## Transformer Reactive Power Demand Example

A major impact of a GMD event is the excess reactive powder demand imposed by transformers saturated by GIC. To study the impact of this increase demand with respect to the system voltage profiles and reactive-source biasing, only the reactive power produced from the fundamental-frequency positive-sequence exciting current component is of interest.

These reactive power demands vary for different transformer types. Figure 1 illustrates the reactive power consumption versus GIC for three-phase transformer configurations.



Figure 1. Reactive power consumption versus GIC for three-phase transformer configurations [1]

Due to the linear relationship, an approximation equation is sometimes used for studying system impact. It is expressed in terms of volts and amperes:

*Qexc* is total three-phase in Mvar

*k* is a transformer specific constant

*IGIC* is the dc amperes per phase

*kVll* is the line-line rms voltage

## Example: GIC var Calculation

The example system represents a hypothetical 20 bus EHV network consisting of 500 kV and 345 kV lines and transformers. Figure 2 shows a single-line diagram of the network. The network includes single transmission lines as well as some that occupy the same transmission corridor. The substations feature both conventional transformers and autotransformers. Also included are series (series capacitors) and neutral connected GIC blocking devices.



Figure 2. One Line Diagram of Example GIC System

Data for the system described in Figure 2 are provided in Tables 1-3.

Table 1.  
GIC Example Substation Location and Grid Resistance

|  |  |  |  |
| --- | --- | --- | --- |
| Name | Latitude | Longitude | Grounding Resistance (Ohm) |
| Sub 1 | 33.613499 | -87.373673 | 0.2 |
| Sub 2 | 34.310437 | -86.365765 | 0.2 |
| Sub 3 | 33.955058 | -84.679354 | 0.2 |
| Sub 4 | 33.547885 | -86.074605 | 1.0 |
| Sub 5 | 32.705087 | -84.663397 | 0.1 |
| Sub 6 | 33.377327 | -82.618777 | 0.1 |
| Sub 7 | 34.252248 | -82.836301 | N/A |
| Sub 8 | 34.195574 | -81.098002 | 0.1 |

Table 2.  
 GIC Example Transmission Line Data

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

Table 3.  
 GIC Example Transformer Data[[1]](#footnote-1)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Name | Type | kVLL1 | kVLL2 | Resistance W1  (Ohms/phase) | Bus No. | Resistance W2  (Ohms/phase) | Bus No. |
| T1 | GSU w/ GIC BD | 20 | 345 | 0.1 | 2 | N/A | 1 |
| T2 | GY-GY-D | 345 | 500 | 0.2 | 4 | 0.1 | 3 |
| T3 | GSU | 20 | 345 | 0.1 | 17 | N/A | 18 |
| T4 | GSU | 20 | 345 | 0.1 | 17 | N/A | 19 |
| T5 | Auto | 345 | 500 | 0.04 | 16 | 0.06 | 15 |
| T6 | GSU | 500 | 20 | 0.15 | 6 | N/A | 7 |
| T7 | GSU | 500 | 20 | 0.15 | 6 | N/A | 8 |
| T8 | GY-GY | 345 | 500 | 0.04 | 5 | 0.06 | 20 |
| T9 | GY-GY | 345 | 500 | 0.04 | 5 | 0.06 | 20 |
| T10 | GSU | 500 | 20 | 0.1 | 12 | N/A | 13 |
| T11 | GSU | 500 | 20 | 0.1 | 12 | N/A | 14 |
| T12 | Auto | 345 | 500 | 0.04 | 4 | 0.06 | 3 |
| T13 | GY-GY-D | 345 | 500 | 0.2 | 4 | 0.1 | 3 |
| T14 | Auto | 345 | 500 | 0.04 | 4 | 0.06 | 3 |
| T15 | Auto | 345 | 500 | 0.04 | 15 | 0.06 | 16 |

### OpenDSS Script for Example System

The following scripts can be used to model the example system in OpenDSS with an Eastward electric field of 1 V/km. See Examples\GICExample on the OpenDSS Website.

**Transmission Lines**

Note: Lines appear wrapped in this document due to Word limitations, but are all one OpenDSS statement in the actual DSS script file.

!GIC Line Data

New GICLine.1-Bus2-Bus3 bus1=2 bus2=3 R=3.512 Lat1=33.613499 Lon1=-87.373673 Lat2=33.547885 Lon2=-86.074605 EE=1.00 EN=0.00

New GICLine.2-Bus2-Bus17 bus1=2 bus2=17 R=3.525 Lat1=33.613499 Lon1=-87.373673 Lat2=34.310437 Lon2=-86.365765 EE=1.00 EN=0.00

New GICLine.3-Bus15-Bus4 bus1=15 bus2=4 R=1.986 Lat1=33.955058 Lon1=-84.679354 Lat2=33.547885 Lon2=-86.074605 EE=1.00 EN=0.00

New GICLine.4-Bus17-Bus16 bus1=17 bus2=16 R=4.665 Lat1=34.310437 Lon1=-86.365765 Lat2=33.955058 Lon2=-84.679354 EE=1.00 EN=0.00

New GICLine.5-Bus4-Bus5 bus1=4 bus2=5 R=2.345 Lat1=33.547885 Lon1=-86.074605 Lat2=32.705087 Lon2=-84.663397 EE=1.00 EN=0.00

New GICLine.6-Bus4-Bus5 bus1=4 bus2=5 R=2.345 Lat1=33.547885 Lon1=-86.074605 Lat2=32.705087 Lon2=-84.663397 EE=1.00 EN=0.00

New GICLine.7-Bus5-Bus6 bus1=5 bus2=6 R=2.975 Lat1=32.705087 Lon1=-84.663397 Lat2=33.377327 Lon2=-82.618777 EE=1.00 EN=0.00

New GICLine.8-Bus5-Bus11 bus1=5 bus2=11 C=32.0 R=3.509 Lat1=32.705087 Lon1=-84.663397 Lat2=34.252248 Lon2=-82.836301 EE=1.00 EN=0.00

New GICLine.9-Bus6-Bus11 bus1=6 bus2=11 R=1.444 Lat1=33.377327 Lon1=-82.618777 Lat2=34.252248 Lon2=-82.836301 EE=1.00 EN=0.00

New GICLine.10-Bus4-Bus6 bus1=4 bus2=6 R=4.666 Lat1=33.547885 Lon1=-86.074605 Lat2=33.377327 Lon2=-82.618777 EE=1.00 EN=0.00

New GICLine.11-Bus15-Bus6 bus1=15 bus2=6 R=2.924 Lat1=33.955058 Lon1=-84.679354 Lat2=33.377327 Lon2=-82.618777 EE=1.00 EN=0.00

New GICLine.12-Bus15-Bus6 bus1=15 bus2=6 R=2.924 Lat1=33.955058 Lon1=-84.679354 Lat2=33.377327 Lon2=-82.618777 EE=1.00 EN=0.00

New GICLine.13-Bus11-Bus12 bus1=11 bus2=12 R=2.324 Lat1=34.252248 Lon1=-82.836301 Lat2=34.195574 Lon2=-81.098002 EE=1.00 EN=0.00

New GICLine.14-Bus16-Bus20 bus1=16 bus2=20 R=4.049 Lat1=33.955058 Lon1=-84.679354 Lat2=32.705087 Lon2=-84.663397 EE=1.00 EN=0.00

New GICLine.15-Bus17-Bus20 bus1=17 bus2=20 R=6.940 Lat1=34.310437 Lon1=-86.365765 Lat2=32.705087 Lon2=-84.663397 EE=1.00 EN=0.00

**Transformers**

Note: Lines appear wrapped in this document due to Word limitations, but are all one OpenDSS statement in the actual DSS script file.

New GICTransformer.T1 busH=2 busNH=2.4.4.4 R1=0.1 type=GSU kVLL1=20 kVLL2=345

New GICTransformer.T2 busH=4 busNH=4.4.4.4 busX=3 busNX=4.4.4.4 R1=0.2 R2=0.1 type=YY kVLL1=345 kVLL2=500

New GICTransformer.T3 busH=17 busNH=17.4.4.4 R1=0.1 type=GSU kVLL1=20 kVLL2=345

New GICTransformer.T4 busH=17 busNH=17.4.4.4 R1=0.1 type=GSU kVLL1=20 kVLL2=345

New GICTransformer.T5 busH=15 busX=16 busNX=15.4.4.4 R1=0.04 R2=0.06 type=Auto kVLL1=345 kVLL2=500

New GICTransformer.T6 busH=6 busNH=6.4.4.4 R1=0.15 type=GSU kVLL1=500 kVLL2=20

New GICTransformer.T7 busH=6 busNH=6.4.4.4 R1=0.15 type=GSU kVLL1=500 kVLL2=20

New GICTransformer.T8 busH=5 busNH=5.4.4.4 busX=20 busNX=5.4.4.4 R1=0.04 R2=0.06 type=YY kVLL1=345 kVLL2=500

New GICTransformer.T9 busH=5 busNH=5.4.4.4 busX=20 busNX=5.4.4.4 R1=0.04 R2=0.06 type=YY kVLL1=345 kVLL2=500

New GICTransformer.T10 busH=12 busNH=12.4.4.4 R1=0.10 type=GSU kVLL1=500 kVLL2=20

New GICTransformer.T11 busH=12 busNH=12.4.4.4 R1=0.10 type=GSU kVLL1=500 kVLL2=20

New GICTransformer.T12 busH=4 busX=3 busNX=4.4.4.4 R1=0.04 R2=0.06 type=Auto kVLL1=345 kVLL2=500

New GICTransformer.T13 busH=4 busNH=4.4.4.4 busX=3 busNX=4.4.4.4 R1=0.2 R2=0.1 type=YY kVLL1=345 kVLL2=500

New GICTransformer.T14 busH=4 busX=3 busNX=4.4.4.4 R1=0.04 R2=0.06 type=Auto kVLL1=345 kVLL2=500

New GICTransformer.T15 busH=15 busX=16 busNX=15.4.4.4 R1=0.04 R2=0.06 type=Auto kVLL1=345 kVLL2=500

### Scripting for var Demand

#### K-Factor Approximation

The var demand in OpenDSS can be calculated using the relationship:

*Qexc* is total three-phase in Mvar

*k* is a transformer specific constant

*IGIC* is the dc amperes per phase

*kVll* is the line-line rms voltage

This will convert the GIC Amps in H winding (winding 1) in the program to Mvar. The default is K=2.2, a commonly-used simple multiplier for estimating Mvar losses for power flow [1].

Using the values above with the default of K=2.2, the Mvars values for this example can be extracted by simply using the exporting GIC command:

Export GIC

The results for the transformers’ Mvar losses and the GIC are as follows:

Table 4.  
 Mvar example results, K=2.2

|  |  |  |
| --- | --- | --- |
| Bus | Mvar | GIC Amps per phase |
| 2 | 1.75E-05 | 0.000398 |
| 4 | 5.268 | 6.941 |
| 4 | 16.506 | 21.747 |
| 4 | 5.268 | 6.941 |
| 4 | 16.506 | 21.747 |
| 5 | 13.581 | 17.893 |
| 5 | 13.581 | 17.893 |
| 6 | 64.996 | 59.087 |
| 6 | 64.996 | 59.087 |
| 12 | 24.621 | 22.383 |
| 12 | 24.621 | 22.383 |
| 15 | 26.481 | 34.889 |
| 15 | 26.481 | 34.889 |
| 17 | 1.388 | 31.548 |
| 17 | 1.388 | 31.548 |

The vars can then be exported for a power flow analysis.

#### Piecewise linear Approxiation

Another option for specifying the var relationship to the GIC is to use an XYCurve object name. The var curve is expected as pu TOTAL vars vs pu GIC amps/phase as shown in Figure 1. Vars are in pu of the MVA property.

Using the values shown in Figure 1 for 3-single phase transformers, the XYCurve is defined as:

New XYCurve.GIC npts=2 xarray=[0 0.3] yarray=[0 0.54]

This var curve is assigned to each transformer:

GICTransformer.T1.Varcurve=GIC

GICTransformer.T2.Varcurve=GIC

GICTransformer.T3.Varcurve=GIC

GICTransformer.T4.Varcurve=GIC

GICTransformer.T5.Varcurve=GIC

GICTransformer.T6.Varcurve=GIC

GICTransformer.T7.Varcurve=GIC

GICTransformer.T8.Varcurve=GIC

GICTransformer.T9.Varcurve=GIC

GICTransformer.T10.Varcurve=GIC

GICTransformer.T11.Varcurve=GIC

GICTransformer.T12.Varcurve=GIC

GICTransformer.T13.Varcurve=GIC

GICTransformer.T14.Varcurve=GIC

GICTransformer.T15.Varcurve=GIC

After this assignment the results can be viewed by the exporting GIC command:

Export GIC

[Note: Because of the linear relationship for this var curve, the MVA rating of the transformer is non-consequential; however, if a non-linear relationship exists between reactive power consumption and the GIC current, the MVA rating needs to be specified.]

The results for the transformers’ Mvar losses and the GIC are as follows:

Table 5.  
 Mvar example results, var curve

|  |  |  |
| --- | --- | --- |
| Bus | Mvar | GIC Amps per phase |
| 2 | 1.75E-05 | 0.000398 |
| 4 | 5.279 | 6.941 |
| 4 | 16.54 | 21.747 |
| 4 | 5.279 | 6.941 |
| 4 | 16.54 | 21.747 |
| 5 | 13.609 | 17.893 |
| 5 | 13.609 | 17.893 |
| 6 | 65.13 | 59.087 |
| 6 | 65.13 | 59.087 |
| 12 | 24.672 | 22.383 |
| 12 | 24.672 | 22.383 |
| 15 | 26.536 | 34.889 |
| 15 | 26.536 | 34.889 |
| 17 | 1.391 | 31.548 |
| 17 | 1.391 | 31.548 |

The vars can then be exported for a power flow analysis.

[1] EPRI Proceedings: Geomagnetically Induced Currents Conference, TR-100450

1. The voltage ratings are added for the var calculations, if none are specified the value for kVLL1 will default to 500 kV. No MVA rating is listed because it is not used when using a K factor equation. If a non-linear relationship exists between reactive power consumption and the GIC current, the MVA rating needs to be specified. In this case the default is 100 MVA for OpenDSS. [↑](#footnote-ref-1)