GIC Calculations Using EPRI OpenDSS Software

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Introduction to OpenDSS
OpenDSS- Background

• DSS development was started at Electrotek Concepts in 1997 (Distribution analysis, DG in particular)
• Acquired by EPRI in 2004
• EPRI released its Distribution System Simulator (DSS) program as open source in Sept 2008
  – Called “OpenDSS”
• Designed to simulate utility distribution systems in arbitrary detail for most types of analyses related to distribution planning.
  – It performs its analysis in the frequency domain
    • Power flow,
    • Harmonics, and
    • Dynamics.
  – It does NOT perform electromagnetic transients (time domain) studies.
Example DSS Applications

- **Geomagnetically Induced Current Simulations**
  - 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.**
OpenDSS Installation
http://sourceforge.net
http://sourceforge.net
Program Files (Version 7.4)

- OpenDSS.EXE Standalone EXE
- OpenDSSEngine.DLL In-process COM server
- KLUSolve.DLL Sparse matrix solver
- DSSgraph.DLL DSS graphics output
  - (These will change with Version 8 due 2nd Q 2012)

- Copy these files to the directory (folder) of your choice
  - Typically c:\OpenDSS OR c:\Program Files\OpenDSS
Registering the COM Server

• If you intend to drive OpenDSS from another program, you will need to register the COM server
  – Some programs require this !!
  – If you are sure you will only use OpenDSS.EXE, you can skip this step
    • You can come back and do it at any time
• In the DOS, or command, window, change to the folder where you installed it and type:
  – Regsvr32 OpenDSSSEngine.DLL

Note: You can open the command window by typing ‘cmd’ in the Run box on the Start menu.
Registering the COM Server – Windows 7

• Special Instructions for Window 7
  – (and probably Windows Vista, too)
  – See Q&A on the Wiki site

  – Go to “All Programs > Accessories” folder
  – right-click on the Command Prompt and select Run as Administrator.

• Then change to the OpenDSS folder and type in
  – "regsvr32 OpenDSSSEngine.DLL" or
  – "RegisterDSSSEngine", which runs the ‘.Bat’ file.
Registering the COM Server – Windows 7

• Another Process for Windows 7 per Andy Keane- UC Dublin

1. Right click on the desktop and select new -> shortcut
2. For location of item just type ‘cmd’
3. This will create a new shortcut to a command prompt on your desktop
4. Right click on the new shortcut and select ‘Properties’
5. On the shortcut tab select ‘Advanced’
6. Tick the ‘Run as Administrator’ box
7. Press Apply/OK and that command prompt will always be run as administrator allowing the user to use regsvr32
OpenDSS Basics
OpenDSS Standalone EXE User Interface

- DSS Main Control Panel: Active Circuit = domphew
- Set Editor = C:\Program Files\EditPlus 2\editplus.exe
- Dump debug dump line * debug
- Dump linecode 1/0 debug
- Show line constants 60 m
- DO FAULT STUDY
- Color mode = 1

Script Window:
- Set "DemandInterval" to true so that energy quantities recorded for each time step and set "casename" to define a directory under which the data is recorded.
- Set "DemandInterval" to true so that energy quantities recorded for each time step and set "casename" to define a directory under which the data is recorded. (NOTE: Setting Demand-trace option is required.)

Result:
- Compile (C:\openDSS\IEEETest\IEEE123Bus\IEEE123Master.dss)
- "Compile" differs from "redirect" in that it changes the default directory to the one in which the referenced file is located.
- "Redirect" returns to the directory from which it was invoked.

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Executing Scripts in the EXE

DSS executes selected line or opens selected file name

Any script window may be used at any time.
DSS Structure

Main Simulation Engine

- Scripts
- COM Interface
- User-Written DLLs

Scripts, Results
DSS Object Structure

DSS Executive

Commands Options

Circuit

Solution

V Y I

PDElement
  Line
  Transformer
  Capacitor
  Reactor

PCElement
  Load
  Generator
  Vsource
  Isource

Controls
  RegControl
  CapControl
  Relay
  Reclose
  Fuse

Meters
  Monitor
  EnergyMeter
  Sensor

General
  LineCode
  LineGeometry
  WireData
  LoadShape
  GrowthShape
  Spectrum
  TCCcurve
DSS Class Structure

**Class**
- Property Definitions
- Class Property Editor
- Collection Manager

Instances of Objects of this class

<table>
<thead>
<tr>
<th>Object 1</th>
<th>Property Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Methods</td>
</tr>
<tr>
<td></td>
<td>Yprim</td>
</tr>
<tr>
<td></td>
<td>States</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Object n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property Values</td>
</tr>
<tr>
<td>Methods</td>
</tr>
<tr>
<td>Yprim</td>
</tr>
<tr>
<td>States</td>
</tr>
</tbody>
</table>
DSS Classes (as of 2008)

- 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
DSS Bus Model
DSS Terminal Definition

1

2

3

N

Power Delivery or Power Conversion Element
Power Delivery Elements

Terminal 1

Power Delivery Element

Terminal 2

$\text{I}_{\text{term}} = [Y_{\text{prim}}] \text{V}_{\text{term}}$
Power Conversion Elements

• Not needed for GIC simulations.

\[ I_{\text{Term}}(t) = F(V_{\text{Term}}, \text{[State]}, t) \]
Load (a PC Element)

- Not needed for GIC simulations.
Putting it All Together

\[ I_{\text{inj}} = Y V \]

ALL Elements

Yprim 1 \hspace{1cm} Yprim 2 \hspace{1cm} Yprim 3 \hspace{1cm} \ldots \hspace{1cm} Yprim n

PC Elements

\{ I_1 \}

\{ I_2 \}

\{ I_m \}

Iteration Loop

Node Voltages
Generic Structuring of Script Files

- **Run_The_Master.DSS**
- **Master.DSS**
- **LineCodes.DSS**
- **WireData.DSS**
- **LineGeometry.DSS**
- **Spectrum.DSS**
- **LoadShape.DSS**
- **Transformers.DSS**
- **Lines.DSS**
- **Loads.DSS**
- **Etc.**

“Compile” the Master file from here

Put a “Clear” in here

Make a separate folder for each circuit

Libraries

Circuit Definition
GIC Calculations Using OpenDSS
GIC Calculations

- The process of computing GIC in a network involves three steps.
  - Step 1 – Create dc system model
  - Step 2 – Compute induced voltages
  - Step 3 – Compute GIC
Step 1 – Create dc System Model
Transformer Models

• dc models are available for the following transformer winding connections:
  – Delta-Grounded Wye (GSU)
  – Grounded-Wye Grounded Wye (with or without delta tertiary)
  – Grounded-Wye Autotransformer (with or without delta tertiary)

• Neutral connections are modeled explicitly so that individual GIC blocking devices can be modeled.

• dc winding resistance is used in the model (NOT $R_1$ or $R_0$!)

• Only windings with connection to ground are included in the model. Delta and ungrounded wye windings are excluded.
Grounded-Wye Grounded Wye Transformer (with or without Delta Tertiary)

Object Class
Object Name
New GICTransformer.1 busH=H.1.2.3 busNH=H.4.4.4 busX=X.1.2.3 busNX=H.4.4.4
~ R1=0.2 R2=0.1 type=YY

Bus Names

Parameters

Can be arbitrarily defined

Sub Ground Field

HX

NHNX

Sub

Ground

Field

New GICTransformer.1 busH=H.1.2.3 busNH=H.4.4.4 busX=X.1.2.3 busNX=H.4.4.4
~ R1=0.2 R2=0.1 type=YY

Allows continuation onto next line
Grounded-Wye Grounded Wye Autotransformer (with or without Delta Tertiary)

Object Class
Object Name
Bus Names

New GICTransformer.1 busH=H.1.2.3 busX=X.1.2.3 busNX=H.4.4.4
~ R1=0.2 R2=0.1 type=Auto

Program automatically makes this connection
Can be arbitrarily defined

Tertiary not shown
Sub Ground Field

Program automatically makes this connection
Can be arbitrarily defined
Generator Step-Up Transformer (GSU)

Object Class: New GICTransformer.1
Bus Names: busH=H.1.2.3 busNX=H.4.4.4
Parameters: R1=0.2 R2=0.1 type=GSU

Can be arbitrarily defined.
Transmission Line Models

- Transmission lines are modeled as a dc resistance in series with a quasi-dc voltage source.
  - OpenDSS uses 0.1 Hz
- dc resistance must be manually corrected for skin effect.
  - Correction factor varies from approximately 0.95 for large conductors (1590 MCM) to 1.0 for smaller conductors (below 750 MCM).
- Earth return effects (e.g. those included in Carson’s equations) do not need to be included in the model since they are negligible at very low frequencies (quasi-dc).
Transmission Line Models

• The quasi-dc voltage is computed internally using Faraday’s Law (voltage value can also be specified by the user).

• The following data are required if the voltage is not specified by the user:
  – Geographic locations of each bus (LAT,LON in degrees).
  – Eastward and Northward geoelectric field (V/km).

• Series capacitance can also be included in the model by specifying the value in uF.
Transmission Line Models

Object Class

Object Name

Bus Names

LAT/LON of Bus 1

New GICLine.1 bus1=1 bus2=2 R=3.512 Lat1=33.613499 Lon1=-87.373673
~ Lat2=33.547885 Lon2=-86.074605 EE=1.00 EN=2.00 C=10.0

LAT/LON of Bus 2

E Field (V/km)

Series Capacitance

Series capacitance can also be included
Substation Ground Field

- Resistance to remote earth of substation ground field is modeled as a lump resistance.
- Modeled as a discrete reactor element in OpenDSS.

New Reactor.SUB1gnd phases=1 bus1=H.4 R=0.200 X=0
GIC Blocking Devices

- Blocking devices are modeled as discrete elements (R or C).

  New Reactor.GICblock1 phases=1 bus1=H.4 bus2=H.5 R=3.0 X=0

  New Capacitor.GICblock1 phases=1 bus1=H.4 bus2=H.5 cuf=10
Step 2 – Compute Induced Voltages
Induced Voltage Calculations

• OpenDSS uses Faraday’s Law to compute the induced voltage in the transmission line due to the geomagnetic field at the earth’s surface.
  – Geographic locations of each bus is required (LAT, LON in degrees).
  – Eastward and Northward geoelectric field data is required (V/km).
• Faraday’s Law is evaluated numerically using the procedure outlined in the following slides.
Faraday’s Law

\[ V = \int \vec{E} \cdot d\vec{l} \]

- Dot product tells you to find the part of \( E \) parallel to \( d\vec{l} \)
- Line Integral – Tells you to sum up all of the contributions along a defined path
- Incremental segment (including direction)

Electric Field (V/km)

Bus A

Bus B
Faraday’s Law (Numerical Solution)

• Using the preceding equation (in closed form) to compute the induced voltage in a transmission line is a formidable task.

• Assumptions are made to reduce the complexity of the closed form solution.
  – We assume that the electric field is constant in the area of the transmission line → Only end points of the line are needed.
  – We compute the dot product using the following relationship, recall:

\[ \vec{A} \cdot \vec{B} = A_x B_x + A_y B_y \quad \rightarrow \quad \vec{E} \cdot \vec{L} = E_E L_E + E_N L_N \]
Determining $L_N$ and $L_E$

- OpenDSS using the following method to compute the Northward and Eastward Distances. Note that there are more accurate methods (e.g. WGS84 model), but the following method is accurate enough for power system calculations.

- Northward Distance ($L_N$)

\[ L_N = 111.2 \cdot \Delta \text{lat} \text{ km} \]

- Eastward Distance ($L_E$)

\[ \alpha = \frac{\text{Lat}A + \text{Lat}B}{2} \text{ degrees} \]

\[ L_E = 111.2 \cdot \Delta \text{long} \cdot \sin(90 - \alpha) \text{ km} \]
Step 3 – Compute GIC
GIC Calculations

• Same calculation technique that is used for AC calculations is used to compute GIC.

$$\begin{align*}
I_{\text{inj}} &= Y \\
V &= \text{Node Voltages}
\end{align*}$$

**Iteration Loop**
Some Examples
GIC Example

**Table 1: Substation Details**

<table>
<thead>
<tr>
<th>Name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Grounding Resistance (Ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub 1</td>
<td>33.613499</td>
<td>-87.373673</td>
<td>0.2</td>
</tr>
<tr>
<td>Sub 2</td>
<td>34.310437</td>
<td>-86.365765</td>
<td>0.2</td>
</tr>
<tr>
<td>Sub 3</td>
<td>33.955058</td>
<td>-84.679354</td>
<td>0.2</td>
</tr>
</tbody>
</table>

**Table 2: Line Details**

<table>
<thead>
<tr>
<th>Line</th>
<th>From Bus</th>
<th>To Bus</th>
<th>Length (km)</th>
<th>Resistance (Ohms/phase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>121.03</td>
<td>3.525</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>5</td>
<td>160.18</td>
<td>4.665</td>
</tr>
</tbody>
</table>

**Table 3: Transformer Details**

<table>
<thead>
<tr>
<th>Name</th>
<th>Resistance W1 (ohm/phase)</th>
<th>Resistance W2 (ohm/phase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>0.5</td>
<td>N/A</td>
</tr>
<tr>
<td>T2</td>
<td>0.2 (series)</td>
<td>0.2 (common)</td>
</tr>
<tr>
<td>T3</td>
<td>0.5</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Three-Phase Equivalent Circuit

GSU T-LINE Autotransformer T-LINE GSU


5. $R_c$ 6. $R_s$ 7. $R_c$ 8. $R_c$


Calculations Using OpenGIC

- OpenGIC utilizes a script based approach.
OpenGIC Results

- Assume \(|E| = 10 \text{ V/km Eastward Direction}\)
OpenGIC Results

- Assume $|E| = 10$ V/km Eastward Direction
Substation Ground Fields
OpenGIC Results

• Graphical Representation
GIC Test Case

• A 20 bus benchmark test case has been developed to validate GIC calculation software.

• Key contributors were:
  – Randy Horton, Roger Dugan – EPRI
  – David Boteler - Natural Resources Canada
  – Risto Pirjola - Finnish Meteorological Institute
  – Tom Overbye – University of Illinois at Urbana-Champaign

• An IEEE paper has been written and submitted to IEEE Transactions on Power Delivery.
  – “A Test Case for the Calculation of Geomagnetically Induced Currents”
20 Bus Test Case – Single Line Diagram

GIC Blocking Device
20 Bus Test Case – Geographical View
# Substation Locations and Grid Resistance Values

<table>
<thead>
<tr>
<th>Name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Grounding Resistance (Ohm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub 1</td>
<td>33.6135</td>
<td>-87.3737</td>
<td>0.2</td>
</tr>
<tr>
<td>Sub 2</td>
<td>34.3104</td>
<td>-86.3658</td>
<td>0.2</td>
</tr>
<tr>
<td>Sub 3</td>
<td>33.9551</td>
<td>-84.6794</td>
<td>0.2</td>
</tr>
<tr>
<td>Sub 4</td>
<td>33.5479</td>
<td>-86.0746</td>
<td>1.0</td>
</tr>
<tr>
<td>Sub 5</td>
<td>32.7051</td>
<td>-84.6634</td>
<td>0.1</td>
</tr>
<tr>
<td>Sub 6</td>
<td>33.3773</td>
<td>-82.6188</td>
<td>0.1</td>
</tr>
<tr>
<td>Sub 7</td>
<td>34.2522</td>
<td>-82.8363</td>
<td>N/A</td>
</tr>
<tr>
<td>Sub 8</td>
<td>34.1956</td>
<td>-81.0980</td>
<td>0.1</td>
</tr>
</tbody>
</table>
## Transmission Line Data

<table>
<thead>
<tr>
<th>Line</th>
<th>From Bus</th>
<th>To Bus</th>
<th>Voltage (kV-LL)</th>
<th>Length (miles)</th>
<th>Resistance (ohm/phase)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>345</td>
<td>77.18</td>
<td>3.512</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>17</td>
<td>345</td>
<td>77.47</td>
<td>3.525</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>4</td>
<td>500</td>
<td>87.51</td>
<td>1.986</td>
</tr>
<tr>
<td>4</td>
<td>17</td>
<td>16</td>
<td>345</td>
<td>102.54</td>
<td>4.665</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>5</td>
<td>500</td>
<td>103.31</td>
<td>2.345</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>5</td>
<td>500</td>
<td>103.31</td>
<td>2.345</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>6</td>
<td>500</td>
<td>131.05</td>
<td>2.975</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>11</td>
<td>500</td>
<td>154.57</td>
<td>3.509</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>11</td>
<td>500</td>
<td>63.59</td>
<td>1.444</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>6</td>
<td>500</td>
<td>205.57</td>
<td>4.666</td>
</tr>
<tr>
<td>11</td>
<td>15</td>
<td>6</td>
<td>500</td>
<td>128.81</td>
<td>2.924</td>
</tr>
<tr>
<td>12</td>
<td>15</td>
<td>6</td>
<td>500</td>
<td>128.81</td>
<td>2.924</td>
</tr>
<tr>
<td>13</td>
<td>11</td>
<td>12</td>
<td>500</td>
<td>102.39</td>
<td>2.324</td>
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<tr>
<td>14</td>
<td>16</td>
<td>20</td>
<td>345</td>
<td>88.98</td>
<td>4.049</td>
</tr>
<tr>
<td>15</td>
<td>17</td>
<td>20</td>
<td>345</td>
<td>152.53</td>
<td>6.940</td>
</tr>
</tbody>
</table>
## Transformer Data

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Resistance W1 (Ohms/phase)</th>
<th>Bus No.</th>
<th>Resistance W2 (Ohms/phase)</th>
<th>Bus No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>GSU w/ GIC BD</td>
<td>0.1</td>
<td>2</td>
<td>N/A</td>
<td>1</td>
</tr>
<tr>
<td>T2</td>
<td>GY-GY-D</td>
<td>0.2</td>
<td>4</td>
<td>0.1</td>
<td>3</td>
</tr>
<tr>
<td>T3</td>
<td>GSU</td>
<td>0.1</td>
<td>17</td>
<td>N/A</td>
<td>18</td>
</tr>
<tr>
<td>T4</td>
<td>GSU</td>
<td>0.1</td>
<td>17</td>
<td>N/A</td>
<td>19</td>
</tr>
<tr>
<td>T5</td>
<td>Auto</td>
<td>0.04</td>
<td>16</td>
<td>0.06</td>
<td>15</td>
</tr>
<tr>
<td>T6</td>
<td>GSU</td>
<td>0.15</td>
<td>6</td>
<td>N/A</td>
<td>7</td>
</tr>
<tr>
<td>T7</td>
<td>GSU</td>
<td>0.15</td>
<td>6</td>
<td>N/A</td>
<td>8</td>
</tr>
<tr>
<td>T8</td>
<td>GY-GY</td>
<td>0.04</td>
<td>5</td>
<td>0.06</td>
<td>20</td>
</tr>
<tr>
<td>T9</td>
<td>GY-GY</td>
<td>0.04</td>
<td>5</td>
<td>0.06</td>
<td>20</td>
</tr>
<tr>
<td>T10</td>
<td>GSU</td>
<td>0.1</td>
<td>12</td>
<td>N/A</td>
<td>13</td>
</tr>
<tr>
<td>T11</td>
<td>GSU</td>
<td>0.1</td>
<td>12</td>
<td>N/A</td>
<td>14</td>
</tr>
<tr>
<td>T12</td>
<td>Auto</td>
<td>0.04</td>
<td>4</td>
<td>0.06</td>
<td>3</td>
</tr>
<tr>
<td>T13</td>
<td>GY-GY-D</td>
<td>0.2</td>
<td>4</td>
<td>0.1</td>
<td>3</td>
</tr>
<tr>
<td>T14</td>
<td>Auto</td>
<td>0.04</td>
<td>4</td>
<td>0.06</td>
<td>3</td>
</tr>
<tr>
<td>T15</td>
<td>Auto</td>
<td>0.04</td>
<td>15</td>
<td>0.06</td>
<td>16</td>
</tr>
</tbody>
</table>
# GIC Calculations for Uniform 1 V/km E Field

<table>
<thead>
<tr>
<th>TRANSFORMER</th>
<th>WINDING</th>
<th>GIC FOR NORTHWARD E FIELD (AMPS/PHASE)</th>
<th>GIC FOR EASTWARD E FIELD (AMPS/PHASE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>HV</td>
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Graphical Representation – 1 V/km Eastward Field
Computing GIC values for other E fields

- Two methods exist for computing GICs due to “non unity” electric fields.
  1. Enter the new E field data into the line models and re-compute the corresponding GIC, or
  2. Compute the resulting GIC using:

\[
GIC_{new} = |E|\{GIC_E \sin \theta + GIC_N \cos \theta\}
\]

where,

- \(GIC_{new}\) = new value of GIC (Amps)
- \(|E|\) = magnitude of E field (V/km)
- \(\theta\) = angle of E field vector (radians)
- \(GIC_E\) = GIC due to 1 V/km Eastward E field (Amps)
- \(GIC_N\) = GIC due to 1 V/km Northward E field (Amps)
Using the COM Server

- Program can be “driven” using Matlab, Excel, etc.
- Very useful in GIC calculations.
  - Allows for dynamic analysis, i.e. entire storm scenarios can be evaluated – not just a particular E field.
  - Allows the use of built in graphing capability, etc.
Using the COM Server

- Program can be “driven” using Matlab.

```matlab
% Check to see if the DSS started properly
if DSSStartOK
    % Compute GIC with Eastward E field (1 V/km)
    DSSCircuit = DSSObj.ActiveCircuit;
    DSSText.Command = ['Clear'; 'New circuit.MyBenchmark'];
    DSSText.command = ['Redirect ', myDir, 'GIClines_E.dss'];
    DSSText.command = ['Redirect ', myDir, 'Benchmark_xfmr.dss'];
    DSSText.command = ['Redirect ', myDir, 'Benchmark_ydnd.dss'];
    DSSText.command = ['Set frequency=0.1'];
    DSSText.Command = ['Export Currents'];
    GIC_E_H = csvread('MyBenchmark_EXP_Currents.csv', 1, 1, [1, num_of_xfmr+1, 1]);
    GIC_E_X = csvread('MyBenchmark_EXP_Currents.csv', 1, 1, [2, num_of_xfmr+1, 1]);
    % Compute GIC with Northward E field (1 V/km)
    DSSText.Command = ['Clear'; 'New circuit.MyBenchmark'];
    DSSText.command = ['Redirect ', myDir, 'GIClines_E.dss'];
    DSSText.command = ['Redirect ', myDir, 'Benchmark_xfmr.dss'];
    DSSText.command = ['Redirect ', myDir, 'Benchmark_ydnd.dss'];
    DSSText.command = ['Set frequency=0.1'];
    DSSText.Command = ['Export Currents'];
    GIC_N_H = csvread('MyBenchmark_EXP_Currents.csv', 1, 1, [1, num_of_xfmr+1, 2]);
    GIC_N_X = csvread('MyBenchmark_EXP_Currents.csv', 1, 1, [2, num_of_xfmr+1, 2]);
    % Determine magnitude and sign (DSS results are phasors)
    for k = 1:length(GIC_E_H)
        GIC_east_H(k,1) = GIC_E_H(k,1)*cos(GIC_E_H(k,2)*pi/180);
        GIC_north_H(k,1) = GIC_N_H(k,1)*cos(GIC_N_H(k,2)*pi/180);
        GIC_east_X(k,1) = GIC_E_X(k,1)*cos(GIC_E_X(k,2)*pi/180);
        GIC_north_X(k,1) = GIC_N_X(k,1)*cos(GIC_N_X(k,2)*pi/180);
    end
```
1 in 100 Year Storm Scenario

![Graph of EN and EE fields over UT (hours)]
GIC Flows for 1 in 100 Year Storm

Geoelectric Field

GIC - Transformer #3
GIC Flows for 1 in 100 Year Storm (Close Up)
Live Software Demo

Together…Shaping the Future of Electricity