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Comment on angeo-2021-63

Anonymous Referee #2

Referee comment on "The Lehtinen–Pirjola method modified for efficient modelling of geomagnetically induced currents in multiple voltage levels of a power network" by Risto J. Pirjola et al., Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2021-63-RC2, 2021

General Comments

This paper provides an update to the Lehtinen-Pirjola (LP) formulation that is widely used to calculate the flow of geomagnetically induced currents (GIC) in power networks. The reformulated LP method, or LPm, provides an improved method for calculating GIC in power networks operating multiple voltages which previously required the use of virtual nodes and high resistance values as approximations for buses isolated from ground. The LPm formulation replaces the earthing impedance matrix with the earthing admittance matrix and determines the voltages at each node/bus as opposed to the current to ground at each node/bus. The current through transmission lines and transformer windings, and to ground through neutrals, are all readily obtained from the formulation.

Replacing the earthing impedance matrix with the earthing admittance matrix means the matrix inversion required for a solution is performed on a sparse symmetric positive definite matrix, as opposed to a matrix that incorporates the earthing impedance matrix which may have numerous high resistance values for buses isolated from ground. This allows for matrix decomposition techniques that give improved efficiency for CPU memory and processing time for large networks containing many nodes. The paper demonstrates these efficiencies and how to apply the new formulation to an example network and a real network.

As suggested by the authors, the matrix inversion need only be performed once for a given network configuration so the efficiencies may not realise significant benefits in an operational environment, however, the LPm formulation provides are more elegant way of calculating the transmission line and transformer winding currents which are typically the more important parameters when understanding the impact of GICs on power network operations as it’s the transformer winding current that leads to half-cycle saturation. The LPm method avoids having to convert very small currents to nodal voltages using very large resistances at the virtual nodes which are then needed for calculation of the

transformer winding currents as required by the LP method. This is an important improvement of the formulation presented in this paper.

The paper is clear, concise, and very well written, makes a valuable contribution to the field, and worthy of publication. Below are very minor suggestions for the authors to consider.

Specific Comments

Line 34: Suggest including "and space weather" after "geophysics".

Page 3, line 1: Perhaps "relate" should be "relates".

Page 4 and throughout: In some instances, the matrix notation is inline (e.g., $[I_e]$ in line 97) and other times it is raised/split above/between lines (e.g., $[I_e]$ in line 106). Perhaps a consistent notation should be used throughout.

Line 154: Appears to use different font for equation 22 (compare with equation 16 for example).

Line 282: Remove space before comma and end of line.

Lines 337-338: "The research that led to these results was in part carried out using funds from "la Caixa" Foundation. Natural Resources Canada contribution number 20210276", seems to require a comma separating the sentences?

Table 5: Formatting of "To/From Bus" column headings perhaps needs adjusting.

Tables 8: Formatting of last 3 column headings perhaps needs adjusting.