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Study Committee C4

Power system technical performance

Paper 10944_2022

Impacts of Transmission System Design Principles on Geomagnetically Induced Currents in the Finnish Transmission Grid

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Motivation

- Finnish transmission system has withstood past geomagnetic storms without any impacts on its operation and damage to its equipment. Reasons are investigated in this study.
- Geomagnetic disturbances caused by solar activity create geomagnetically induced currents (GICs) to flow in power grids.
- The GICs flowing through transformers causes increased reactive power losses, harmonics, and hot spot heating of the transformers which can lead to the operation of the protection relays.

Study setup & results

Four system design principles that affect the GIC flows and effects were defined
GIC simulations with two fictive uniform and two measurement based non-uniform electric fields were studied
Results include GIC flows through transformers and GIC-caused reactive power losses
Specific system design principle's significance to GIC flows was determined from the results

Method/Approach

Four different Finnish transmission system design principles that have a considerable impact on the GIC flows and effects were investigated. All design principles presented below expect "Transformer design" were included in the GIC simulations with their respective simulation cases.

System design principle	Description	Significance to GIC
System grounding	Transmission system transformers are effectively grounded via the reactors to limit ground fault currents	Grounding reactors have relatively high resistance which limits GIC flows
Series compensation	The Finnish 400 kV transmission grid is heavily series compensated in central and northern Finland to increase the transmission capacity	The series capacitor blocks the GIC flows on the compensated transmission line
110 kV sub-transmission grid topology	In Finland, the line lengths are quite long at the 110 kV level. For reliability reasons, the Finnish 110 kV grid is partly meshed	Meshed and partly grounded 110 kV grid can lead to considerable GIC flows in 110 kV system
Transformer design	Majority of power transformers between the 400 kV and 110 kV are three phase full-wound core-type five-limb three-winding transformers (20 kV tertiary)	3-phase transformers are more resistant to GIC effects when comparing with 1-phase units

The Finnish transmission grid

- Over 5000 km of 400 kV, 1000 km of 220 kV and 7000 km of 110 kV power lines.
- About 100 grounded transformers

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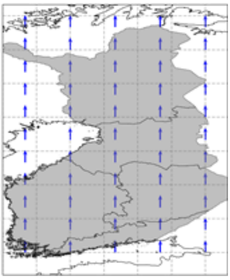
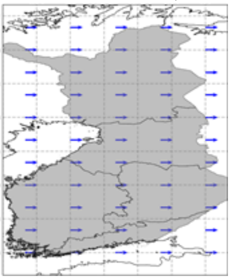
Electric field formation

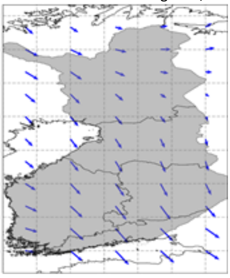
Uniform Northward 1 V/km



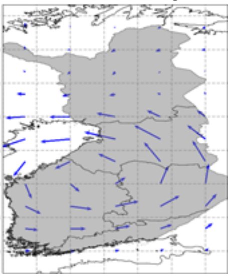
Uniform Eastward 1 V/km



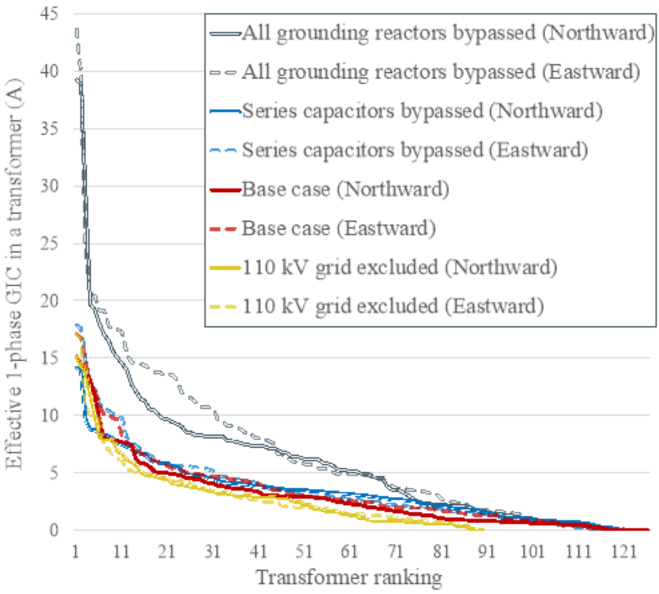
Non-uniform "SE" average 1 V/km

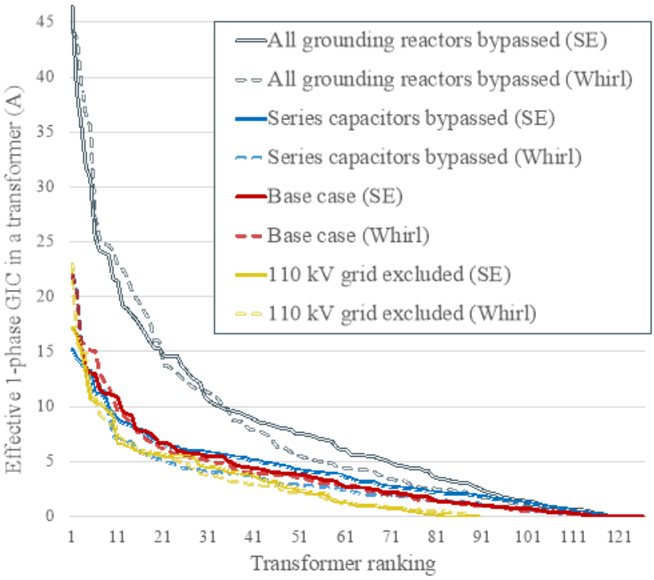


Non-uniform "Whirl" average 1 V/km



Transformers ranked by GIC flows simulated using electric fields on the left





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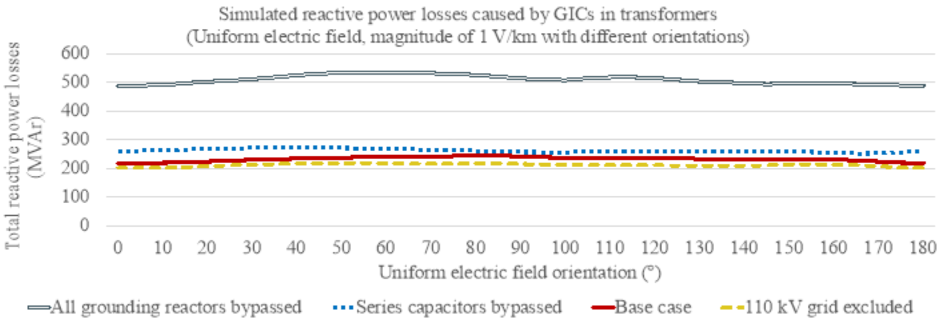
continued

The sum of effective GIC flows in transformers with electric field magnitude of 1 V/km

Electric field formation	"Base case" case	"All grounding reactors bypassed" case	"Series capacitors bypassed" case	"110 kV grid excluded" case
Northward (uniform)	370 A	752 A	419 A	293 A
Eastward (uniform)	426 A	841 A	444 A	288 A
SE (non-uniform)	473 A	1021 A	508 A	343 A
Whirl (non-uniform)	467 A	971 A	404 A	331 A



Discussion

- Previously, Fingrid used an in-house software for GIC calculations which included only the 400 kV and 220 kV grids. The GIC flows of 110 kV Finnish grid were first simulated in 2020 using a commercial software. This paper indicates that the Finnish 110 kV transmission grid has considerable impact on effective GIC of the transformers, which means that it is important to include the 110 kV grid in GIC simulations.
- Earlier, the assumption was that grounding reactors have a significant impact on GIC flows in the Finnish transmission grid but this was not properly analyzed. The results of this paper indicate that indeed grounding reactors have a major impact on reducing GIC flows in the Finnish transmission grid. According to the results, it seems that grounding reactors have helped the Finnish power grid to avoid impacts caused by GICs.
- In the past, the thinking has been that series compensation has a considerable effect on reducing GIC flows in the Finnish transmission grid transformers. The results of this paper indicate otherwise: the total GIC flows through transformers change only slightly and total GIC flows can even decrease in certain cases when series capacitors are bypassed.

Conclusions

- Grounding reactors between transformer neutral points and the ground have a major impact of reducing GIC flows in the Finnish transmission grid.
- Meshed 110 kV grid has notable GIC flows and therefore it should be included in the Finnish GIC simulations.
- The effect of series capacitors on the GIC flows was mixed and seemed to depend on the electric field formation.