Case Study – Effects of GIC Neutral Blocking Device

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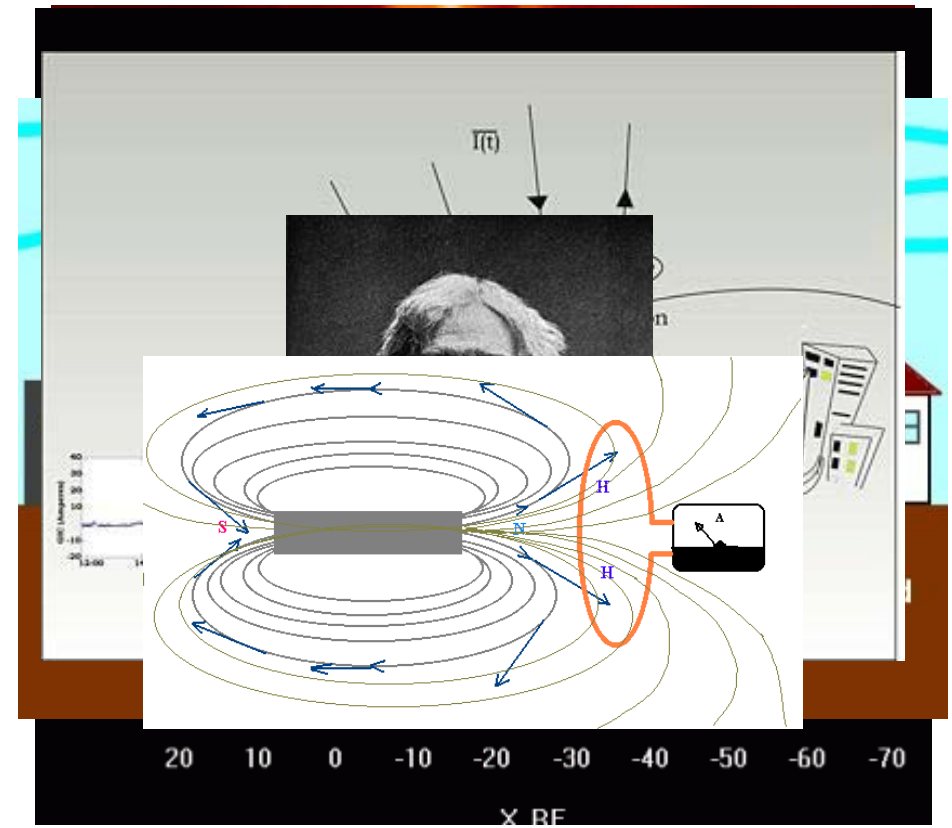
Outlines

- **Introduction**
- **System Vulnerability Assessment**
- **Effects of Neutral Blocking Device (NBD)**
- **Conclusions and Future Studies**

Introduction

Where Does GIC Come From

- Coronal mass ejection (CME) temporarily disturbances the Earth's ionosphere, magnetosphere and heliosphere. **The Earth's magnetic field** will vary in response to these dynamic processes.
- The variation of the magnetic field external to Earth induces telluric current which creates **a secondary magnetic field**.
- By Faraday's law of induction, a time varying magnetic field at the surface of Earth can induce an electric field which produces a quasi DC current along the transmission line.



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How Does GIC Impact the Power System

- Transformer half wave saturation
- Additional reactive power losses
- Transformer over heating and harmonics

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What Can be Done for Mitigations

- Series capacitor
- Transformer neutral blocking
  - Resistor
  - Capacitor
- Equipment hardening
- Operation procedure
  - Monitoring – alarm and force cooling
  - Re-dispatch

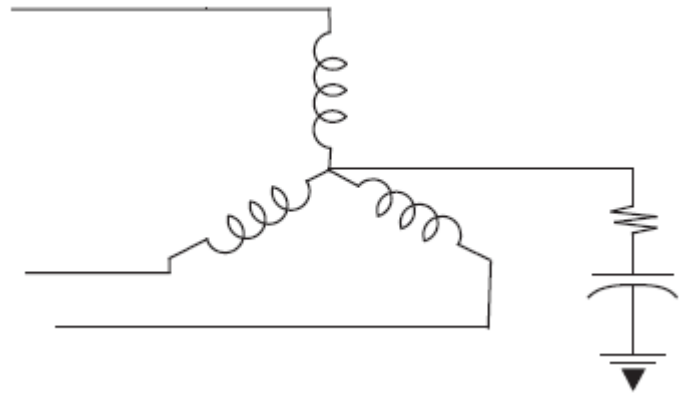

Fig. 1 Transformer neutral Blocking

System Vulnerability Assessment

Strength of The Geomagnetic Storm

- NERC benchmark event: $\mathbf{E_{peak}} = 8 \times \alpha \times \beta$ V/km, frequency 1 per 100 years

- Geomagnetic latitude scaling factor and soil structure: for AEP (PJM) system, a uniform 3.52V/km has been used for study

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Orientation of The Geomagnetic Field

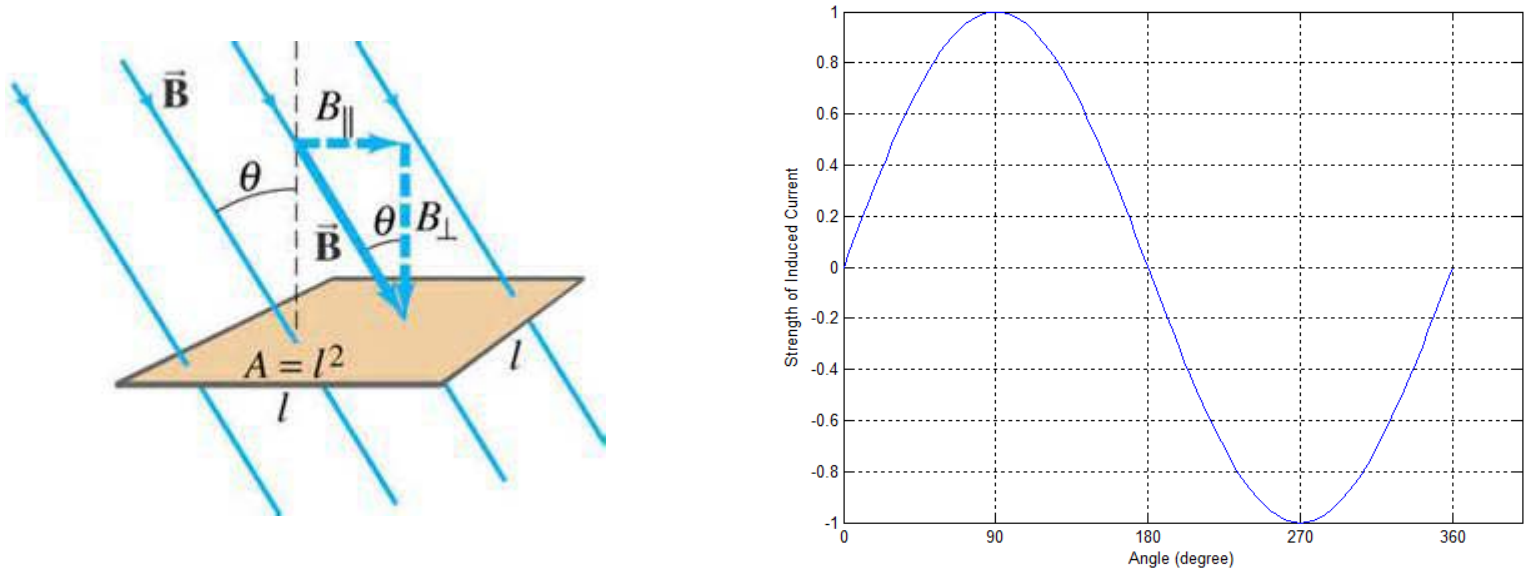

Fig. 2 Orientation of Earth Magnetic Field vs GIC Strength

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Effective GIC $I_{E\text{-}GIC}$

$$I_{E-GIC} = \frac{\alpha_t I_H + I_L}{\alpha_t} = I_H + (I_N/3 - I_H)V_X/V_H \qquad (1)$$

Where:

I_H	Per phase DC current going into the transformer high side;
I_L	Per phase DC current going into the transformer low side;
I_N	The neutral DC current (3-phase);
a_t	Transformer turns ratio, $a_t = V_H/V_X$;
V_H	rms rated voltage at the transformer high side;
V_X	rms rated voltage at the transformer low side.

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Transformer Reactive Power Losses

$$Q_{Loss} = K\left(\frac{V_{Nom}}{500}\right) V_{pu} I_{E-GIC} \qquad (2)$$

Where:

K	K-Factor used in transformer reactive power losses calculation
V_{Nom}	Nominal voltage at transformer high side in kV
I_{E-GIC}	Effective GIC
V_{pu}	High side voltage in per unit

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Effective GIC in Wye -Delta Transformer

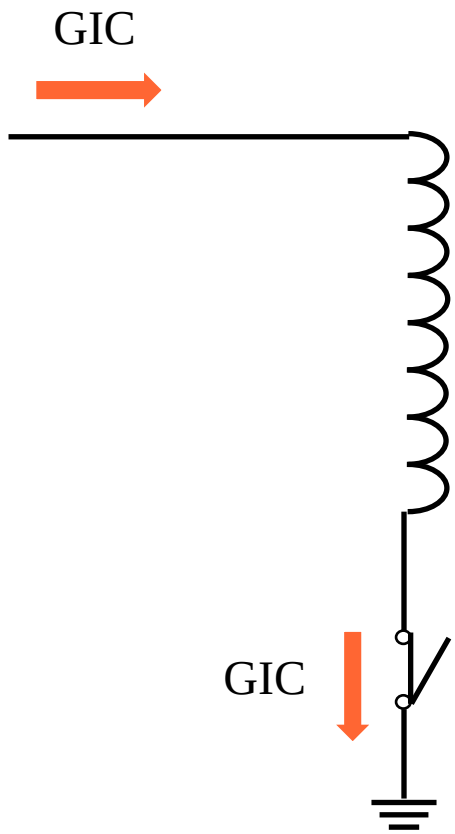

Fig. 3 GIC Flow in Wye-Delta Transformer

With neutral blocking:

$$I_{E-GIC} = 0$$

$$Q_{Loss} = K\left(\frac{V_{Nom}}{500}\right) V_{pu} I_{E-GIC} = 0$$

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Effective GIC in Auto Transformer

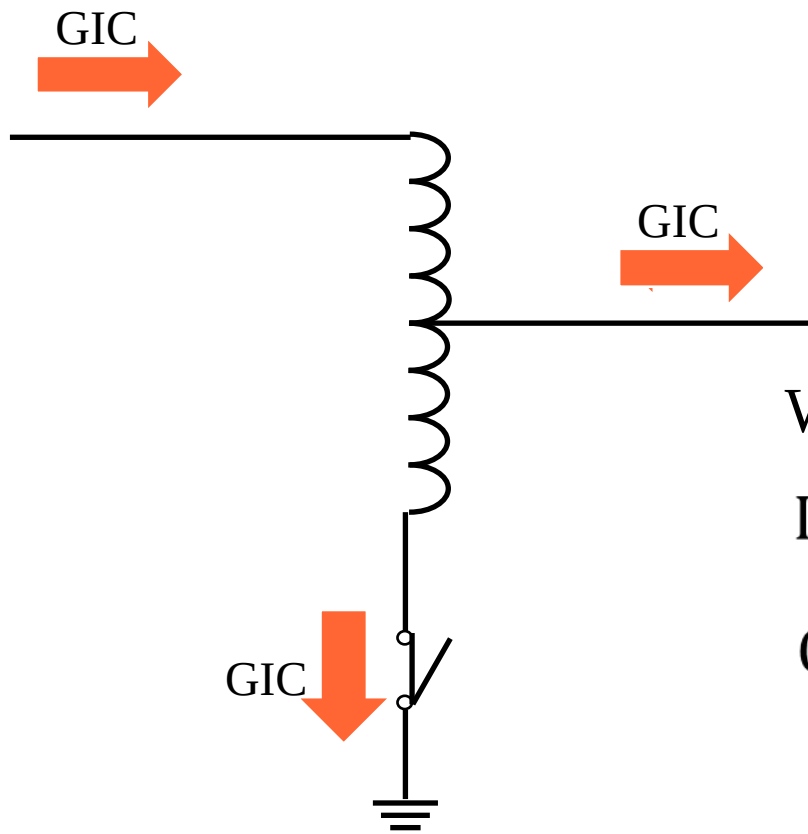

Fig. 4 GIC Flow in Auto Transformer

With neutral blocking:

$$I_{E-GIC} \neq 0$$

$$Q_{Loss} = K\left(\frac{V_{Nom}}{500}\right) V_{pu} I_{E-GIC} \neq 0$$

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Auto Transformer Example

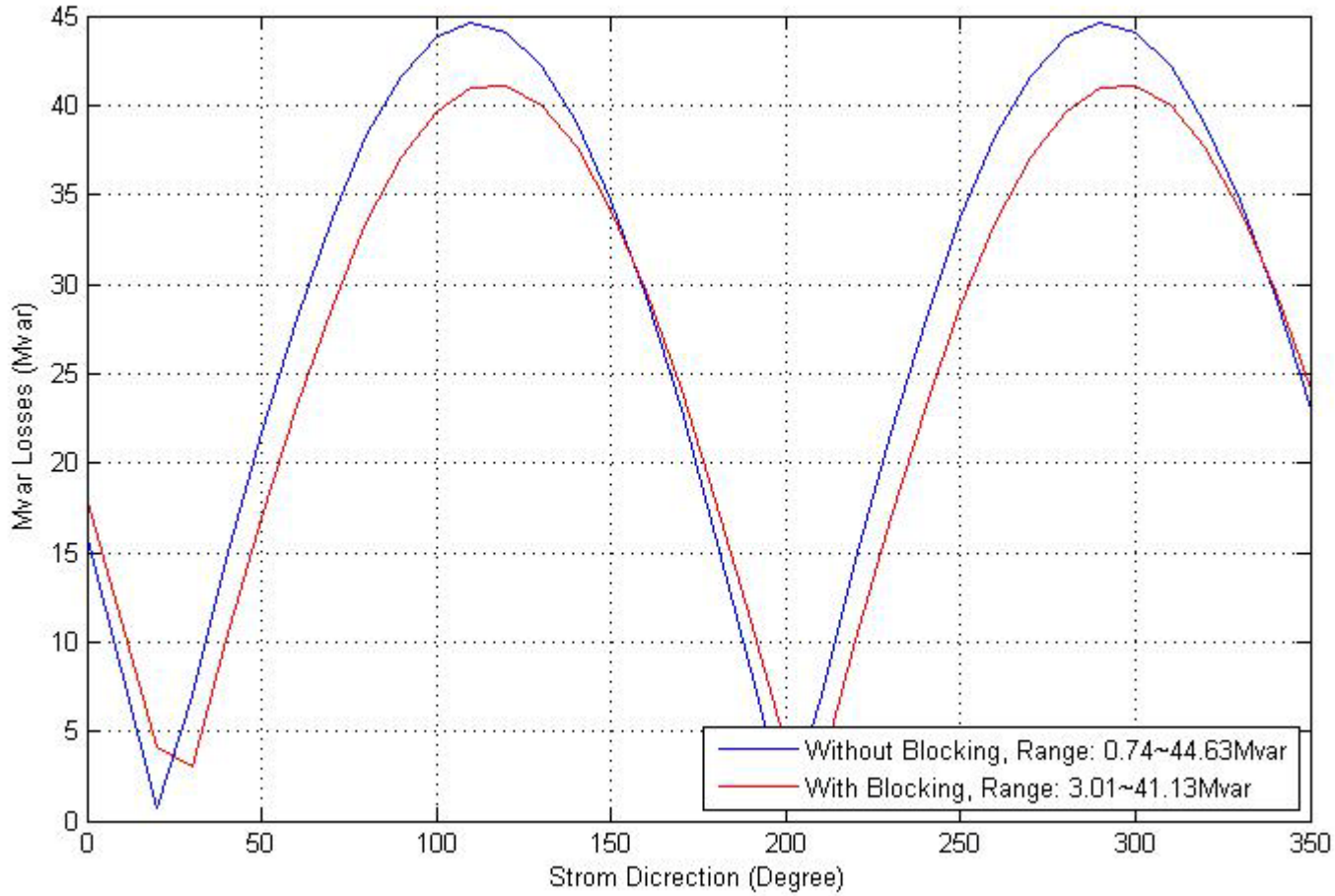

Fig. 5 GIC Flow, E-GIC & MVar Loss Comparison for an Auto Transformer

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Negative Impact of NBD

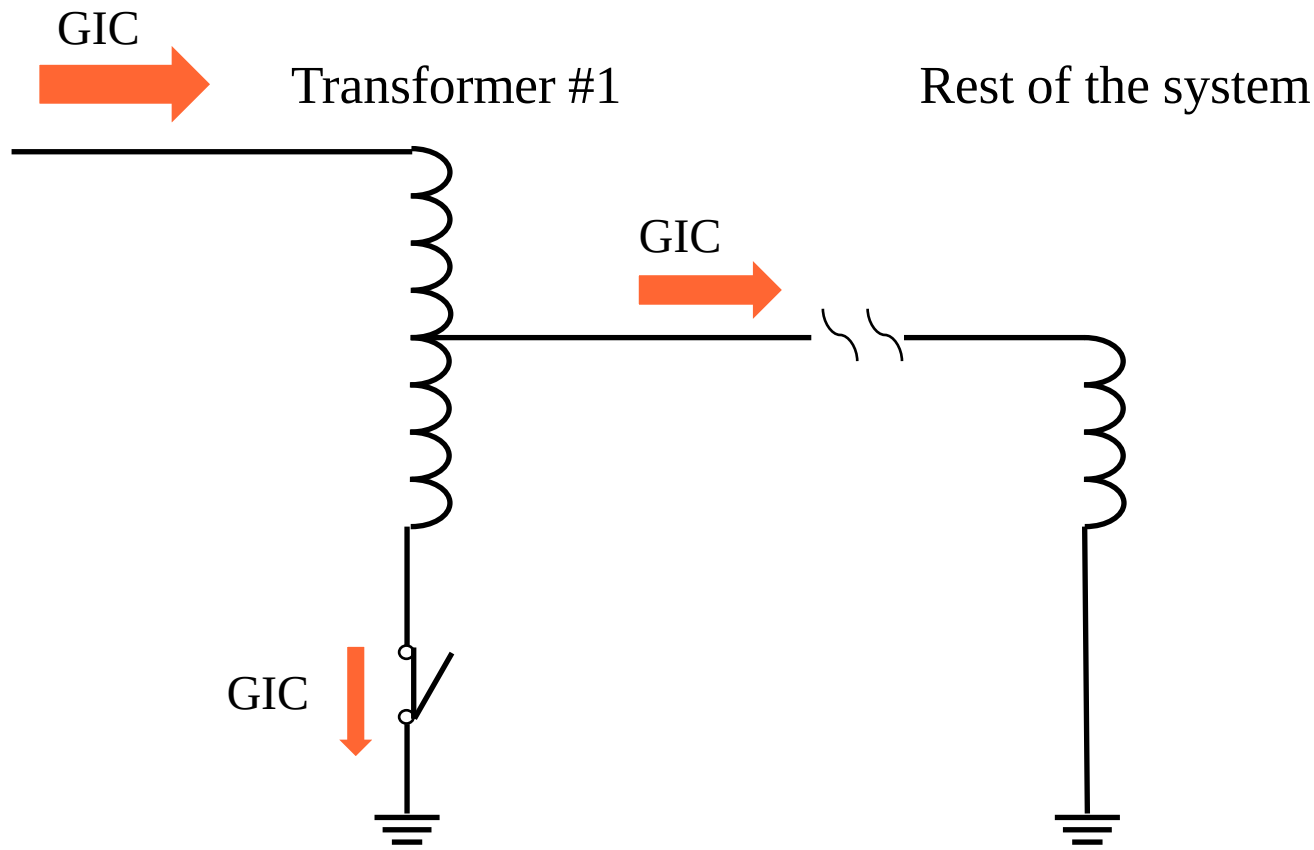

Fig. 6 GIC Redistribution

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Negative Impact of NBD

Table 1 Number of Transformers with Negative Impact due to Blocking

XF (E-GIC>15A) w/NBD	MVar Loss Elevated	
	Ave. XF #	Elevated%
Top 20%	93	36.9
Top 33%	98	38.6
Top 66%	105	41.4
Top 100%	109	42.9

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Impact of GIC Blocking on Total System Effective and Neutral GIC

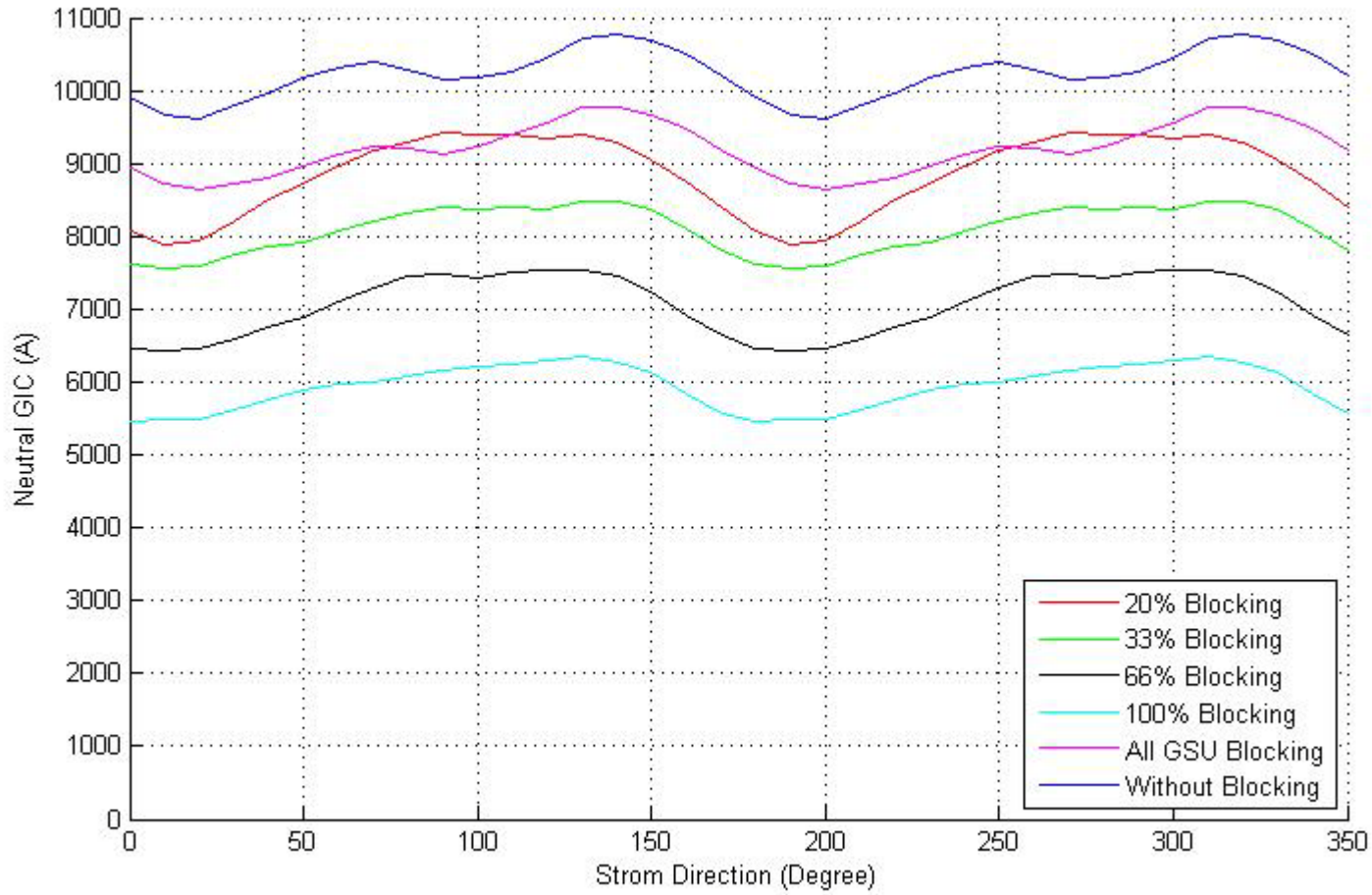

Fig. 7 Total Effective GIC and Neutral GIC

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Impact of GIC Blocking on Total System Effective and Neutral GIC

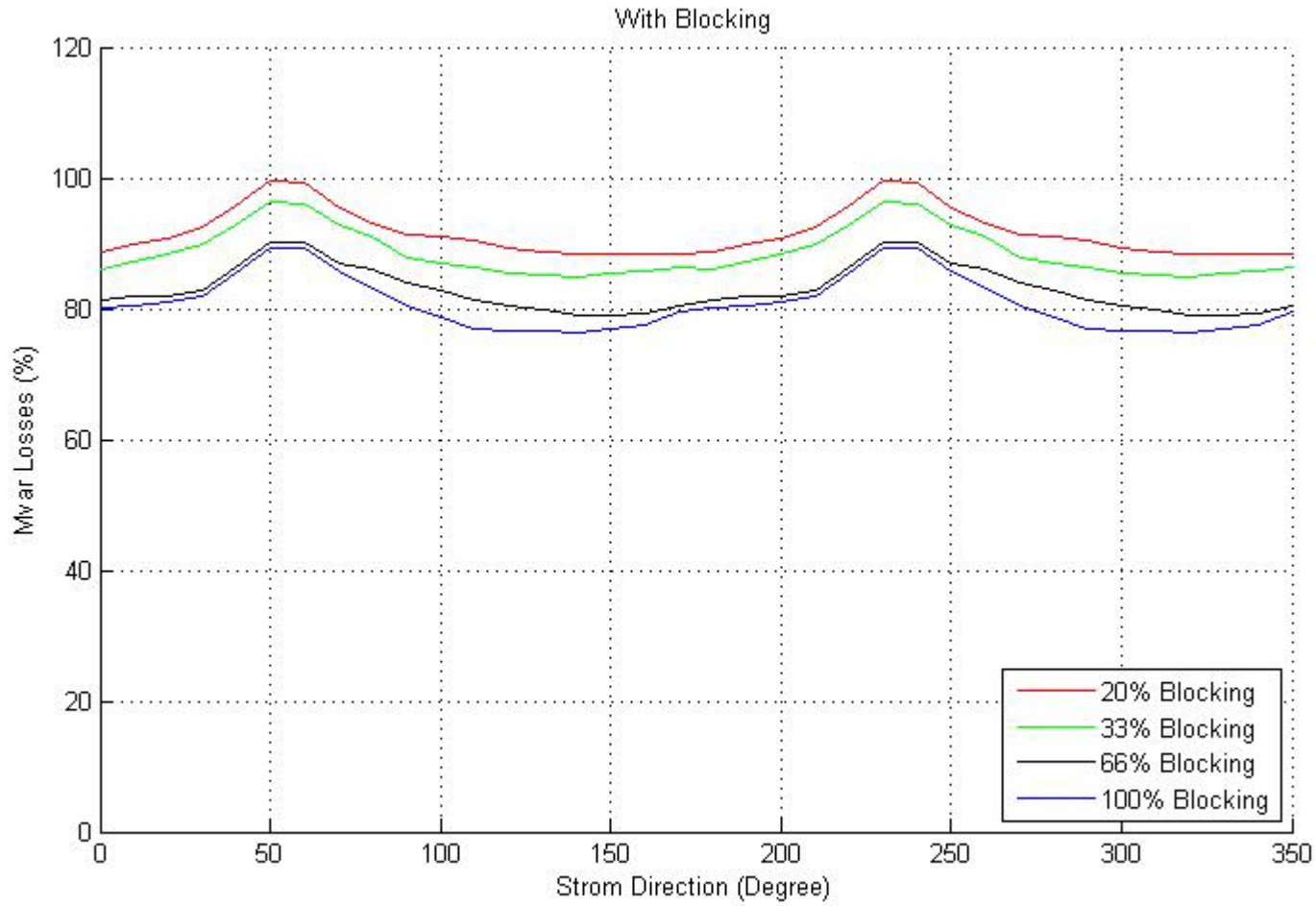

Fig. 8 Percentage of Total Effective GIC, Neutral GIC and Mvar loss

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Impact of GIC Blocking on Total System Effective and Neutral GIC

Table 2 Changes of Total Effective GIC, Neutral GIC and MVar Loss after Blocking

Blocking%	Average System MVar Loss Elevated			
	Sys. MVar Reduced	Sys. MVar Elevated	Net Change	Elevated/ Reduced
Top 20%	819	458	360	56%
Top 33%	1009	521	488	52%
Top 66%	1299	580	719	45%
Top 100%	1470	660	809	45%

Impact of GIC Blocking on Total System Effective and Neutral GIC

Shift Factor:

$$\text{Shift Factor} = \frac{\text{Total Elevated Effective GIC (or Mvar Loss)}}{\text{Total Reduced Effective GIC (or Mvar Loss)}} \times 100\%$$

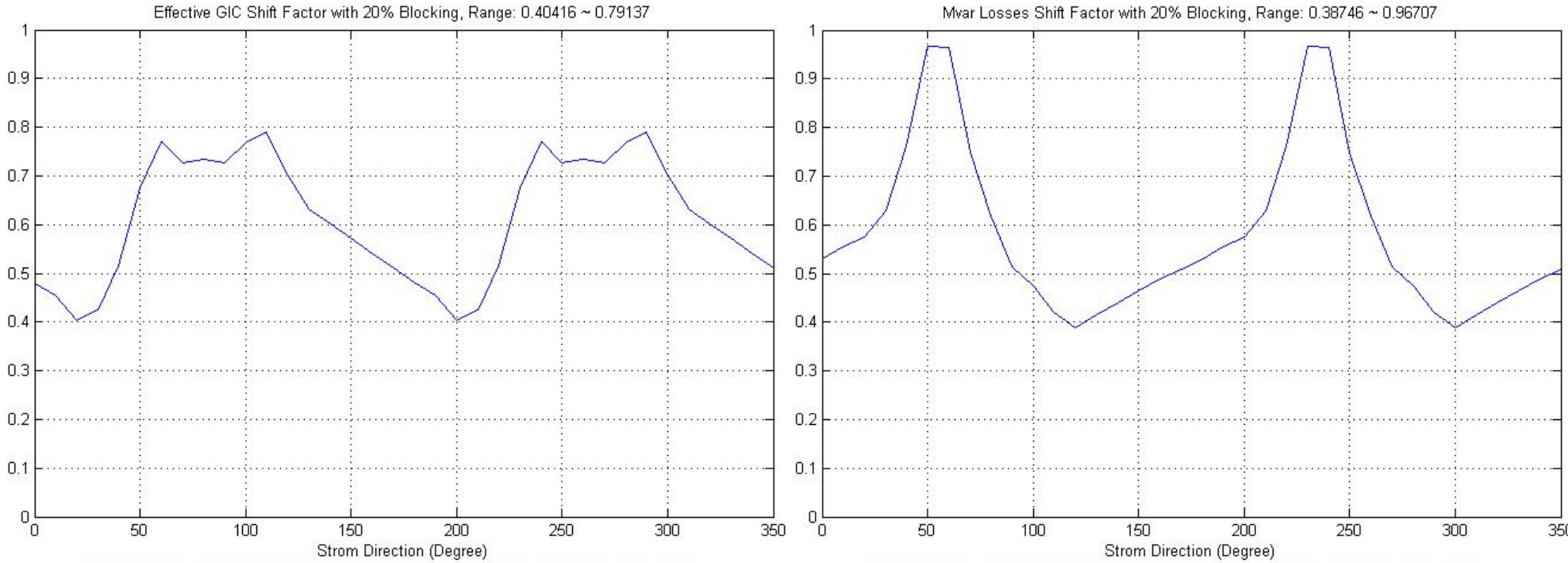

Fig. 9 Shift Factors

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Impact of GIC Blocking on Total System Effective and Neutral GIC

Table 3 Number of Transformers with Effective GIC > 15A
(At Maximum Storm)

Blocking%	Number of XFs w/ E-GIC > 15A			
	In the base list	Not in the base list	Total # of XF	# of XF Decreased
Base - 0%	70	0	70	0
Top 20%	65	5	70	0
Top 33%	62	6	68	2
Top 66%	54	8	62	8
Top 100%	41	10	51	19

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Impact of GIC Blocking on Total System Effective and Neutral GIC

Table 4 Neutral Blocking Device Effects on System E-GIC

XF (E-GIC>15A) w/NBD	Average System GIC	
	GIC	Reduction%
Base - 0%	3183	0
Top 20%	2988	6.1
Top 33%	2851	10.4
Top 66%	2640	17.1
Top 100%	2583	18.9

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Impact of GIC Blocking on Total System Effective and Neutral GIC

Table 5 Neutral Blocking Device Effects on System Reactive Power Loss

XF (E-GIC>15A) w/NBD	Ave. System MVar Loss	
	MVar Loss	Reduction%
Base - 0%	4148	0
Top 20%	3787	8.7
Top 33%	3659	11.8
Top 66%	3428	17.4
Top 100%	3338	19.5

Conclusions and Future Studies

Conclusions

- Neutral blocking device on an auto transformer can also disperse GIC to other transformers and elevates other transformer's effective GIC and MVAR loss.
- The total reduced effective GIC and MVAR loss does not decrease proportionally with the percentage of transformer blocked.
- Other sensitive study should be performed to evaluate other factors such as ground grid resistance, network topological changes and etc., that have significant impact on the GIC redistribution and reactive power consumptions.