Use of PMU Data for Geomagnetic Disturbance Model Validation

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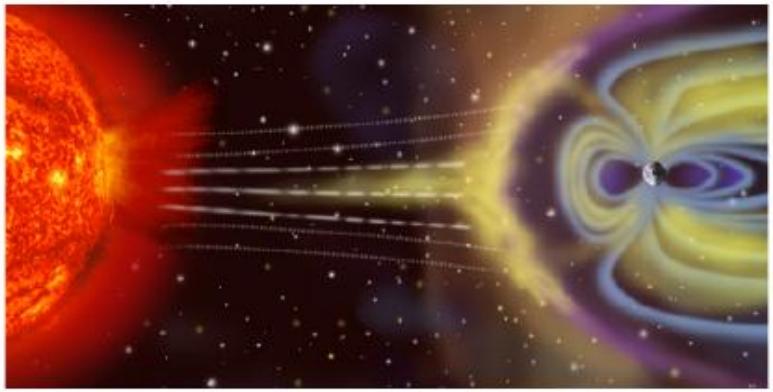
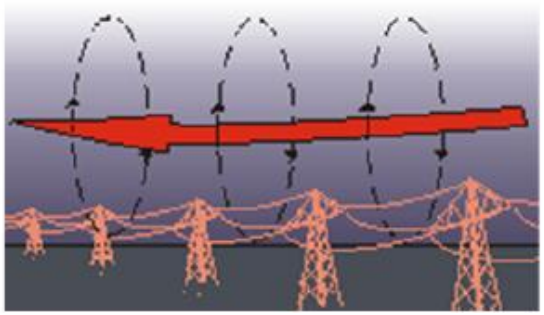
Introduction

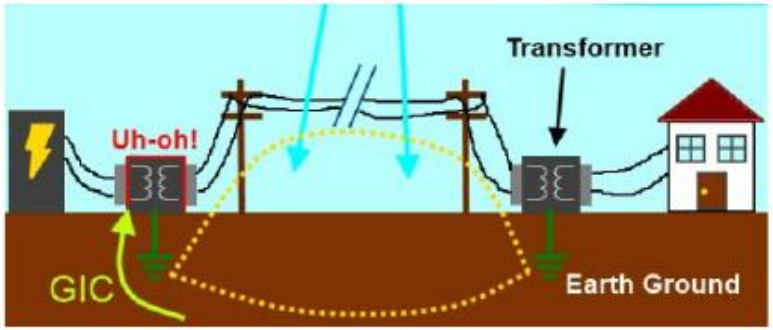
- Solar storms disturb the Earth's magnetic field.



- Change of magnetic field induces electric field.

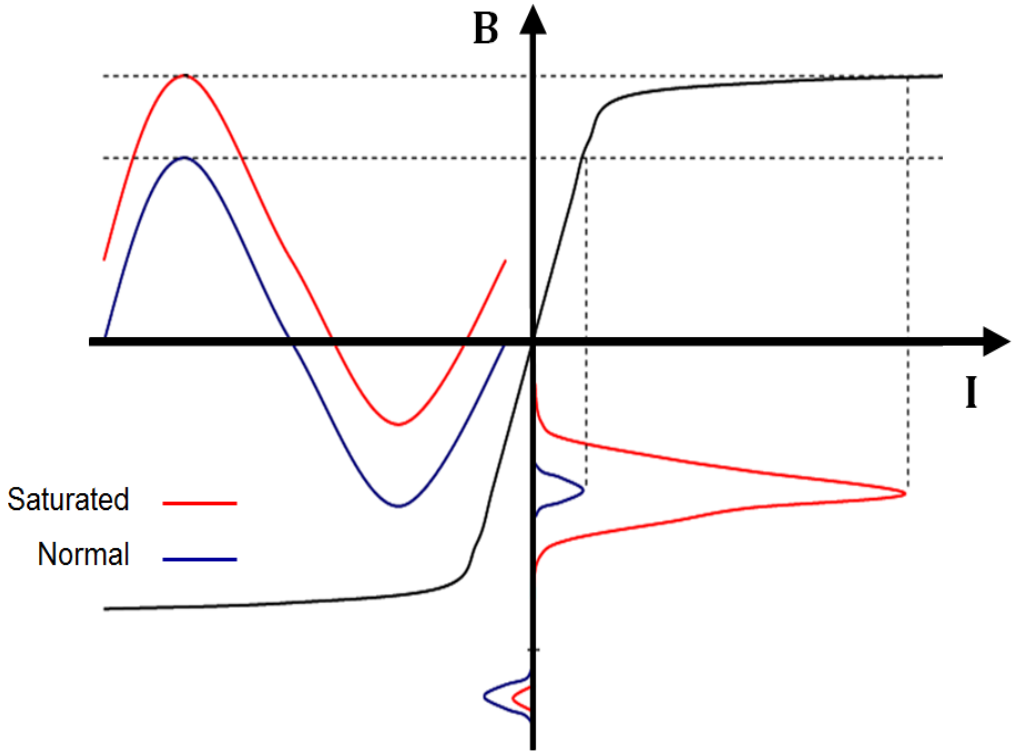


- Geomagnetic induced currents (GICs) flow through the lines.



- GICs are DC Currents.
- GICs have negative impacts on the network.

Half-cycle saturation of Transformers

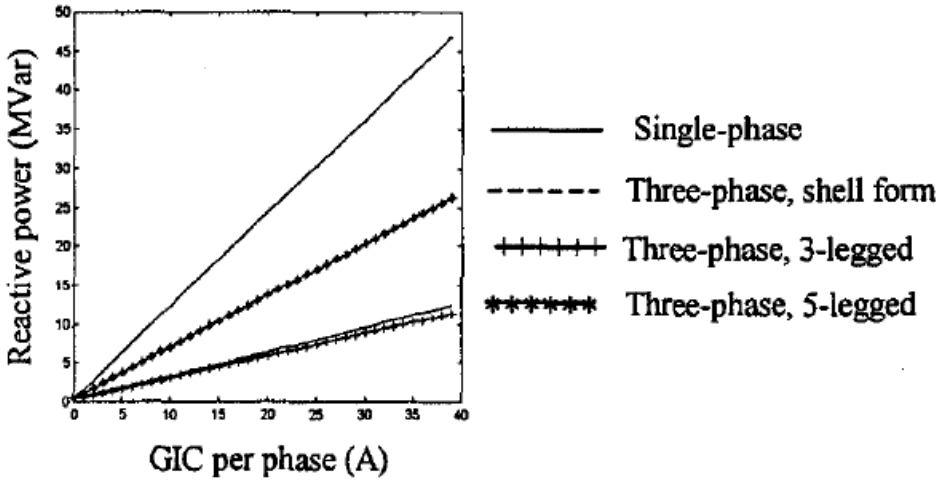


- The GICs cause half-cycle saturation of transformers.
- Reactive power loss is increased due to high magnetizing current and harmonics.
- Modeling the reactive power during GMDs is very important.

GIC-Saturated Reactive Power Loss

GIC-saturated reactive power loss is linearly related to the GIC at transformer neutral.

$$Q_{GIC} = KV_{HV}I_{GIC}$$

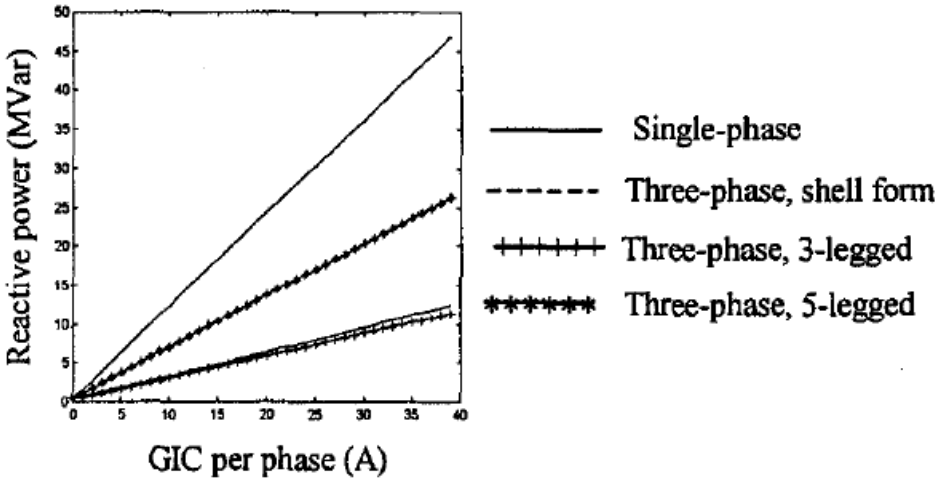


X. Dong, Y. Liu, J. G. Kappenman, "Comparative analysis of exciting current harmonics and reactive power consumption from GIC saturated transformers", 2001.

Example of K Values For Different Core Types

Core Type	K Value
Single Phase	1.8
Three Phase, Shell Form	1.45
Three Phase, Core From Generic	1.5
Three Phase, 5-Legged	1.5
Three Phase, 7-Legged	1.2

GIC-Saturated Reactive Power Loss



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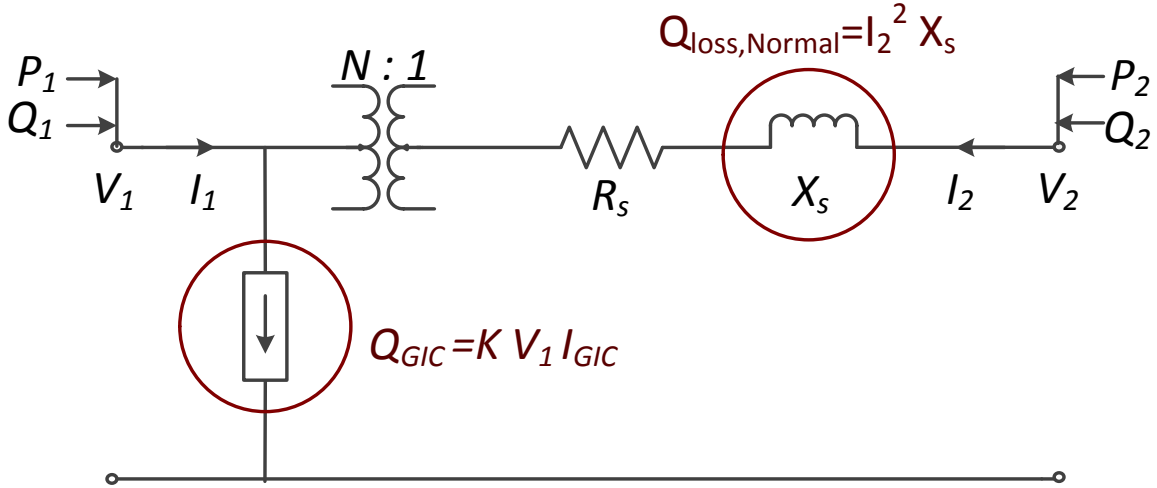
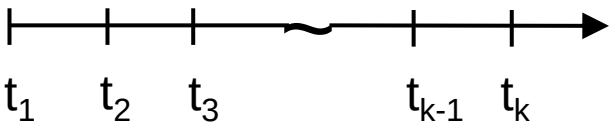
Estimating the Transformer Mvar Parameter

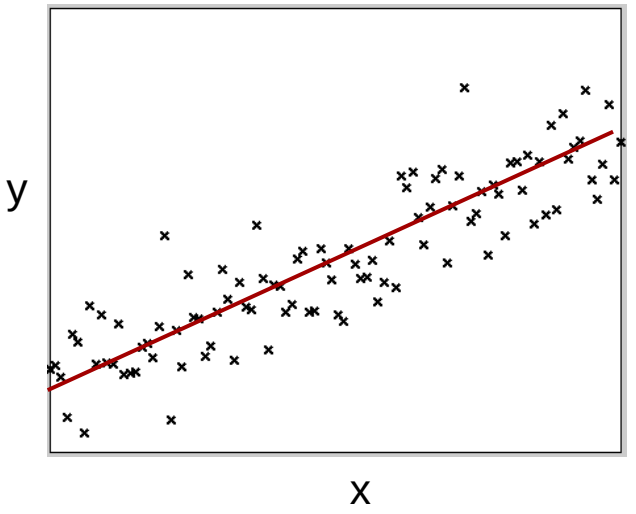


$$Q_{loss} = Q_1 - Q_2 = Q_{loss,Normal} + Q_{GIC}$$

$$\Longrightarrow \underbrace{Q_1 - Q_2 - I_2^2 X_s}_{y} = K \underbrace{V_1 I_{GIC}}_{x}$$

We have PMU data over time





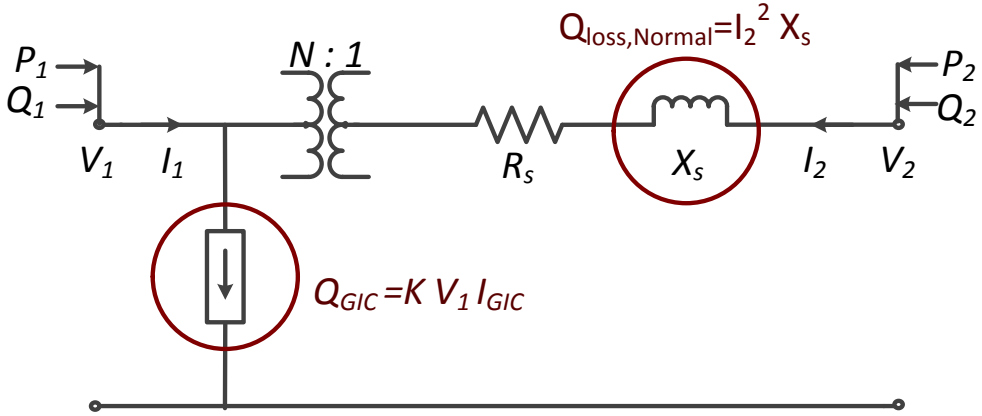
Per Unit GIC Q Approach

Per unit system for GICs:

$$I_{base,HV} = \frac{S_{base}}{\sqrt{3} V_{HV,Nominal}}$$

$$I_{GIC,pu} = \frac{I_{GIC}}{I_{base,HV}}$$

$$Q_{GIC,pu} = \frac{Q_{GIC}}{S_{base}} = V_{pu}\ K\ I_{GIC,pu} \quad (K_{pu} = 1.154\ K_{Old})$$



We need P, Q, and V to calculate the current at low voltage side of the transformer:

$$I_2 = \frac{\sqrt{P_2^2 + Q_2^2}}{V_2}$$

The required fields for estimating K are:

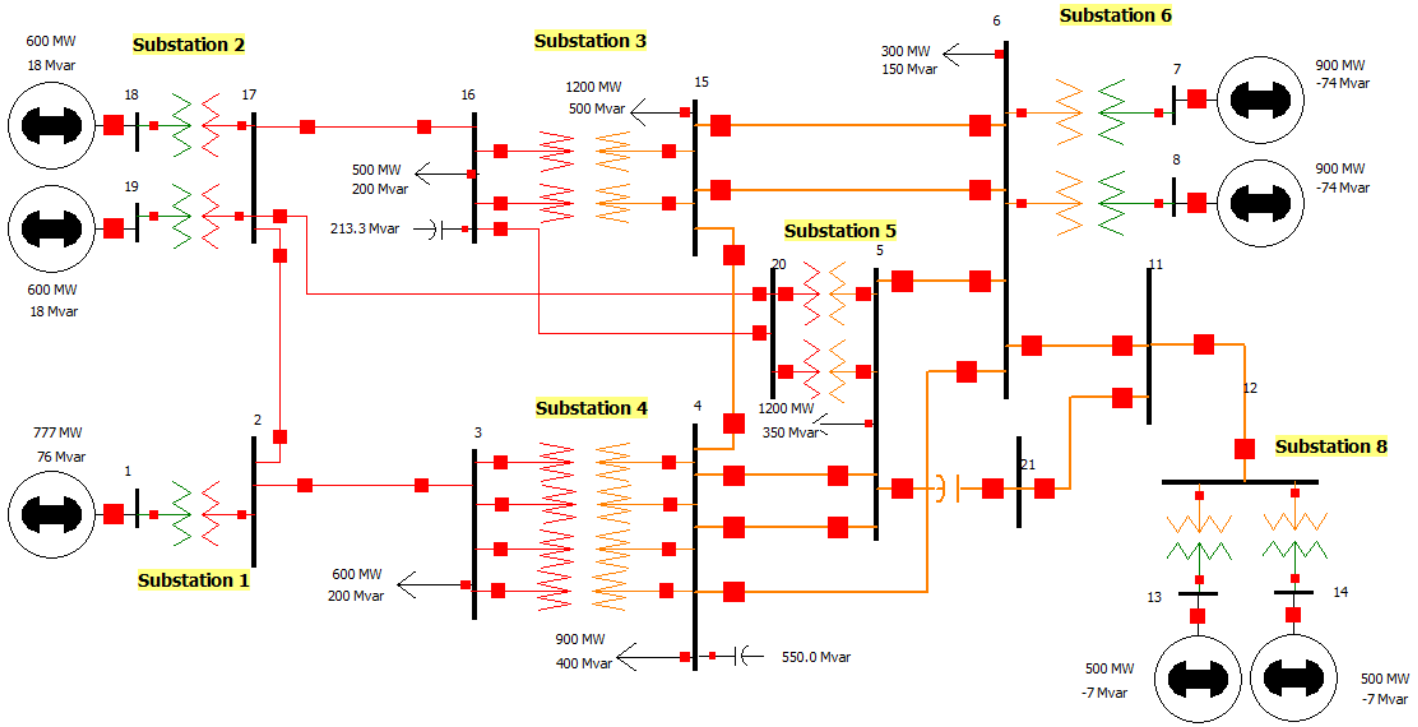
P_1
Q_1
V_1

P_2
Q_2
V_2

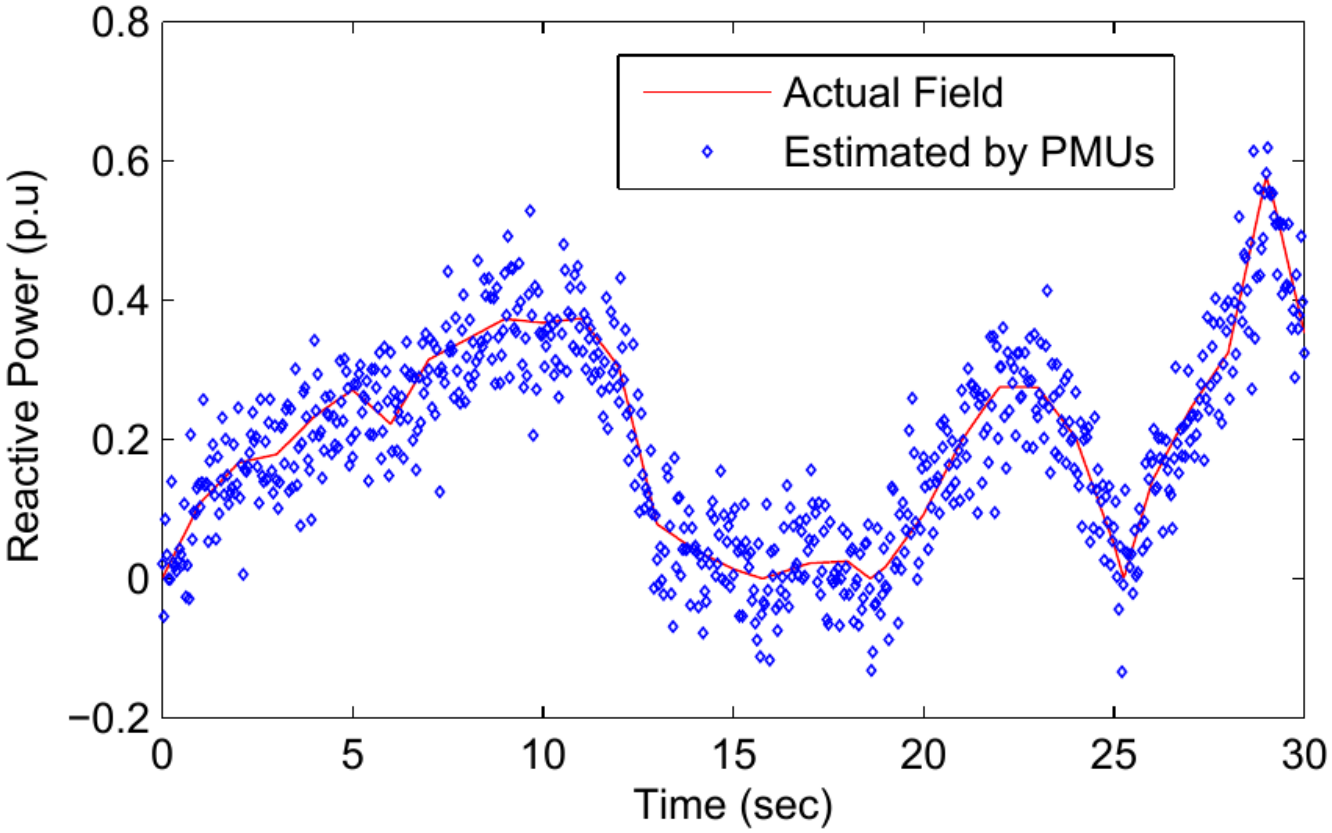
I_{GIC}

Simulation Setup

- A geomagnetic storm is enforced to the 20-bus test case [Horton et al., 2012] and the response of the system is monitored.
- Synthetic PMU data is generated using the transient stability toolbox. The data contains P, Q and V at all busses with frequency of 60Hz.
- Synthetic GIC data is generated using the GIC add on.
- Gaussian noise with signal-to-noise ratio (SNR) of 20 is added to all measurements.

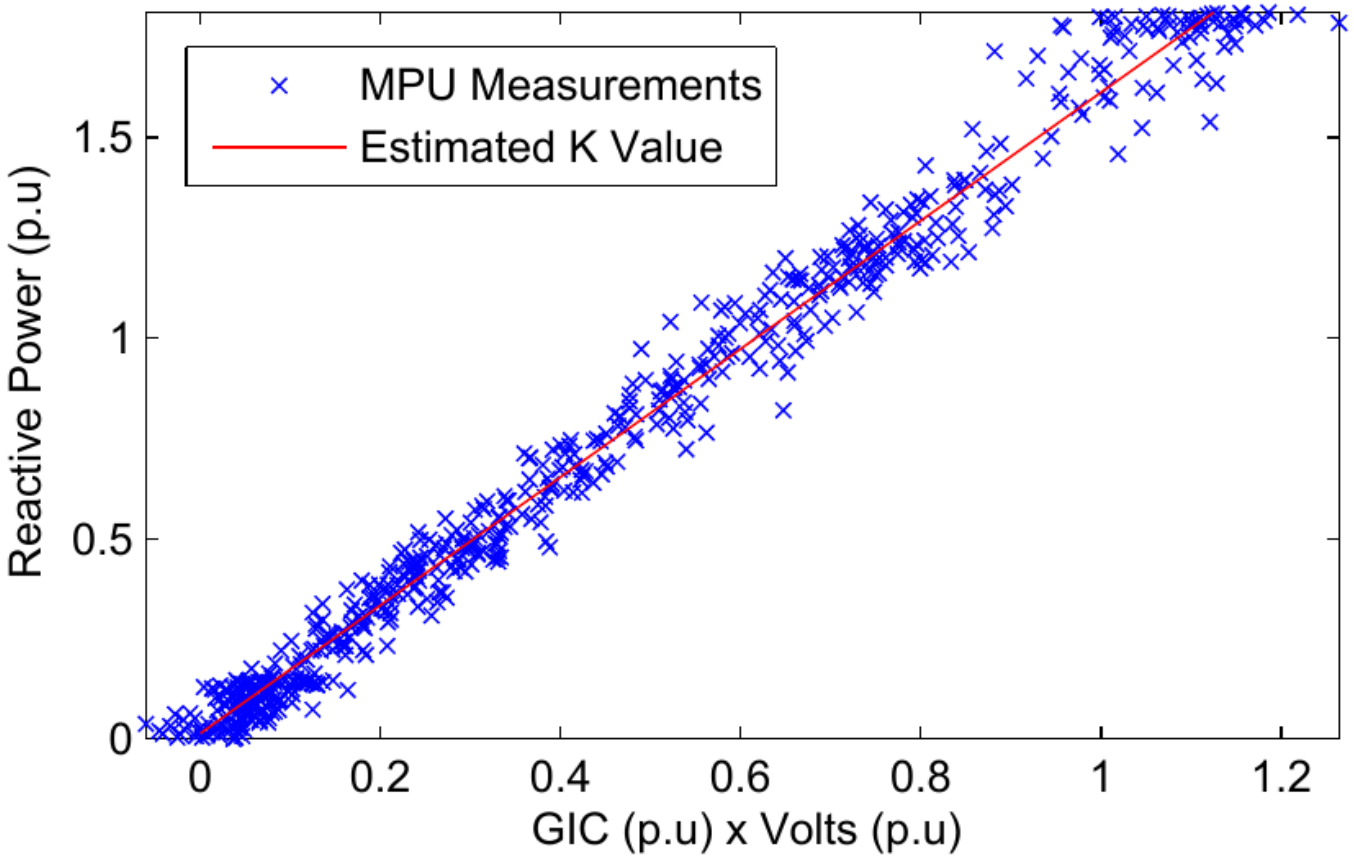


Reactive Power Estimation



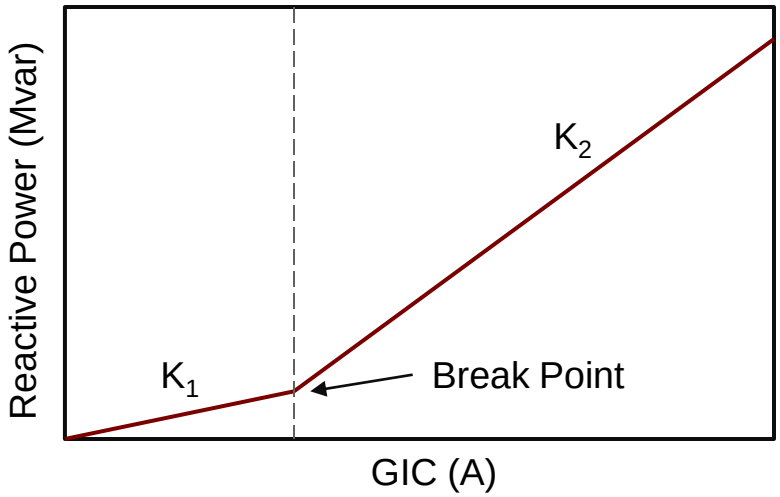
The actual GIC-saturated reactive power (Q_{GIC}) as compared with the one obtained from PMU data.

K Value Estimation

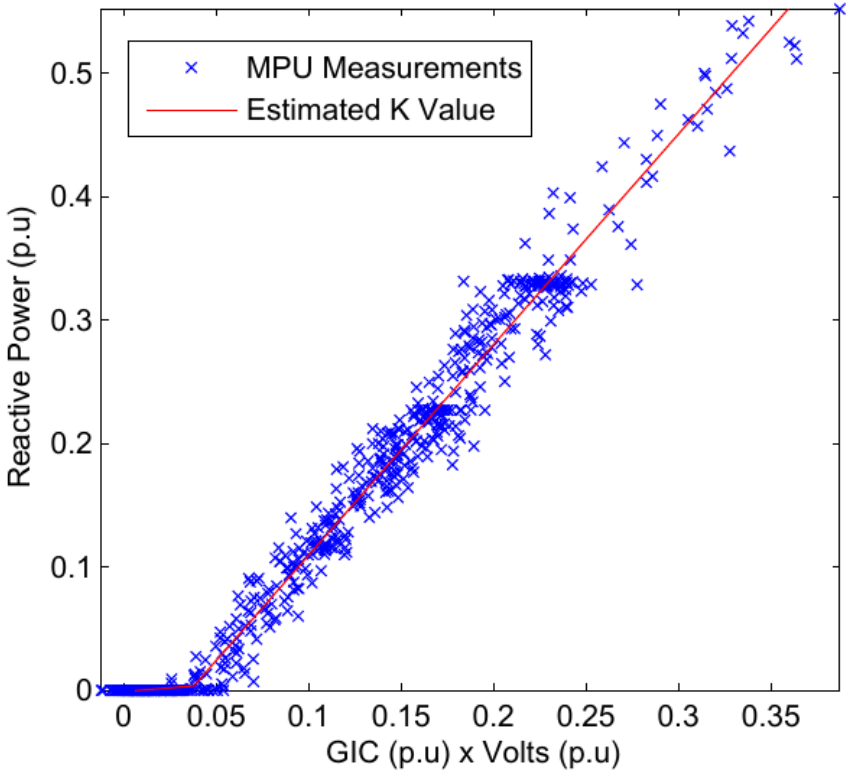


The variation of the GIC-saturated reactive power with respect to the GIC (The slope is used to estimate K).

Two Segmented Model



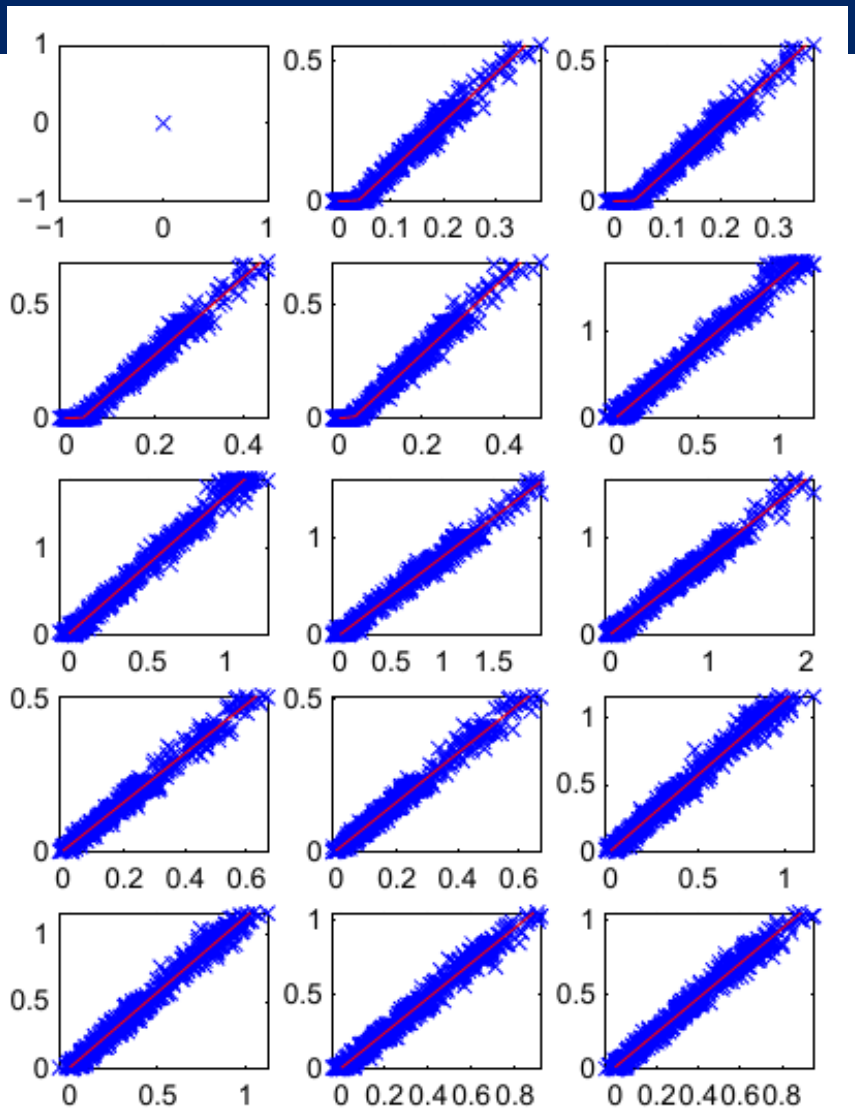
- A Two segmented model may be used to relate GICs to reactive power loss.
- Piecewise linear regression techniques are used to estimate K_1 and K_2.



- The break point current is .038 and is assumed to be given to the estimator.
- K_1 and K_2 are estimated with high accuracy.

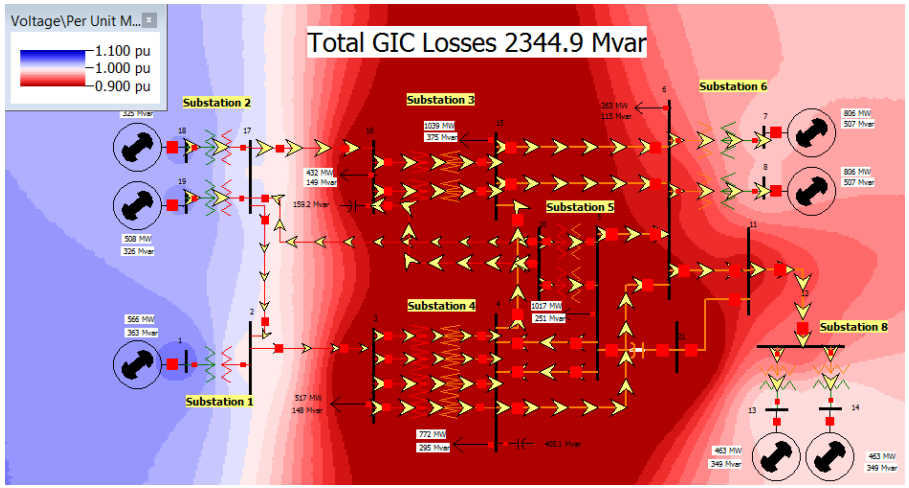
K Value Estimation

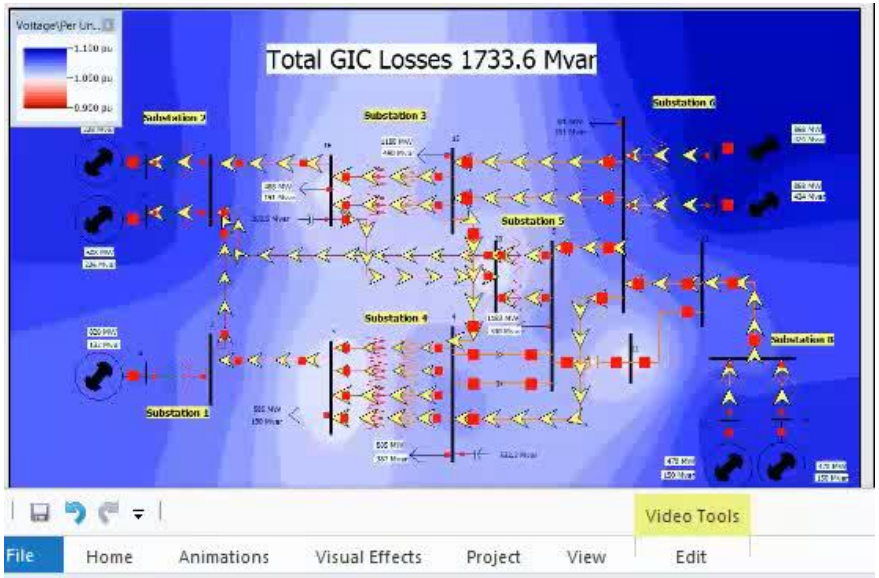
Transformer ID	Actual	Estimated	Error (%)
1	1.18	-	-
2	1.75	1.71	2.49
3	1.75	1.7	2.79
4	1.75	1.71	2.1
5	1.75	1.69	3.23
6	1.63	1.62	1.05
7	1.63	1.61	1.35
8	0.82	0.81	0.75
9	0.82	0.81	0.87
10	0.82	0.8	1.52
11	0.82	0.8	2.06
12	1.14	1.13	0.85
13	1.14	1.13	1.58
14	1.18	1.18	0.05
15	1.18	1.17	1.37
Maximum Error < 4%			



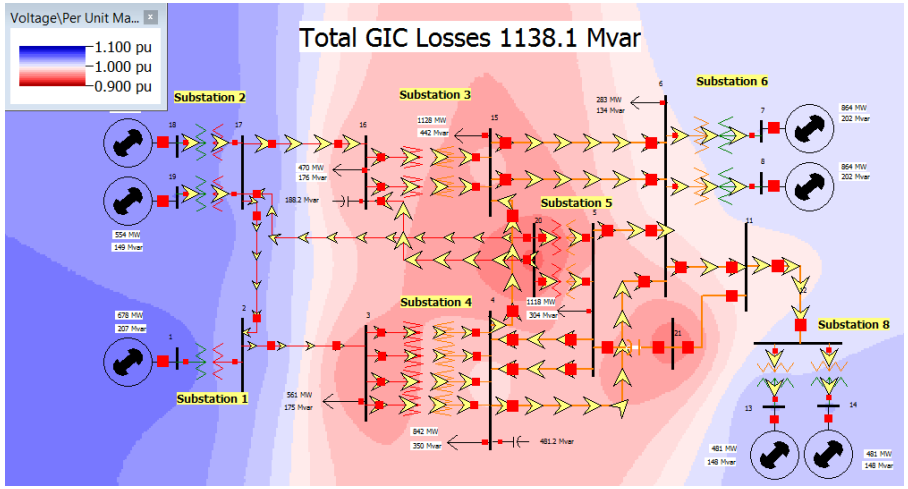
Effect of K Value on Voltage

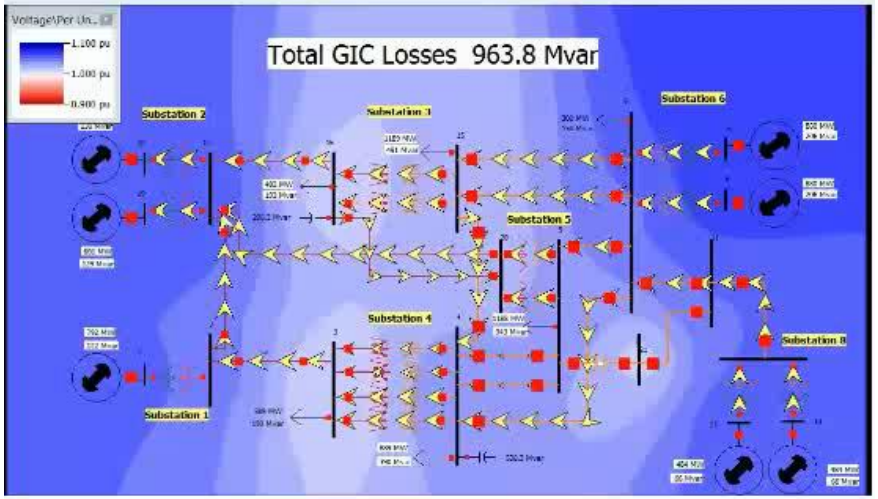
All transformers have K value of 1.8





All transformers have K value of 0.9





Conclusions

- Modeling of the transformers reactive power loss during geomagnetic disturbances is presented.
- PMU data is used to estimate the transformer parameters.
- The effectiveness of the proposed estimation technique is validated through simulation using a 20-bus test case.

Future Work

- Use actual PMU data for real systems instead of the synthetic data for a test case.
- Explore the possibility of using the PMU data at only one side of the transformer for estimating its parameters.

Thank You

Questions & Comments

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