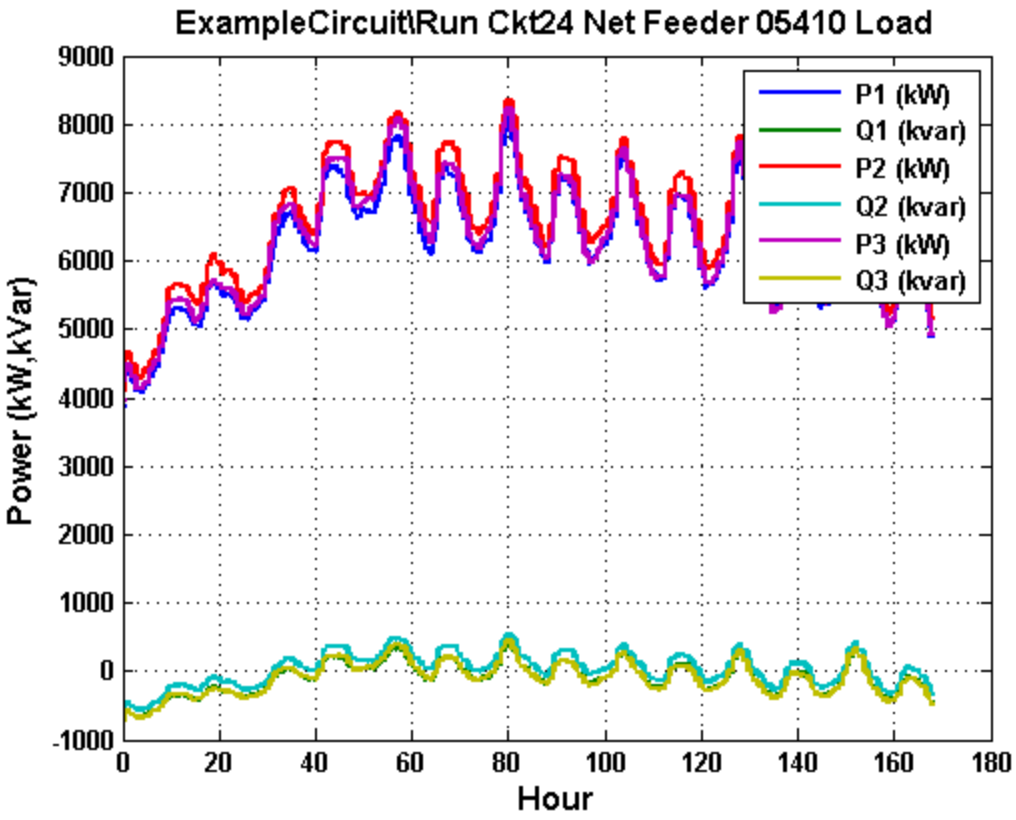
Outputs

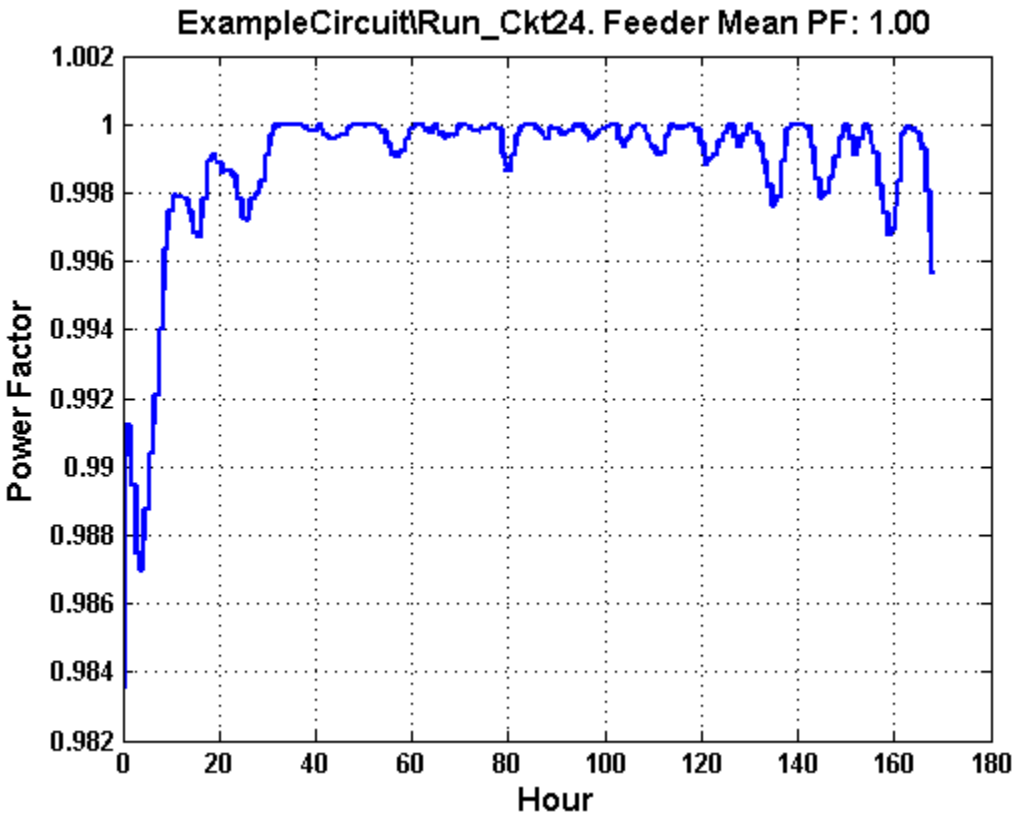
- **none** - generates several figures and saves them

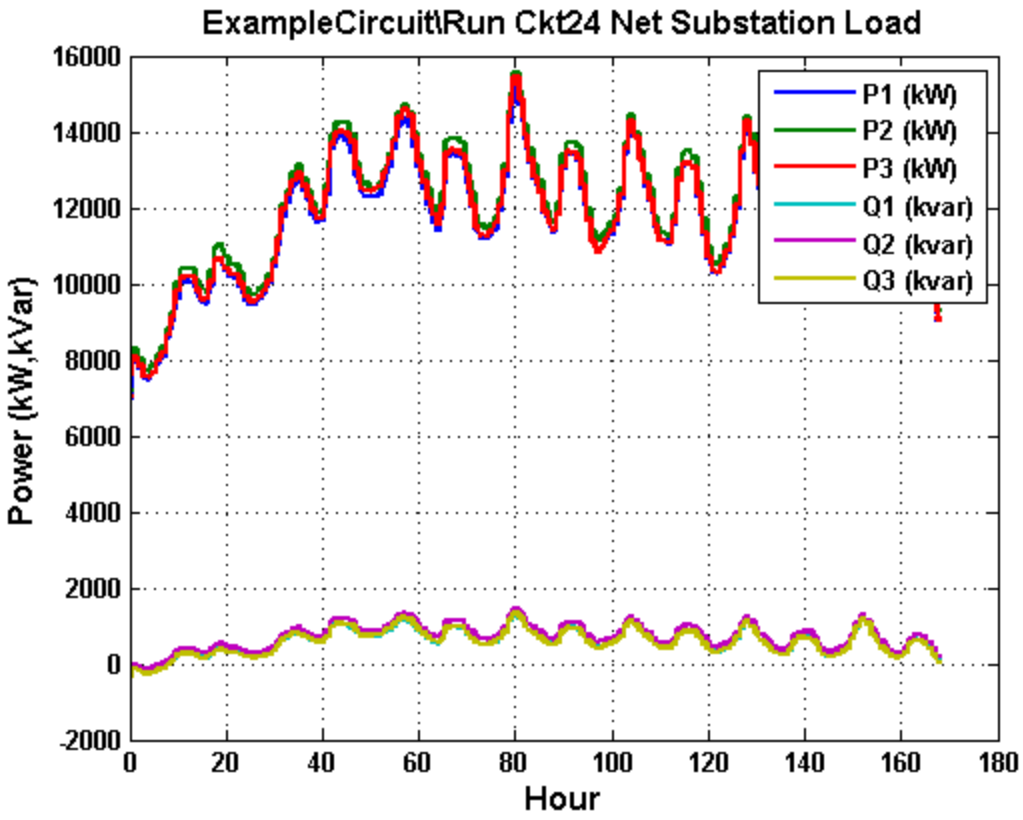
Example

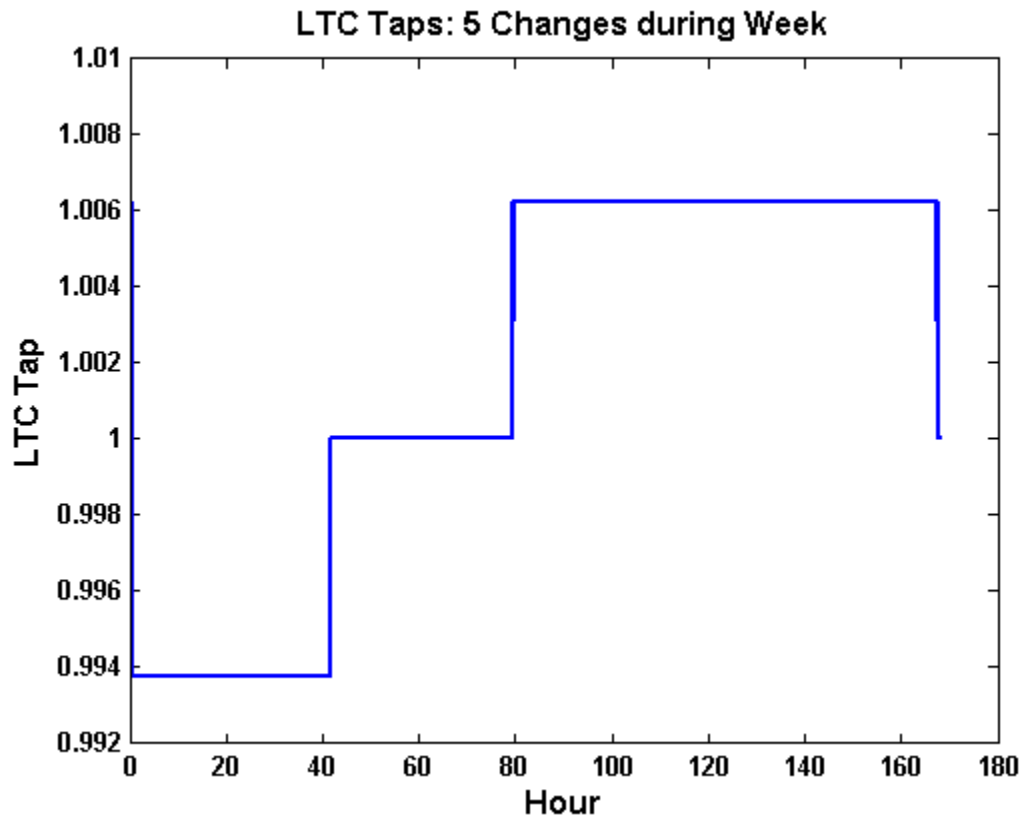
Runs the basecase circuit and the distributed solar case

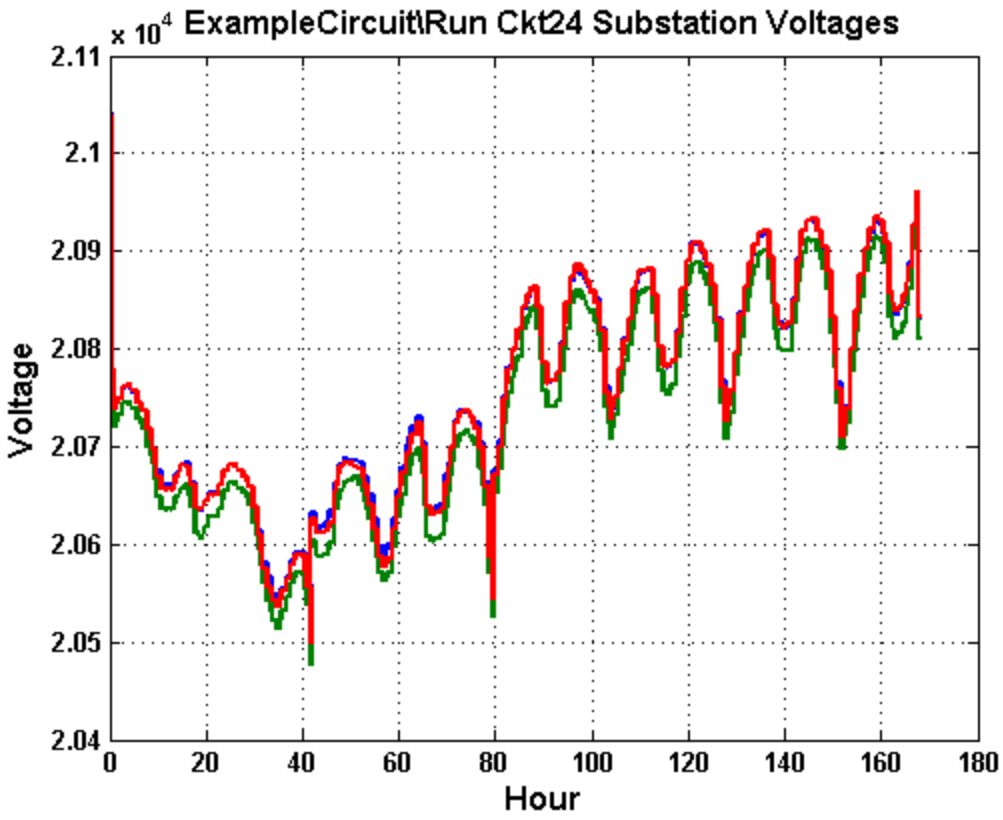
```
exampleTimeseriesAnalyses('ExampleCircuit\Run_Ckt24.dss',{'ExampleCircuit\Ckt24_PV_Central_7_5
.dss'})
```

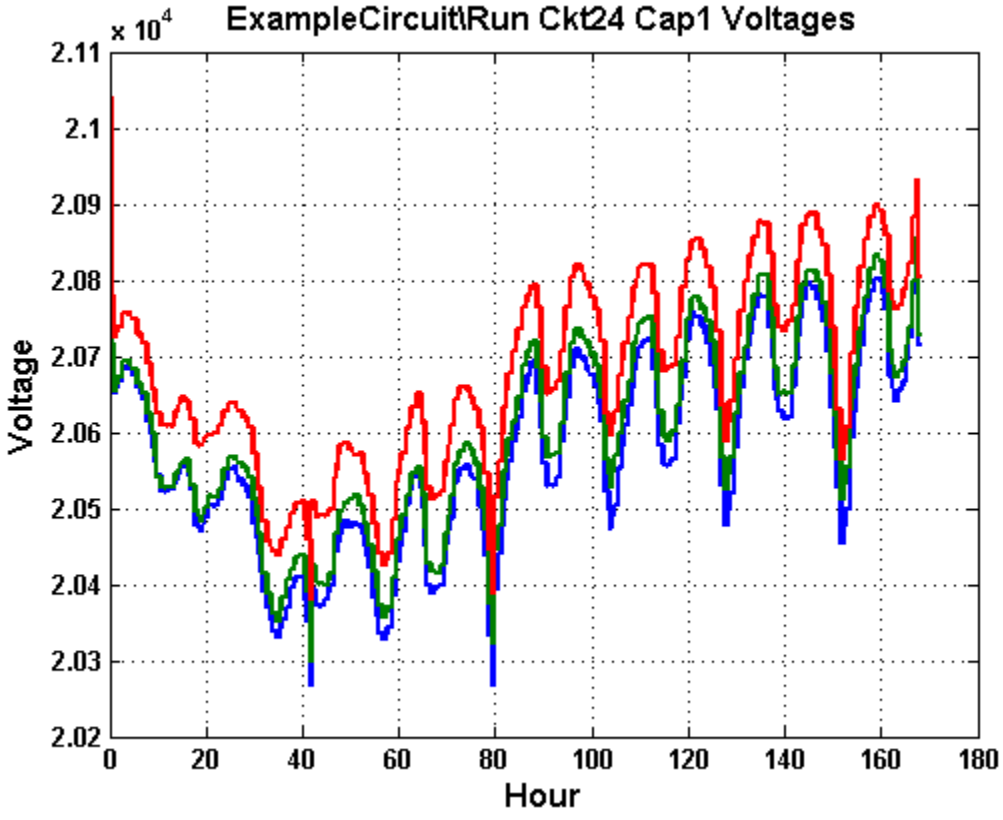

ExampleCircuit\Run Ckt24 Net Feeder 05410 Load
Power (kW,kVar)
Hour
P1 (kW)
Q1 (kvar)
P2 (kW)
Q2 (kvar)
P3 (kW)
Q3 (kvar)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
0
20
40
60
80
100
120
140
160
180

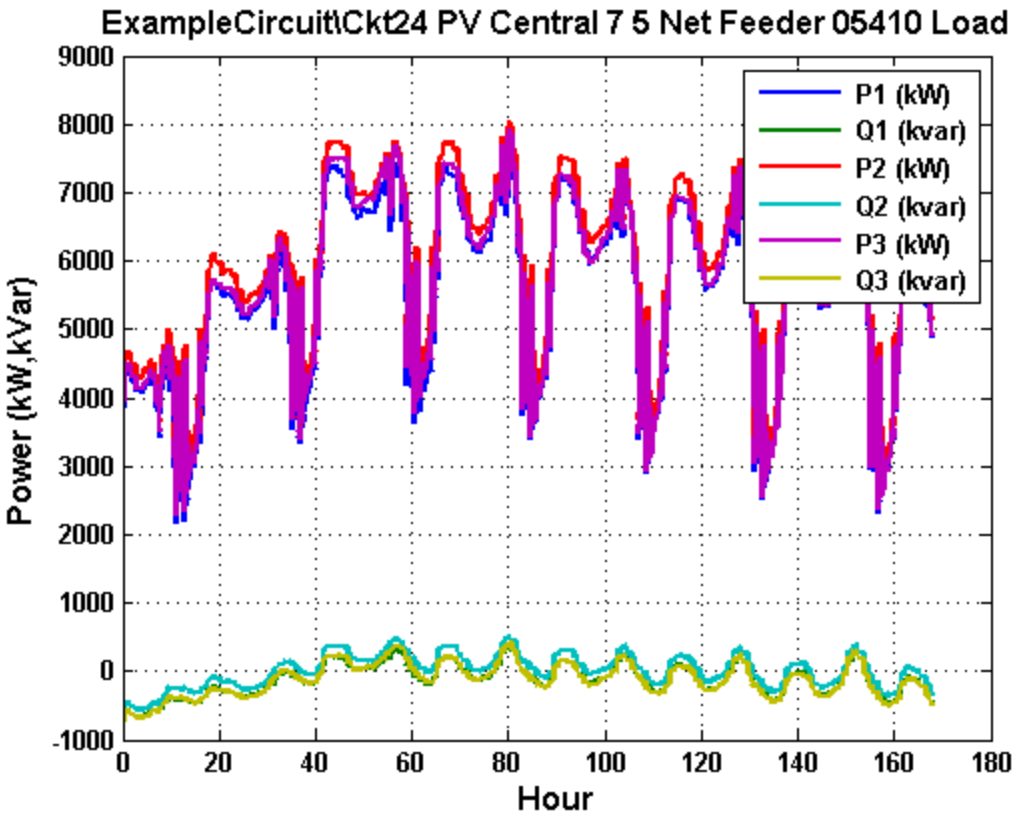

ExampleCircuit\Run_Ckt24. Feeder Mean PF: 1.00
Power Factor
Hour
1.002
1
0.998
0.996
0.994
0.992
0.99
0.988
0.986
0.984
0.982
0
20
40
60
80
100
120
140
160
180

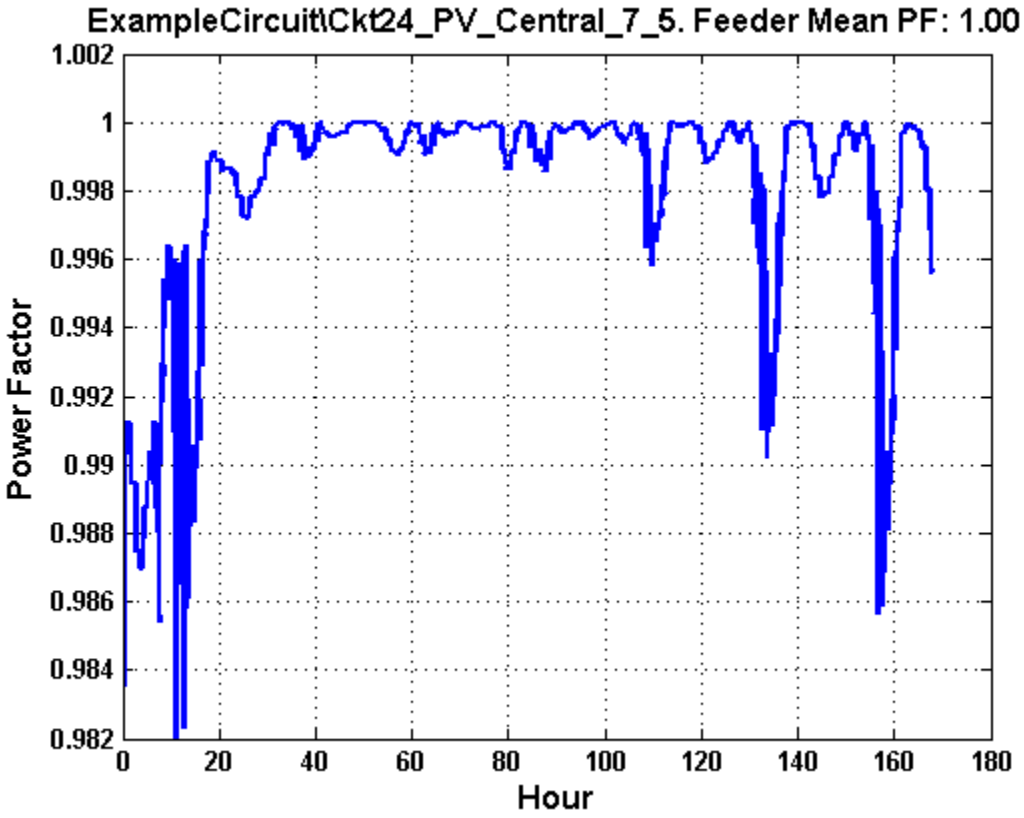

ExampleCircuit\Run Ckt24 Net Substation Load
Power (kW,kVar)
Hour
P1 (kW)
P2 (kW)
P3 (kW)
Q1 (kvar)
Q2 (kvar)
Q3 (kvar)
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
0
20
40
60
80
100
120
140
160
180

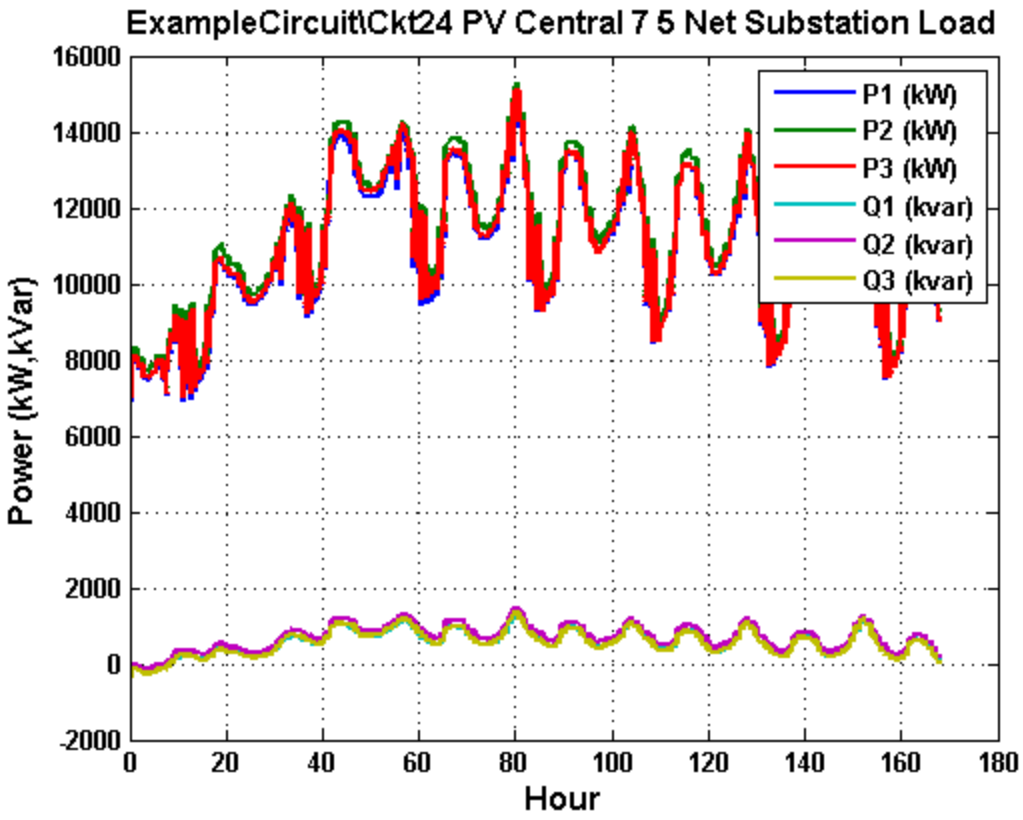

LTC Taps: 5 Changes during Week
LTC Tap
Hour
1.01
1.008
1.006
1.004
1.002
1
0.998
0.996
0.994
0.992
0
20
40
60
80
100
120
140
160
180

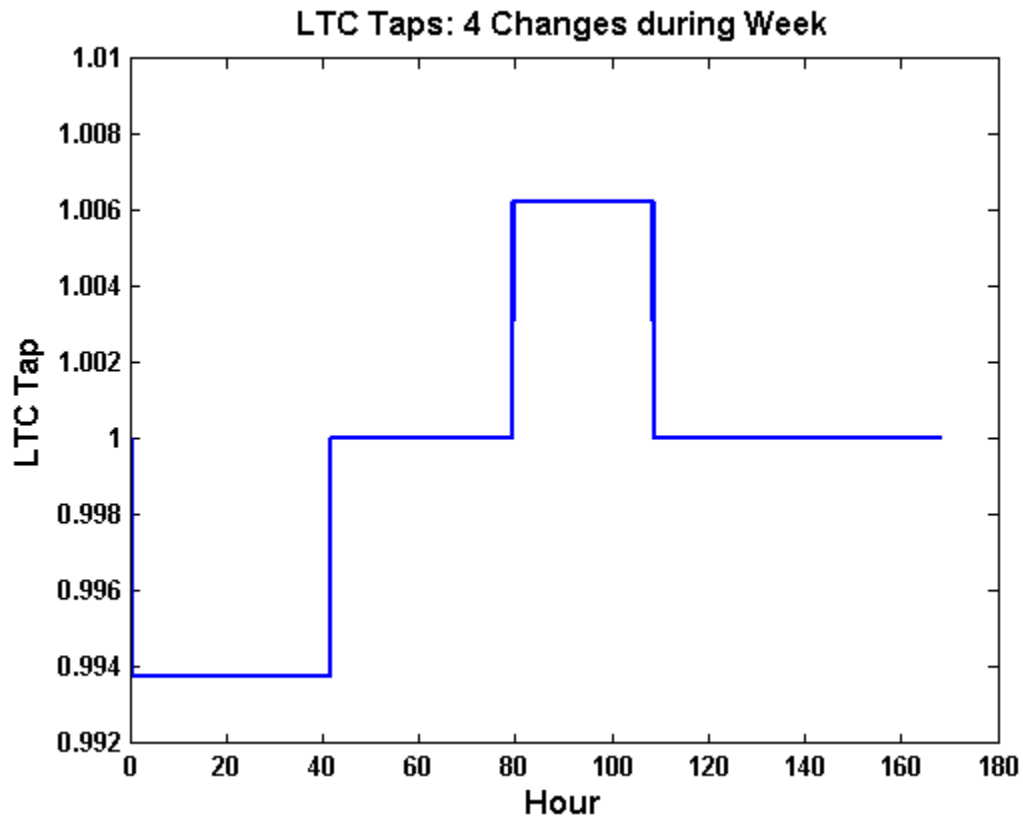

x 10^4 ExampleCircuit\Run Ckt24 Substation Voltages
Voltage
Hour
2.11
2.1
2.09
2.08
2.07
2.06
2.05
2.04
0
20
40
60
80
100
120
140
160
180

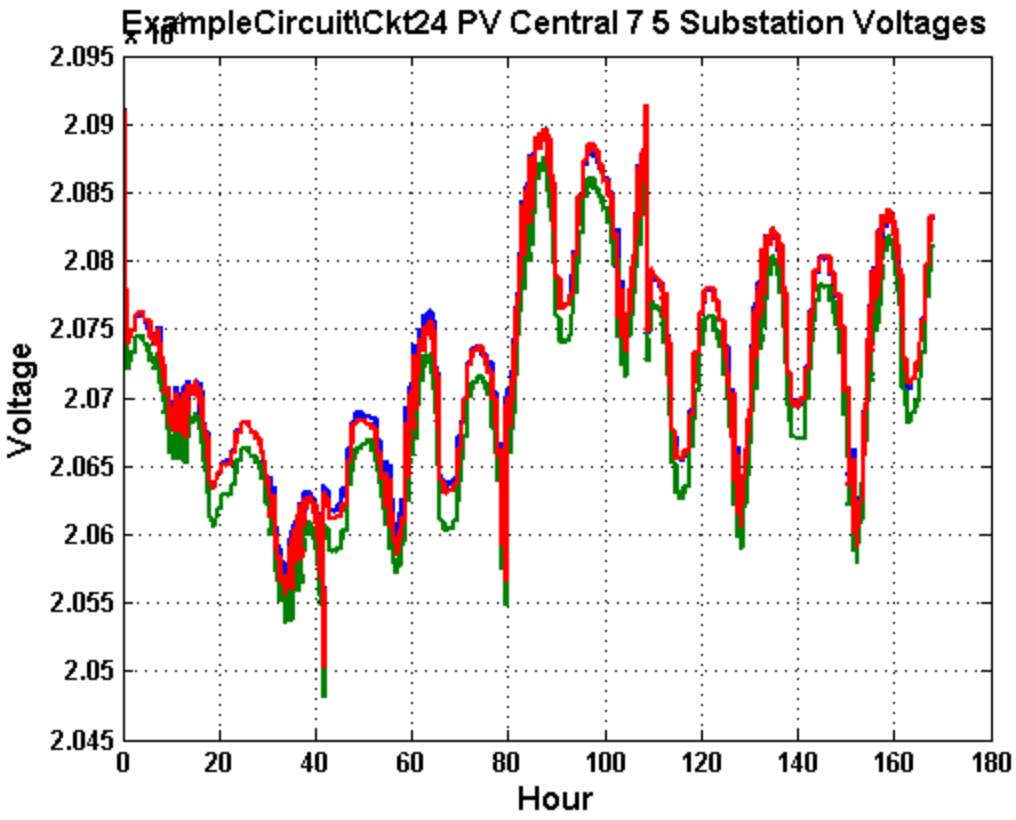

x 10^4 ExampleCircuit\Run Ckt24 Cap1 Voltages
Voltage
Hour
2.11
2.1
2.09
2.08
2.07
2.06
2.05
2.04
2.03
2.02
0
20
40
60
80
100
120
140
160
180

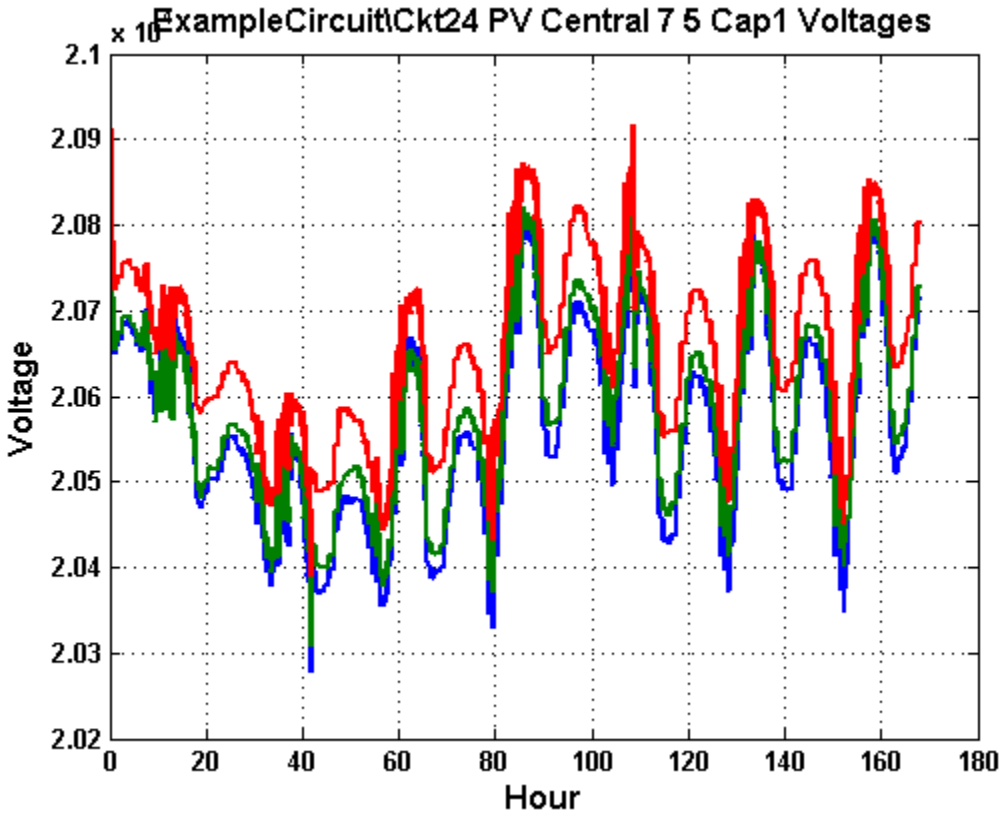

ExampleCircuit\Ckt24 PV Central 7 5 Net Feeder 05410 Load
P1 (kW)
Q1 (kvar)
P2 (kW)
Q2 (kvar)
P3 (kW)
Q3 (kvar)
Power (kW,kVar)
Hour


ExampleCircuit\Ckt24_PV_Central_7_5. Feeder Mean PF: 1.00
Power Factor
Hour


ExampleCircuit\Ckt24 PV Central 7 5 Net Substation Load
P1 (kW)
P2 (kW)
P3 (kW)
Q1 (kvar)
Q2 (kvar)
Q3 (kvar)
Power (kW,kVar)
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
0
20
40
60
80
100
120
140
160
180
Hour


LTC Taps: 4 Changes during Week
LTC Tap
1.01
1.008
1.006
1.004
1.002
1
0.998
0.996
0.994
0.992
0
20
40
60
80
100
120
140
160
180
Hour


ExampleCircuit\Ckt24 PV Central 7 5 Substation Voltages
x 10^4
2.095
2.09
2.085
2.08
2.075
2.07
2.065
2.06
2.055
2.05
2.045
Voltage
0
20
40
60
80
100
120
140
160
180
Hour


ExampleCircuit\Ckt24 PV Central 7 5 Cap1 Voltages
x 10^4
2.1
2.09
2.08
2.07
2.06
2.05
2.04
2.03
2.02
Voltage
0
20
40
60
80
100
120
140
160
180
Hour

7.6.3. exampleVoltageAnalysis

Example analysis of maximum and minimum feeder voltages through time

Syntax

```
exampleVoltageAnalysis(basecaseFile,solarScenarioFiles);
exampleVoltageAnalysis();
```

Description

Example function for analysis of maximum and minimum feeder voltages through time. The simulation stops at each time step for MATLAB to process the state of the OpenDSS simulation

Inputs

- `basecaseFile` - optional input with the link to the OpenDSS file with the circuit.
- `solarScenarioFiles` - optional input with a cell array of links to the OpenDSS files with the solar scenarios to run

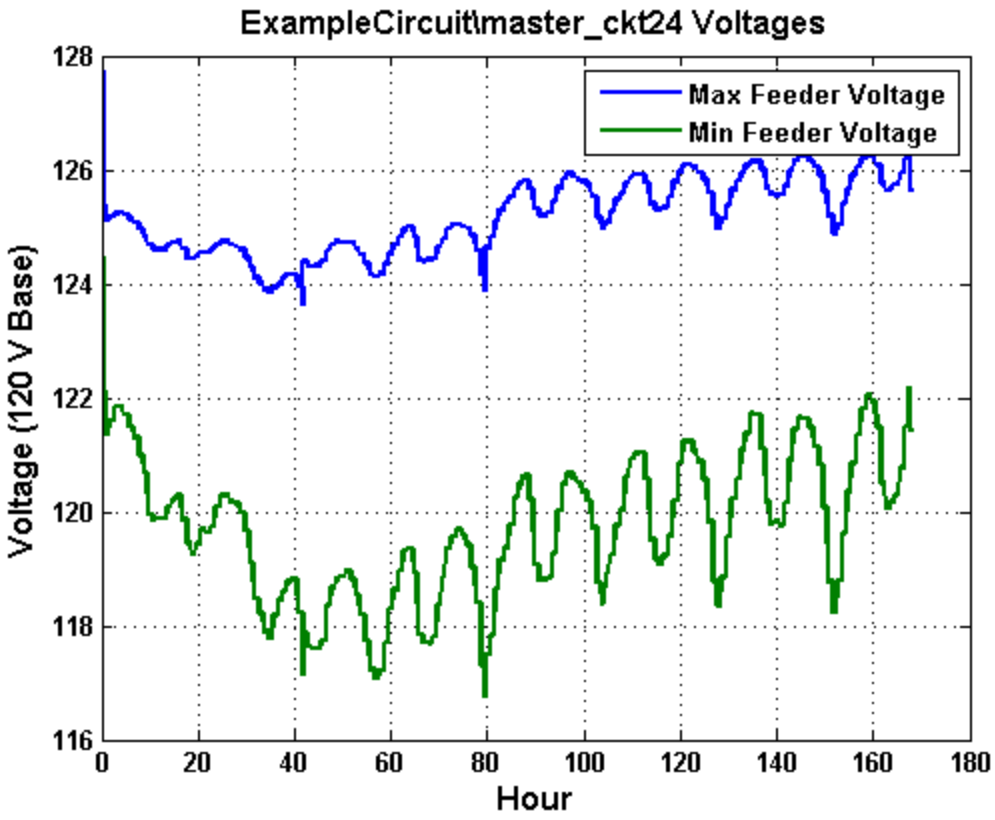
Outputs

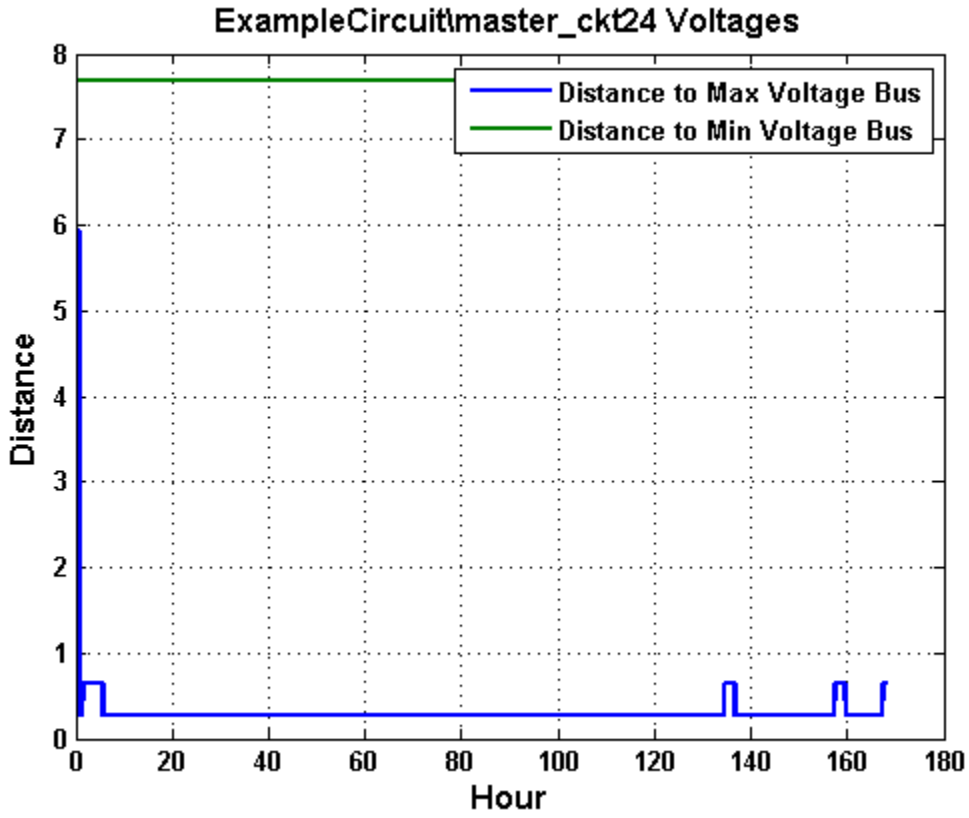
- **none** - generates a plot of maximum and minimum voltage through time

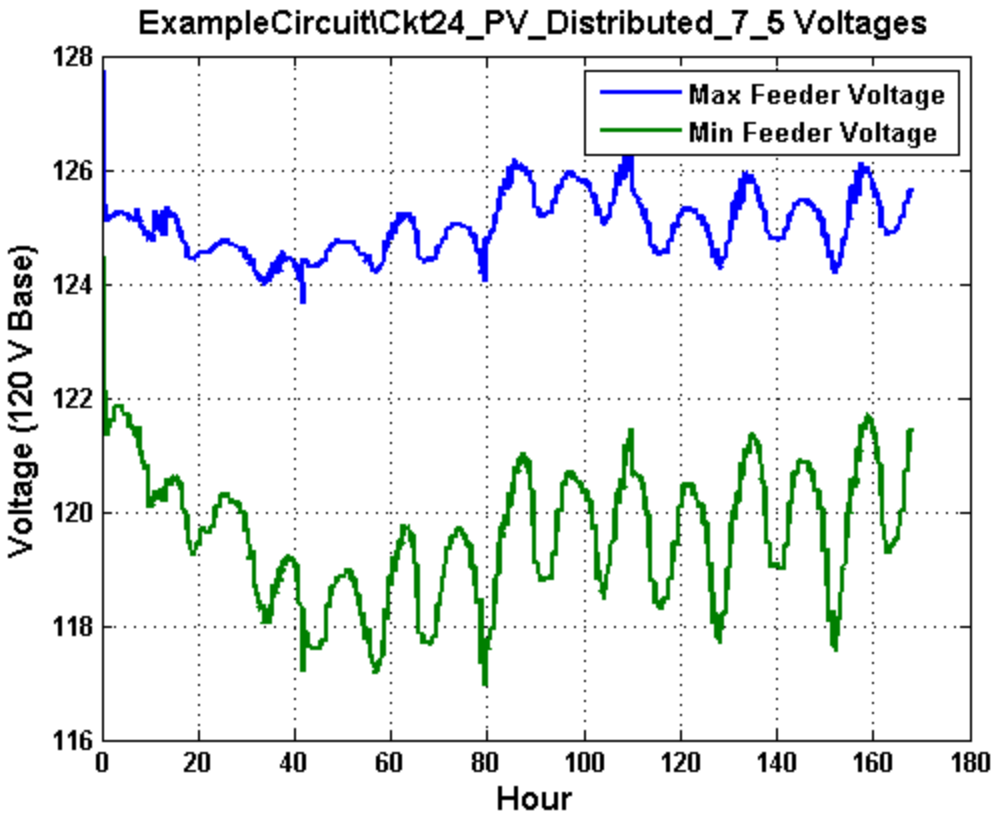
Example

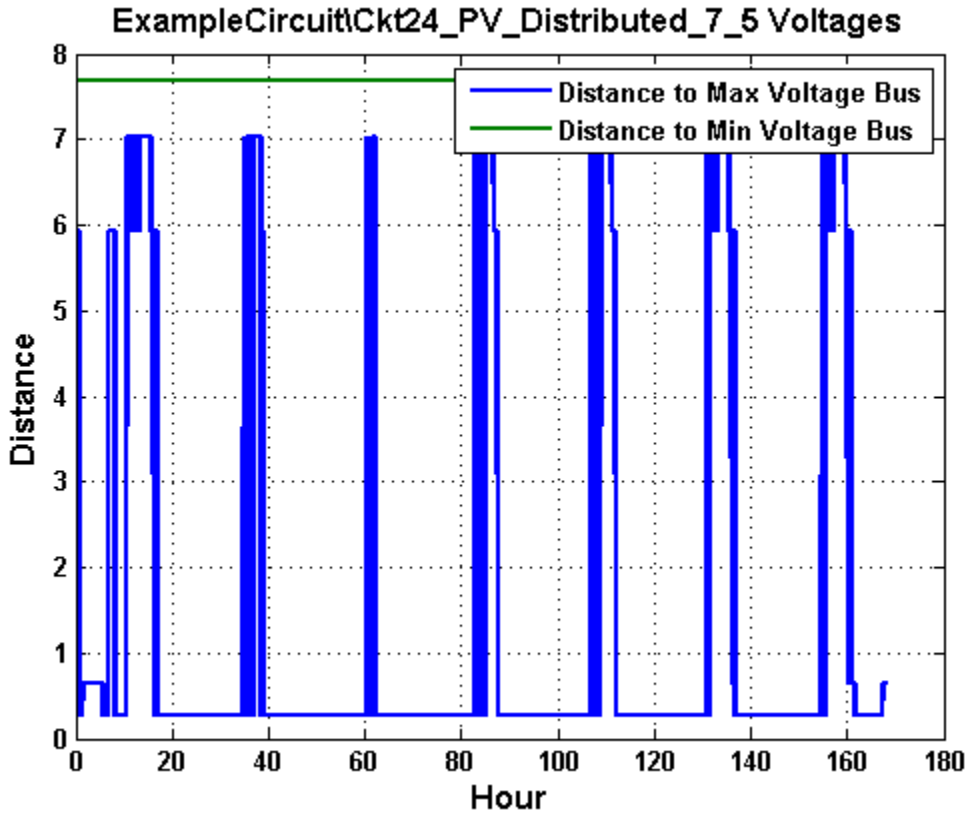
Runs the basecase circuit and the distributed solar case

```
exampleVoltageAnalysis('ExampleCircuit\master_ckt24.dss',{'ExampleCircuit\Ckt24_PV_Distributed
_7_5.dss'})
```


ExampleCircuit\master_ckt24 Voltages
Max Feeder Voltage
Min Feeder Voltage
Voltage (120 V Base)
Hour
128
126
124
122
120
118
116
0
20
40
60
80
100
120
140
160
180


ExampleCircuit\master_ckt24 Voltages
Distance to Max Voltage Bus
Distance to Min Voltage Bus
Distance
Hour
8
7
6
5
4
3
2
1
0
0
20
40
60
80
100
120
140
160
180


ExampleCircuit\Ckt24_PV_Distributed_7_5 Voltages
Max Feeder Voltage
Min Feeder Voltage
Voltage (120 V Base)
Hour
128
126
124
122
120
118
116
0
20
40
60
80
100
120
140
160
180


ExampleCircuit\Ckt24_PV_Distributed_7_5 Voltages
Distance to Max Voltage Bus
Distance to Min Voltage Bus
Distance
Hour
8
7
6
5
4
3
2
1
0
0
20
40
60
80
100
120
140
160
180

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