Solar storms: what is the risk to power transformers?

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This article discusses the problem of the influence of geo-magnetically induced currents (GIC) during solar storms on power transformers. It is shown that there is no experimental data confirming the necessity to revise the traditional viewpoint regarding the dangers of GIC arising in the southern hemisphere on power transformers.

The problem of power transformers being damaged by GIC during solar storms is widely known [1, 2]. Quasi-direct currents of GIC flowing through grounded neutral terminals of power transformers located in the northern regions can reach between 100 to 300 A. These currents result in deep saturation of magnetic cores, reduction of impedance and overheating of windings and magnetic cores, which can even lead to winding blow-out.

The collapse of the Hydro-Québec power grid in Canada resulted in 6-million people losing electric power for nine hours. Another case is a blow-out of a power transformer belong to the Public Service Electric and Gas Company in New Jersey, USA during a solar storm in March 1989 (Fig. 1) [3].

In 2005 and 2012, GICs (with an amplitude of up to 200 A) were registered in the neutral terminals of power transformers in Finland, while in Sweden the amplitude of a GIC reached 300 A in 2000. The GIC impact on transformers in August 2003 resulted in a collapse of the power grid in northern USA and a part of Canada.

Until recently, all the registered cases of damaged supply transformers happened in the circumpolar regions on northern latitudes, Fig. 2.

Typically, GIC is of lower intensity in the southern hemisphere than in the northern hemisphere [4].

Thus, until recently, it was thought that only regions close to the poles are susceptible to significant impacts from geo-magnetically induced currents.

However, in 2007 an article by two authors from Cape Town University in South Africa was published under the title: "Transformer failures in regions incorrectly considered to have low GIC risk" [5]. This article attracted the attention of researchers in various countries and is cited in a number of articles by other authors; it is even referenced in official reports [6, 7].

If the data provided in the article is correct, it will require a revision of the existing approach and viewpoint regarding GIC and its influence on supply transformers. There are many other countries on the same latitude with South Africa, where the danger of GIC was previously not considered. Moreover, some authors take the findings of the article and apply them to other regions, including the Middle East. For example, one of the reports issued on request of the Ministry of Energy in Israel states that Israel's power grid could be severely impacted by GIC.

There are also speculations about the dangers of GIC in Russia. One of four articles published in 2013 in the *News of Electric Engineering* magazine is "Geomagnetic storms. A threat to national security of Russia" [8]. It should be noted that these articles do not provide any registered measurement results, which would substantiate the thesis regarding the danger of high GIC values in Russia.

What arguments are given by the authors from Cape Town University to substantiate their claim? Let's review key points of this article step by step in the sequence, in which they appear in the article.

- There are references to several other articles, which were published earlier. These conclude that the main type of damage to old, large transformers in South Africa is often internal insulation damage. The authors put special emphasis on the fact that none of the previously published works mentions

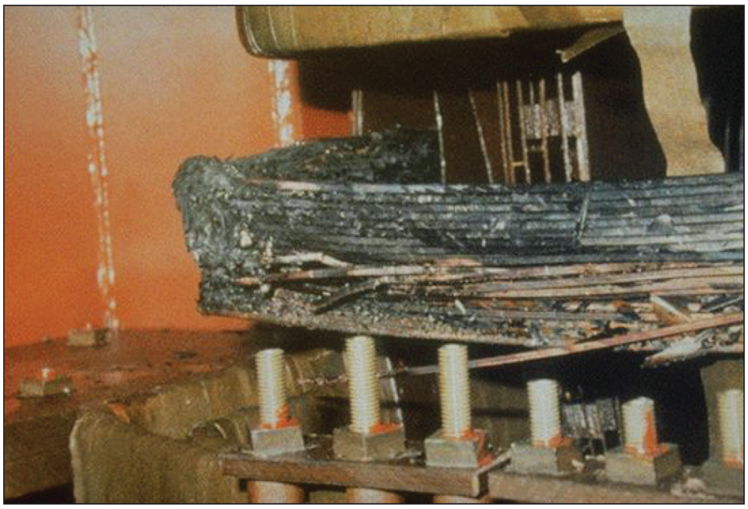

Fig. 1: Public Service Electric and Gas Company's damaged transformer [3].

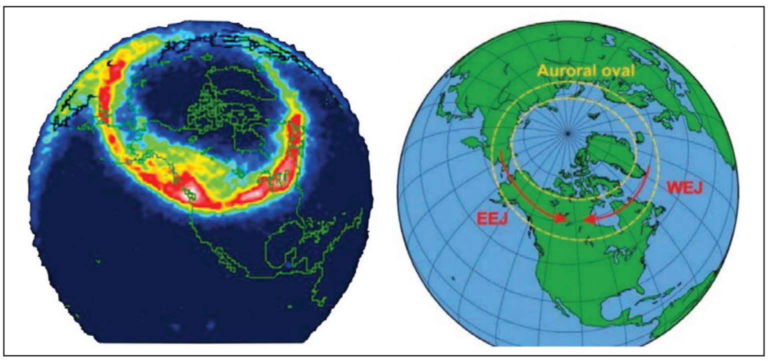

Fig. 2: Zones of intensive GIC in Northern Hemisphere. Left - according to Goodard Space Flight Centre NASA (USA); right - according to Istituto Nazionale di Geofisica e Vulcanologia (Italy).

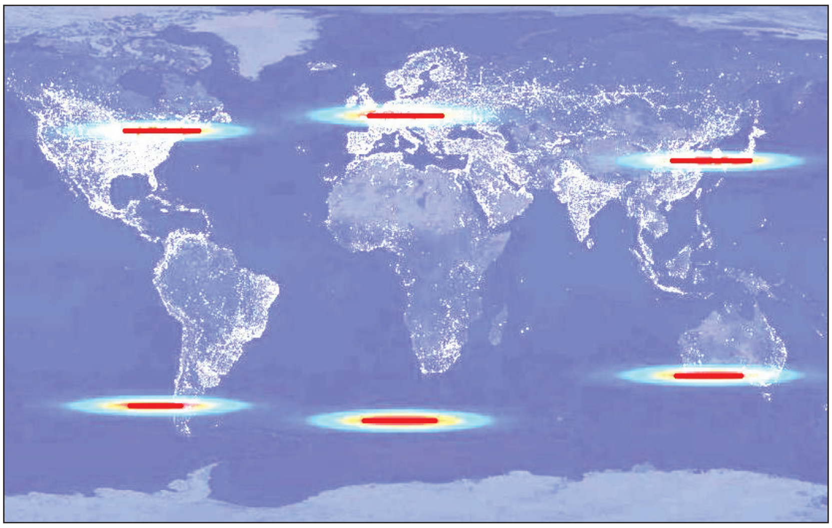

Fig. 3: The zones in northern and southern hemispheres are more susceptible to GIC impact (according to [4]). Red areas correspond to maximum possible intensity of GIC for a corresponding hemisphere.

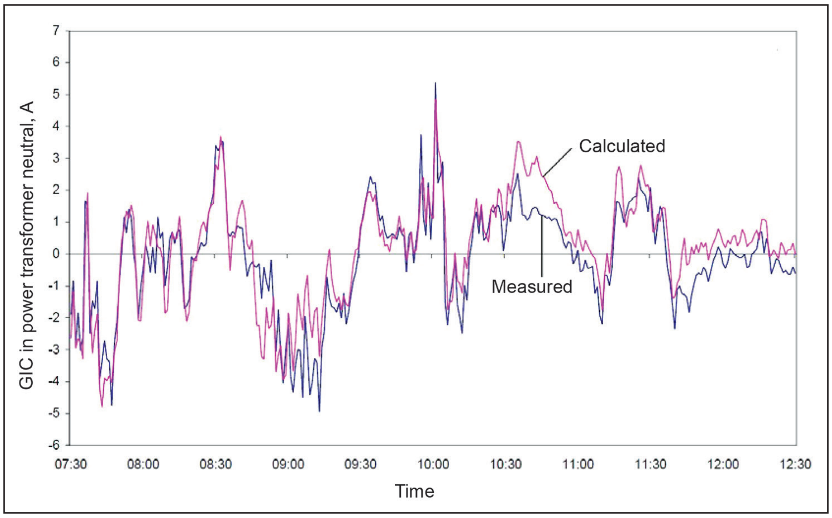

Fig. 4: GIC currents in a neutral terminal of 500 MVA power transformer during a solar storm in March of 2001 (South Africa).

GIC as a reason for power transformer damage in the South African power grid.

- There are references to known cases of power grid collapse in Canada (Hydro-Quebec) and the damage to a supply transformer at a nuclear power plant in New Jersey, USA as a result of GIC impact.
- There is a reference to a doctoral thesis of one of the authors of the article, Dr. J Koen where he implemented a known method of GIC measurement to the South African power grid and showed that it agrees with experimental measurements of GIC in power transformers (Fig. 4). The graph shows that the maximum amplitude of measured GIC values in a powerful transformer does not exceed 6 A and is flowing for a very short period of time.
- Among the references to articles by other authors it is stated that there were multiple cases of saturation of three-phase, three-leg cored transformers (also known as significantly more resistant to GIC than single-phase or five-leg cored three-phase transformers – "shell form" core transformers) with GIC currents reaching up to 2 A. However, there is no indication who obtained this data or from where.
- The section called "Thermal damage by GICs during November 2003" depicts photographs of transformers with blown-out windings, which resemble the damage to the transformer in New Jersey, where GIC currents reached hundreds of Amps; also, a high concentration of oil-diluted gases was recorded.

It is also mentioned that those gases appeared after several geomagnetic storms, while some transformers experienced emergency shutdown many months after the registered geomagnetic storms. It is noteworthy that regardless of continuous monitoring of GIC, the article doesn't mention any real current values of GIC registered in these specific transformers, which could result in such serious damages of the transformers shown in Fig. 5.

- The section "Other possible causes of damage" mentions that the damage to transformers due to GIC currents does not happen only during the geomagnetic storms. They can appear even a year after a GIC impact as a result of experienced stress. However, these conclusions are not justified or substantiated.

Thus, it is fair to say that the only experimentally confirmed fact is a GIC with an amplitude of up to 6 A in power transformers in the South African power grid. All the other data is based on speculation and assumptions, which are not confirmed by registered measurement results.

GIC and power transformer damages

We now turn our attention to how dangerous GIC with amplitude of up to 6 A is for large power transformers. The new IEEE standard [9], which summarises the state-of-art experience in the area of GIC impact on power transformers discusses various aspects, which weaken or strengthen the GIC impact, including structural features of transformers, the level of load, etc. So, this standard does not consider or mention GIC currents lower than 10 A due to their insignificant influence on transformers. Section 6.5 of this standard directly mentions that temperature increase of windings and other structural elements of supply transformers at 10 A GIC currents is negligible.

Other publications that discuss the reasons for the faults in the South African power grid include, among many others, a report which contains analysis of 12 229 emergency cases in the South African power grid (from 1993 towards the end of 2009) [10]. The report includes the period of 2003 to 2004, which, according to the authors of the previous article, is when a lot of damage to supply transformers due to geomagnetic storm impact occurred. This analysis is based on data provided to the authors by such authoritative organisations as Advanced Fire Information System, which implements special registering equipment installed on NASA satellites, as well as on data from other organisations.

Reasons for transformer faults

The reasons for transformer faults are given as: 38% of all faults were caused by large birds; 26% by lightning; 22% by fire on power equipment. Other reasons include vandalism, unskilled personnel, falling of trees, etc. Furthermore, among more than 12 000 cases of faults, geomagnetic storms are not even mentioned.

What do other authors write about the power grid of South Africa?

The article [11] provides the results of

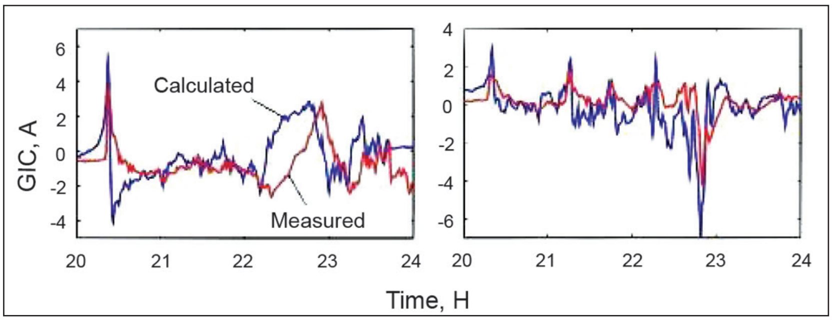

Fig. 5: GIC currents in a neutral terminal of 500 kV transformer during a solar storm in October of 2013 (Brazil).

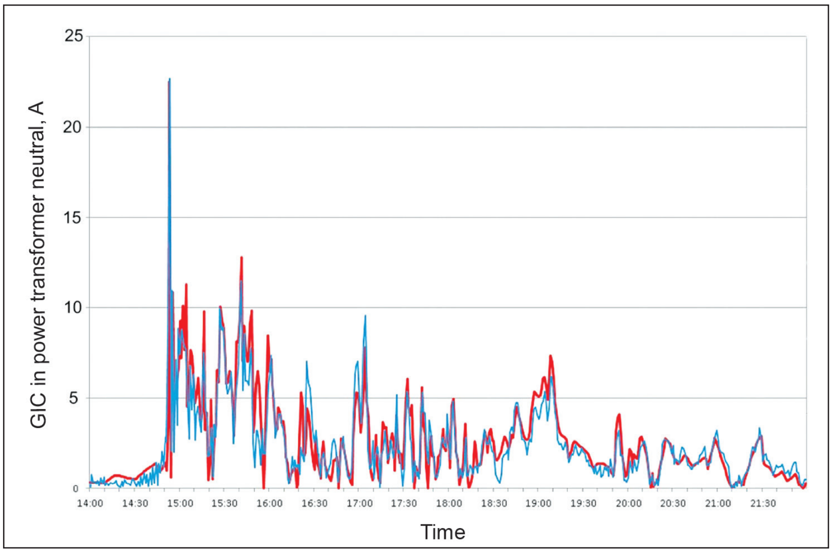

Fig. 6: GIC in the neutral terminal of power transformer during a solar storm in New Zealand in November of 2001 [20].

analysis of faults of 188 supply transformers (88 – 765 kV, 20 – 800 MVA) over a 5-year period. More than 80% of the transformers are rated at over 400 MVA. The article concludes that the most frequent causes of faults for this group of transformers are related to internal insulation failures. The article doesn't even mention the damage caused by GIC.

The report of Mitigation Action Plans and Scenarios (MAPs), prepared for the South African Ministry of Energy [12] mentions the very poor state of the electrical energy industry in South Africa is due to the lack of investment over the last 20 years.

After thorough examination of the reasons given in the above mentioned article and familiarisation with the results of analysis of transformer damage in South Africa, performed by various authors, there is reason to doubt the creditworthiness of the statement mentioned in the article and suspicion in an attempt to include solar storms to transformer damage in order to hide the real problems in the electrical energy industry.

What about countries located almost on the same latitudes as South Africa?

The impact of GIC on power transformers in South Australia has been thoroughly analysed [13]. Real GIC current measurements in transformers during the geomagnetic storms return values which do not exceed 4 to 5 A, i.e. they are very close to the values obtained in South Africa. The authors, however, mention that the expected GIC currents during other geomagnetic storms can theoretically be higher.

There is no experimental data for transformers in the power grid of Uruguay [14]. Theoretical calculations return results similar to those for South Africa. The GIC currents experimentally registered in southern Brazil between 2009 and 2013 were also very close to current values registered in South Africa (Fig. 5).

When analysing the reasons of power transformer failures in India [16], Iran [17] and Pakistan [18] the GIC impact is not even mentioned. In Japan, GIC values registered in power transformers during solar storms did not exceed 4 A [19]. In New Zealand, which is rather close to the area of southern maximum of GIC, GIC currents with an amplitude not exceeding 6 A – although at one point reached as high as 22 A (Fig. 6) – were registered in several transformers during the heavy solar storm in November 2001.

It should be noted that individual emissions of GIC with an amplitude exceeding 10 A are very short, lasting 20 seconds [20], while the thermal time constant of power transformers' heating according to the standard [9] amounts to 30 to 45 minutes, i.e., the temperature will not have enough time to change significantly during these emissions. Even long lasting GIC ranging from 20 to 30 A (according to the same standard) are not enough to damage supply transformers.

Thus, the geomagnetic induced currents occurring during solar storms in all of the regions located in the southern hemisphere do not reach the values capable of damaging supply transformers. Alternatively, when passing through power transformers these currents convert the transformers into powerful sources of harmonics, interfering with other types of electric equipment in power grids, primarily protection relays. This interference may explain faulty protection relay activation and the tripping of transformers. However, this is another problem, which can also be solved (e.g through installation of additional filters in the relay protection circuits) and which has nothing to do with real damage of supply transformers.

Conclusions

The analysis shows that there is no experimental data confirming the damage of power transformers by geo-magnetically induced currents during solar storms in South Africa, countries located on South African latitudes, Middle Eastern countries, Russia, India and many others.

There is no experimentally confirmed data, which would urge a revisit of the established zones of high levels of GIC, which pose a danger for power transformers.

The references made elsewhere regarding the damage to power transformers during solar storms (which supposedly happened in South Africa) are actually indefensible and should not be considered when studying the issue regarding the necessity of taking special measures to protect such transformers in any region.

Attention should be paid to the influence of harmonics generated by transformers during solar storms. They can interfere with relay protection devices, eliminating faulty actuation of relay protection devices due to saturation of magnetic cores of supply transformers by GIC currents.

References

The references for this article can be found with the online version at: http://wp.me/p5dDng-ASB

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