Investigation of Geomagnetic Induced Current Effects on Power Transformer

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Abstract - Geomagnetic induced currents are generated on the power system by solar storms and solar flare, which causes damages to power transformer. GIC (DC) current when enter the power grid through the neutral point of transformer causes saturation of the transformer and the transformer gets damaged hence a novel hardware model was fabricated and the effects were analyzed. A software simulation was done using MATLAB and the effects on power transformer were observed to be increase in reactive power consumption and fluctuating harmonics in neutral current and the excitations current. Were analyzed which has got significance in the practical field to give warnings before the occurrence of the damage to the transformer and the subsequent interruption of power supply.

Key Words*:* ***G***eomagnetially Induced Current (GIC), Transformer,power system,harmonics.

1. INTRODUCTION

Normally power transformers are designed to operate with a sinusoidal voltage. Due to solar activity on Earth Surface and ESP Earth surface potential is induced which distorts the input voltage of the power grid and cause superimposition of DC current on transformer and causes various damages to the system.In power system, neutral points of transformer are generally grounded for providing protection to the system. Therefore due to variation in geomagnetic field it will produce potential difference and induce current between neutral point of transformer. This current is known as Geomagnetically induced current. Flow of current between neutral is known as geomagnetically induced current (GIC) and causes instability issues and equipment damage in power systems during geomagnetic storms.

The simulation is carried out to analyze the effect of GIC (DC) on transformer. This paper presents the simulation results to show the effects of GIC on the waveform of neutral current of transformer. The simulation model and results of transformer are presented in section

1.1 Hardware Implementation To Analyze The Effect of DC on Transformer

Figure 1: Hardware Implementation of

Transformer with injection of DC Current

Three phase AC voltage in the range of (0-440V) is applied to three phase transformer with the help of autotransformer and digital multimeter. The DC source injects a current depending upon the three phase load having resistance value, of 40Ω. As the maximum secondary voltage is 12V a maximum DC current of 1 A is injected into the star point, hence 0.333 A per phase was recorded. This has lead to saturation effects within the transformer core material.

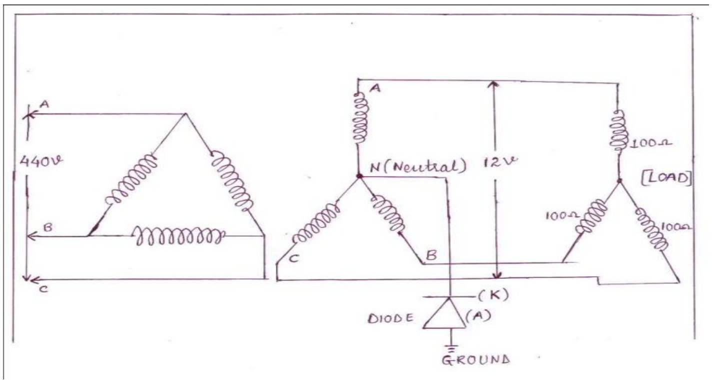

Figure 2: Single Line Diagram of Transformer with DC Injection

When 440V/12V transformer with secondary star connected with diode for blocking AC during half cycle. The readings are obtained by measuring the effect on the waveform of phase to phase and phase to neutral is shown in table 4.1

Input voltage (volt)	V_{RN}	V_{YN}	V_{BN}	V_{AB}	V_{BC}	V_{AC}
30	0.94	1.02	0.13	1.70	1.82	1.67
60	2	2.05	2.02	3.51	3.54	3.46
90	2.64	2.67	2.65	4.62	4.60	4.57
120	3.56	3.6	3.55	6.10	6.18	6.16
150	5.07	5.09	5.2	7.55	7.48	7.49
180	5.90	5.93	5.76	10.27	10.12	10.02
210	6.84	6.88	6.67	11.90	11.70	11.57

Table 1: Measurement of Phase and Neutral voltage

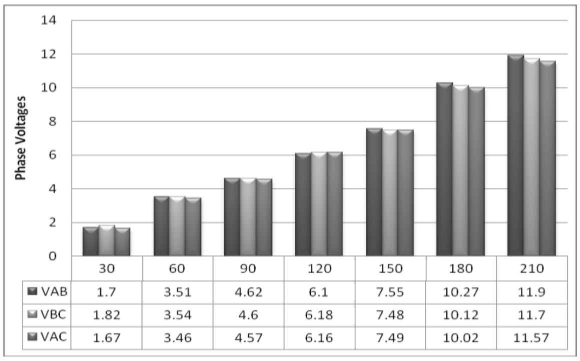

Figure 3: Variations in Phase to Phase Voltage

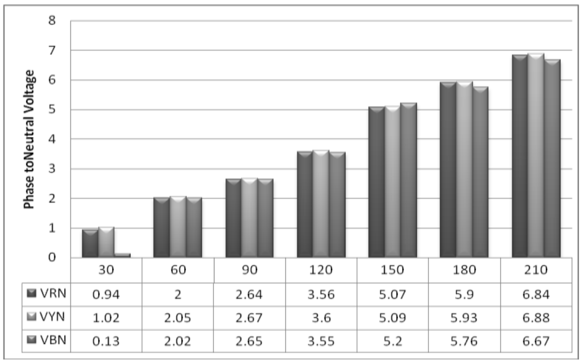

Figure 4: Variations in Phase to Neutral Voltage

Sr No	Primary Side	Secondary Side	
	Input Voltage(Volt)	$V_{RMS\,(1)}$	$V_{RMS\,(2)}$
1	30	2.40	8
2	60	5.20	9
3	90	8.20	10

4	120	10.40	12
5	150	12.80	16
6	180	36	18
7	210	18	20

Table 2: Measurement of RMS Voltage between Phase and Neutral

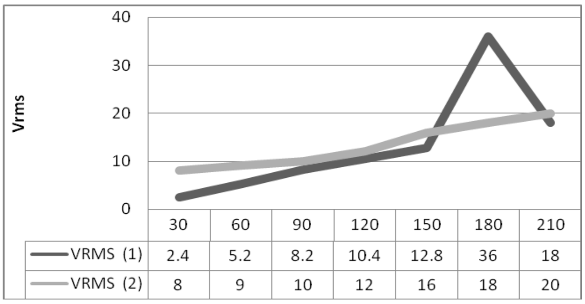

Figure 5: Variations in RMS voltage between Phases to Neutral Voltage

Sr No	Primary Side	Secondary Side	
	Input Voltage(Volt)	$V_{PP\ (1)}$	$V_{PP\ (2)}$
1	30	10	32
2	60	15.60	34
3	90	17.60	36
4	120	23.60	38
5	150	28	48
6	180	110	54
7	210	50	62

Table 3: Measurement of Peak to Peak Voltage between Phase and Neutral

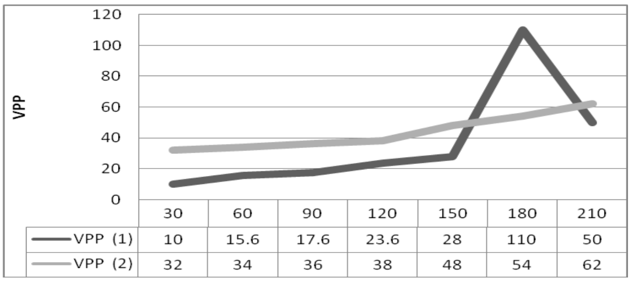

Figure: 6 Variations in Peak to peak Voltage between Phases to Neutral

Sr No	Primary Side	Secondary Side	
	Input Voltage(Volt)	$V_{MAX\ (1)}$	$V_{MAX\ (2)}$
1	30	5.60	17
2	60	10.40	18
3	90	13.20	19
4	120	19.60	20
5	150	24	30
6	180	42	34
7	210	64	36

Table 4: Measurement of Maximum to Maximum Voltage between Phases to Neutral

Figure: 7 Variations in Maximum to Maximum Voltage between Phases to Neutral

Sr No	Primary Side	Secondary Side	
	Input Voltage(Volt)	$V_{MIN\ (1)}$	$V_{MIN\ (2)}$
1	30	-2.80	-14
2	60	-5.20	-17
3	90	-9.20	-18
4	120	-11	-18
5	150	-3.0	-18
6	180	-20	-20
7	210	-22	-20

Table 5: Measurement of Minimum to Minimum Voltage between Phases to Neutral

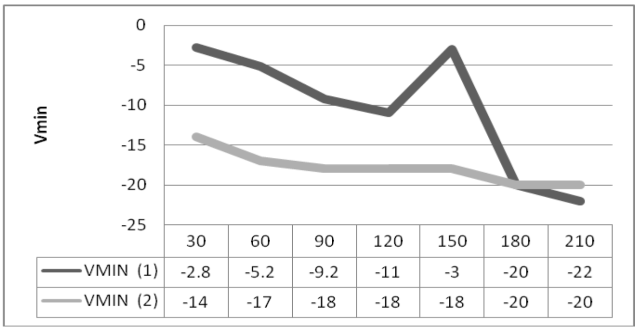

Figure: 8 Variations in Minimum to Minimum Voltage between Phases to Neutral

In real high voltage power transformer it is difficult to conduct test due to high magnitude of the currents and power. This problem was resolved by using reduced scale transformer. Thus effect and investigation of it is done in a laboratory setup by injecting DC currents into a three phase transformer.

For monitoring of the primary and secondary side voltage to ground a digital storage oscilloscope (DSO) is used. The primary side and secondary side current are metered with the help of clamp meter. The waveform of voltage before and after DC current injected is shown in figure 2 and figure 3

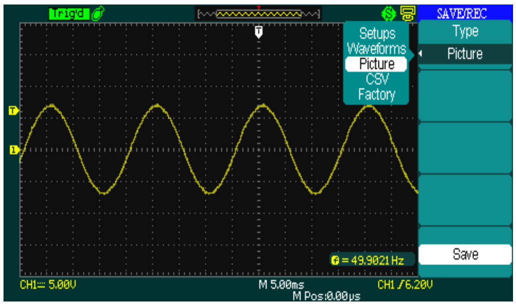

Figure: 9 Waveform on Primary Side of Transformer before DC Current is injected

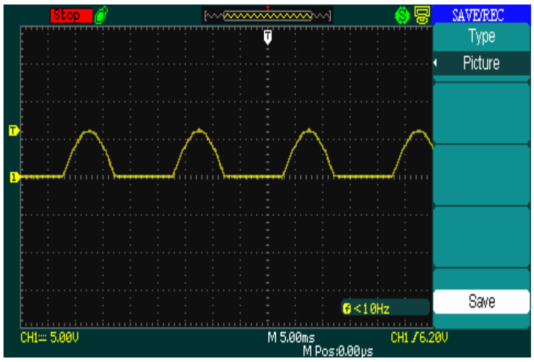

Figure: 10 Waveform on Secondary Side of Transformer after DC is injected into Transformer

III) Simulation and Result to Analyze the Effect of GIC (DC) Current on Three Phase Transformer

The simulink model consist of a transformer with three phase saturable transformer, resistive load, current and voltage measurement meter to measure current and voltage in respective phase, DC voltage source to produce DC current in order to simulate GIC effect.

Figure 4 shows simulation model to analyze the effect of GIC (DC) on transformer using simulation on MATLAB. Three phase saturable transformer is designed with a voltage of 440V in the primary and the secondary voltage of 12V, and a resistive load. The aim of this is to evaluate the effect of GIC with the transformer operating with DC. The rating of three phase transformer is a 12VA, 50 Hz. The line voltage of primary winding is 400 V & line voltage of secondary winding is 12V.

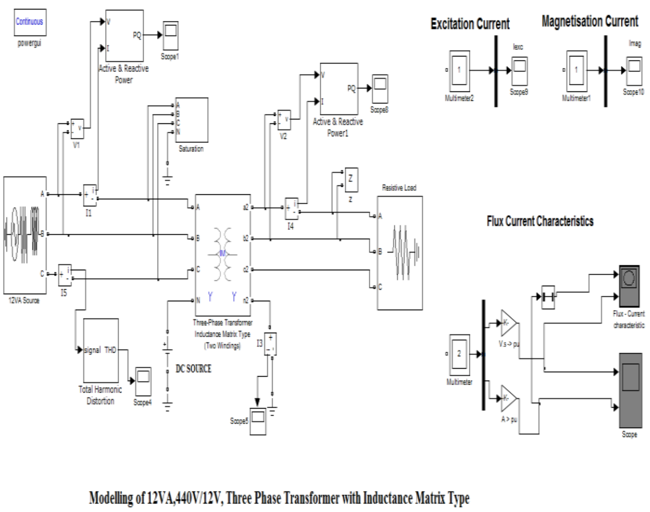

Figure: 11 Simulink Model of Transformer with effect of GIC (DC)

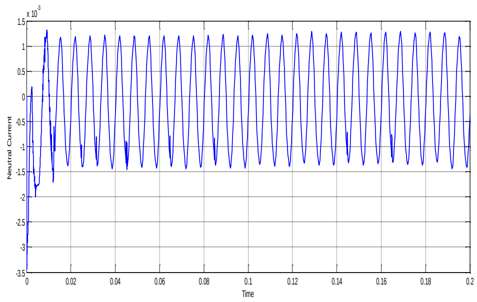

Figure: 12 Neutral Current When DC is induced at Secondary Side of Transformer

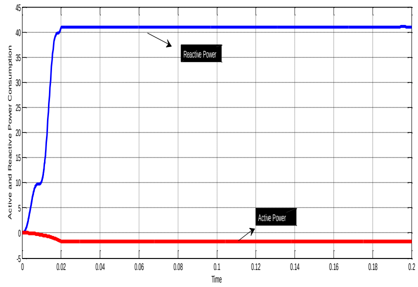

Figure: 13 Active and Reactive Power Compensation of Transformer

The simulation is carried out at different frequency and at different GIC current injection then it is found that the level of distortion increases in active and reactive power consumption as shown in figure 7:

SR.No	DC current Injected in Neutral (Amp)	THD (%)
1	50	3095
2	100	3150
3	120	3366
4	140	3992
5	160	4324
6	180	6050

Table 6: Variation of Total Harmonic Distortion When DC is Injected

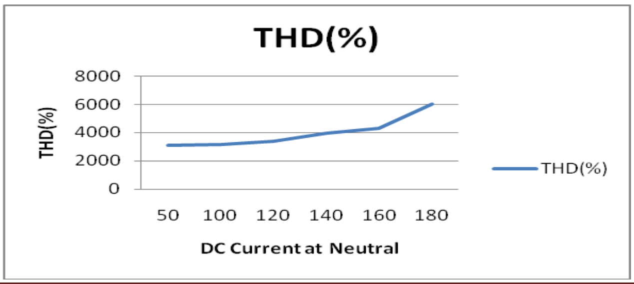

Figure 14: Variation of Total Harmonic Distortion with DC Current Injected

GIC	FREQ	THD (%)			
		I_p	V_P	I_S	V_S
0	60	22.27%	35.74%	22.22%	34.85%
10		22.24%	35.25%	22.19%	34.78%
20		22.24%	35.25%	22.19%	34.78%
30		21.11	35.02	21.07	33.14
40		22.39	35.96	22.34	35.03
50		21.72	35.1	21.68	34.03
60		22.86	35.34	22.81	35.66

Table 7: Variation in Total Harmonic Distortions at 60Hz

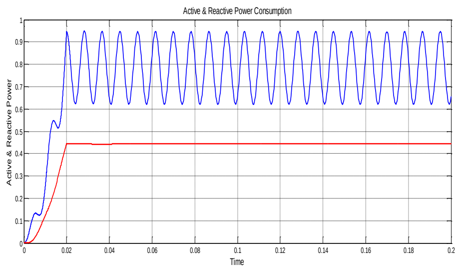

Figure 15: Active & Reactive Power Consumption at 60 Hz

GIC	FREQ	THD (%)			
		I_p	V_P	I_S	V_S
0	50	0.09%	0.03%	0.08%	0.03%
10		0.18%	0.24%	0.17%	0.10%
20		0.39	0.42	0.38	0.24
30		0.39	0.42	0.38	0.24
40		0.29	0.3	0.29	0.19
50		0.18	193.66	0.16	0.1
60		0.33	0.36	0.33	0.2

Table 8: Variation in Total Harmonic Distortions at 50Hz

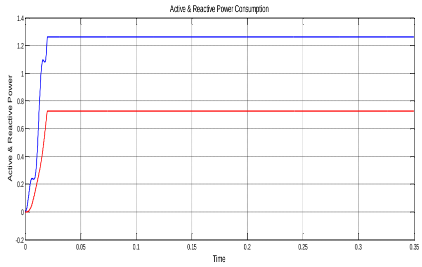

Figure 16: Active & Reactive Power Consumption at 50 Hz

GIC	FREQ	THD (%)			
		I_p	V_P	I_S	V_S
0	40	29.49%	14.72%	29.48%	31.64%
10		29.48%	14.60%	29.46%	31.58%
20		29.74%	14.42%	29.72%	31.60%
30		29.77	14.48	29.76	31.77
40		29.73	14.43	29.71	31.71
50		29.58	14.36	29.56	31.56
60		29.71	2715.63	29.64	31.61

Table 9: Variation in Total Harmonic Distortions at 40Hz

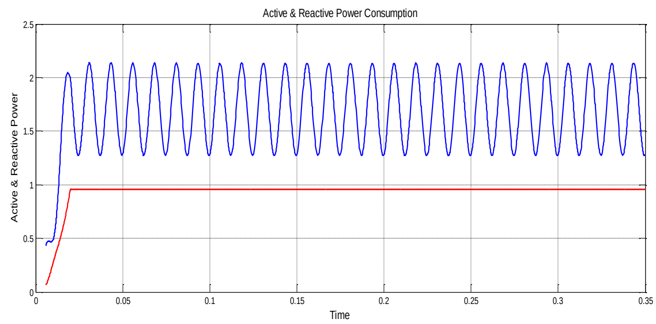

Figure 17: Active & Reactive Power Consumption at 40 Hz

Simulation at No Load: The total harmonic distortion in secondary current of transformer is shown in figure below.

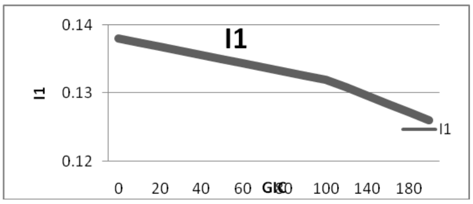

Figure 18: Variation in I_1 with respect to GIC

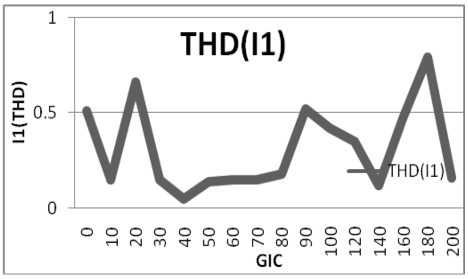

Figure 19: Variation in Total Harmonic Distortion in I_1 with respect to GIC

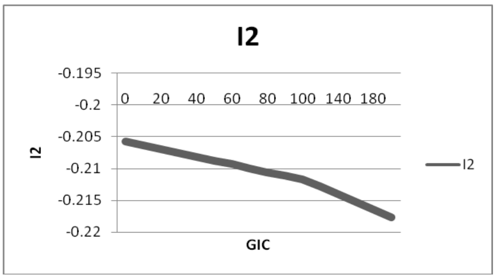

Figure 20: Variation in I_2 with respect to GIC

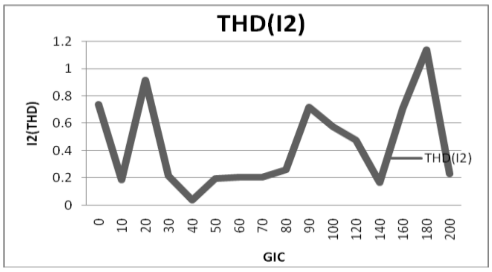

Figure 21: Variation in Total Harmonic Distortion in I_2 with respect to GIC

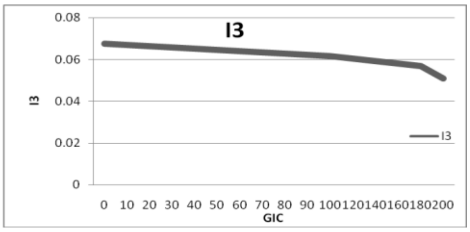

Figure 22: Variation in I_3 with respect to GIC

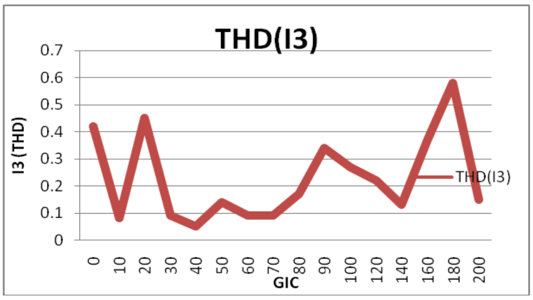

Figure 23: Variation in Total Harmonic Distortion in I_3 with respect to GIC

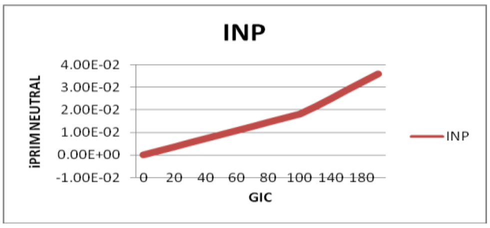

Figure 24: Variation in I_{NP} with respect to GIC

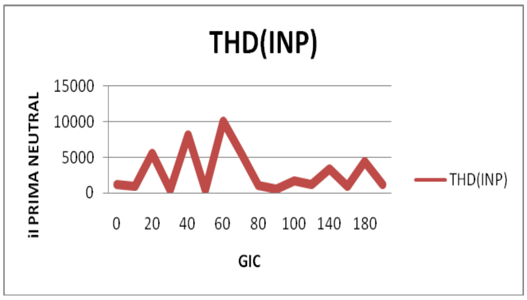

Figure 25: Variation in Total Harmonic Distortion in I_1 with respect to GIC

3. CONCLUSIONS

Conclusion

The simulations of GIC using a three phase saturable transformer model shows

1) Reactive power consumption is increasing from 0 to 0.02 m sec and after 0.02 m sec it becomes constant while the active power of transformer decreases from 0 to 0.02 m sec and thereafter it becomes constant.
2) The neutral current fluctuations are observed predominantly as the DC is injected into the neutral of the saturable transformer.
3) The fluctuating harmonics in neutral current using power GUI FFT tool is found to be 0.03%.
4) The fluctuating harmonics is also found in the excitation current of transformer.
5) The B-H curve is also plotted and the area of the curve increases which shows the hysteresis losses are proportionally increasing as DC current is being increased.

The hardware and simulation model has given the results which will be of immense importances to the practical field engineers. Further studies could observe effects which happen in a bigger scaled power transformer leading to damages of the insulation or even to failures occurring after GIC events. Further investigations about these phenomena on large scaled setups shall be followed and the scalability of the setup needs to be investigated.

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