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### **Impact of GIC on Noise Performance of Large Power Transformers**

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#### **SUMMARY**

Two large 3-phase Autotransformers of the same design, located at two different Substations in the Northeast region of USA, have been experiencing significant changes in their sound level as well as occasional high sound level excursions of short duration. A first step analysis could partly correlate the noise performance of these transformers to the operational parameters of both the power system and the transformers. A subsequent, more detailed, analysis, performed over several months, has found a high degree of correlation between the occasional high sound level excursions and magnitudes of the Geomagnetically Induced Current (GIC) flowing into the neutral of these transformers. The correlation is found to be even better with the Effective GIC current which represent GIC currents flowing into the windings of the transformers in Autotransformers.

This paper presents the analysis performed by the authors, the results obtained, and the conclusions reached in regard to the nature of the relationship between transformer noise and magnitudes and signature of GIC.

Finally, it is the conclusion of this work that differences in the magnitude of the increase of sound level of Transformers of the same design due to GIC are mainly caused by the following factors:

1. Difference in magnitudes of GIC going into the neutral of the transformers
2. Difference in the ratio of the magnitude of the effective GIC to magnitude of GIC flowing into the neutrals of the transformers
3. Difference in the operating core flux density in the transformers

#### **KEYWORDS**

Geo-magnetically induced current, GIC, Transformer noise, Power Transformers, GMD

## INTRODUCTION

The impact of GIC on noise performance of power transformers has been generally recognized by the industry [1, 2] and has been a subject of great interest in the past few years. In Reference [3] significant increases in transformer tank vibrations, measured on transformers experimented with DC, have been reported.

As stated in the Summary, two large 3-phase autotransformers of the same design, located at two different substations in the north-eastern region of USA, have been experiencing significant changes in their sound level as well as occasional high sound level excursions of short durations. Figure 1 below presents an example of the recorded Sound pressure level of one of the two transformers measured during a 3-day period. The figure shows variations of several dBs during certain time periods as well as large sound level excursions of up to 20 dB during other periods.

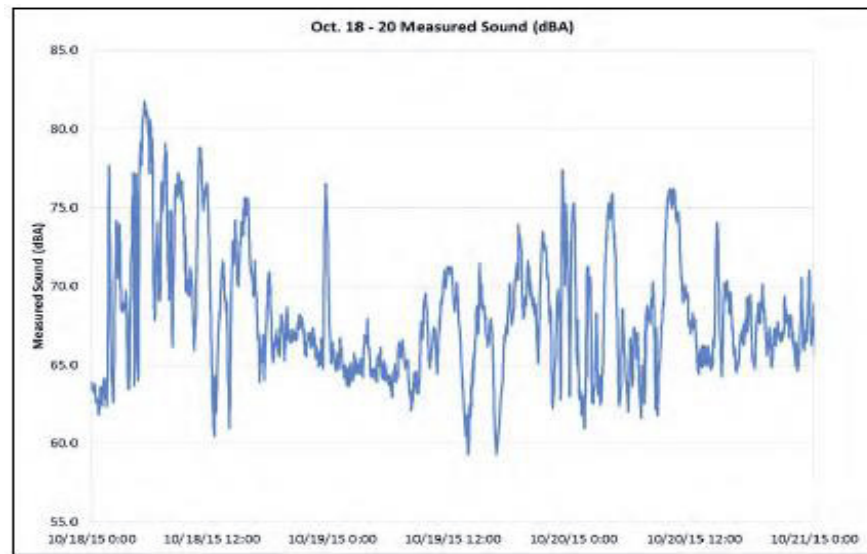


Figure 1: Measured Sound Pressure levels around one transformer for a 3-day duration

The low magnitude variations of the sound level of these transformers were correlated to the operational parameters of both the power system and the transformers. However, a more detailed analysis, performed over several months, has found a high degree of correlation between the occasional high sound level excursions and magnitudes of GIC current flowing through the neutrals of these transformers.

Presented in Section I of this paper is measured core noise performance of the two transformers operating under two different operating conditions while not exposed to GIC. In Section II, the theoretical impact of GIC on the magnitude and frequency spectrum of core noise is presented. Section III presents the detailed investigations performed to correlate between the on – site noise performance of these two transformers and measured signatures of GIC current flowing into them.

## NOISE PERFORMANCE OF TRANSFORMERS IN ABSENCE OF GIC

Figure 2 below presents measured frequency spectrum of the two referenced, same design, Autotransformers operating under two different conditions in absence of GIC. The figure shows the typically dominant 400 Hz frequency component of core noise for this size of transformers; especially when the core design has a mechanical resonance frequency in the neighborhood of 360 Hz. The difference between the corresponding measured total noise levels was about 8 dB (Transformer # 1: 70.9 dB (A) and Transformer # 2: 78.8 dB (A)).

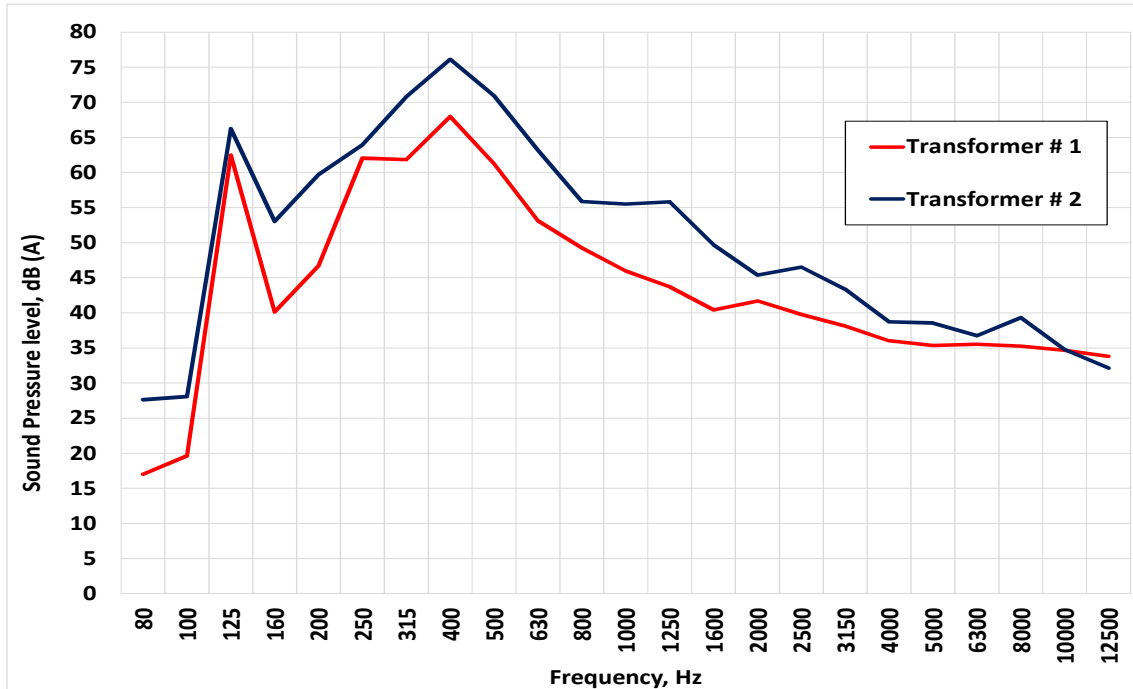


Figure 2: Measured frequency spectrum of referenced transformers in absence of GIC

## THEORETICAL IMPACT OF GIC ON CORE NOISE

### Impact on transformer total sound level

Table 1 below presents a summary of the calculated sound pressure level of core noise for this 3-phase core form transformer design with a 5-limb core when subjected to a GIC neutral current of up to 8 Amps. The sound levels represent sound at a distance of 6 feet from the perimeter of the transformer when the core is operating at 100% Voltage excitation.

The data shows that the calculated sound levels increase as the magnitude of GIC in the windings increases. The rate of this sound level increase is greater at GIC levels of 1 to 3 Amps and is negligible at higher GIC current levels. The reason for this noise performance impact is that low levels of GIC already drive the core of this transformer into the magnetic saturation region resulting in significant increases in the core sound level. Higher levels of GIC do not increase the core flux density much further and, hence, high levels of GIC do not correspondingly increase the core sound level as much as lower levels of GIC do.

GIC current in the Neutral, Amps	Core sound level, dB (A)	$\Delta$ Sound level increase*, dB
0	74	--
1	80	6
2	86	12
3	90	16
4	92	18
5	93	19
6	93	19
7	94	20
8	94	20

Table 1: Calculated core sound level vs. GIC

\* Referenced to Core sound level with no GIC

### Impact of GIC on frequency spectrum of core noise

Figure 3 below presents a summary of the calculated A-weighted sound pressure levels of the 1/3-Octave frequency spectrum of the core noise of the referenced transformer design when subjected to different GIC levels. The data demonstrates that while the impact of GIC is significant on all frequency components, the impact is much greater on higher frequency components ( $\geq 400$  Hz). This is in full agreement with previously observed measurements of high noise excursions. These were always characterized by significantly increased levels of higher frequency components; especially the 400, 500, and 630 Hz components.

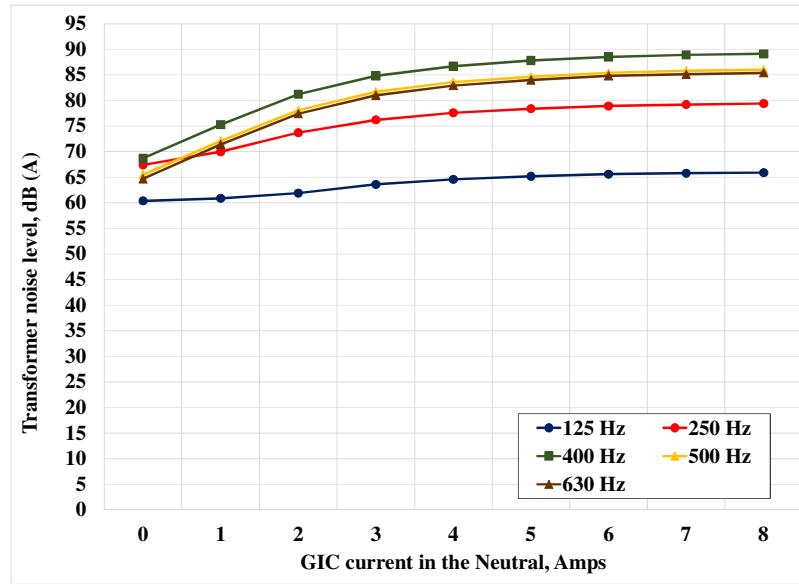


Figure 3: Calculated frequency spectrum of Core noise vs. GIC

### CORRELATION BETWEEN MEASURED SOUND LEVEL AND GIC

#### Correlation of sound level and measured GIC in the neutral of Transformer # 1

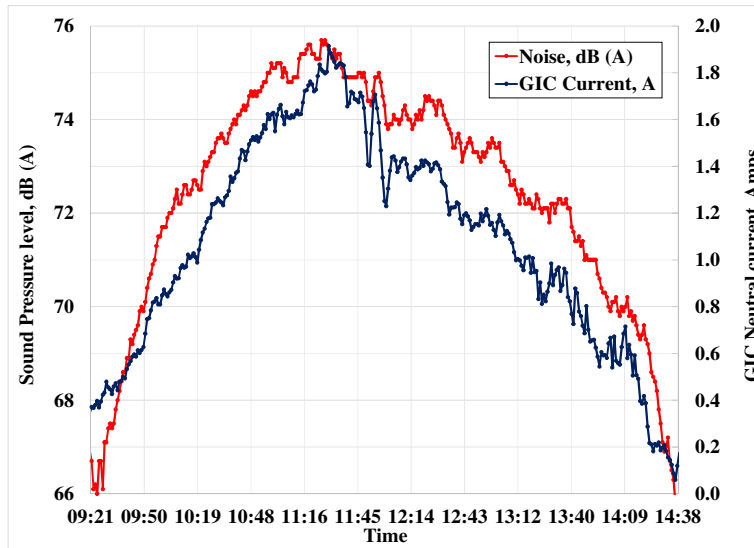
Figure 4 presents transformer sound level measurements performed in a close vicinity of Transformer # 1 as well as the concurrently recorded GIC current through the neutral of the transformer during two time periods in a 24-hour period.

Figure 4 (a) shows very good correlation between the signature of GIC and the resulting sound level of the transformer. The highest increase in the transformer sound levels is about 10 dB between 11:30 and 14:30; corresponding to a GIC level increase from 0 to 1.9 Amps. Such an increase in sound level is consistent with the calculated levels presented in Table I of this paper. Figure 4 (b) shows the correlation between sound level and GIC during the period of the high noise excursions. It demonstrates how short duration high level GIC pulses do not result in greater increases in the transformer sound level. The increase in this case is 13 dB while the GIC current is greater than 7 Amps. In fact, the figure shows that the noise level of the transformer does not increase any further beyond a GIC current of about 4 Amps in the neutral of this 3 phase transformer.

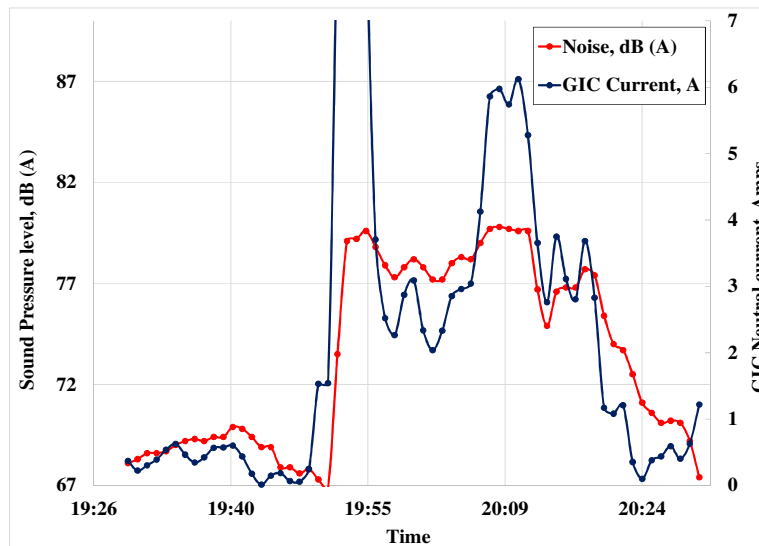
#### CORRELATION BETWEEN MEASURED SOUND LEVEL AND EFFECTIVE GIC

In autotransformers, the GIC current in the neutral flows through the common windings of the transformer (lower voltage windings). A portion of this current, however, goes into the low-voltage power system through the auto point of the transformer. The balance of the current flows into the series windings of the transformer (high voltage windings and into the high-voltage power system. In order to account for this phenomenon, the concept of “Effective

GIC current,  $I_{\text{effective}}$ ” has been adopted by the industry [2]. It will be shown later in this paper that correlation of the sound levels with the Effective GIC is quantitatively better than that with the GIC through the neutral.



(a) Period of low level GIC activity



(b) Period of high sound level excursions

Figure 4: Measured sound level vs. GIC current in the neutral

### Correlation of sound level with magnitudes of GIC in the neutral

Figure 5 below presents the measured sound levels of Transformer # 1 concurrently with the measured GIC current through the neutral as well as the Effective GIC current ( $I_{\text{effective}}$ ) in the transformer.  $I_{\text{effective}}$  was calculated using measured values of GIC in the neutral and in the high voltage bushings.

The figure shows a high degree of correlation between the sound levels and both the GIC current flowing through the neutral and the Effective GIC. Figure 5 additionally demonstrates that the ratio between the peak magnitudes of the Effective GIC and the GIC through the neutral is about 0.8 (1.5 A / 1.9 A).

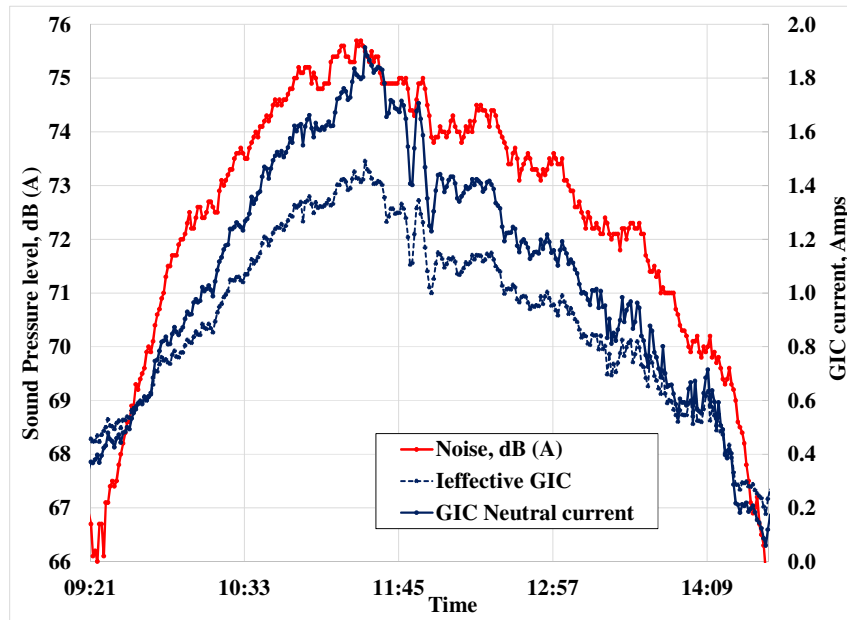
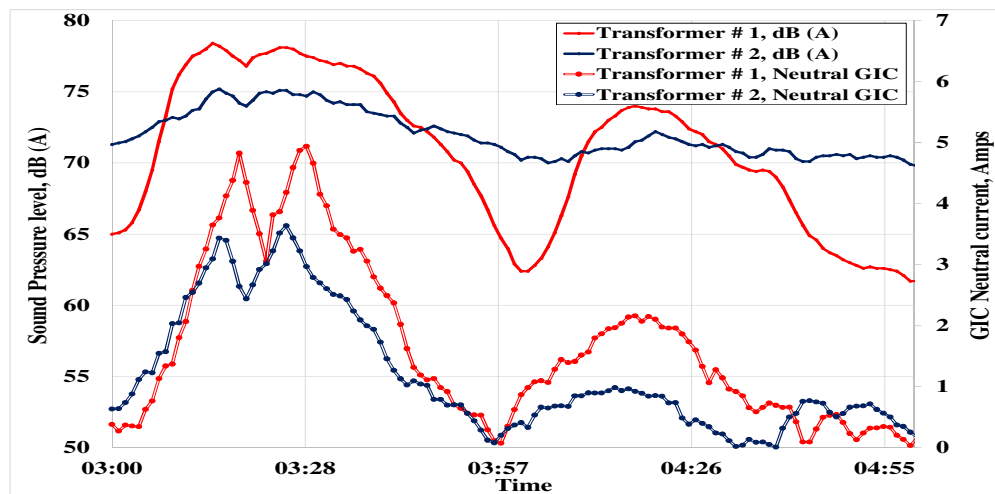


Figure 5: Measured sound levels of reference Transformer # 1 vs. GIC currents

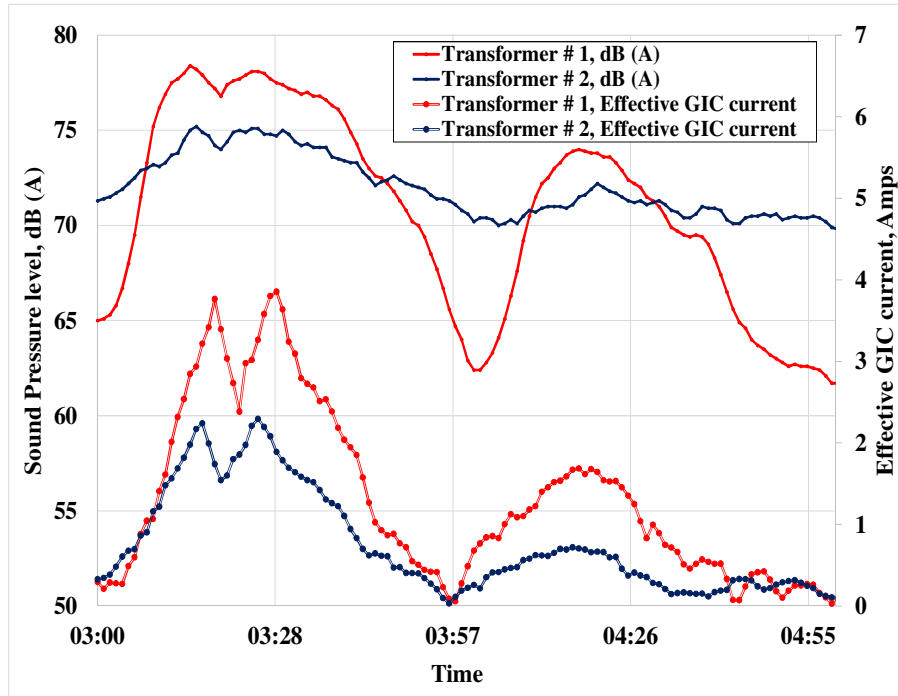
### Correlation of sound level with magnitudes of GIC in the neutral and I effective

In an attempt to understand, in more detail, the correlation between sound level and GIC, Figure 7 (a) presents sound data vs. measured GIC in the neutral for both transformers # 1 and 2 during a 2 – hr period while Figure 7 (b) presents the corresponding sound data vs. the calculated Ieffective. Figure 7 (a) shows that, in the time-period between 3:00 and 4:00, Transformer # 1 experienced a peak GIC current in the neutral of about 5 Amps and caused the transformer sound level to increase by about 13 dB. During the same time-period, Transformer # 2 experienced a GIC current in the neutral of about 3.7 Amps and caused the transformer sound level to increase by only 5 dB.

As stated earlier, the Effective value of GIC should be the GIC level that correlates better with the sound level of transformers. This is confirmed by data presented in Figure 7 (b) below; where measured sound levels of the two transformers are plotted concurrently with the corresponding magnitudes of the effective GIC current.



(a) Correlation with the GIC current in the neutral



(b) Correlation with the Effective GIC current

Figure 7: Measured sound levels of Transformers # 1 & 2 vs. GIC

Figure 7 (a) and (b) demonstrate differences in magnitudes between the GIC currents in the neutral and Effective GIC currents experienced by the two transformers. In Figure 7 (a), the ratio of the peak neutral GIC currents, between the two transformers, is about 1.35 (5.0/3.7 A) while Figure 7 (b) shows a ratio of about 1.65 (3.8/2.3 A) for the Effective GIC currents. The corresponding sound level increases of that two transformers during the same periods are 15 dB for transformer # 1 and 5 dB for Transformer # 2. This is a much improved correlation between sound performance and the GIC current than previously observed with the relative magnitudes of GIC current in the neutral.

Finally, it is to be noted that another factor in determining the difference in the magnitude of the increase of sound level of Transformers # 1 and # 2 due to GIC is caused by the difference in the operating core flux density of the transformer.

#### ACKNOWLEDGMENT

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