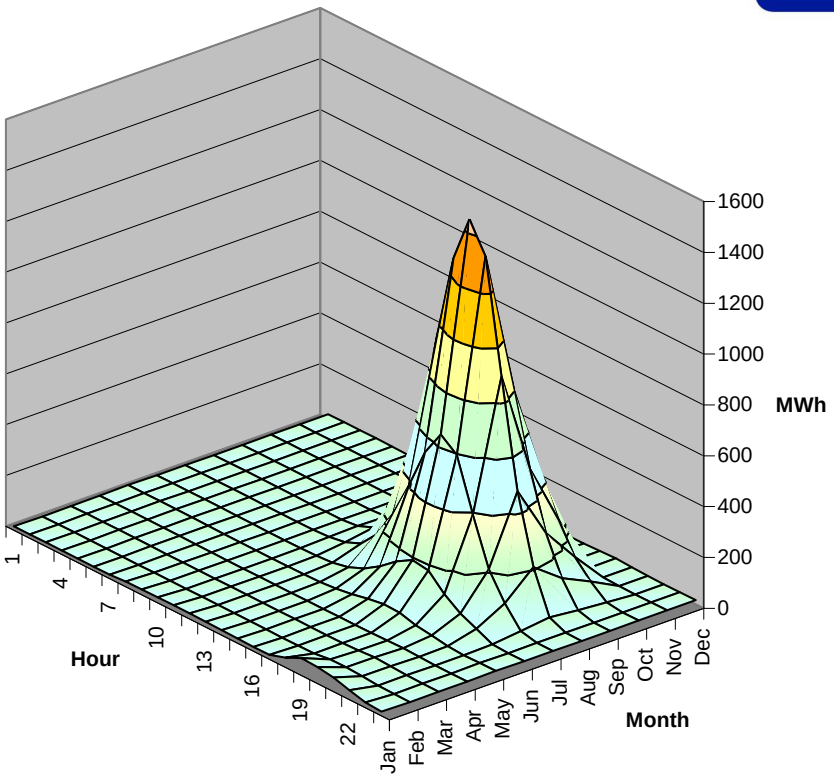


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# OpenDSS Introductory Training Level 1

28 APR 2009

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# Introduction

# Why DSS?

- DSS was developed to provide a very flexible research platform and a foundation for special distribution analysis applications such as DG analysis
- Fills gaps left by other distribution system analysis tools.
  - These do very well in traditional distribution system analysis meeting the needs of their respective user bases
  - Integration of user interface, GIS and other databases quite important, but results in slower implementation of innovative modeling to meet new challenges

# Current Related EPRI Activities

- Intelligrid
  - Distribution Fast Simulation & Modeling
  - DSE – Distribution State Estimator
- CIM/DCIM
- OpenDSS – Distribution System Simulator
  - Multipurpose distribution system analysis tool
  - Open source version has been released – 5 Sept 2008
  - Official release – November 2008
  - (Focus of this Presentation)

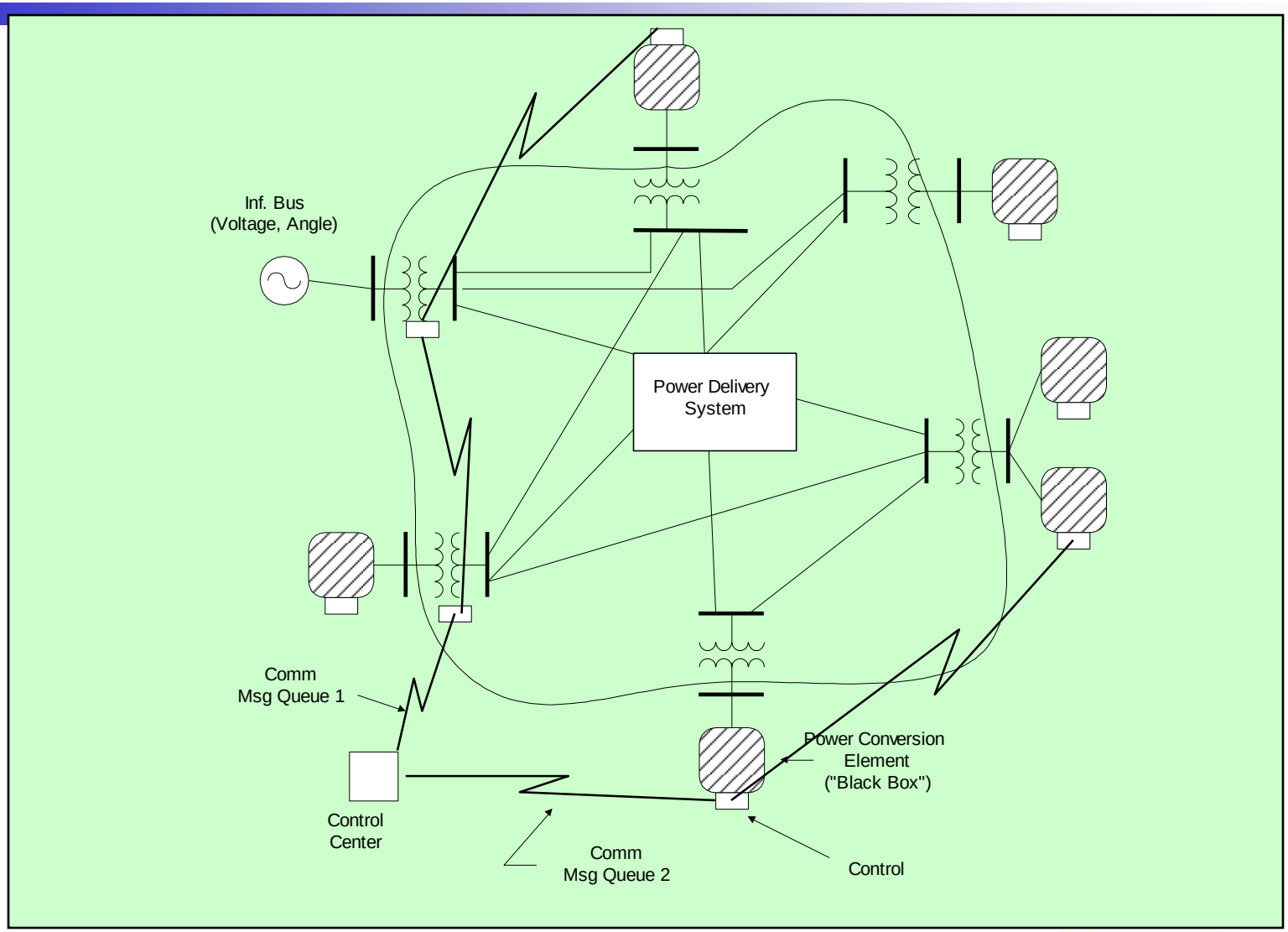
# DSS Background

- Under development for more than 10 Years
  - Started at Electrotek Concepts in 1997
  - Purchased by EPRI in 2004
- Objectives in 1997
  - Tool to support all distribution planning aspects of distributed generation
  - Implement a flexible research platform
  - Incorporate object-oriented data ideas
- Key Future work
  - Platform for DSE for North American Systems
  - Research platform for reliability tools

# Distribution System Simulator (DSS)

- The DSS is designed to simulate utility distribution systems in arbitrary detail for most types of analyses related to distribution planning.
  - It performs its analysis types in the *frequency domain*,
    - Power flow,
    - Harmonics, and
    - Dynamics.
  - It does NOT perform electromagnetic transients (*time domain*) studies.

# Overall Model Concept



# Example DSS Applications

- Neutral-to-earth (stray) voltage simulations.
- Loss evaluations due to unbalanced loading.
- Development of DG models for the IEEE Radial Test Feeders.
- High-frequency harmonic and interharmonic interference.
- Losses, impedance, and circulating currents in unusual transformer bank configurations.
- Transformer frequency response analysis.
- Distribution automation control algorithm assessment.
- Impact of tankless water heaters on flicker and distribution transformers.
- Wind farm collector simulation.
- Wind farm impact on local transmission.
- Wind generation and other DG impact on switched capacitors and voltage regulators.
- Open-conductor fault conditions with a variety of single-phase and three-phase transformer connections.

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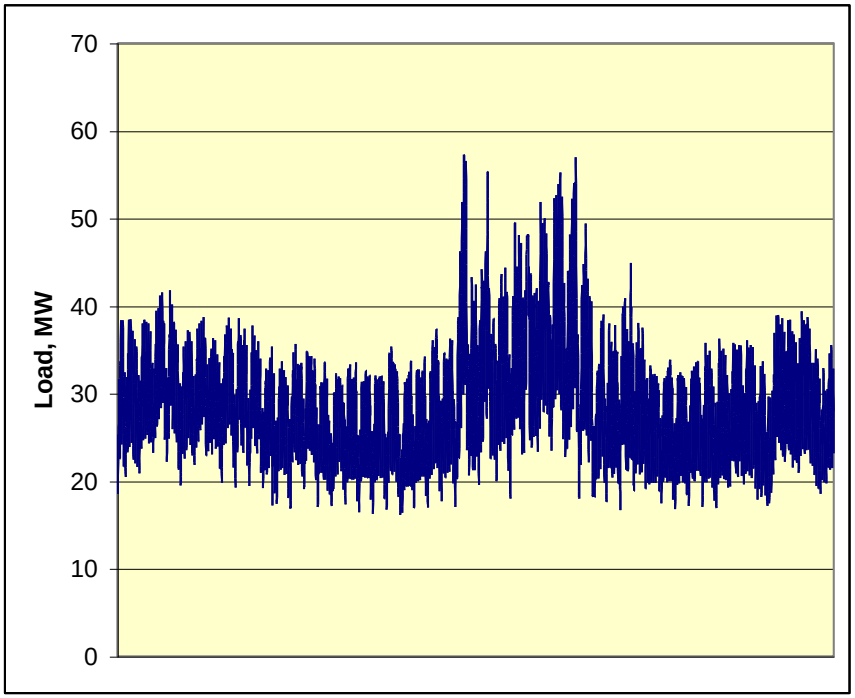
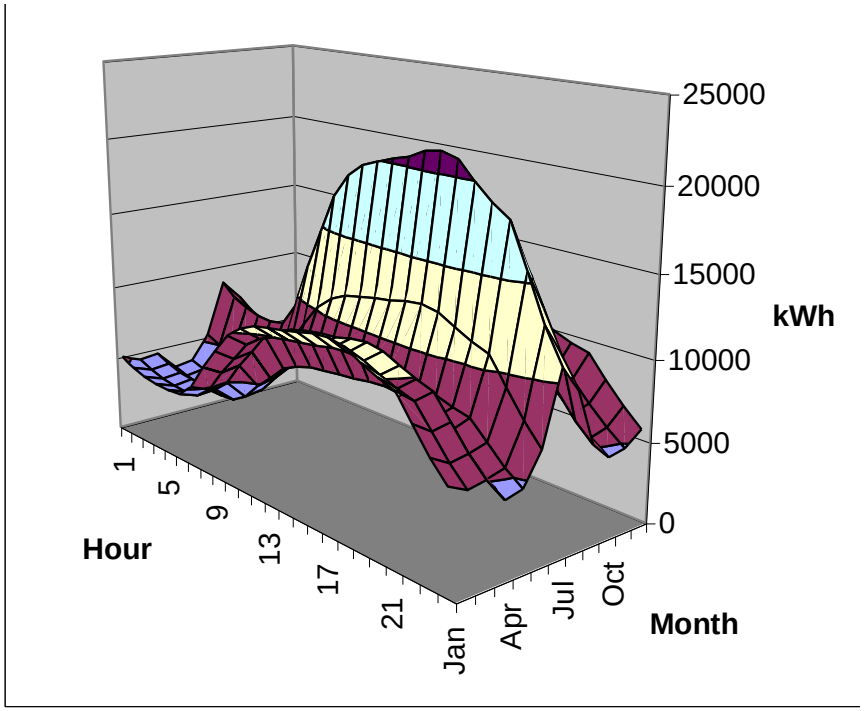
# Examples of Analysis Performed by DSS

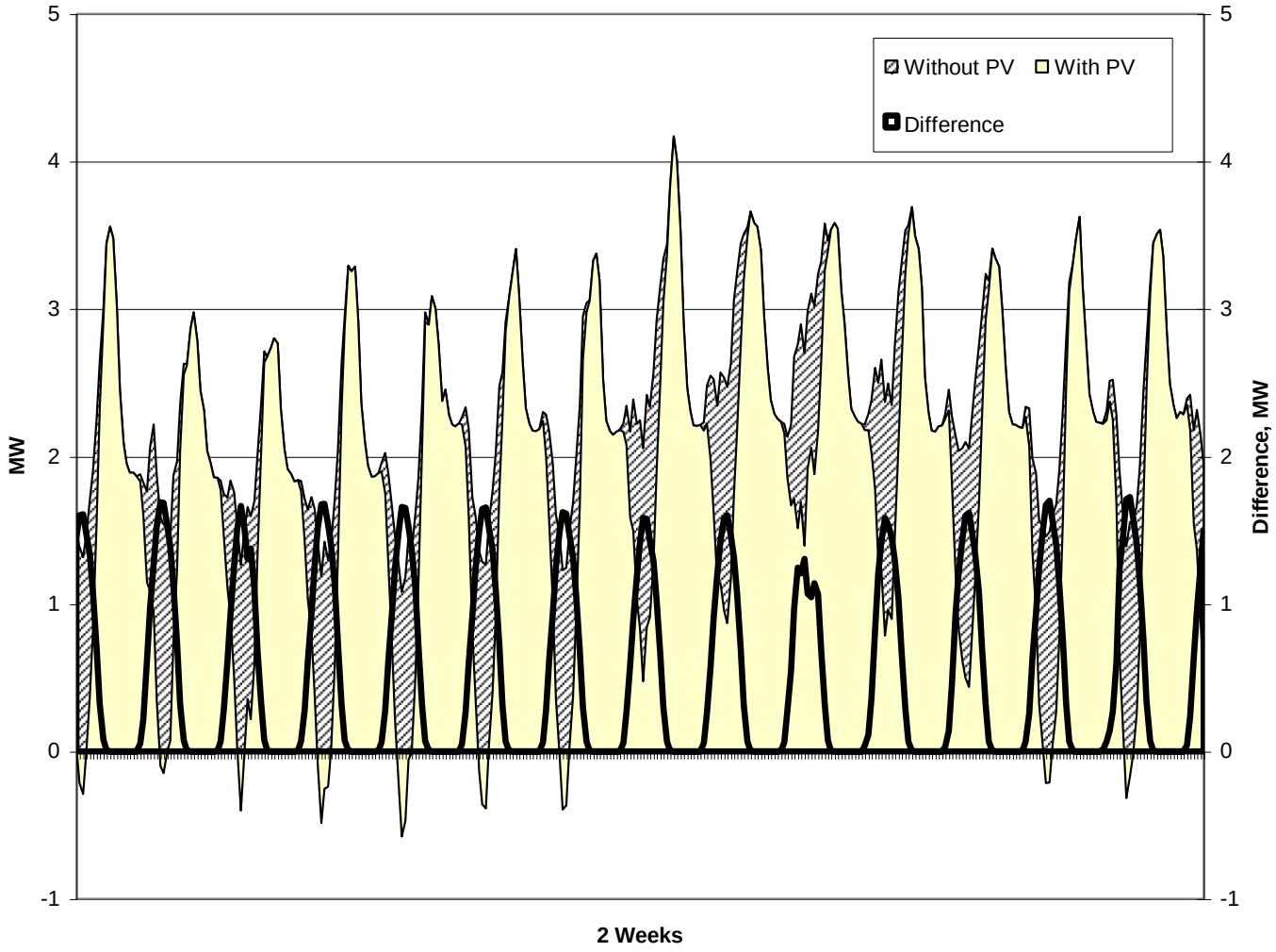
# Annual Losses

Peak load losses are not necessarily indicative of annual losses

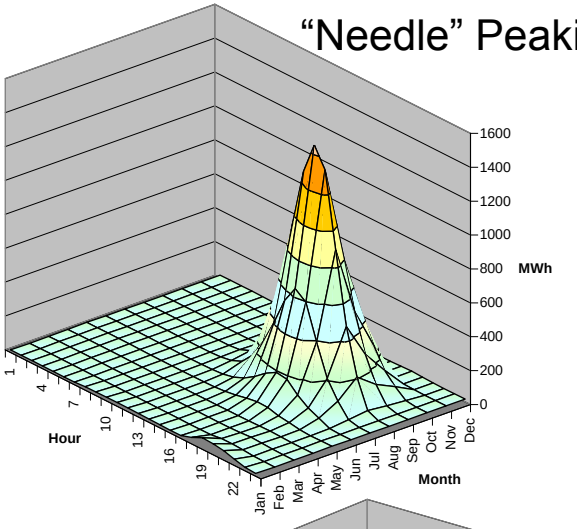


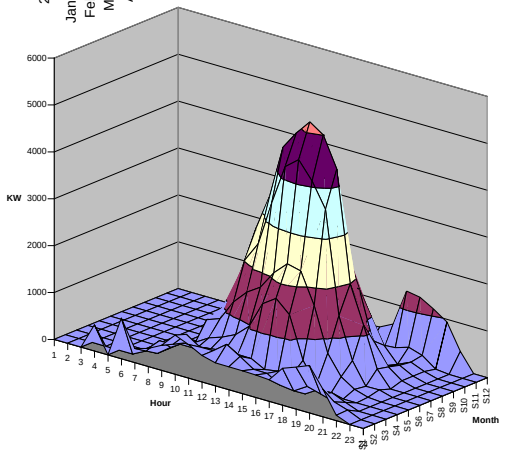



# Solar PV Simulation

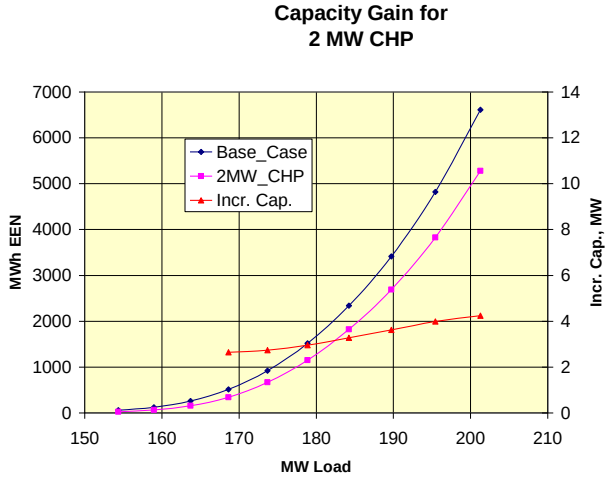


# Using DSS to Determine Incremental Capacity of DG




Broad Summer Peaking System




"How much more power can be served at the same risk of unserved energy?"





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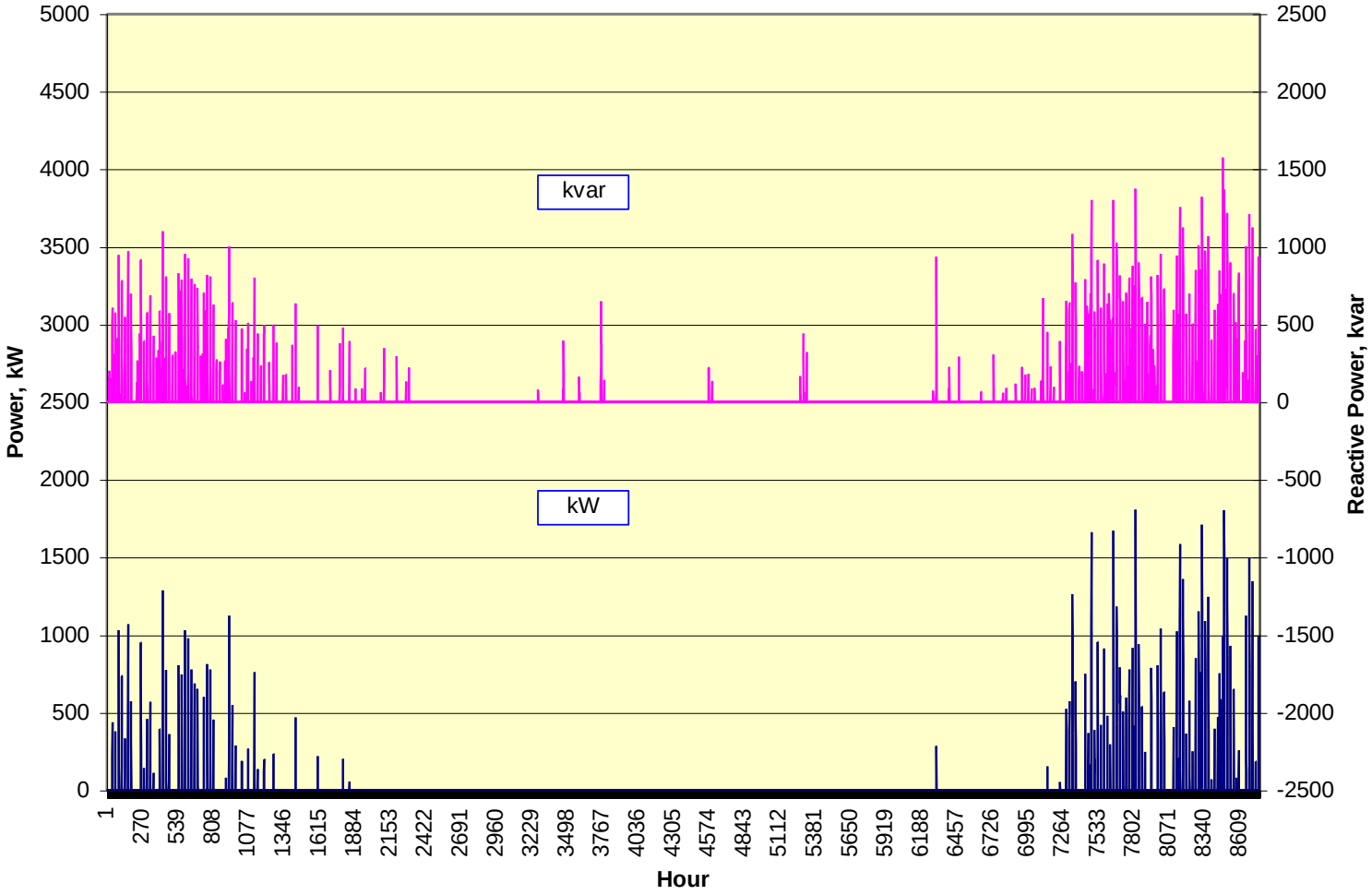
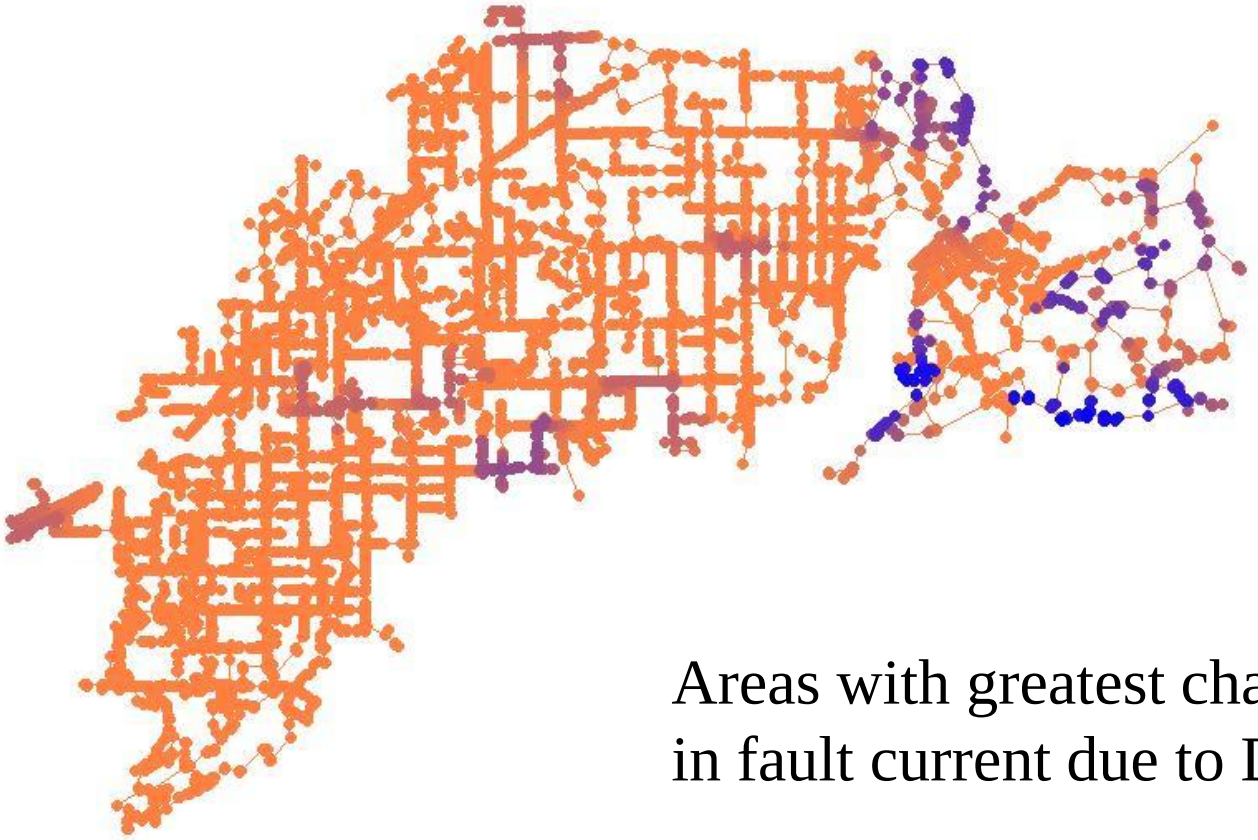
# DG Dispatch

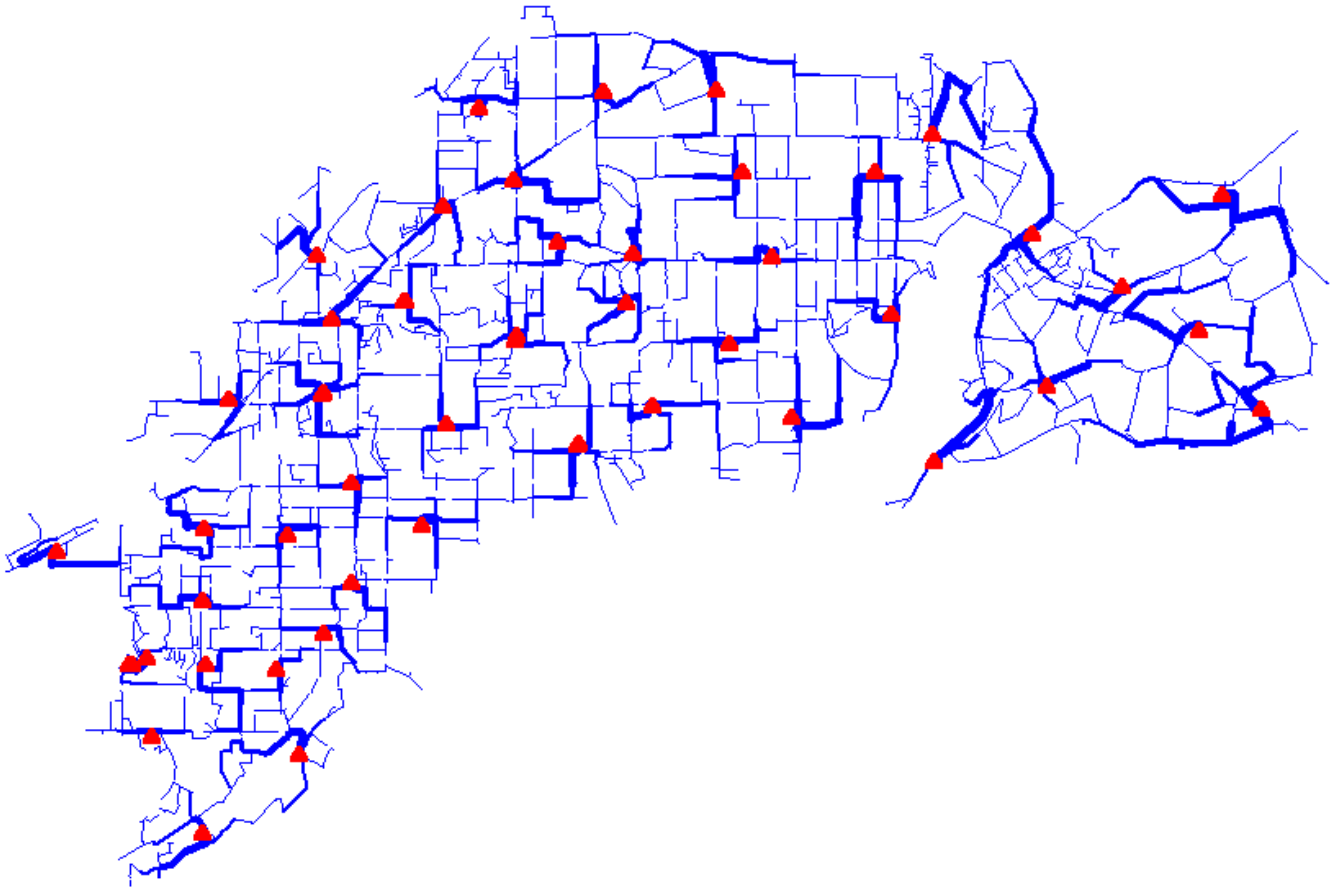


# DG Impact Visualization

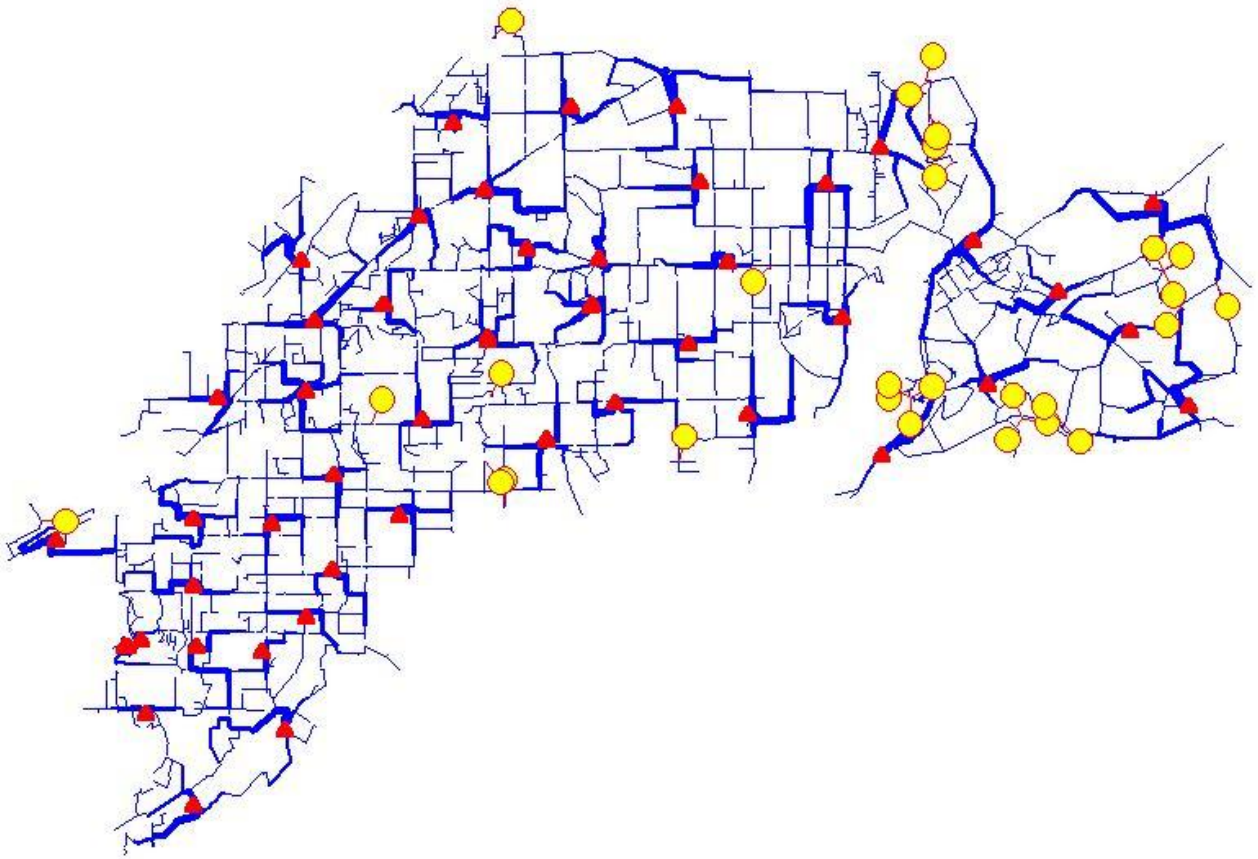


Areas with greatest change in fault current due to DG

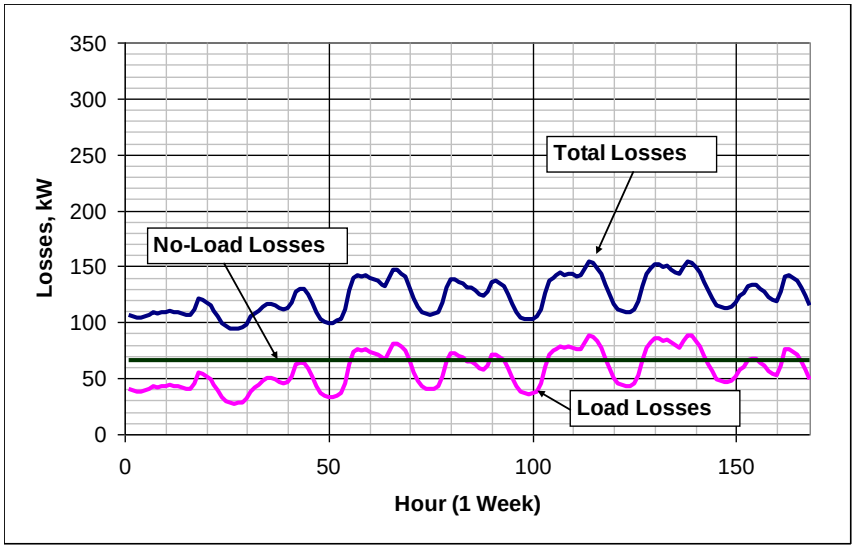
# Power Flow Visualization



# Optimal DG Siting

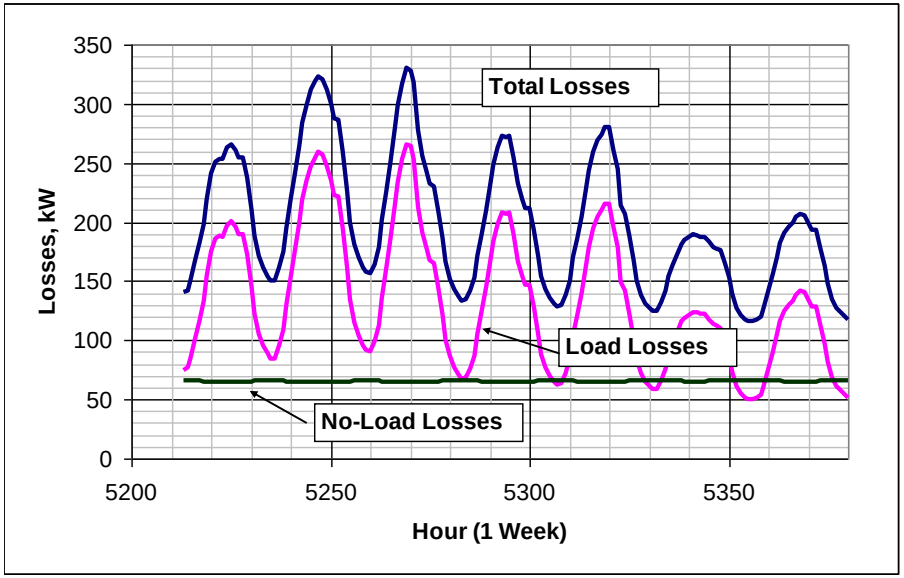


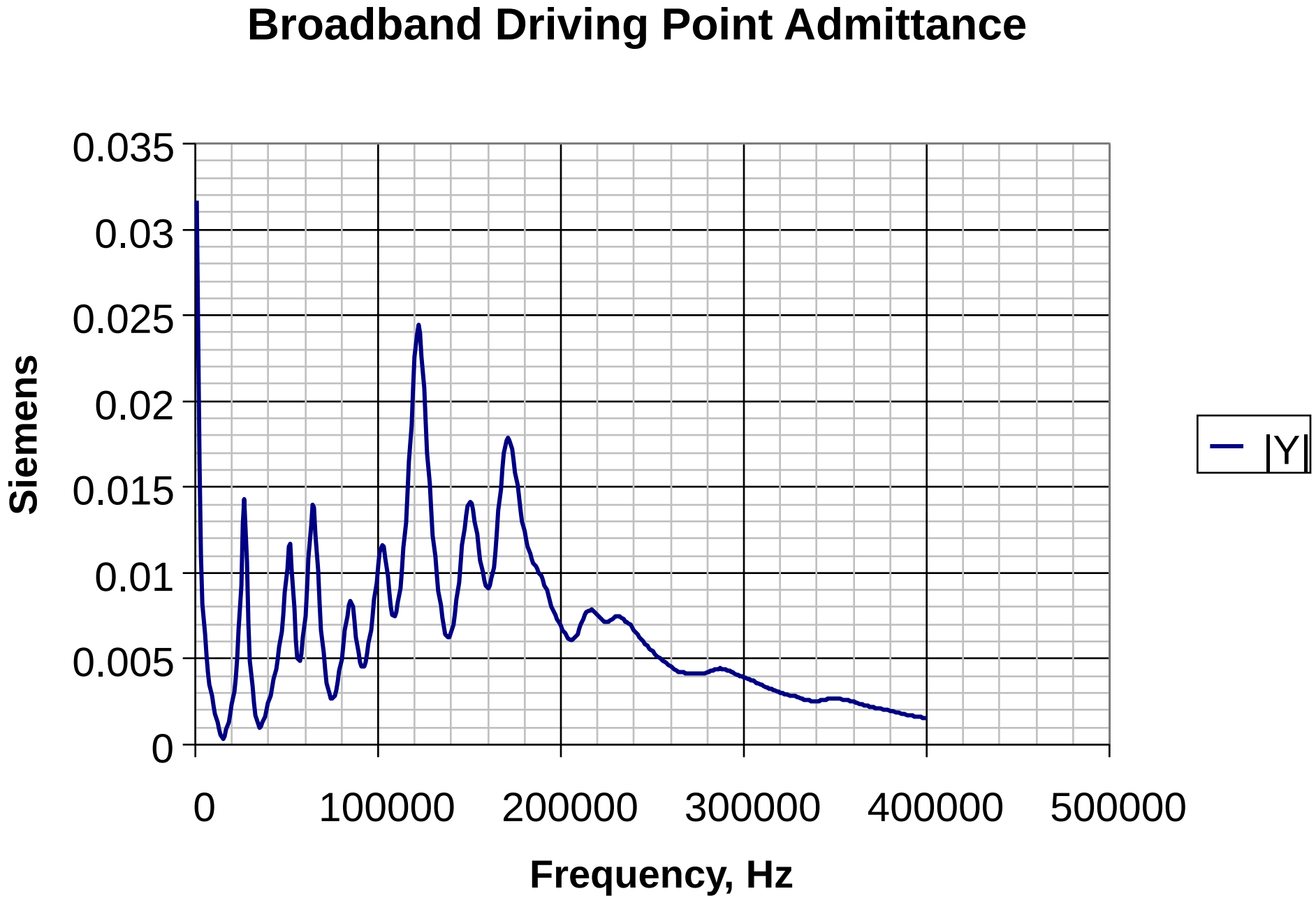
# Power Distribution Efficiency



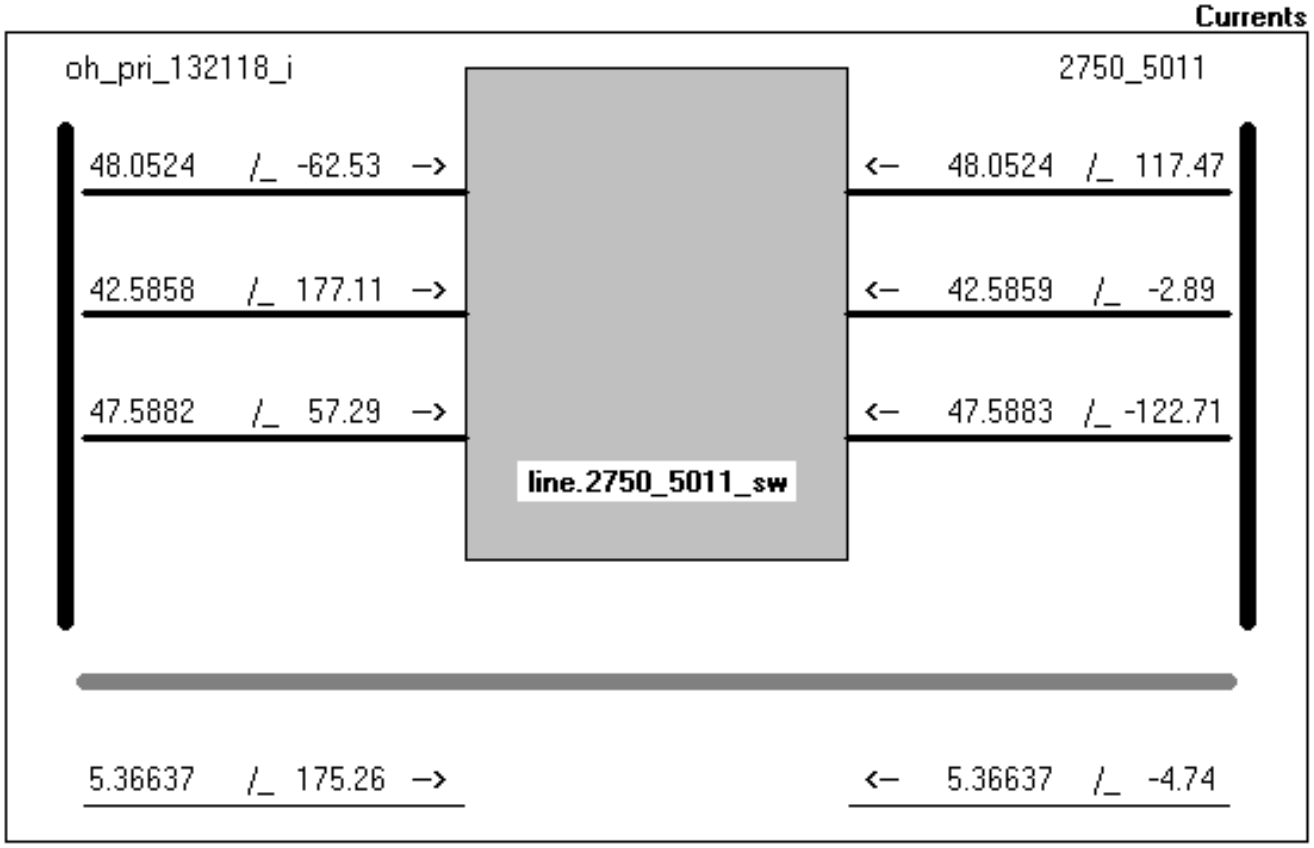

Light Load Week

Peak Load Week

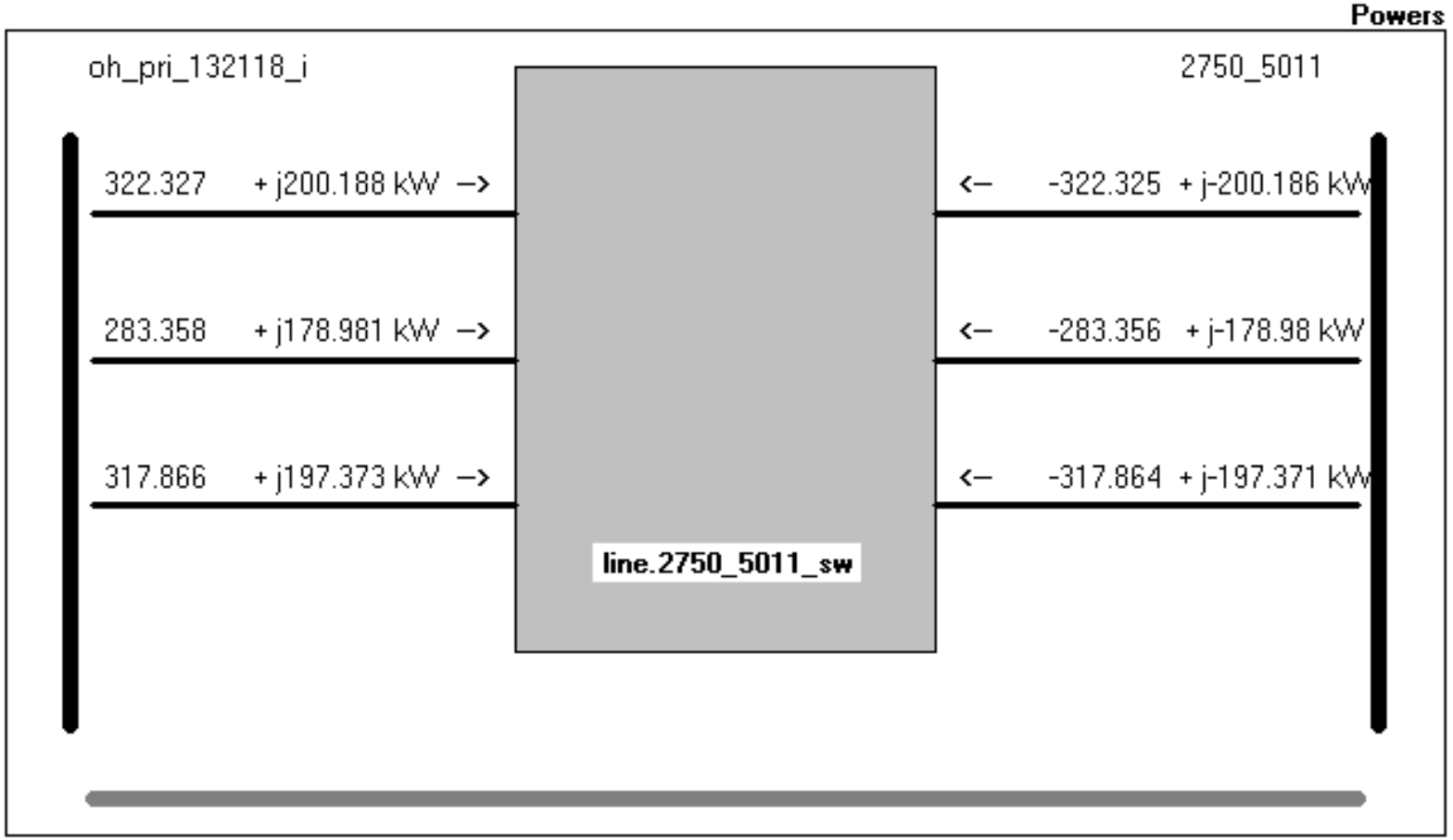



Broadband Driving Point Admittance
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
Siemens
0
100000
200000
300000
400000
500000
Frequency, Hz
|Y|

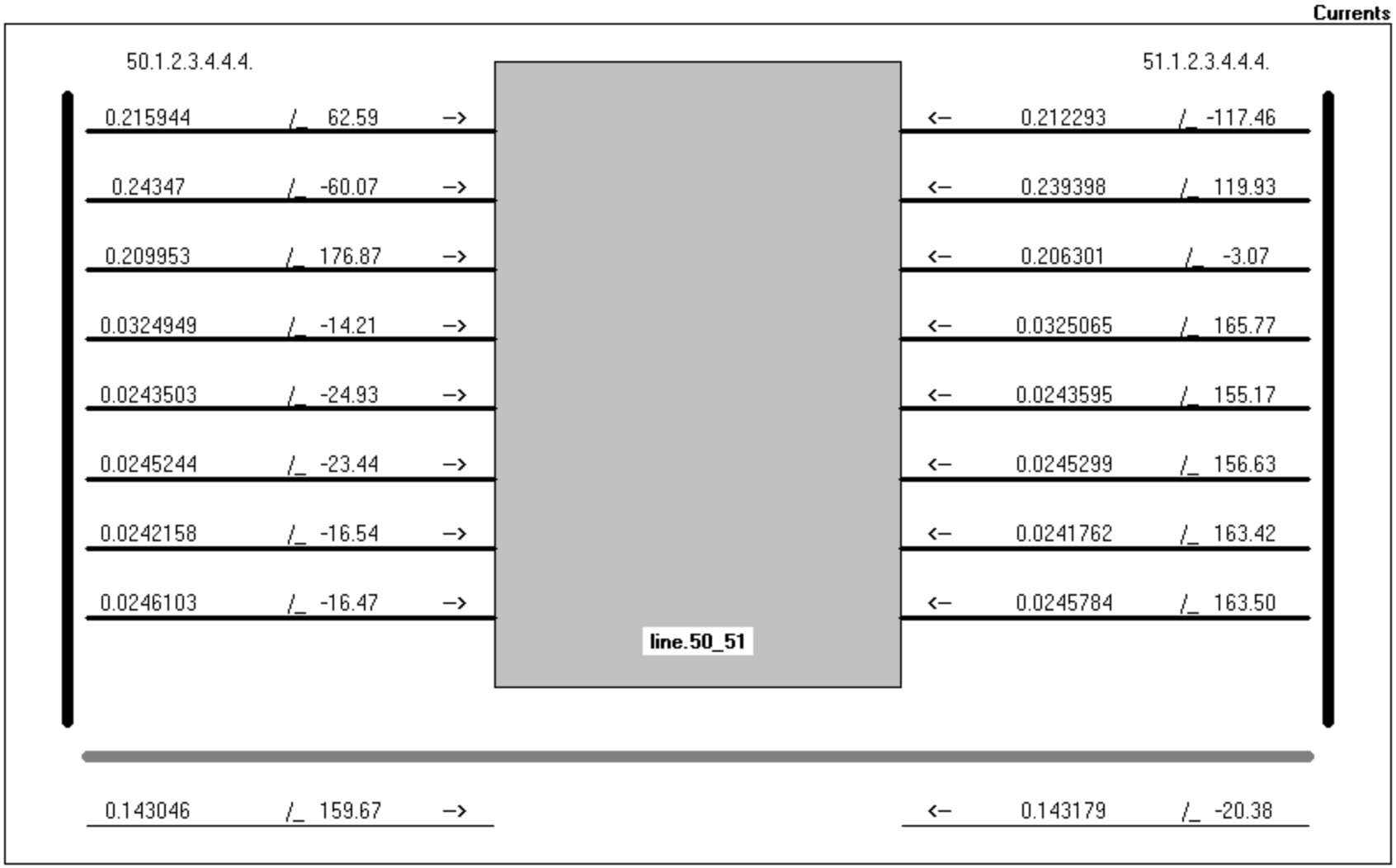
# Current



# Power



# A Bit More Complicated …



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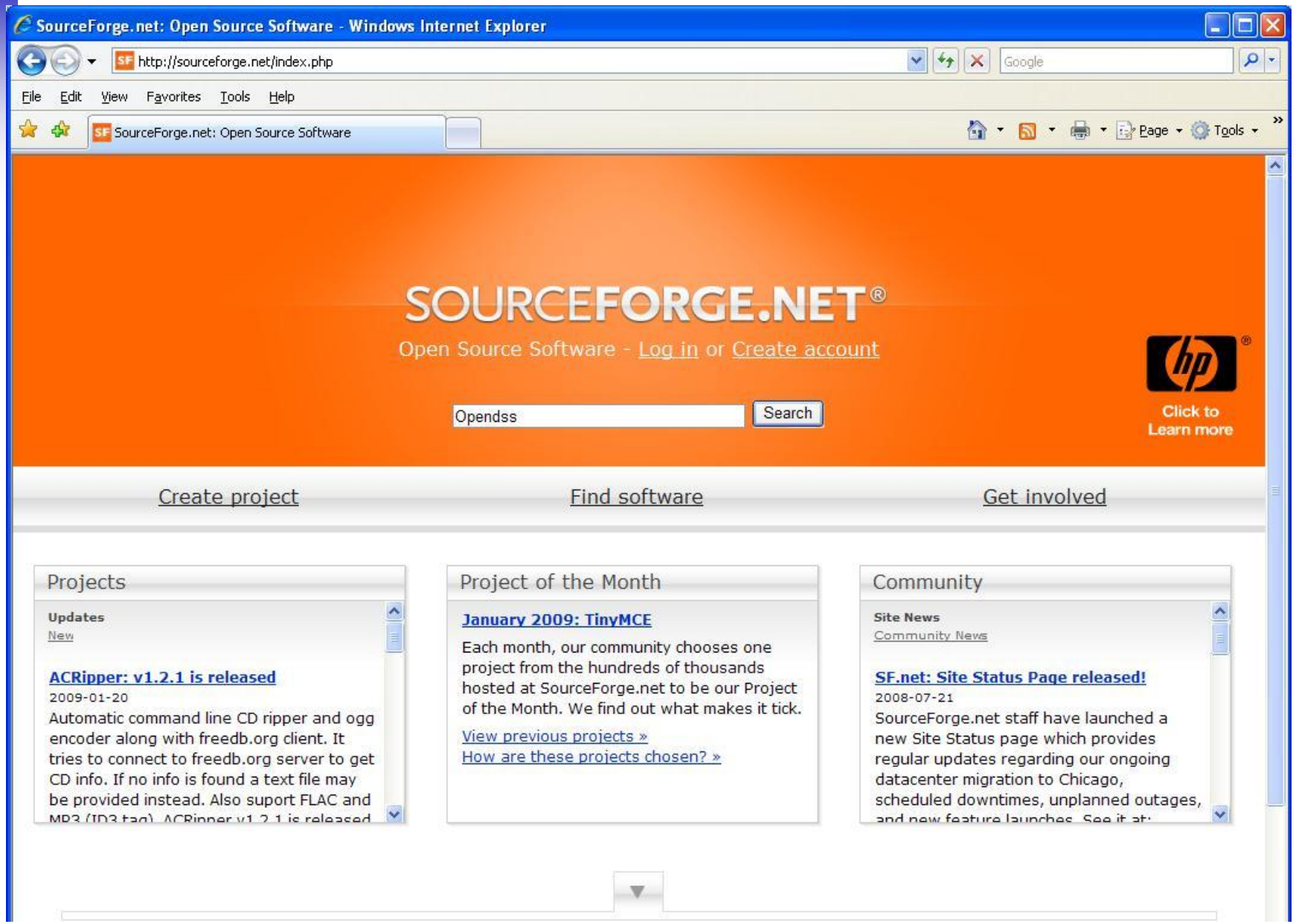
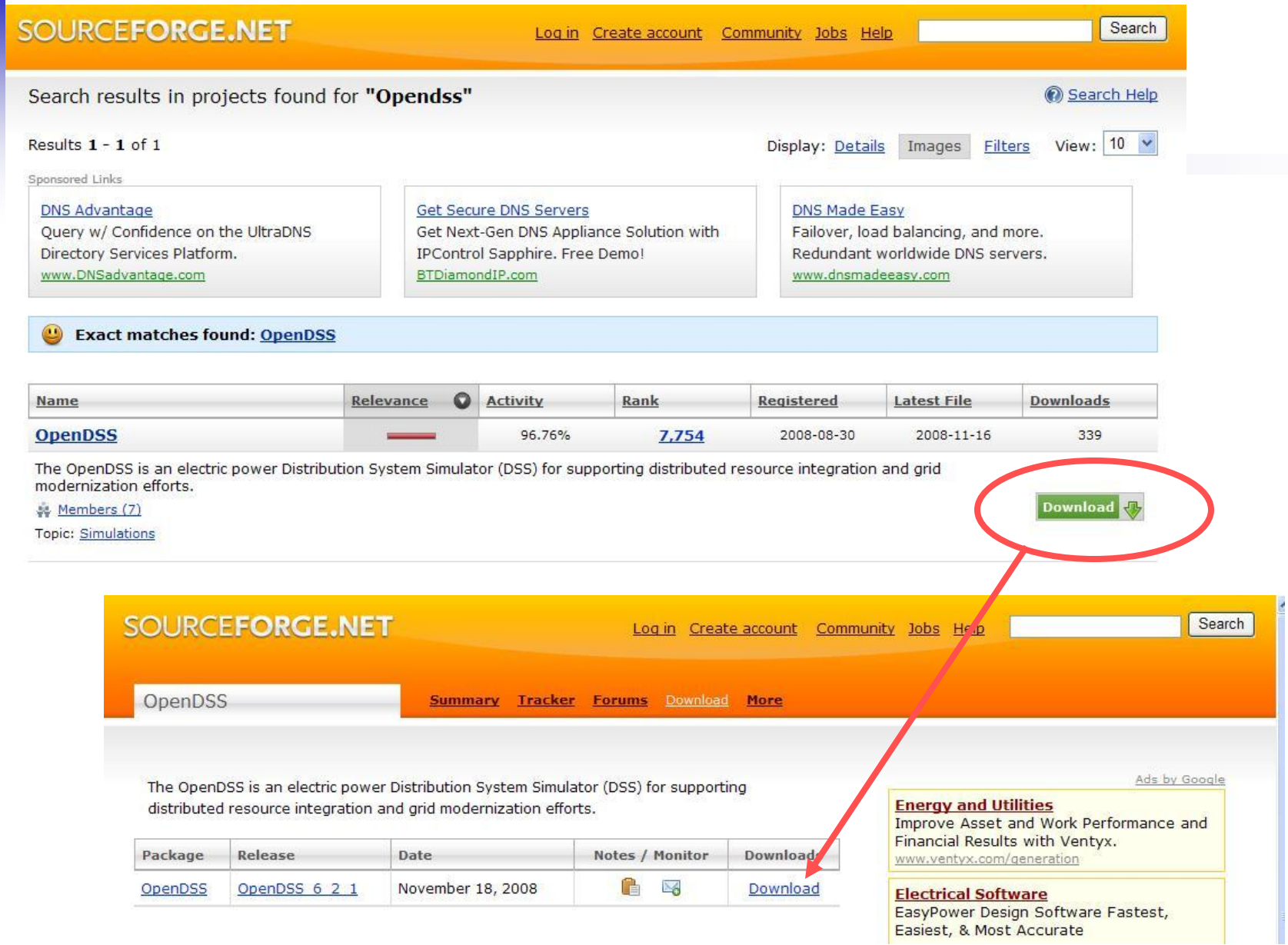
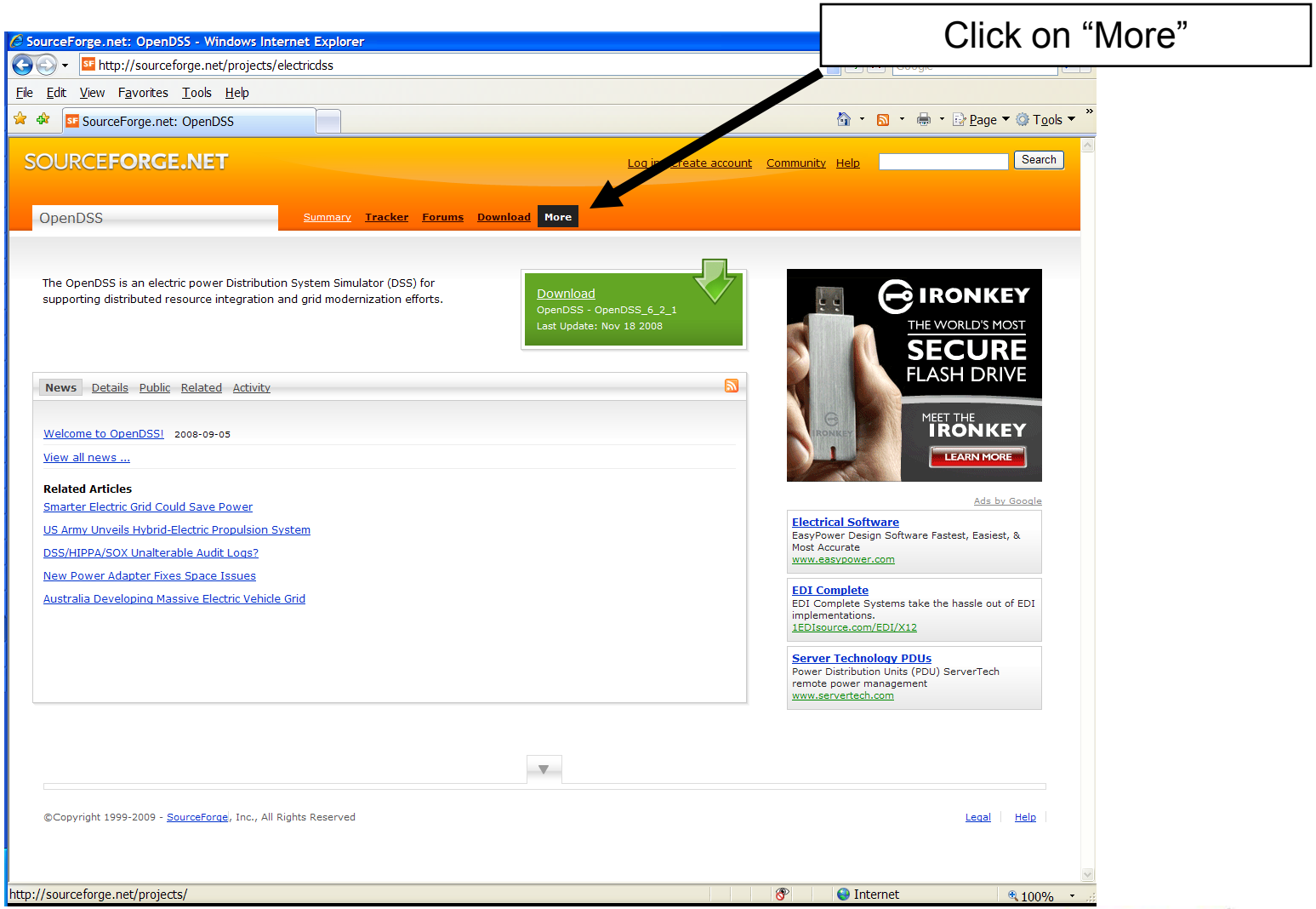
# Installation

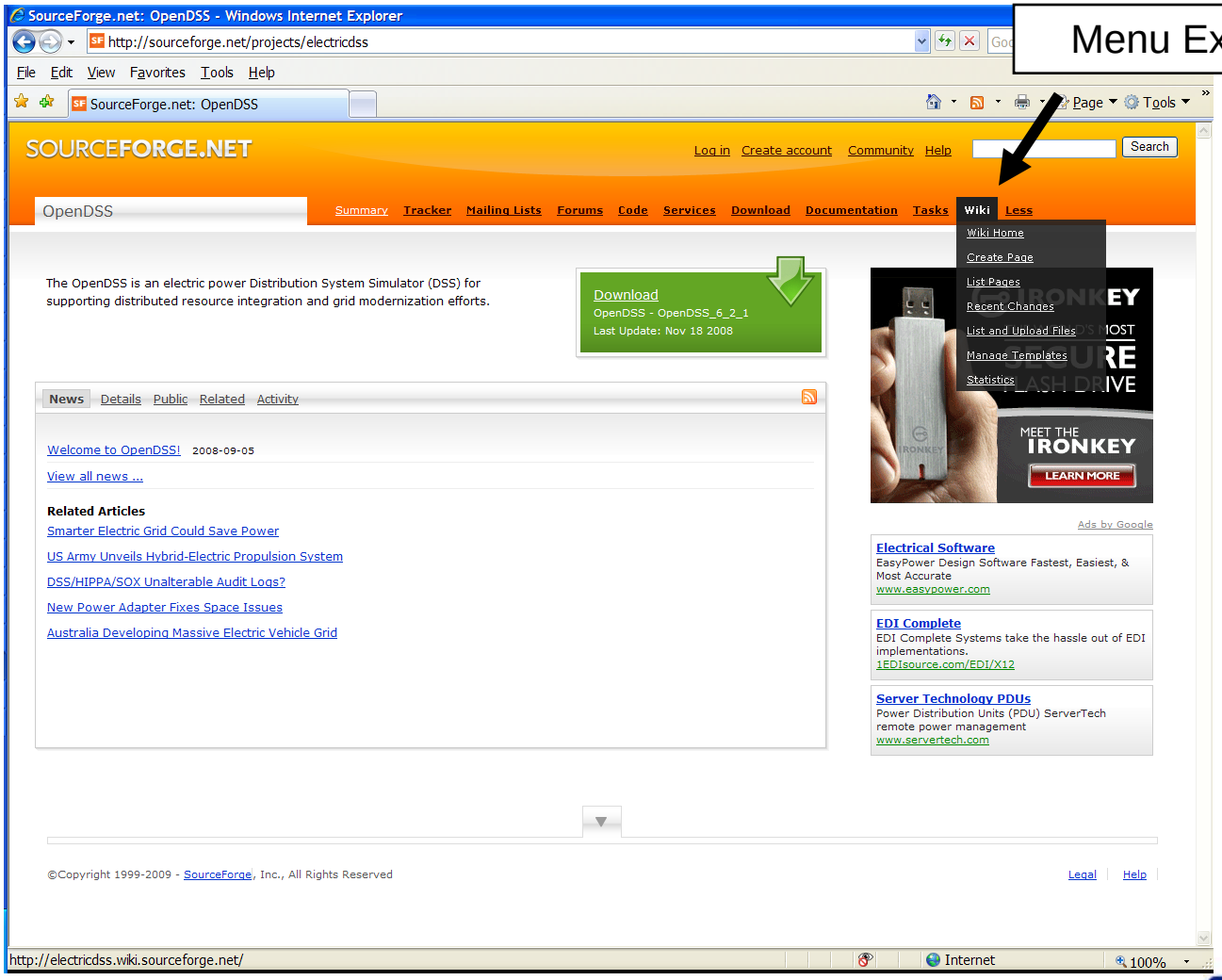




# Finding the Wiki …



# Finding the Wiki, cont'd




Menu Expands; Select Wiki





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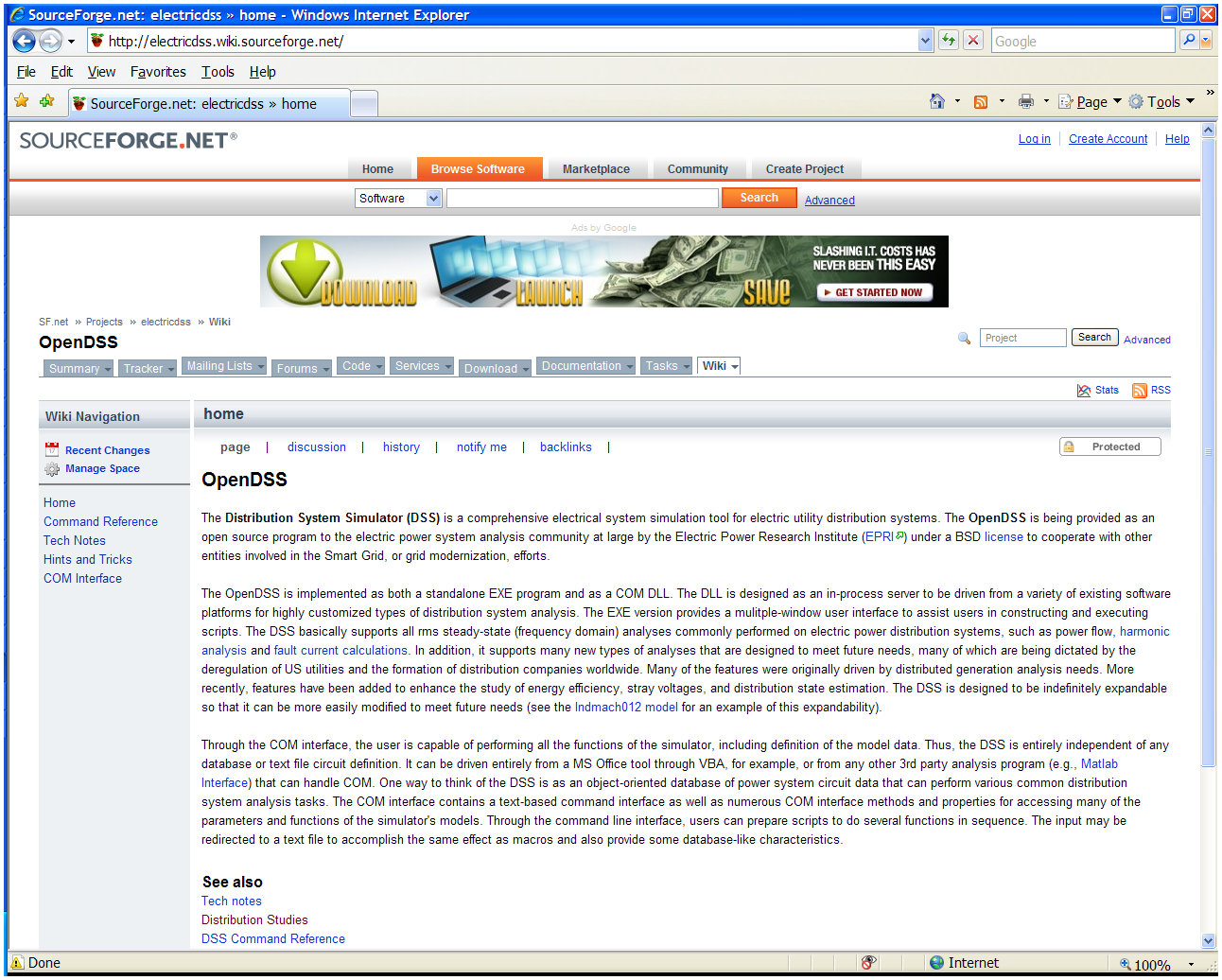
# Wiki Home Page (Latest documentation)





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# Program Files

- OpenDSS.EXE — Standalone EXE
- OpenDSSEngine.DLL — In-process COM server
- KLUSolve.DLL — Sparse matrix solver
- DSSgraph.DLL — DSS graphics output

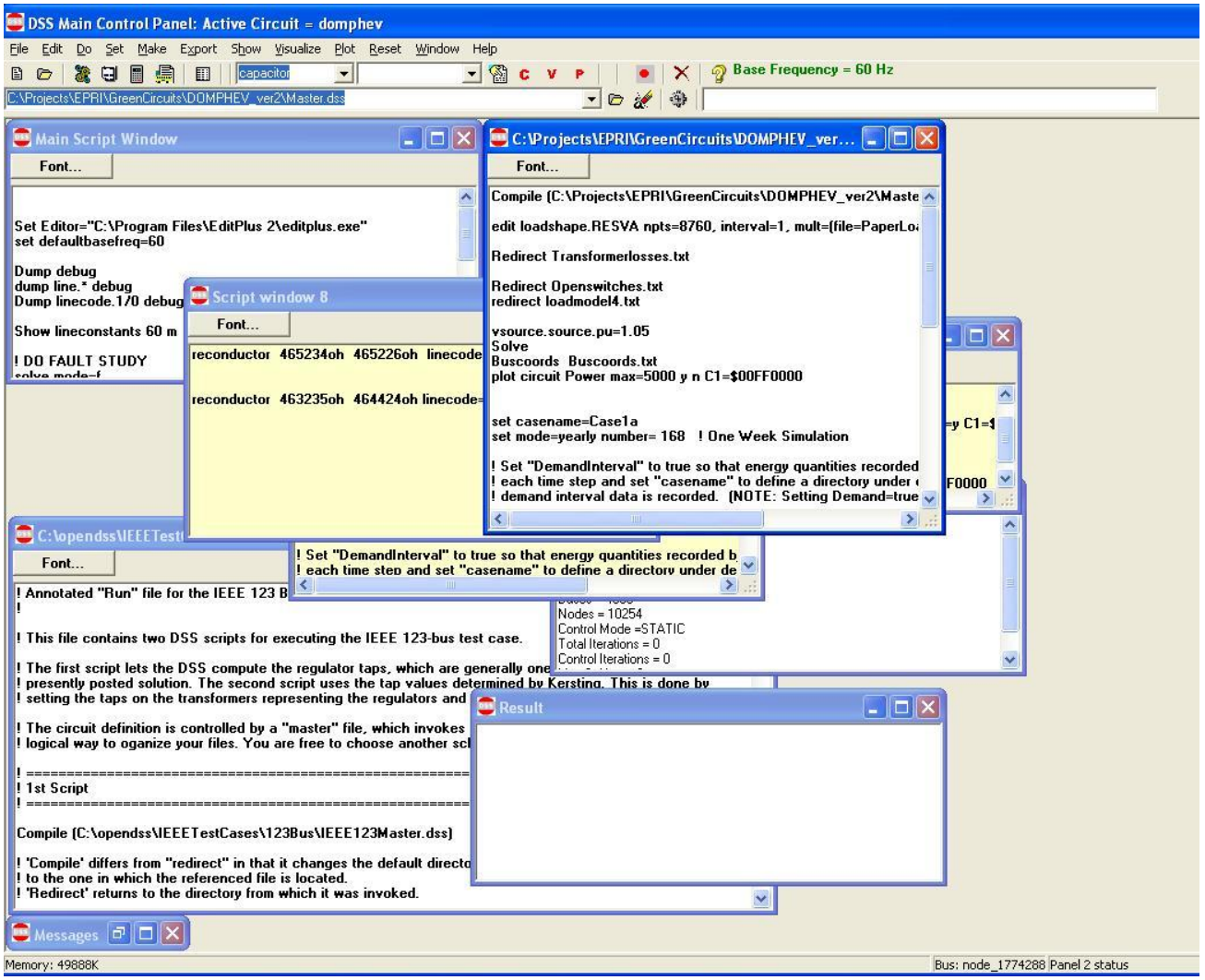
- Copy these files to the directory (folder) of your choice
  - Typically **`c:\OpenDSS`** *or* **`c:\Program Files\OpenDSS`**

- If you intend to drive OpenDSS from another program, you will need to register the COM server

# Registering the COM Server

- In DOS window, change to folder where you installed it and type:
  - **`Regsvr32 OpenDSSEngine.DLL`**
- The Server shows up as "**OpenDSSEngine.DSS**" in the Windows Registry
- For Example, to include in Matlab:
  - **`DSSobj = actxserver('OpenDSSEngine.DSS');`**
- In VBA:
  - **`Public DSSobj As OpenDSSEngine.DSS`**
    **`Set DSSobj = New OpenDSSEngine.DSS`**

# OpenDSS Standalone EXE User Interface





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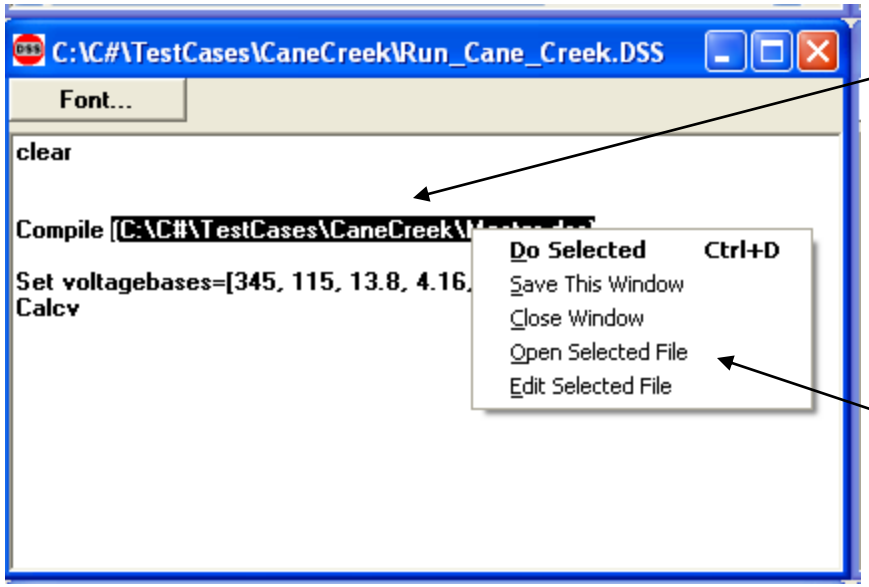
# Executing Scripts in the EXE



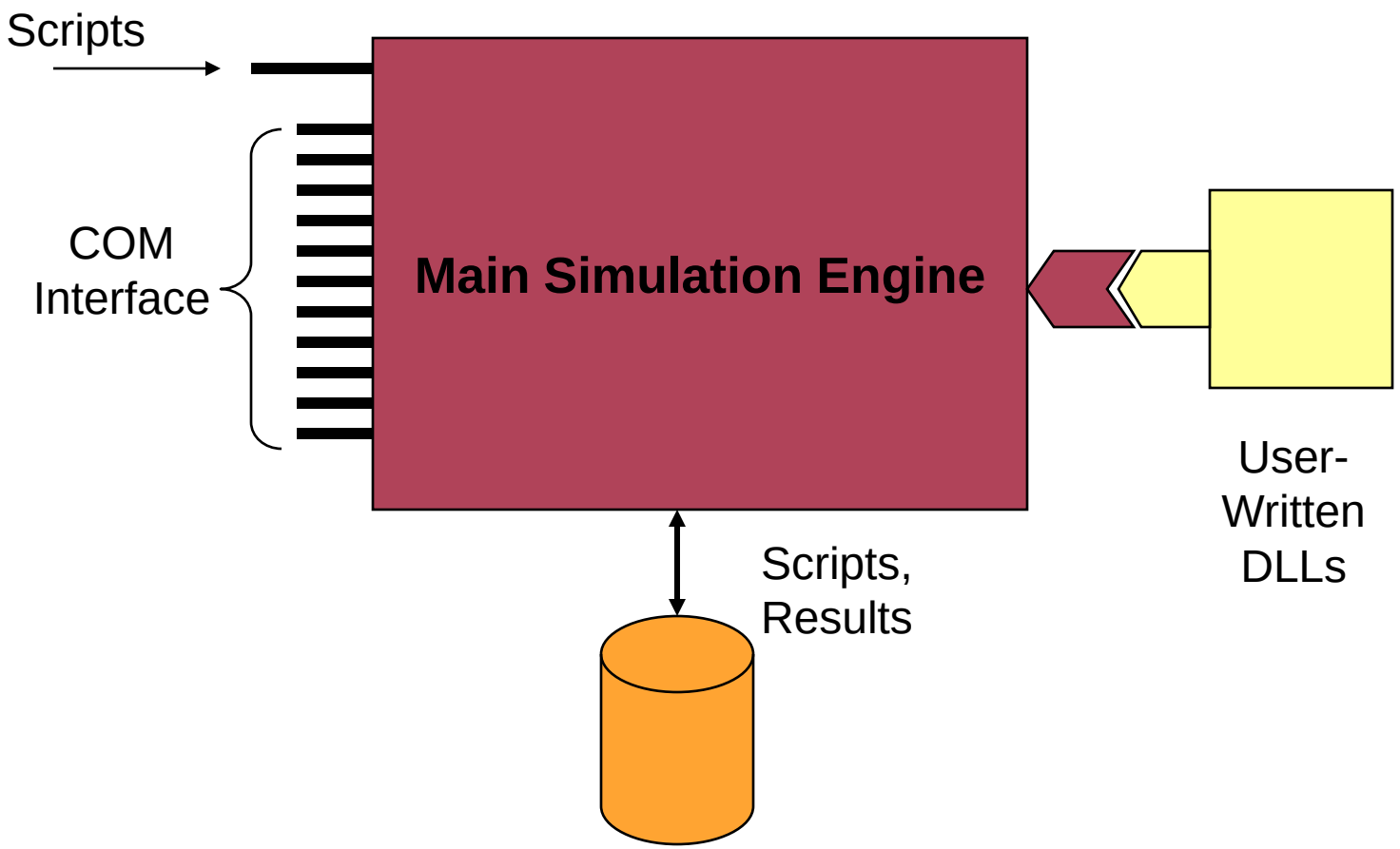

Select all or part of a line

Right-Click to get this pop-up menu

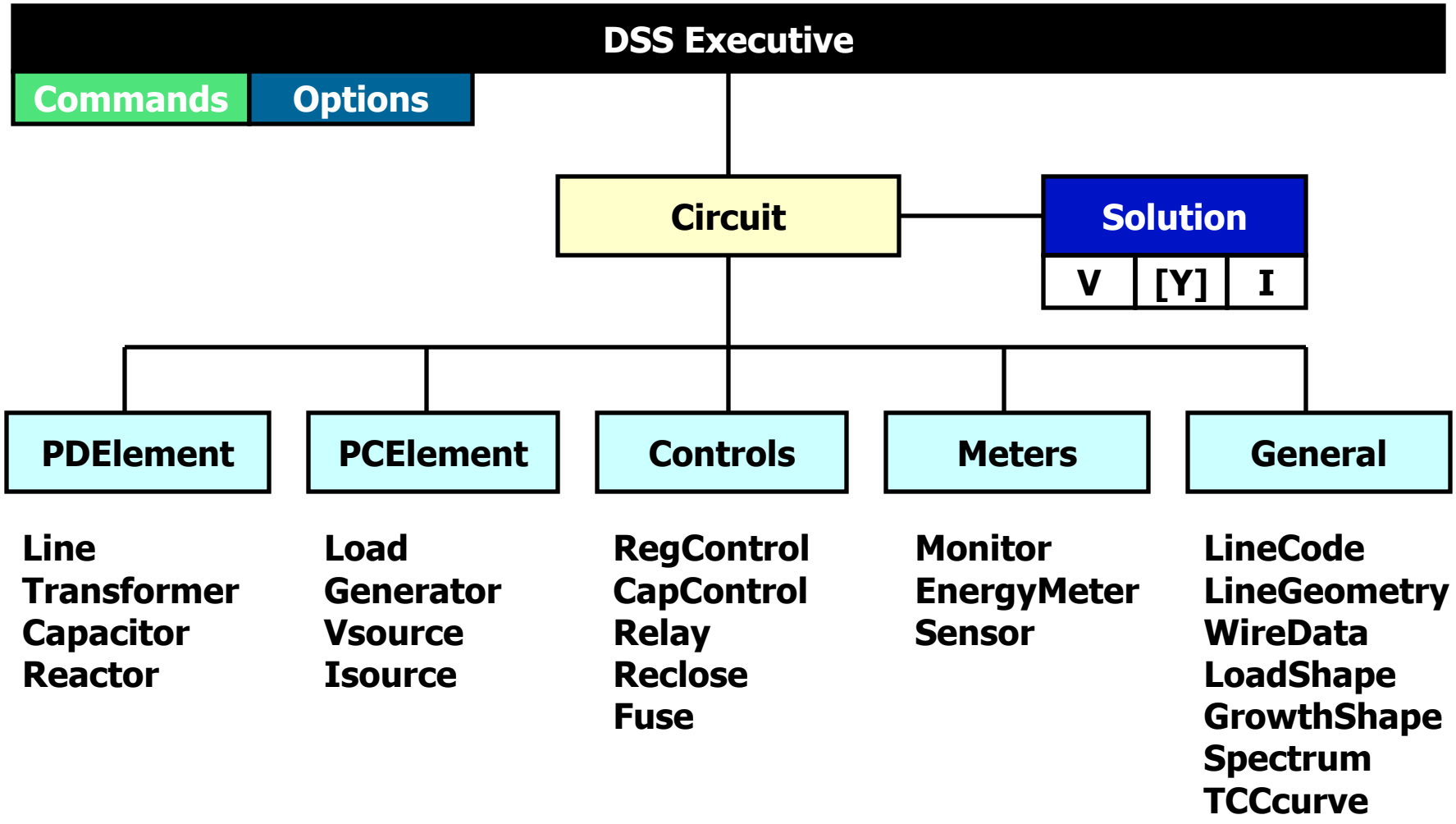
DSS executes selected line or opens selected file name

Any script window may be used at any time.

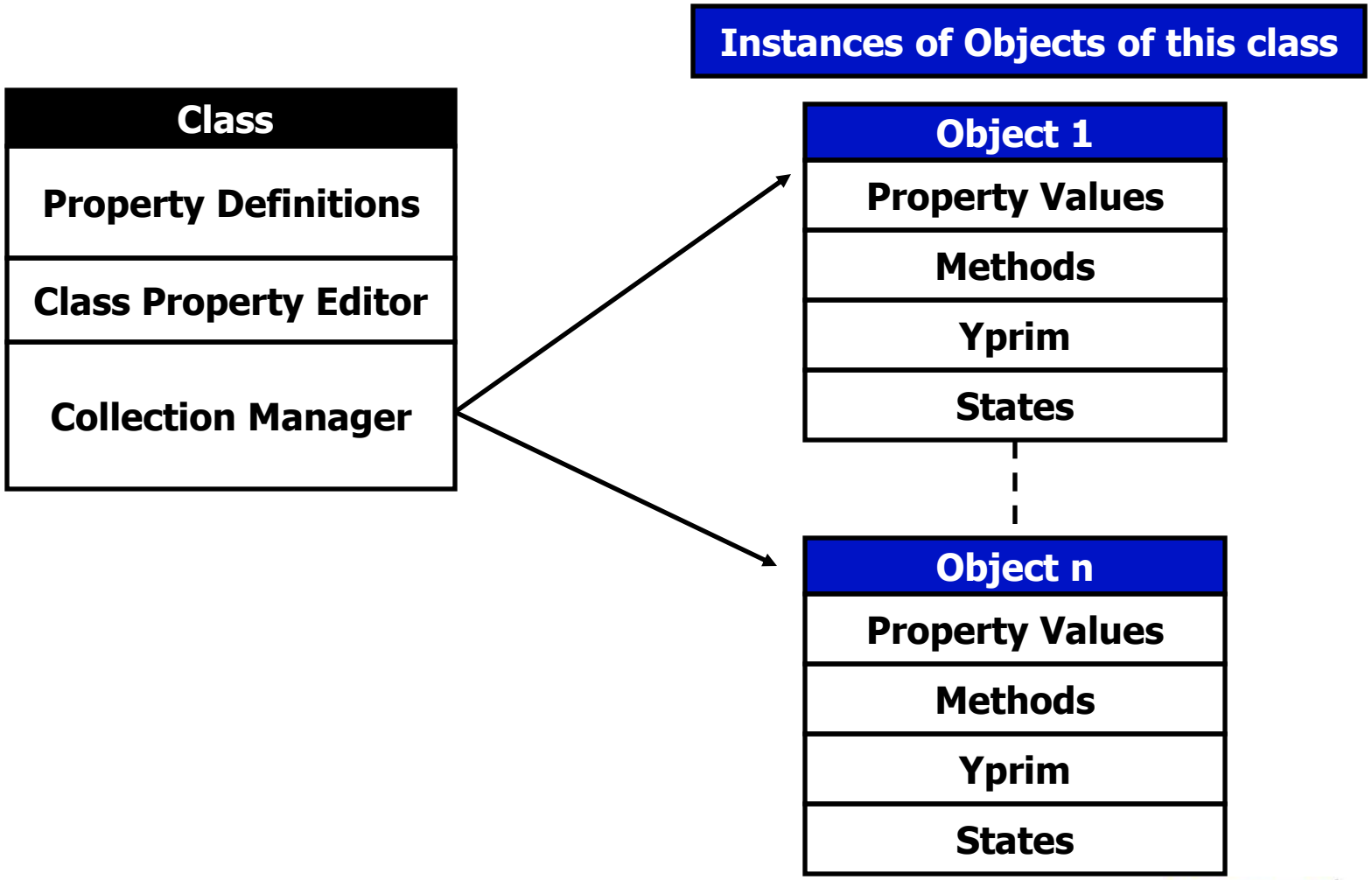
# DSS Structure



# DSS Object Structure



# DSS Class Structure



# DSS Classes

- Power Delivery (PD) Elements
  - **Line**
  - **Transformer**
  - **Reactor**
  - **Capacitor**
- Power Conversion (PC) Elements
  - **Load**
  - **Generator**
  - **Vsource**
  - **Isource**
- Control Elements
  - **RegControl**
  - **CapControl**
  - **Recloser**
  - **Relay**
  - **Fuse**

- Metering Elements
  - Monitor
  - EnergyMeter
  - Sensor
- General
  - LineCode
  - LineGeometry
  - Loadshape
  - Growthshape
  - Wiredata
  - Spectrum
  - TCC Curves

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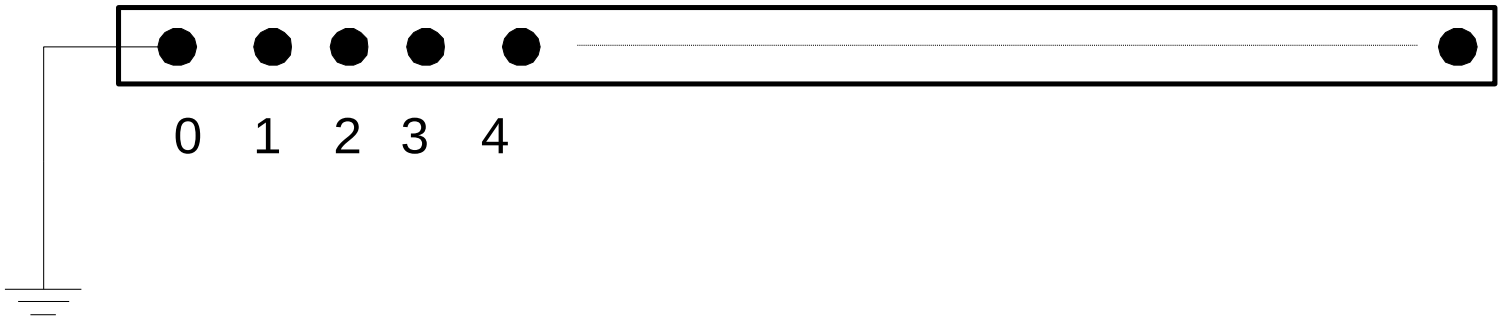
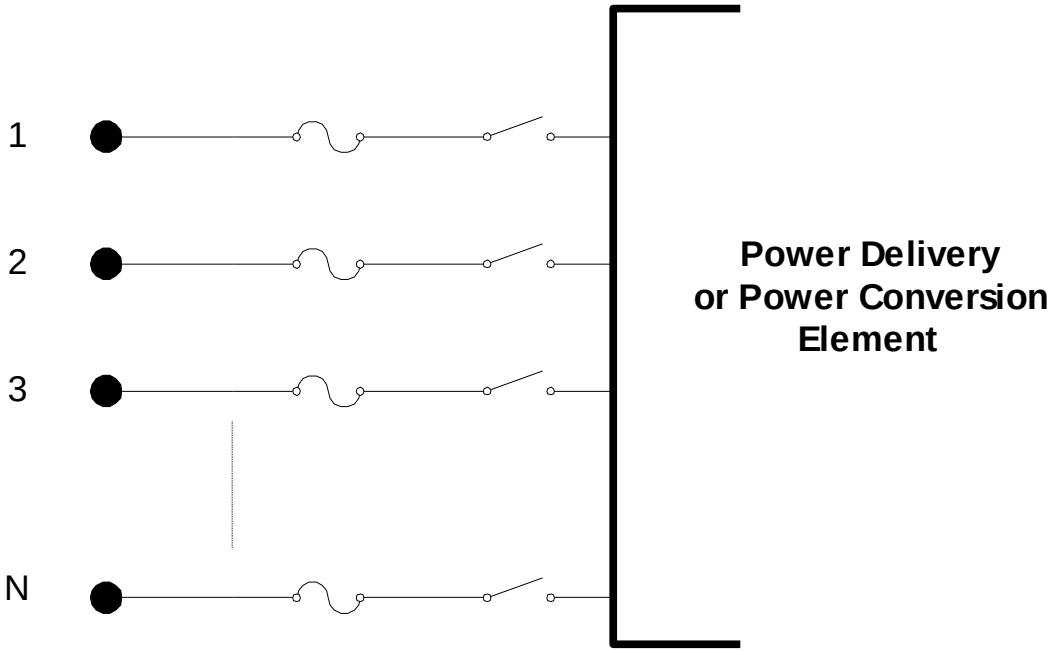
# Circuit Principles

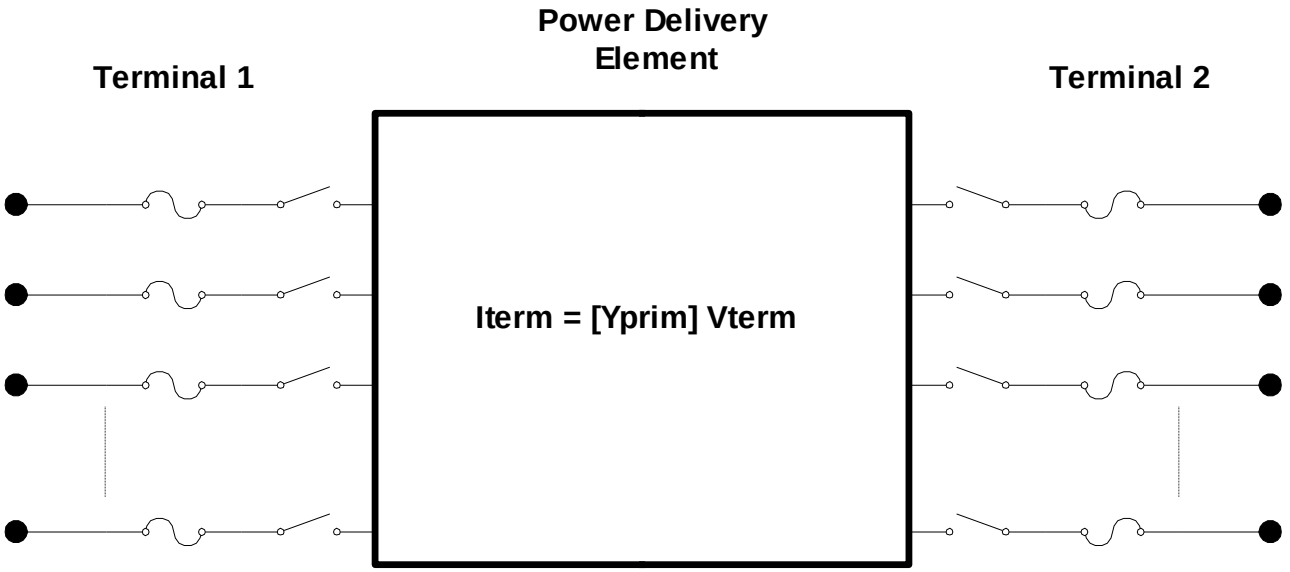
# DSS Bus Model



# DSS Terminal Definition

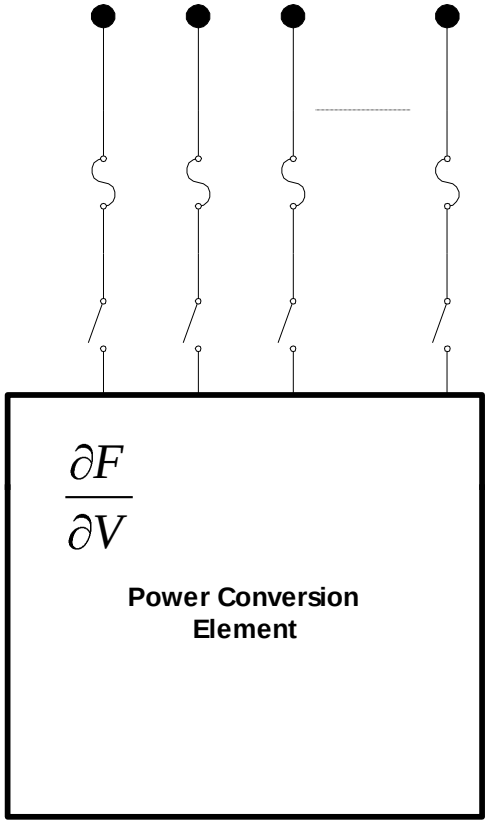


# Power Delivery Elements

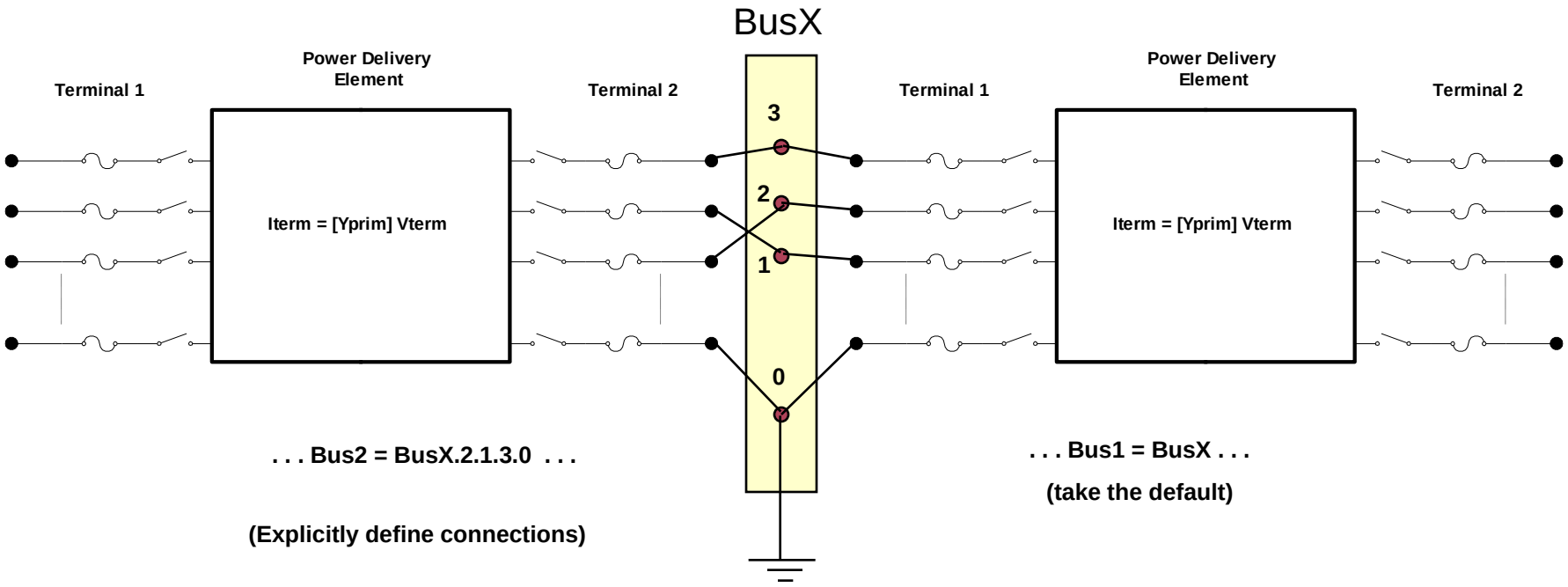


# Power Conversion Elements

$I_{Term}(t) = \mathbf{F}(V_{Term}, [State], t)$



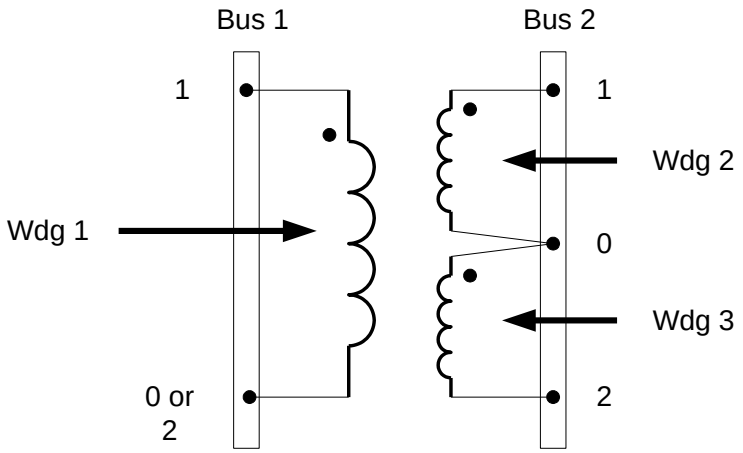
# Circuit Elements are Connected together at the Nodes of Buses




DSS Convention: A *Terminal* can be connected to only one *Bus*. You can have any number of *Nodes* at a bus.

# Connections for 1-Phase Residential Transformer

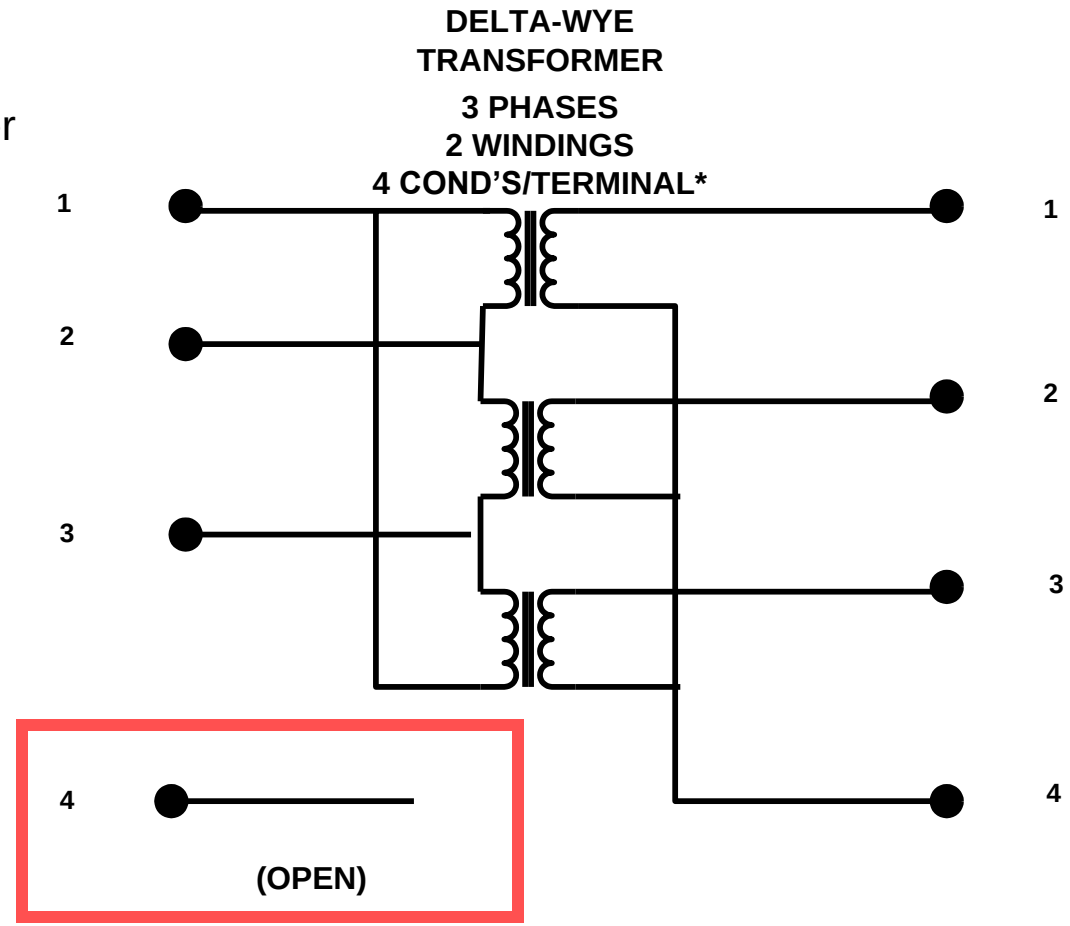
```
! Line-to-Neutral Connected 1-phase Center-tapped transformer
New  Transformer.Example1-ph  phases=1  Windings=3
~ Xhl=2.04  Xht=2.04  Xlt=1.36  %noloadloss=.2
~ Buses=[bus1.1 bus2.1.0  bus2.0.2]   !!! Note polarity
~ kVs=[7.2 .12  .12]     ! ratings of windings
~ kVAs=[25 25 25]
~ %Rs = [0.6  1.2  1.2]
~ conns=[wye wye wye]    ! default
```




Center-Tapped 1-Phase Transformer Model

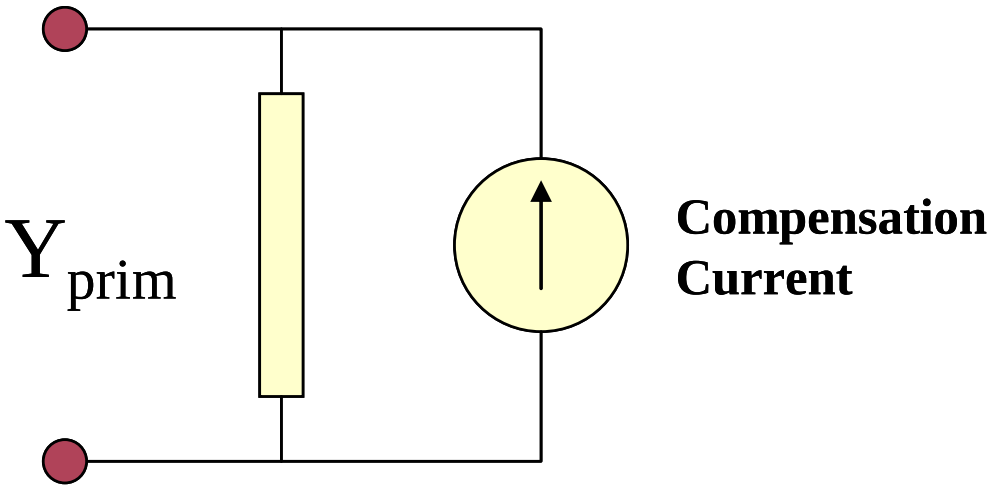
# All Terminals of a Circuit Element Have Same Number of Conductors

3-Phase Transformer



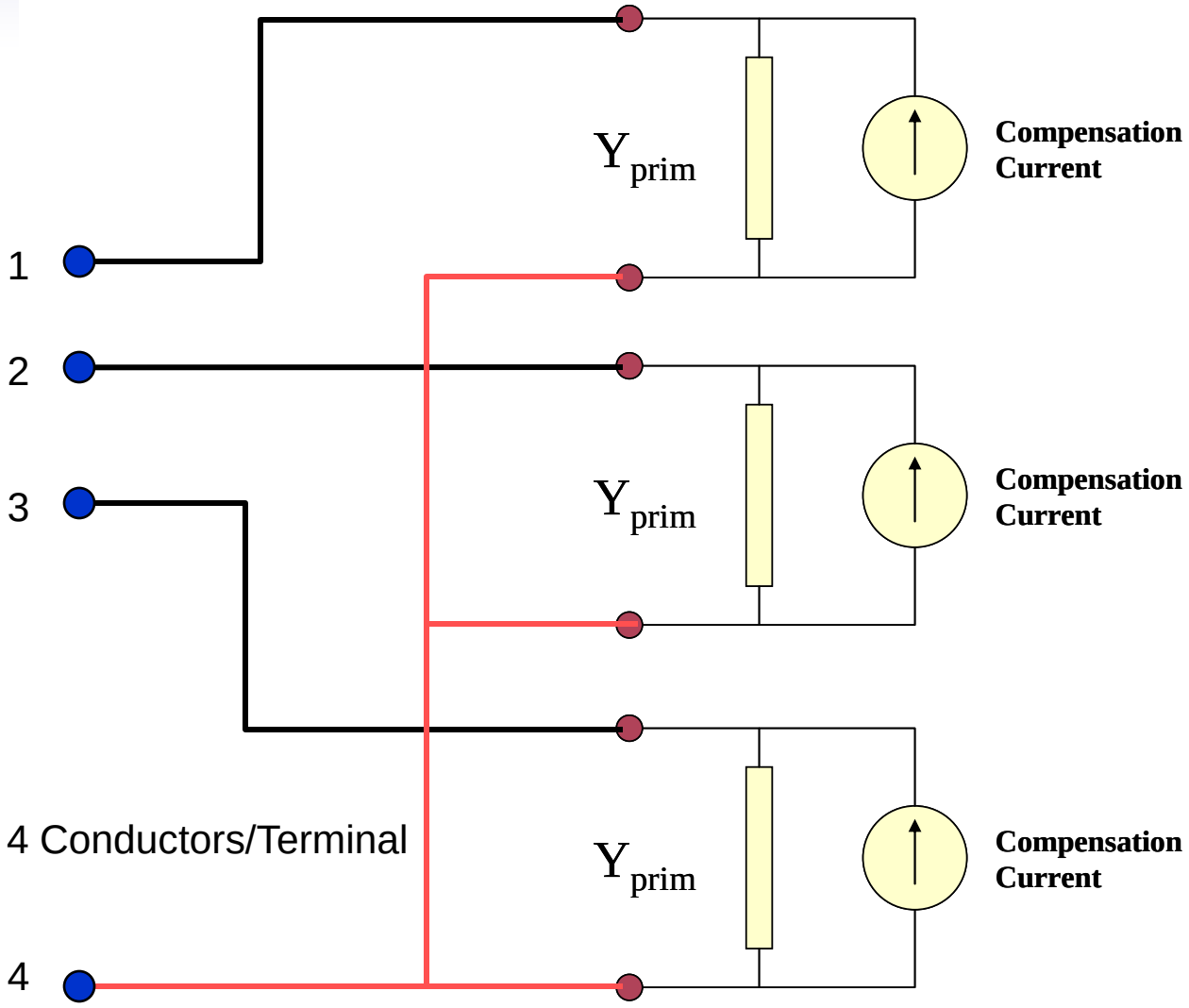

*** MUST HAVE THE SAME NUMBER OF CONDUCTORS FOR EACH TERMINAL**

# Load (a PC Element)

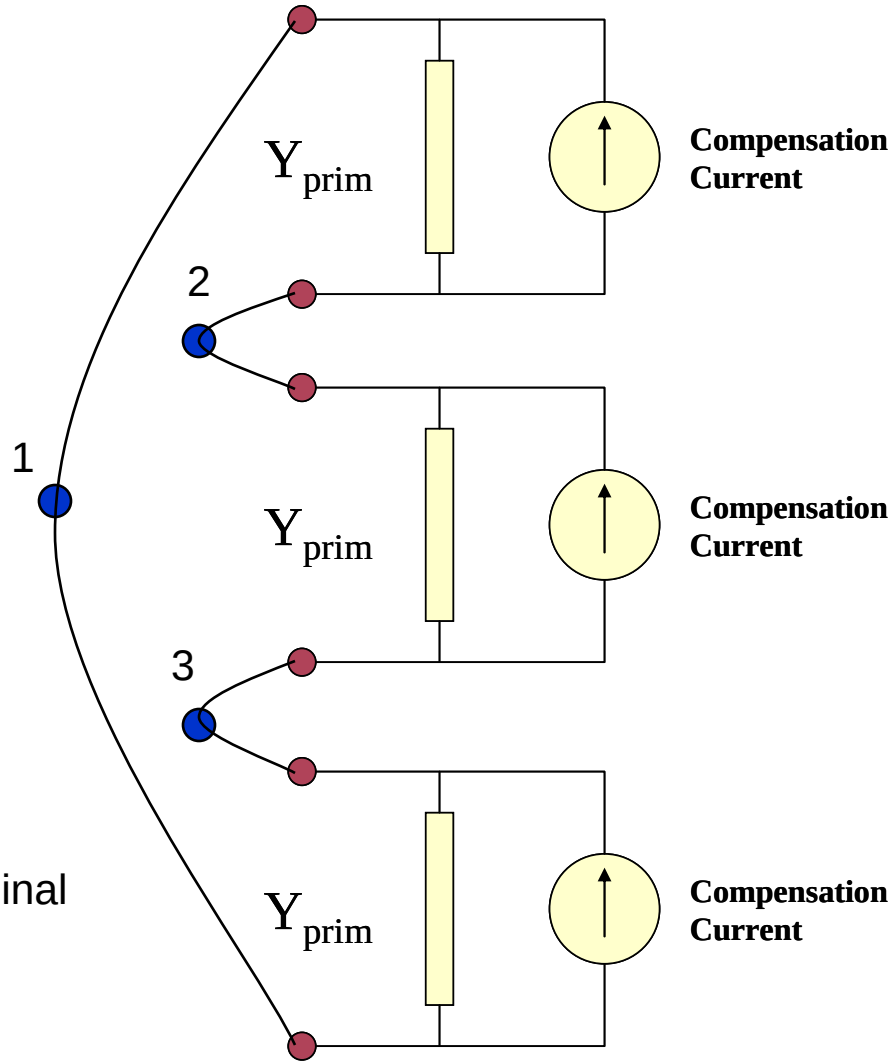



(One-Line Diagram)

# Load - 3-phase Y connected

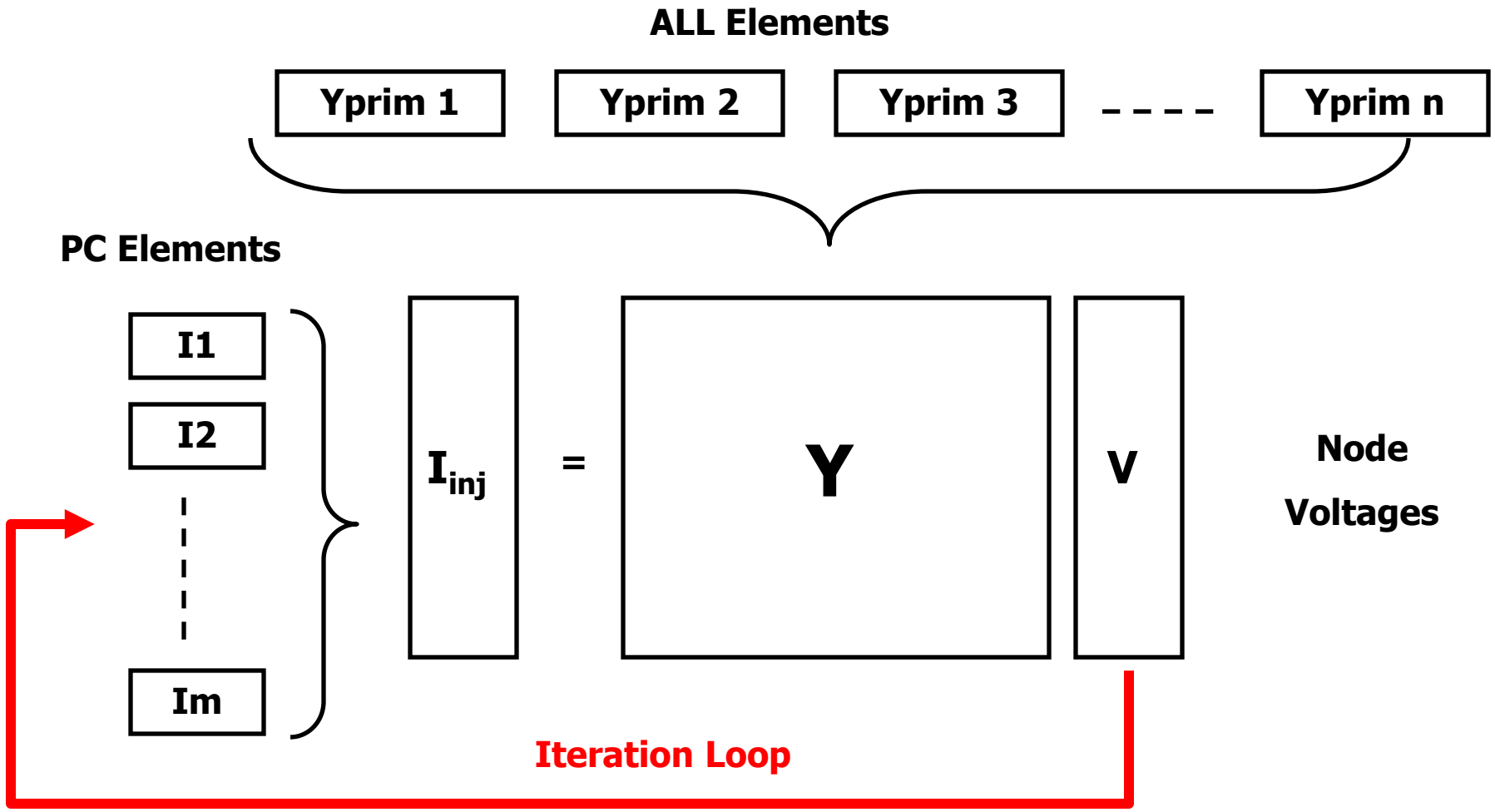


# Load - 3-phase Delta connected




3 Conductors/Terminal

# Putting it All Together

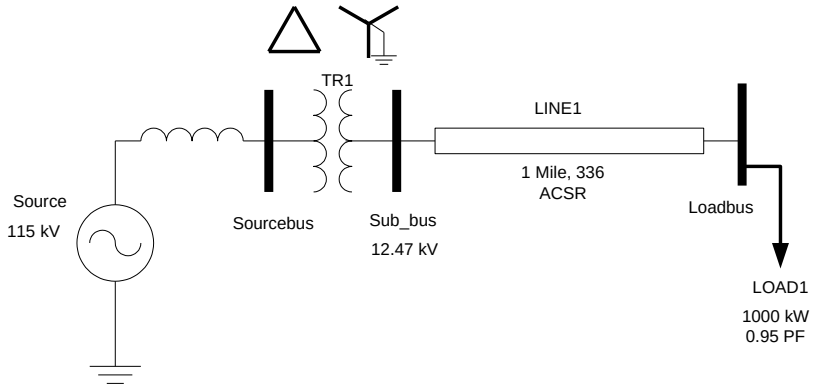


# Solution Speed

- Distribution systems generally converge quite rapidly with this method.
- The OpenDSS program seems to be on par with the faster commercial programs – or faster
- It is set up to run annual simulations easily
  - Our recommendation:
    - *Err on the side of running more power flow simulations*
    - That is, don't worry about the solution time until it proves to be a problem
    - That reveals more information about the problem.


# Scripting Basics

# A Basic Script




```
New Circuit.Simple     ! Creates voltage source  (Vsource.Source)
Edit Vsource.Source BasekV=115 pu=1.05  ISC3=3000  ISC1=2500  !Define source V and Z
New Transformer.TR1 Buses=[SourceBus, Sub_Bus] Conns=[Delta Wye] kVs= [115 12.47]
~ kVAs=[20000 20000] XHL=10
New Linecode.336ACSR R1=0.058 X1=.1206 R0=.1784 X0=.4047 C1=3.4 C0=1.6 Units=kft
New Line.LINE1 Bus1=Sub_Bus Bus2=LoadBus Linecode=336ACSR Length=1 Units=Mi
New Load.LOAD1 Bus1=LoadBus kV=12.47 kW=1000 PF=.95
Solve
Show Voltages
Show Currents
Show Powers kVA elements
```

# Command Syntax

- *Command parm1, parm2 parm3 parm 4 ….*

- Parameters may be positional or named (tagged).
- If named, an "**=**" sign is expected.
  - ***Name=value*** *(this is the named form)*
  - ***Value*** *(value alone in positional form)*
- *For example, the following two commands are equivalent:*

  - ***New Object="Line.First Line" Bus1=b1240 Bus2=32 LineCode=336ACSR, …***
  - ***New "Line.First Line", b1240 32 336ACSR, …***

Comma or white space

# Delimiters

- Array or string delimiter pairs: **[ ] , { },( ),“ “,‘ ‘**
- Matrix row delimiter: **|**
- Value delimiters: **,** (comma)
  any white space (tab or space)
- Class, Object, Bus, or Node delimiter: **.** (period)
- Keyword / value separator: **=**
- Continuation of previous line: **~** (More)
- Comment line: ***//***
- In-line comment: **!**
- Query a property: **?**

# Array and Matrix Parameters

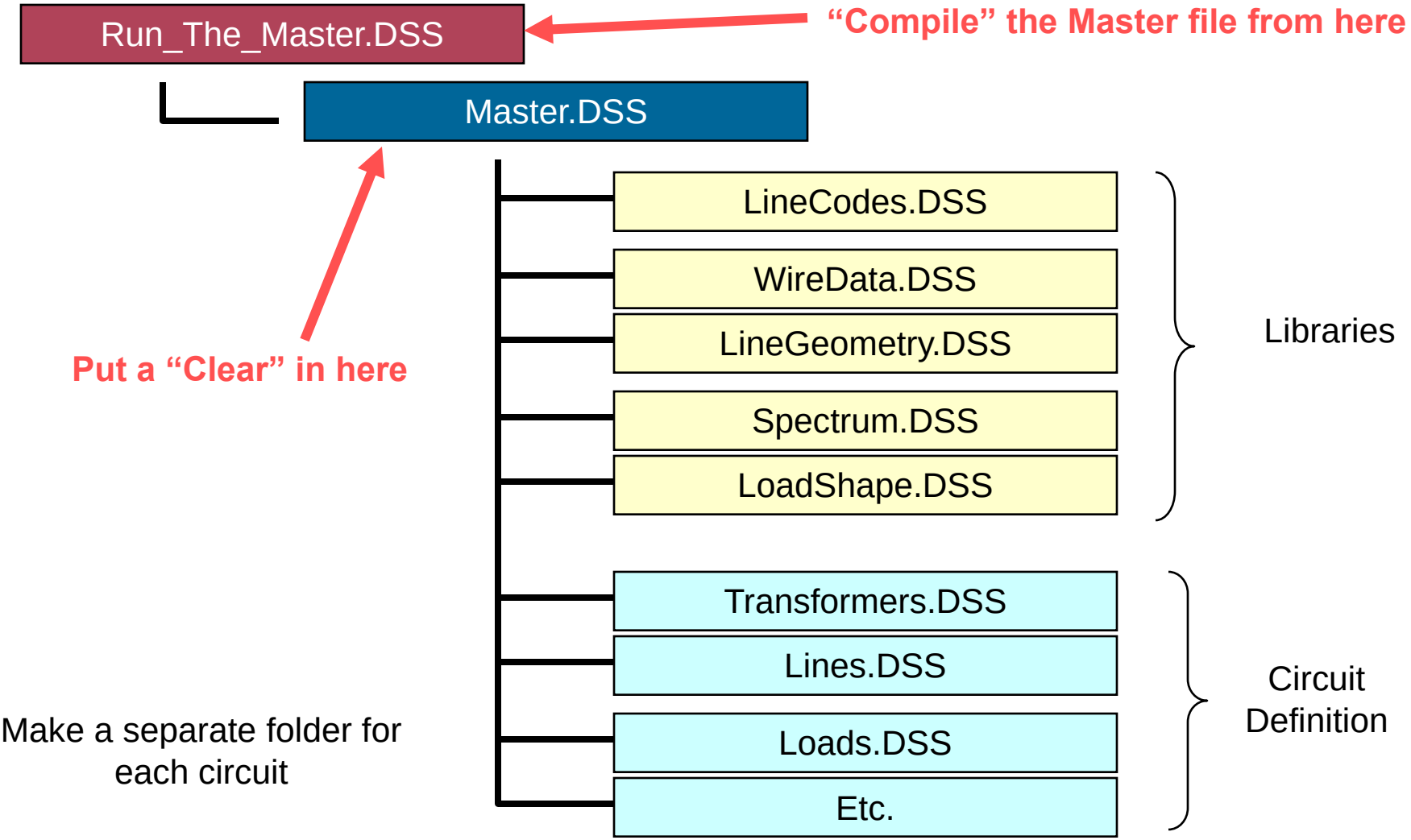
- Array
  - **kvs = [115, 6.6, 22]**
  - **kvas=[20000  16000 16000]**

- Matrix
  - ***(3x3 matrix)***
    - **Xmatrix=[1.2  .3  .3 | .3  1.2  3 | .3  .3  1.2]**
  - ***(3x3 matrix – lower triangle)***
    - **Xmatrix=[ 1.2  | .3 1.2  | .3  .3  1.2 ]**

# Specifying Bus Connections

- Shorthand (implicit)
  - `New Load.LOAD1 Bus1=LOADBUS`
  - Assumes standard 3-phase connection by default
- Explicit
  - `New Load.LOAD1 Bus1=LOADBUS.1.2.3`
    - Explicitly defines which node
  - `New Load.1-PHASELOAD Phases=1 Bus1=LOADBUS.2`
    - Connects 1-phase load to phase 2
- Default Bus template (defaults to grounded Wye)
  - `... LOADBUS.1.2.3.0.0.0.0.0.0.0.` (*ad infinitum*)
- Ungrounded-Wye Specification
  - `Bus1=LOADBUS.1.2.3.4` **(or some other unused Node number)**

# Common Sense Structuring of Script Files



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The Distribution System Simulator™ (DSS)

# Solution Modes

# Distribution System Analysis Tools

- DSS has the basic tools for Planning built in:
  - Power Flow
  - Short Circuit Calculations
- In Addition, it has Several Advanced Capabilities
  - “Dynamic” Power Flow
  - Other power flow modes
  - Dynamics
  - Harmonics
- If it is not built in, you can drive it from another program such as Matlab
  - For example: Reliability Analysis

# Classes of Solution Modes

- Power Flow
  - Snapshot
  - Direct
- Dynamic Power Flow
  - Daily
  - Yearly
  - DutyCycle
  - Peakday
- Dynamics
- Harmonics
- Other Power Flow
  - LD1
  - LD2
  - Monte Carlo
    - M1
    - M2
    - M3
- Short Circuit
  - Faultstudy
  - MF - Monte Carlo Fault

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# Power Flow Modes

# Snapshot Mode

- This is the DEFAULT MODE
- Does one power flow solution at the present load level
  - Controlmode is set to “static”
  - All Control devices execute in sequence of their time delays – shortest first
    - Next control action may then be cancelled
  - You can change the default control mode if driving the DSS externally
  - You have to explicitly tell monitoring devices to “sample”
- Watch the SUMMARY window for lack of convergence

# Bus List in DSS

- The Bus List in the DSS is NOT FORMED until you do something requiring a solution or explicitly request that it be formed:
  - Solve
  - CalcVoltagebases  (zero-load power flow)
  - MakeBusList   (explicitly forms the bus list)
- If you do something that adds a bus after you do a Solve-related command the bus list is NOT automatically updated!

# CalcVoltageBases

- This command was implemented to avoid having to specify base voltages for each bus
  - You can do that by "`Setkvbase bus=… kvln|kvll =…`"
- Solves a ZERO LOAD SNAPSHOT power flow
- Set voltage bases = closest value in the set defined by
  - `Set Voltagebases=[115  12.47  0.48 …]`
- Note: this will not always work if you have two voltage bases really close together such as 12.0 and 12.47
- Remember: **The DSS works in Volts, Amps, and Ohms**
  - Voltage bases are provided for convenience

# Direct Solution Mode

- Solve System Y matrix directly
  - **I = [Y]V** (assume nominal I value)
  - No iterations
  - No compensation currents from load and generator models
    - Primitive admittance should reflect load
- Load updating forced
- Rebuilds System Y if necessary
- All Voltage and Current sources accounted for
  - Including generators if in dynamics or harmonics mode

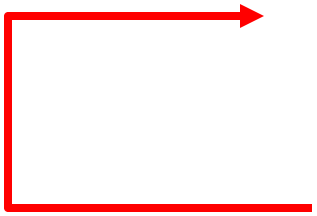

# “Dynamic” Power Flow Modes

# Daily

- Does 24 hour solution following load shape defined as “Daily”
  - See Load definition
  - There is a default loadshape defined called “default”
  - Note: the LOAD model default is NONE
- You may change the default values
  - To use a 15-min load shape,
  - Set NUMBER=96 and stepsize=(3600 4 /) … 900 s
- Meters and Monitors are reset when entering mode
  - Are not reset until mode is changed
  - Automatically sampled at end of each power flow solution
- Static control mode
  - Be careful specifying time delays! If all the same, they will all try to operate at once!

# Daily Solution Algorithm

For Number of solutions specified (set number =…)



t = t + stepsize

Solve snapshot

Sample meters and monitors

Finally,

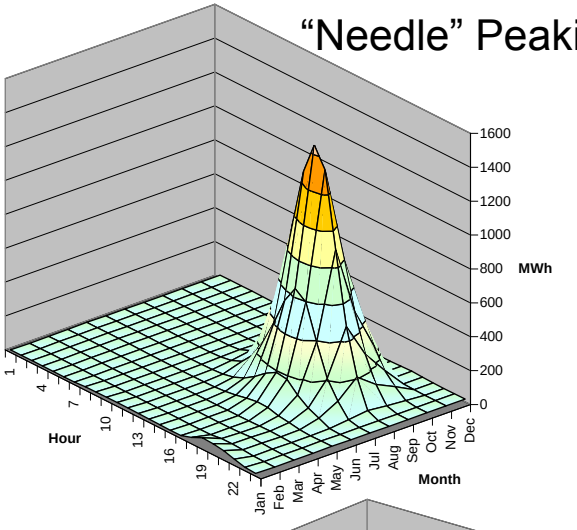
Save meters and monitors (does not reset them)

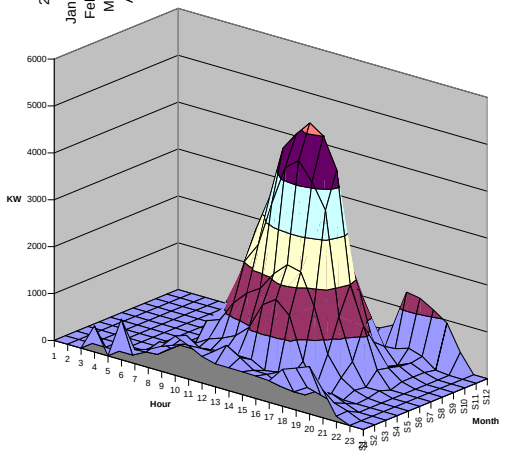
(Energymeter demand intervals may be used)

# Yearly

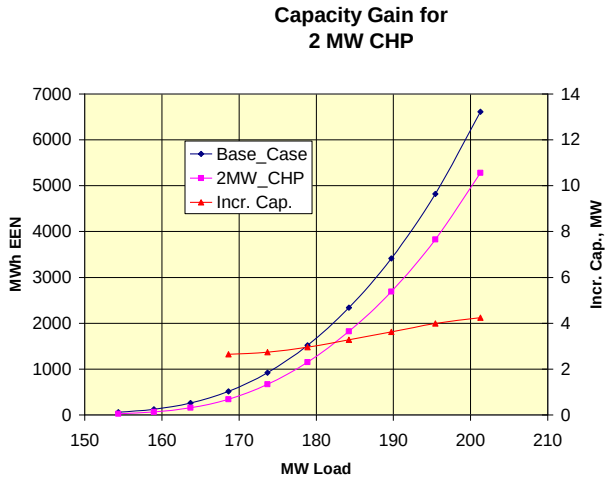
- Similar to Daily
- Defaults to
  - 1 hr stepsize (3600 s)
  - Number = 8760
- Adjusts load for growth (Set Year = …)
- Load uses loadshape defined for Yearly=…
  - Defaults to Daily … repeats over and over
  - If Daily is NONE, then load is constant
- Note: Energymeters stay open; (Monitors are saved)
  - Have to be explicitly closed by Reset or Set Year=

# Using DSS to Determine Incremental Capacity of DG




Broad Summer Peaking System




"How much more power can be served at the same risk of unserved energy?"

# Energy Meter Registers (As of Jan 2009)

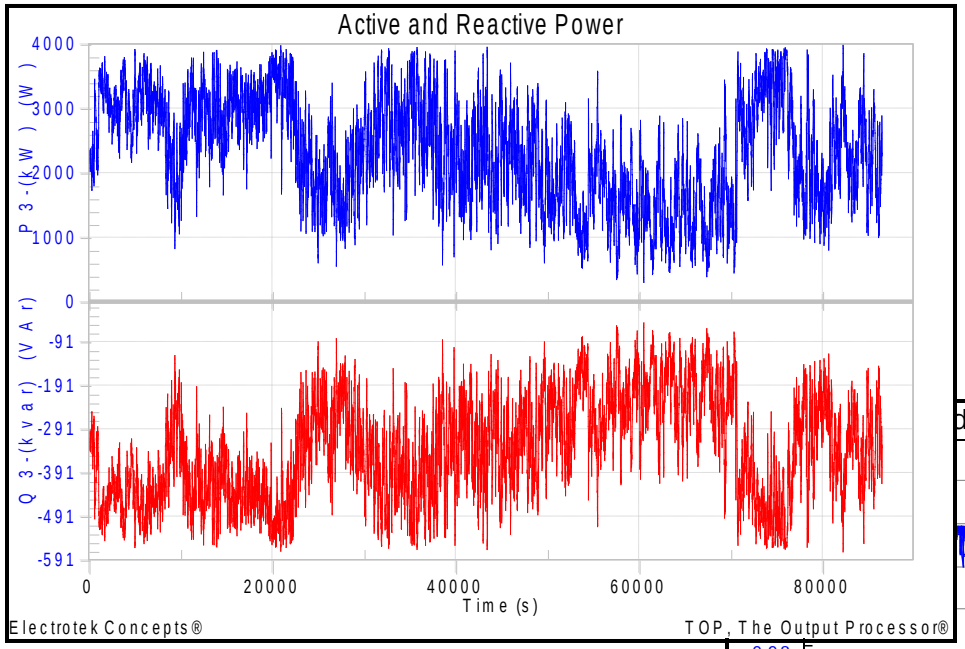
Reg 1 = kWh
Reg 2 = kvarh
Reg 3 = Max kW
Reg 4 = Max kVA
Reg 5 = Zone kWh
Reg 6 = Zone kvarh
Reg 7 = Zone Max kW
Reg 8 = Zone Max kVA
Reg 9 = Overload kWh Normal
Reg 10 = Overload kWh Emerg
Reg 11 = Load EEN
Reg 12 = Load UE
Reg 13 = Zone Losses kWh
Reg 14 = Zone Losses kvarh
Reg 15 = Zone Max kW Losses
Reg 16 = Zone Max kvar Losses
Reg 17 = Load Losses kWh
Reg 18 = Load Losses kvarh
Reg 19 = No Load Losses kWh

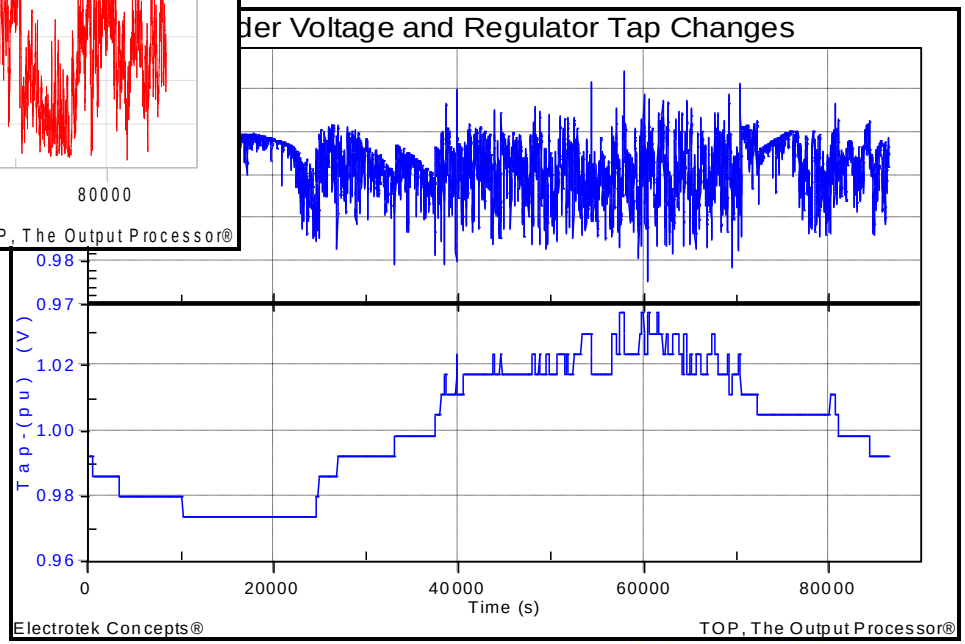
Reg 20 = No Load Losses kvarh
Reg 21 = Max kW Load Losses
Reg 22 = Max kW No Load Losses
Reg 23 = Line Losses
Reg 24 = Transformer Losses
Reg 25 = Line Mode Line Losses
Reg 26 = Zero Mode Line Losses
Reg 27 = 3-phase Line losses
Reg 28 = 1-and 2-phase Line Losses
Reg 29 = Gen kWh
Reg 30 = Gen kvarh
Reg 31 = Gen Max kW
Reg 32 = Gen Max kVA
Reg 33 = 34.5 kV Losses
Reg 34 = 0.208 kV Losses
Reg 35 = 4.16 kV Losses
Reg 36 = 230 kV Losses
Reg 37 = Aux5
Reg 38 = Aux6
Reg 39 = Aux7

# Dutycycle

- Meant to study
  - Rock crushers
  - Wind turbines
  - Rolling mills and other cyclic large motor loads
- Loads follow shape defined by Duty property
- Monitors are sampled & saved
- Energymeters are NOT sampled during the loop

# Wind Plant 1-s Simulation



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# Short Circuit Modes

# In a Power Flow Mode

- The DSS will allow you to put a FAULT object on the circuit at almost any time, even for a SNAPSHOT solution
  - Be sure to check for convergence
  - Answer may differ slightly from Faultstudy mode
- Safer (for accuracy) procedure:
  - Solve snapshot
  - Set mode=dynamics number=1 stepsize=.00001 (small)
  - Add/Enable Fault object
  - Solve  (does a direct solution with generators converted to Thevenin equivalent)

# FaultStudy Mode

- Algorithm
  - Disable all FAULT objects defined in the circuit
  - Sets Loadmodel=Admittance
  - Does DIRECT solution
    - Generators included (Thevenin equivalent)
    - Save Open-circuit voltages, Voc
  - Computes Ysc matrix at each bus
  - Computes Isc by applying
    - Isc = Ysc*Voc
  - Answer could differ slightly from specific fault solution
- Show Fault to see answers

# MF – Monte Carlo Fault Mode

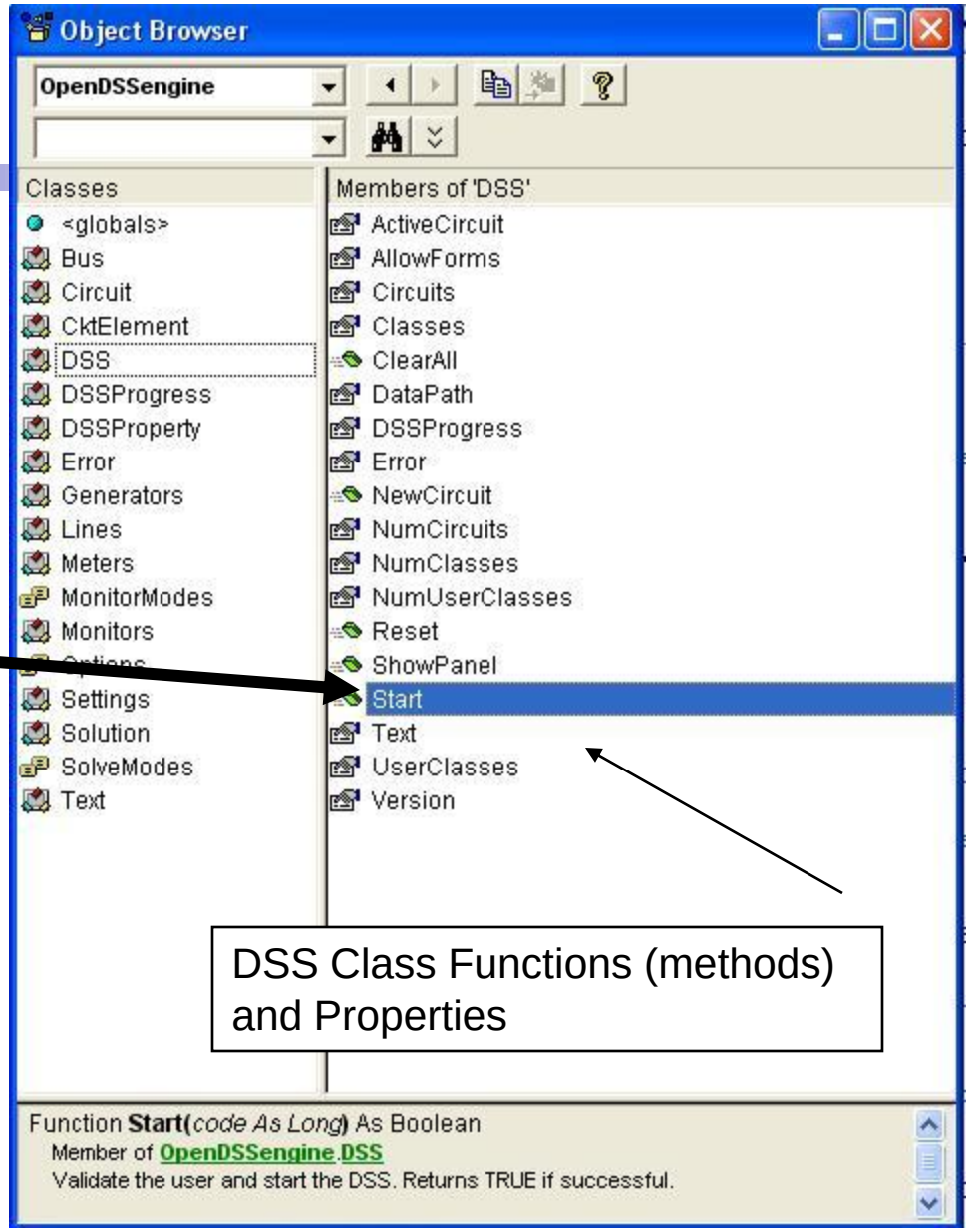
- First, define FAULT objects at all buses of interest
  - All fault types of interest
- Changes loadmodel to ADMITTANCE
- Algorithm
  - For the number of times specified
  - Picks one fault at random; disables the others
  - Randomizes the fault resistance
    - Uniform
    - Gaussian
    - Log-Normal


# Introduction to Driving the COM Server from another Application

# DSS Interface

This interface is instantiated upon loading OpenDSSEngine.DSS and then instantiates all other interfaces

Call the Start(0) method to initialize the DSS



# Instantiate the DSS Interface and Attempt Start

```
Public Sub StartDSS()

' Create a new instance of the DSS
    Set DSSobj = New OpenDSSengine.DSS
' Start the DSS
    If Not DSSobj.Start(0) Then
        MsgBox "DSS Failed to Start"
    Else
        MsgBox "DSS Started successfully"
      ' Assign a variable to the Text interface for easier access
        Set DSSText = DSSobj.Text
    End If


End Sub
```

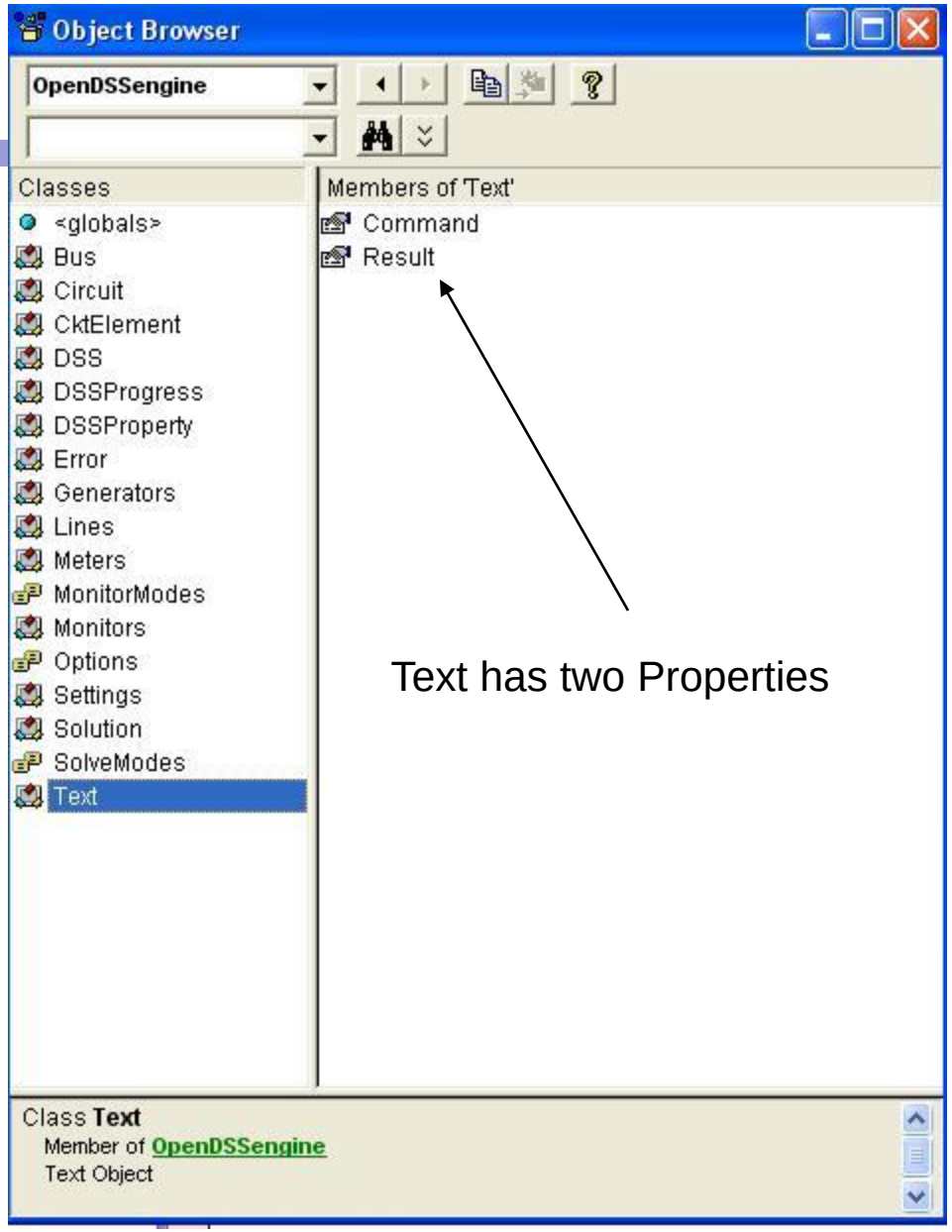
# Assign a Variable to the Text Interface

```
Public Sub StartDSS()


' Create a new instance of the DSS
    Set DSSobj = New OpenDSSengine.DSS
' Start the DSS
    If Not DSSobj.Start(0) Then
        MsgBox "DSS Failed to Start"
    Else
        MsgBox "DSS Started successfully"
      ' Assign a variable to the Text interface for easier access
        Set DSSText = DSSobj.Text
    End If



End Sub
```

# COM Interface

Interfaces as Exposed by VBA Object Browser in MS Excel

Text interface is simplest




Text has two Properties

# Result Property

- The Result property is a Read Only property that contains any result messages the most recent command may have issued.
  - Error messages
  - Requested values

```
' Example: Query line length
DSSText.Command = "? Line.L1.Length"
S = DSSText.Result       ' Get the answer
MsgBox S                 ' Display the answer
```

# Running OpenDSS From Matlab

- Starting the DSS

```
%Start up the DSS
[DSSStartOK, DSSObj, DSSText] = DSSStartup(myDir);
```

```
function [Start,Obj,Text] = DSSStartup(mydir)
% Function for starting up the DSS
% make sure we are in the proper directory
cd(mydir);
%
%instantiate the DSS Object
Obj = actxserver('OpenDSSEngine.DSS');
%
%Start the DSS.   Only needs to be executed the first time w/in a
%Matlab session
Start = Obj.Start(0);

% Define the text interface
Text = Obj.Text;
```

# Using the DSS through the DSSText Interface from Matlab (harmonics example)

```
%Compile the DSS circuit script
DSSText.Command = 'compile master.dss';

% get an interface to the active circuit called "DSSCircuit"
DSSCircuit = DSSObj.ActiveCircuit;

%Determine which connection type for the source and call
%appropriate DSS file
switch XFMRType
case 1
 DSSText.Command = 'redirect directconnectsource.DSS';
case 2
 DSSText.Command = 'redirect deltadelta.DSS';
case 3
 DSSText.Command = 'redirect deltawye.DSS';
otherwise
 disp('Unknown source Connection Type')
end

%Set the system frequency and vsource frequency for harmonic requested
DSSText.Command = ['set frequency=(' num2str(Freq) ' 60 *)'];
DSSText.Command = ['vsource.source.frequency=(' num2str(Freq) ' 60 *)'];
```

# Using the DSS through the DSSText Interface from Matlab (harmonics example) (cont'd)

```
% Vary the parameters according to a random distribution
% If more parameters need to be varied, just add them to the below
% list.  Set ParamNum to total number of parameters varied
 ParamNum = 6;    %ParamNum used for sorting/plotting
 for Case_Count = 1:Max_Cases
%Create index in the OutputData matrix to keep the cases in order
 OutputData(Case_Count,1) = Case_Count;
 % Generate random new coordinates for each conductor
 [x1 y1 x2 y2 x3 y3 geomean] = RandomGeometry(8,0.75,30);
            (... etc. etc. )
%define a new line geometry with random spacing
DSSText.Command = ['New LineGeometry.OHMOD nconds=3 nphases=3  cond=1
wire=acsr336    x=' num2str(x1) '   ' num2str(y1) '   units=ft  cond=2
wire=acsr336    x=' num2str(x2) '   ' num2str(y2) '   units=ft cond=3
wire=acsr336    x=' num2str(x3) '   ' num2str(y3) '   units=ft'];
%Solve the circuit
 DSSText.Command = 'solve';
              (etc. etc.)
```

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# Questions?