An investigation into space weather impacts on UK power station transformers

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[i] Abstract

It is well documented that space weather can impact electricity infrastructure, and several incidents have been observed in recent decades and directly linked to large geomagnetic storms (e.g. the Hydro Quebec incident in 1989). However, less is understood about the impact of lower-level Geomagnetically Induced Currents (GICs) on the health of transformers in the long term. Direct measurements of GIC at power stations are still quite rare, but all transformers sense and record levels of dissolved gases within the insulation, as a way of monitoring transformer health.

In this study, the long term impact of geomagnetic activity on 13 power station transformers in the UK was investigated. Dissolved gas measurements between 2010-2015 were used to look for evidence of a link between degradation of the transformer insulation and heightened levels of global SYM-H and the rate of change of the horizontal magnetic field (dB/dt) as measured at the Eskdalemuir magnetometer station. First, case studies of the most significant storms in this time period were examined using dissolved gas analysis (DGA) methods, specifically the Low Energy Degradation Triangle (LEDT). These case studies were then augmented with a statistical survey, including Superposed Epoch Analysis (SEA) of multiple storm events. No evidence of a strong space weather impact can be found during this time period, likely owing to the relatively quiet nature of the Sun during this epoch and the modernity of the transformers studied.

[ii] Dissolved Gas Analysis Data

- DGA data were analysed from **13 UK power station transformers** from **2010-2015** (exact time range differs for each transformer).
- The transformers have been anonymised (A-M), and the six gas concentrations shown are the 'key' gases used in DGA: **methane, ethylene, ethane, hydrogen, acetylene and carbon monoxide**.
- An **LEDT** was plotted for each of the 13 transformers, for each of the 10 largest storms in the 2010-2015 period. The storm list used was produced as described in Walach & Grocott [2019], extended to cover the timeframe of 1981 to 2019.

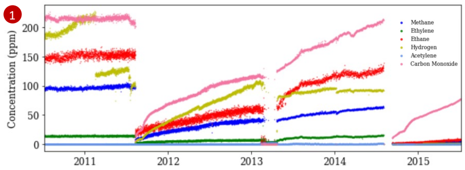
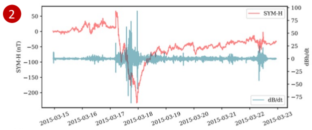


Figure 1 Typical DGA gas concentrations for one of the transformers in the data set (E). Note the general upwards trend on a multi-year scale and gaps indicative of maintenance or oil change.



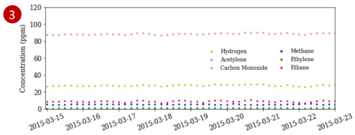
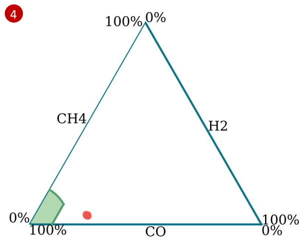
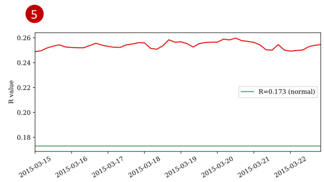


Figure 2 SYM-H and dB/dt for St Patrick's day storm, 2015 and **Figure 3** raw gas data for the same period in transformer J.

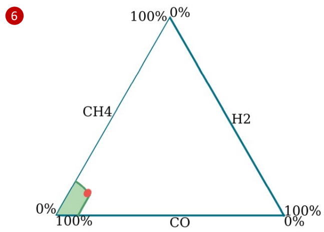
[iii] The Low Energy Degradation Triangle

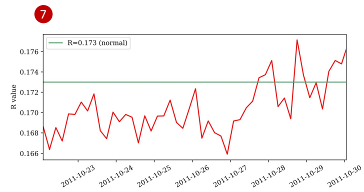
- The LEDT method was developed in Moodley and Gaunt [2017] and differs from other DGA methods as it **aims to predict a fault before it occurs**.
- The LEDT combines three gas concentrations on a triangular plot: **methane, hydrogen and carbon monoxide**. One vertex corresponds to 'normal' operation of the transformer and any movement away from this region corresponds to early indication of a fault. The degradation R index refers to the distance from the origin, where R = 0.175 marks the limit of the normal region, and is an indicator of fault likelihood.
- **Figure 4** presents the LEDT (plotted for 72 hours before and 120 hours after the minimum value of SYM-H, for the St Patrick's day storm) alongside the degradation R index (**Figure 5**). The LEDT shows the transformer to be operating away from the normal region but the location on the triangle is stable throughout the storm period.





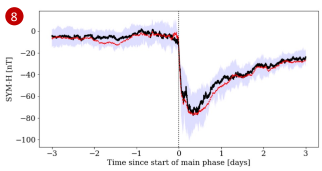
- **Figure 6** and **Figure 7** shows another storm 24th-25th October 2011. The LEDT and R index for transformer D show a small movement away from the normal region during the recovery phase of the storm. This is possibly a direct effect of GIC within the transformer, but the change is very small (+0.006 in the R index).
- **Of the 98 transformer storm combinations studied (not all transformers had data for every storm), 63% of the LEDTs showed the transformer to be outside of the normal region throughout the entire storm period.**
- This increased likelihood of failure does not appear to be linked to GIC activity, as only 1 case (**Figures 6 and 7**) showed convincing movement out of the normal region after onset of the storm. Considering the number of cases studied, this is not likely to be a significant result.



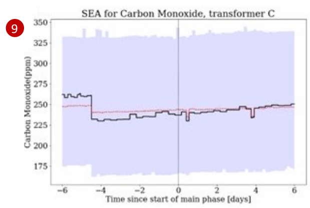


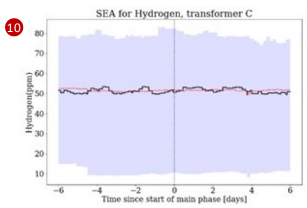
[iv] Superposed Epoch Analysis

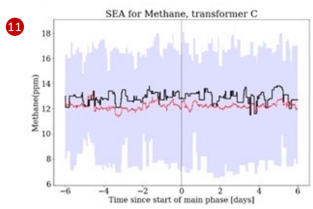
- A superposed epoch analysis (SEA) was performed. **Figure 8** shows the SYM-H data superposed and lined up on the **start of the main phase of the storm** as defined in Walach & Grocott [2019] The three gas concentrations considered in the LEDT (methane, hydrogen and carbon monoxide) were then centred on the same epoch with 6 days either side, and plotted individually for each transformer.

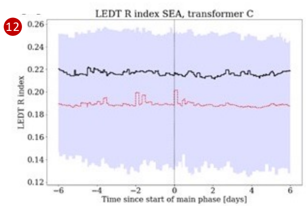


- **Figures 9, 10 and 11** show the results for a particular transformer, including the degradation R index from the LEDT plot (shown in **Figure 12**). The black line shows the median, the red dotted line shows the mean and the blue shaded region the interquartile range.
- **33 storms were included in this analysis**, which reflects all the storms which occurred during the time period covered by data for this transformer.
- These results show that **no general upwards trend exists in the transformer** following the onset of the storm. The interquartile range is large, owing to the noisy and highly variable nature of the gas data.









Summary

In this study, DGA measurements were exploited to look for trends in transformer health related to geomagnetic activity. Case studies were considered for the 10 largest geomagnetic storms between 2010-2015, and the Low Energy Degradation Triangle method was used to look for low-level changes to transformer health. The LEDTs showed that in the majority of cases, the transformers appear to be operating away from the normal region, but no equipment anomalies were recorded. However, it is noted in Moodley & Gaunt [2017] that an abnormal LEDT result does not indicate absolute likelihood of a transformer failure. Superposed epoch analysis showed no correlation between storm onset and an increase in the rate of change of individual gas concentrations during this epoch of moderate geomagnetic activity. Future work should include an extension of this analysis to periods of more disturbed solar and geomagnetic activity.

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