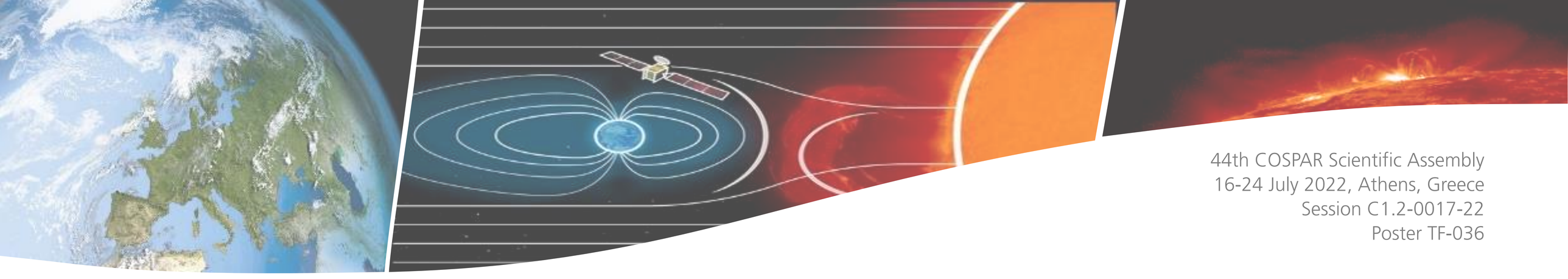


44th COSPAR Scientific Assembly
16-24 July 2022, Athens, Greece
Session C1.2-0017-22
Poster TF-036

Assessing the risk of geomagnetically induced currents in the German power grid

Leonie Pick[1], Aoife McCloskey[1], Aline Guimaraes Carvalho[1], Jens Berdermann[1]
[1]German Aerospace Center (DLR), Institute for Solar-Terrestrial Physics, Neustrelitz, Germany

Motivation / Introduction

Space weather driven geomagnetically induced currents (GICs) can disrupt the operation of electrically conducting systems like power grids and have thus received increased international interest[1]. GICs occur under conditions of intense geomagnetic disturbance (GMD) as a result of the electric field induced in the conducting subsurface. Storm-time GMDs are particularly strong in the vicinity of the high-latitude ionospheric currents which are known to expand equatorward during extreme events putting mid-latitude regions at potential risk. **However, to date, there is no comprehensive research published on GIC risk in Germany**.

Here, we present current progress, challenges and future prospects towards this goal. We reduce the complexity of the problem by applying a 1-D conductivity model with a plane-wave approach in order to estimate the induced electric field from the GMD input (physical parts 1 & 2) and constructing a preliminary model of the German high-voltage electricity transmission network from publicly available sources (engineering part 3). We illustrate the approach by means of an application to a recent geomagnetically disturbed period, i.e., the geomagnetic storm in September 2017.

1. Geomagnetic disturbance

Observations

- 9 INTERMAGNET observatories (4 German + 5 surrounding): **WNG**, **NGK**, **BFO**, **FUR**, [BFE], BDV, WIC, MAB, CLF
- One-minute means from FTP-server via automated request
- Available within 72h (usually 3h)

Interpolation based on SECS[2,3]

- Horizontal magnetic disturbances ($\boldsymbol{B}_\perp$, quiet-time level subtracted) caused by divergence-free (DF) part of 2D ionospheric equivalent current at 110 km altitude
- DF Spherical Elementary Current Systems (SECS) represent local DF equivalent current on sphere
- Invert $\boldsymbol{B}_\perp = \underline{T}\boldsymbol{S}^{DF}$ for scaling factors $\boldsymbol{S}^{DF}$ ($\underline{T}$ is known from geometry)

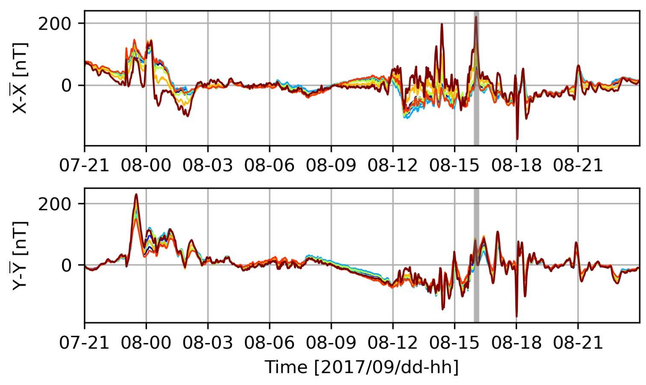
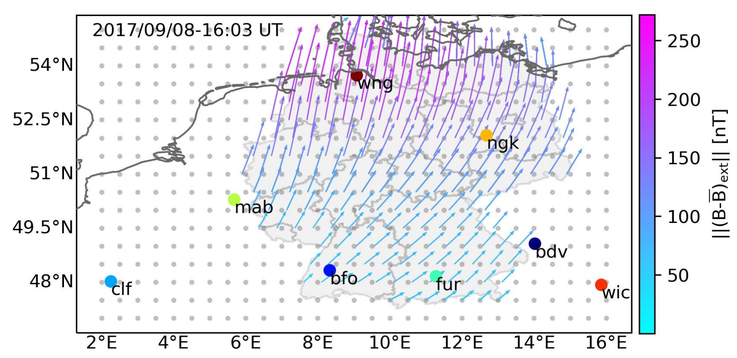


Fig. 1: Geomagnetic input for 7-8 September 2017 storm. Top: North- (X) and eastward (Y) disturbance measured at 8 observatories (color-coded).



Bottom: Snapshot of the SECS-interpolated horizontal disturbance field.

2. Geoelectric field modeling

Input

- 1-D EURISGIC resistivity/conductivity model[4] (Fig. 2)
- 8 different models for German region
- 1-min SECS-interpolated geomagnetic disturbance $\boldsymbol{B}_\perp(t)$

Plane-Wave Method[5]

- Assumes plane electromagnetic wave propagates downward into a layered Earth
- Frequency-dependent (ω) plane-wave equations describe relation between horizontal electric and magnetic field:

$$E_x(\omega) = \frac{z(\omega)}{\mu_0} B_y(\omega) \qquad (1)$$

$$E_y(\omega) = \frac{-z(\omega)}{\mu_0} B_x(\omega) \qquad (2)$$

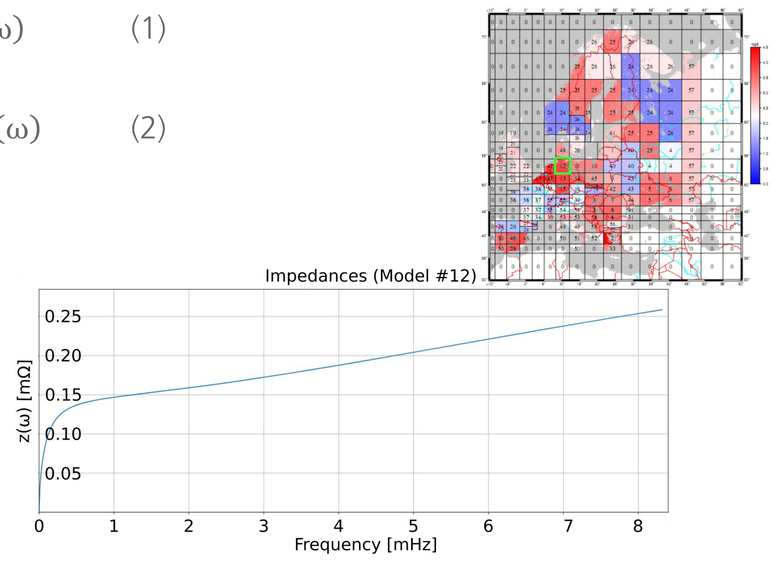


Fig. 2 (up): Conductance (upper 80 km) according to 1-D EURISGIC model. Model #12 for northern Germany is highlighted (green box).

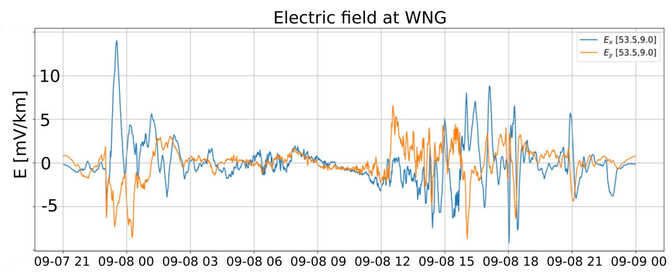


Fig. 3 (right): Modeled electric field for 7-8 September 2017 storm. Top: Impedance for EURISGIC model #12. Bottom: Geoelectric field at Wingst observatory (see map Fig. 1).

3. German power grid model

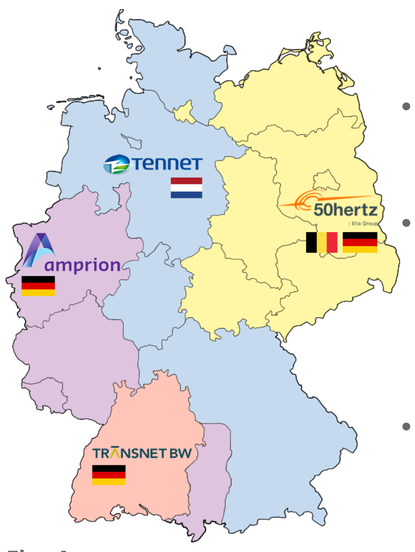


Fig. 4: Transmission System Operators.

- 4 Transmission System Operators (TSOs, Fig. 4)
  - Public partial models ("Static Network Models")
- Grid model data (Fig. 5) sourced from TSOs and Open Street Map Transmission Grid model (osmTGmod[6])
  - Map construction with PostgreSQL & QGIS
- High voltage (HV) transmission network most susceptible to GICs
  - Mainly 220 & 380 kV lines (incl. up to 450 kV)
  - Line lengths up to 250 km (total ~30,000 km)
  - 166 substations

	Acquired	Problem
HV Transmission Lines	- Voltages - Lengths - Geogr. coordinates - Resistances - Reactances - Total number - Bus connections	- TransetBW info missing (osmTGmod)
Substations	- Geogr. coordinates - Names - Line connections	- Incomplete
Transformer Properties	- Winding resistances, reactances - Rated Power - Rated Current	- Transformer types - TransnetBW info incomplete

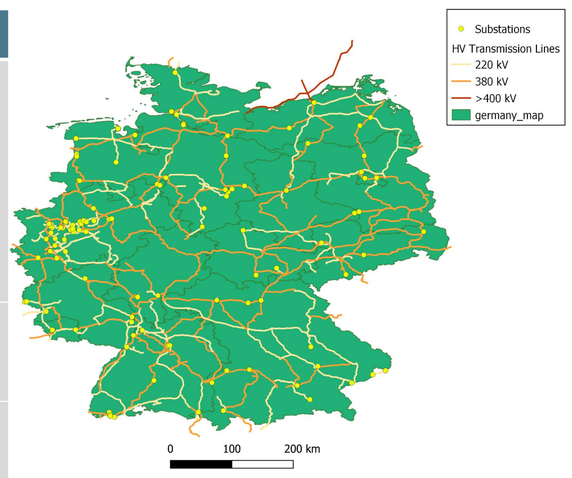


Fig. 5: Map produced from collected grid model data.

Conclusion / Outlook

Conclusion

- Geomagnetic input is available as 1-min means in near real-time (INTERMAGNET) and is processed with well-established methods (SECS)
- Plane-wave method & EURISGIC 1-D layered Earth conductivity model give E-field estimates
- TSOs & osmTGmod provide publicly available (incomplete) datasets of HV transmission system

Outlook

- Complete GIC calculation chain (combine power grid model with estimated E-fields)
- Implement 2-D thin-sheet method for E-field modeling (lateral conductivities)
- Acquire magnetotelluric survey data – potentially use 3-D Earth conductivity maps instead
- Obtain missing grid information through additional models (e.g., PyPSA European grid model) & establish collaboration with TSOs

References

[1] Ngwira, C.M. & Pulkkinen, A.A. (2019), An Introduction to Geomagnetically Induced Currents, in *Geomagnetically Induced Currents from the Sun to the Power Grid*, (eds. Gannon, J.L. et al.), American Geophysical Union
[2] Amm, O. (1997), Ionospheric Elementary Current Systems in Spherical Coordinates and Their Application, *J. Geomag. Geoelectr.*, 49, 947-955
[3] Amm, O. and Viljanen, A. (1999), Ionospheric disturbance magnetic field continuation from the ground to the ionosphere using spherical elementary current systems, *Earth, Planets and Space*, 51, 431-440
[4] Adapted from Pirjola, R. (2002), Review On The Calculation Of Surface Electric And Magnetic Fields And Of Geomagnetically Induced Currents In Ground-Based Technological Systems, *Surveys in Geophysics* 23, 71-90
[5] Adám, A. et al. (2012), Estimation of the electric resistivity distribution (EURHOM) in the European lithosphere in the frame of the EURISGIC WP2 Project, *Acta Geodaetica et Geophysica Hungarica*, 47(4), 377-387
[6] Scharf, M. & Nebel, A. (2017), osmTGmod v0.2, https://github.com/openego/osmTGmod

DLR Deutsches Zentrum für Luft- und Raumfahrt

Acknowledgments:
We would like to thank our collaborators, particularly Rachel Bailey (ZAMG), Frank Schuldt (DLR, VE-EST OL) and Michael Schühle (BSS Hochspannungs GmbH), for their input.

Leonie Pick
DLR, Institute for Solar-Terrestrial Physics
Kalkhorstweg 53, 17235 Neustrelitz
Tel.: +49 3981 480-279, Email: Leonie.Pick@dlr.de