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Operational Research and Innovation at Austrian Power Grid – Overview of Selected Projects

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SUMMARY

Overview Operational Situation at APG:
Due to the central geographical location, power grid operation at APG is highly influenced by power flows in central continental Europe. The challenges in power system operation in this region have increased dramatically in the recent past, mostly driven by the massive increase of volatile generation – especially in Germany. This can be seen in various key figures, like necessary redispatch costs or market intraday stops.
Operational research and development have thus been also gaining increasing attention and the currently most prominent ones are briefly described.
Development of the restoration concept of APG based on voltage ramping:
Voltage ramping in case of grid restoration after a major blackout has several advantages e.g. prevention of inrush phenomena as well as significant time savings for restoration of long power lines. APG has started a theoretical investigation in 2014 and has already successfully ramped a ~500km power line (220 kV+380 kV) all across southern Austria.
Development of Wide Area Monitoring System - WAMS at APG:
The massive system changeover in the recent years, especially in the generation sector, leads into a significant change in power system characteristics. To be able to monitor the dynamic state of the Austrian system (and continental Europe in the future) a high resolution WAMS has been set up.
Research Project "Space Weather":
The impact of solar storms on wide-area power grids is a well-known phenomenon mostly associated with the polar regions. Newest research results of APG together with Graz University of Technology and other partners have shown that correlation of space weather induced quasi direct currents in grounding systems can also be measured in central Europe (Austria), also depending on the regional ground conductance. For example, these currents can practically lead to higher noise exposition of power transformers.

KEYWORDS
Wide Area Monitoring System, geomagnetically induced currents, voltage ramping, restoration, black start, islanded operation

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1) Development of the restoration concept of APG based on voltage ramping – practical test:

APG as transmission system operator (TSO) in Austria is obliged by law to contract power plants, which are capable of black start and islanded grid operation and are able to restore preliminary “top down” from the transmission system. To ensure the functionality, APG performs yearly practical black start tests and islanded operation tests every two years. The results and findings of these tests are the basis for a continuous update and optimization process of APG’s restoration concept.
This also requires a close cooperation with the DSOs as the restoration of the transmission grid is followed by load pick up and the synchronization of selected generators also at the distribution side. Also some DSOs with generation connected to <110 kV are able to build up an islanded system in case of longer lasting black outs. The common strategy is coordinated based on individual restoration concepts with the major DSOs in Austria.

The restoration concept of APG currently foresees a stepwise reconnection of power lines, starting from the black starting units in the western part towards eastern Austria. After reconnection of the power line segment load from the distribution grid is restored (loading of first generators) and further power plants are synchronized.

To provide enhanced flexibility to the system operator in case of large disturbances APG developed a voltage ramping method for the re-energization of a long, pre-compensated power line (220 kV and/or 380 kV) at no load to achieve the following advantages:

- Fast restoration of the transmission grid in eastern Austria, complementing the stepwise approach.
- Redundant variant to restore auxiliary supply in APG substations in eastern Austria in case of long lasting disturbances.
- Avoidance of inrush-phenomena due to simultaneously ramping transformers to the distribution grid.
- Ramping also gives the opportunity to recognize and roughly locate existing faults along the line at low voltage level (prevent further damage to lines/substations)

Before implementing the new method into the restoration concept a strict evaluation process has to be made. This process was divided in a theoretical study as well as a practical test approximating the first critical steps of the restoration concept.

The overview of the power line section for the practical test is shown in figure (1).

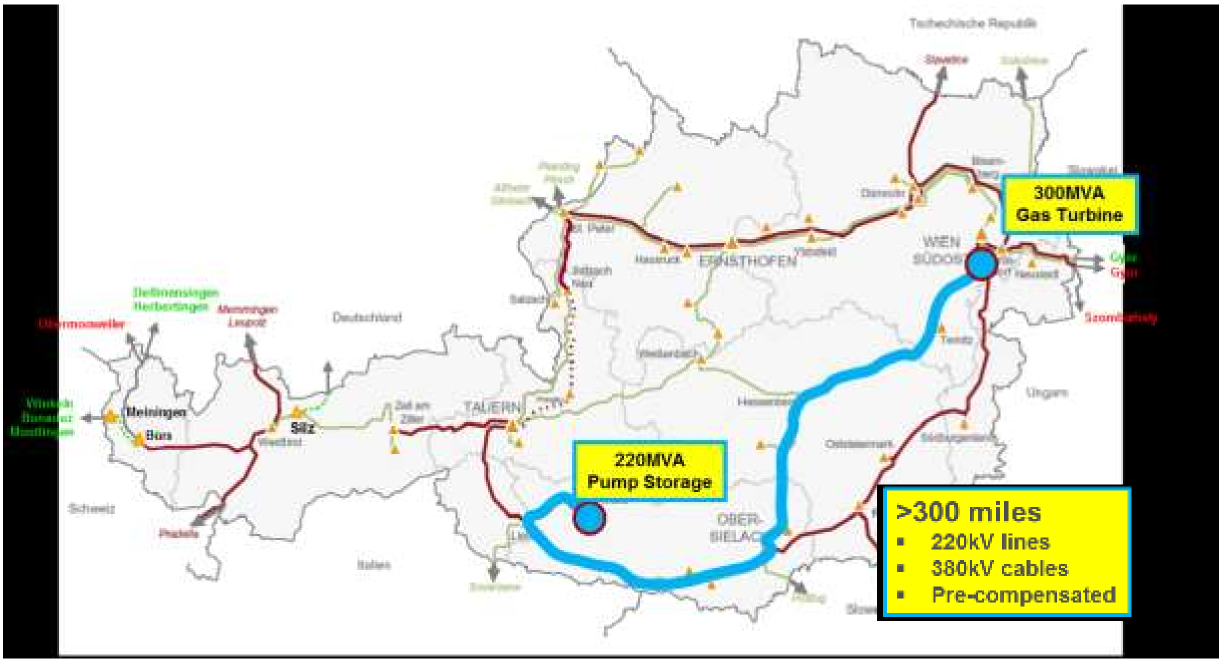

Figure (1): Transmission grid of APG and overview of islanded operation test section, including two generators, a ~ 500km 220kV power line and a 380kV cable section of ~15km

Structure of the practical test

The test section including the power plants were disconnected from the superior grid for the test purpose. This implies a challenge for grid operation since an influence of consumers must be avoided at any time.

The gas turbine that was used for test purpose is currently not part of APG's restoration concept.

The principal test procedure was structured as follows:

- Blackstart of the 220 MVA pump storage power plant at no load, generator not excited
- Ramping of the previously pre-connected power line, including transformers
- Loading of the pump storage power plant with pump loads, P_{load} ~ 70 MW
- Synchronization of the 300 MVA Gas Turbine in the area of Vienna
- Varying operating points of the generators, proper load sharing
- Loading tests of the islanded system
- Coordinated return to normal operation

The aim of the test was to:

- Learn about the handling of long power lines in islanded operation.
- Learn about the swinging behavior of synchronous machines at no load or a low load.
- Invest possible benefit from an additional generator in eastern Austria at the very beginning of the restoration process. For this purpose a gas turbine with a rated power of 300MVA was used during the test.

Behavior of generators at no load:

The nonlinear relationship between the controller output of the governor and the actuator position is relevant to the sensitivity of the governor towards small movements. Especially in lower operating points, for example during grid restoration, these nonlinearities can lead to instable behavior of the governing system. Around the rated operating point the influence is comparatively small [1].

The nonlinear behavior is inherent to the mechanical system of governor systems. It's key for the restoration process to optimize respectively individualize the governor settings taking into account the oscillatory behavior at no load.

The behavior of the generators at no load is shown in the following section.

Results:

The shown measurement were done by two Phasor Measurement Units (PMUs). The Wide Area Monitoring System (WAMS) in more detail is described in section 2 in more detail.

Figure (2) shows the voltage, starting from almost 0kV up to nominal voltage in 8 steps, taking about 20 minutes.

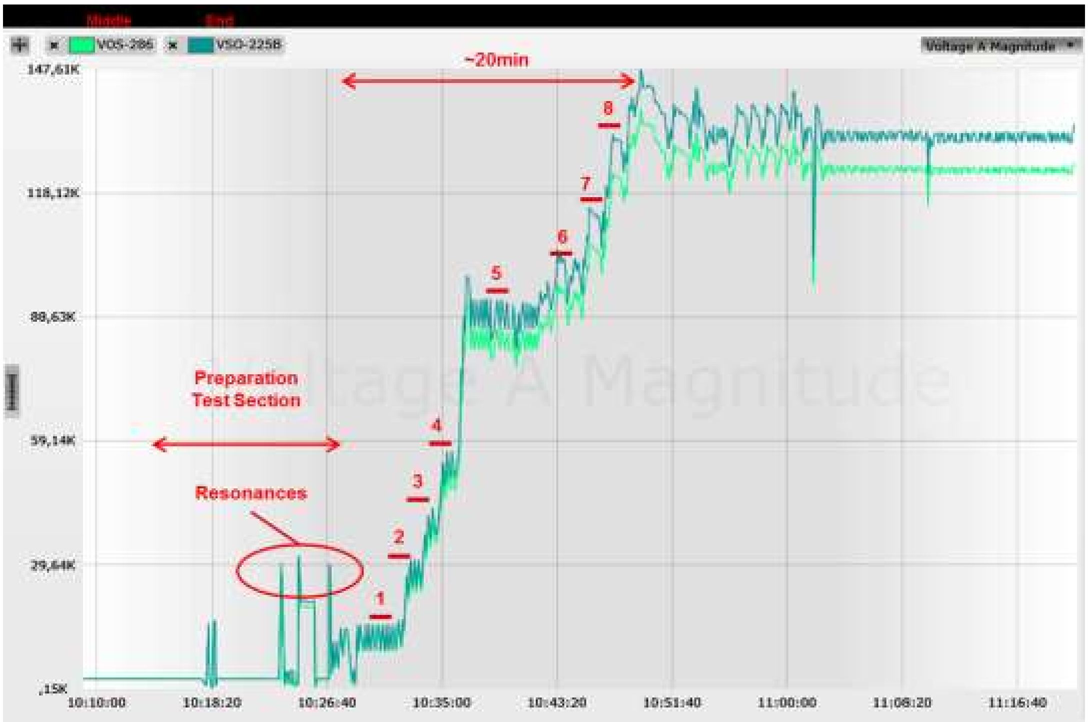

Figure (2): Disconnection of test section from superior grid, voltage ramp, measured at in the middle and at the end of the test section

The ramp duration is in general free of choice. In figure (2) after step 5 the ramping process was paused for the reconfiguration of the hydro governor parameters.

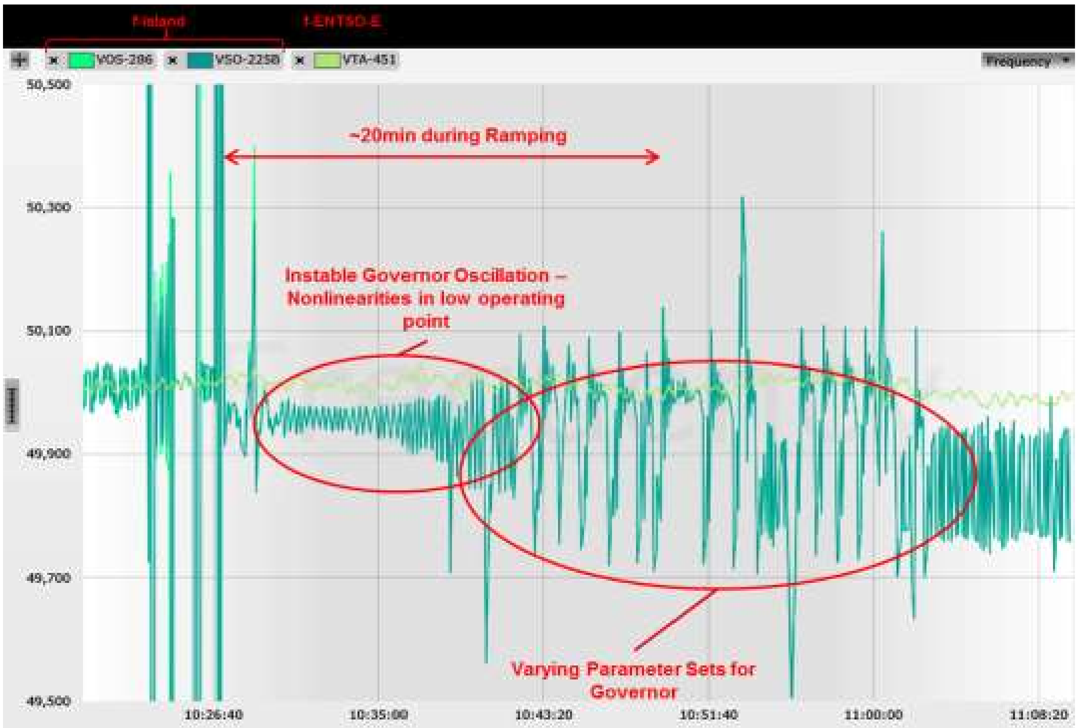

Figure (3): Frequency plot, governor oscillation of the 220MVA pump storage power plant during the voltage ramp at no load

Figure (3) shows the pump storage power plant (220MVA synchronous generator) during the voltage ramp. This is still done at no load. After varying the parameter set of the governor, the amplitude becomes smaller.

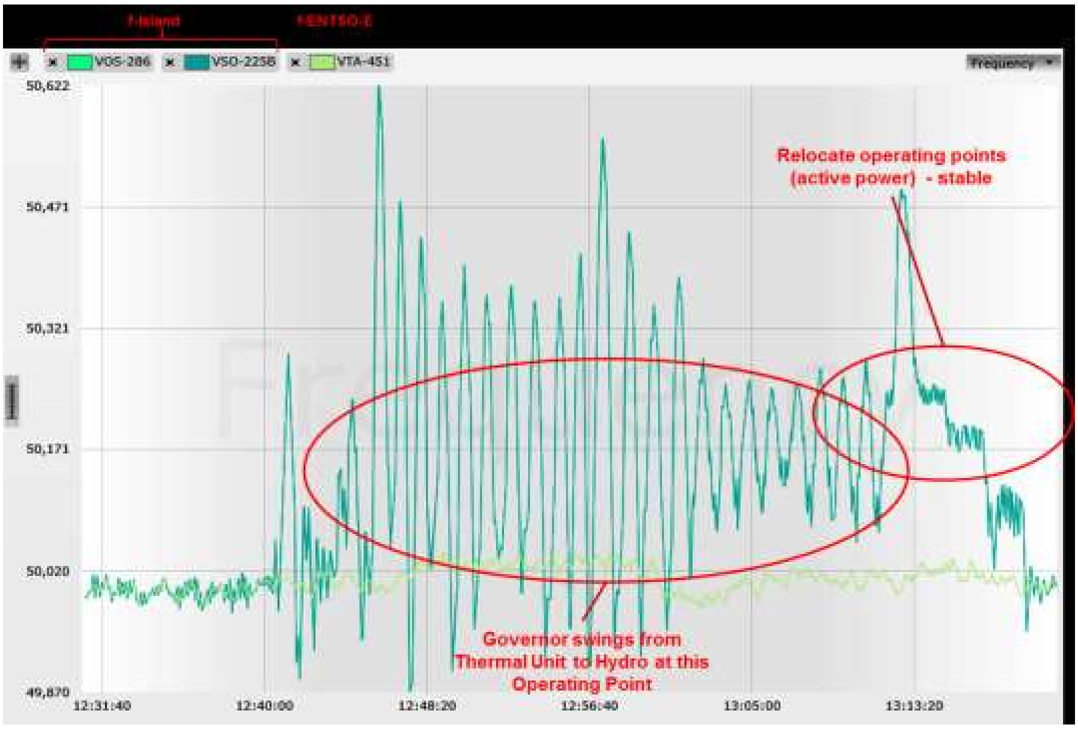

Figure (4): Frequency plot; governor oscillation between hydraulic and gas generator; ~60s period

Figure (4) shows the governor oscillation between the two active generators. At this stage both generators where loaded with ~30MW. The load in the islanded system was provided by pump loads which approximate the behavior of real loads.
After shifting the operational point at the gas turbine +10MW the oscillation disappeared.

Figure (5) shows the successful synchronization of the islanded system with the superior ENTSO-E system. This is a very important step in a restoration process starting originally from bottom up as the existing islands need to synchronize at a certain size. Synchronization is in focus during every practical test and is done by the use of the synchro check function.

Figure (5) Synchronization of the islanded system with ENTSO-E

Conclusions:
The practical test was successfully completed on March 13th 2016. Although the final results are still under development the test results showed already that in principal the method can provide the expected benefits for APG's restoration concept.
Nevertheless, the first critical steps of the restoration process are dominated by the nonlinear behavior of the governor systems. This is being counteracted as much as possible (mechanical nonlinearities remain) with individual governor parameter sets.
Besides the practical testing APG provides simulatory tests with national and international partners several times per year.

Major findings:

- The nonlinear characteristics of governor systems determine the frequency behavior and therefore also the dynamic stability at the very beginning of the grid restoration.
- It is key to do practical testing in order to find proper parameter sets for the governors and also for the voltage regulation, individually for each generator of a power plant.

- It is key to do practical testing in order to detect operational points where possible generator swings among the first generators may occur.
- The lower operating points of the generators shall be passed as fast as possible to avoid nonlinear oscillation of the mechanical system.
- Avoid high frequencies in the islanded system with long, unloaded lines as the higher speed of the generator as well the change in line impedances may lead to very high voltages.

2) Development of Wide Area Monitoring System - WAMS at APG:

Transmission grids in Europe are progressively facing critical operational situations characterized by high line loadings, volatile and geographical centralized generation and possible security violations. The reasons are manifold, reaching from the increased number of actors in the liberalized electricity markets to massive integration of renewables and sagging realization of grid extensions plans.

Conventional generating units, mostly synchronous generators are partly substituted by must-run renewable units. These circumstances lead to a volatile change in the grid's oscillatory behavior resulting from a permanently change in the constitution of the type of active generation units and thus changes in grid inertia.

The situation is in principle similar for most member countries of the ENTSO-E association with varying influences and consequences for the overall system operation and stability [1].

To be able to monitor the (local-in a sense of the interconnected power system) dynamic state of the power grid, APG designed and implemented a new Wide Are Monitoring System (WAMS). The principle configuration is shown in Figure (6).

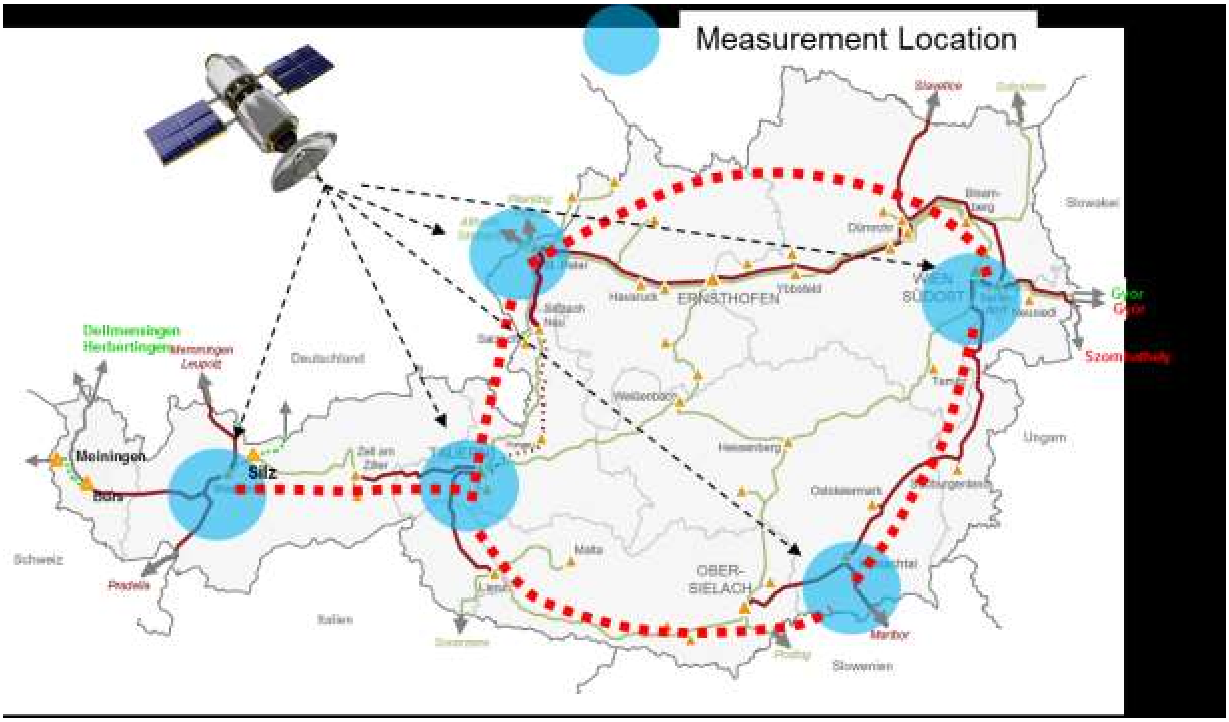

Figure (6) WAMS configuration in Austria

At present there are 12 Phasor Measurement Units (PMUs) installed in five measurement locations. The geographical distribution of the PMUs is based on the grid topology in Austria's high voltage grid, placing four measurement locations in the 380-kV-ring and one location in the very western part.

Figure (7) shows the implemented architecture and gives an overview about the most important components.

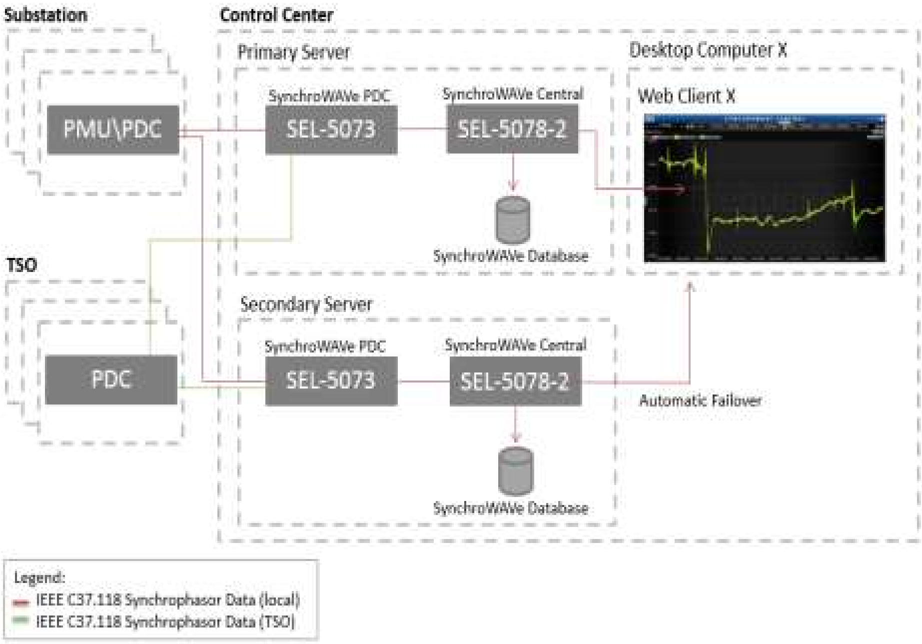

Figure (7) WAMS architecture and overview

The PMUs are connected to a dedicated closed network. Furthermore, the servers are locked into a de-militarized zone (DMZ) with special authorization schemes.
The system is set up with a redundant server system (Phasor Data Concentrator – PDC) is two different geographical locations and are running hot/hot with SynchroWAVe Central Software.

Conclusion:
The data exchange among TSOs is currently predominated by bilateral agreements in a decentralized way. In order to reach the highest efficiency and usability for all TSOs an advanced data exchange is aspired in the future.
Also the development of dynamic remedial actions in case of dynamic stability issues will be in the focus in various working groups.

3) **Research Project "Space Weather":**
This section is given a rough summary based on the content in [2]. The research project is together with the Technical University of Graz and the Zentralanstalt für Meteorologie und Geodynamik (ZAMG).

Solar storms, which hit the earth's magnetic field, cause field fluctuations and are the source of geomagnetic disturbances (GMD). These geomagnetic variations induce a geoelectric field on the earth's surface. Consequently, geomagnetic induced currents (GIC) with extremely low frequencies (relevant frequencies from 1 Hz to 0.1 mHz [1] – quasi DC) can be driven through transformer's direct grounded neutral point and overhead lines, causing transformer saturation [2].
Triggered by unexpected audible noise at some HV transformers, investigations into the possible cause were started. These indicated that DC are responsible for the increased noise emission. First measurements in a substation of the Austrian power grid revealed the expected

DC components in the transformer neutral current caused by GIC for the first time in Austria [2].
Generally, the impact of GIC is more significant for regions located in higher latitudes than for mid-latitudes regions (e.g. Central Europe). In Austria this effect was not expected and was verified by measurements just recently.
Basically the project is divided in two parts: The enhancement of the calculation and prediction of GIC based on a plane wave model. Furthermore, the resulting GIC are calculated and the effects in the electrical grid are derived from a regional grid model. The basic scheme is shown in Figure (8).

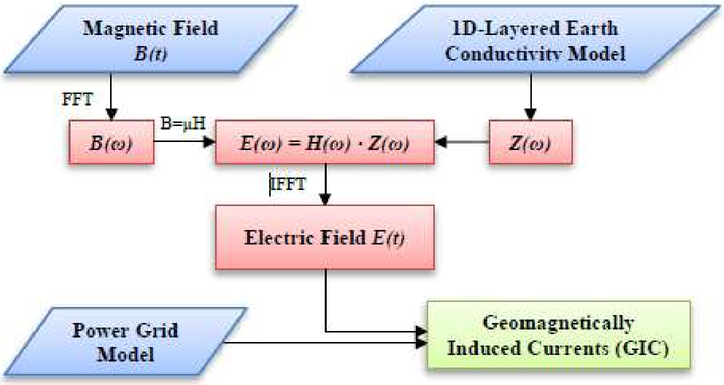

Figure 8: Schematic of the GIC calculation with the geomagnetic field B, 1D-layered earth model and a power grid model as input parameters [2]

Results:
The simulation model used for calculating the geoelectric field E and GIC in the Austrian transmission grid, based on measured geomagnetic field fluctuations is in focus in this research project.

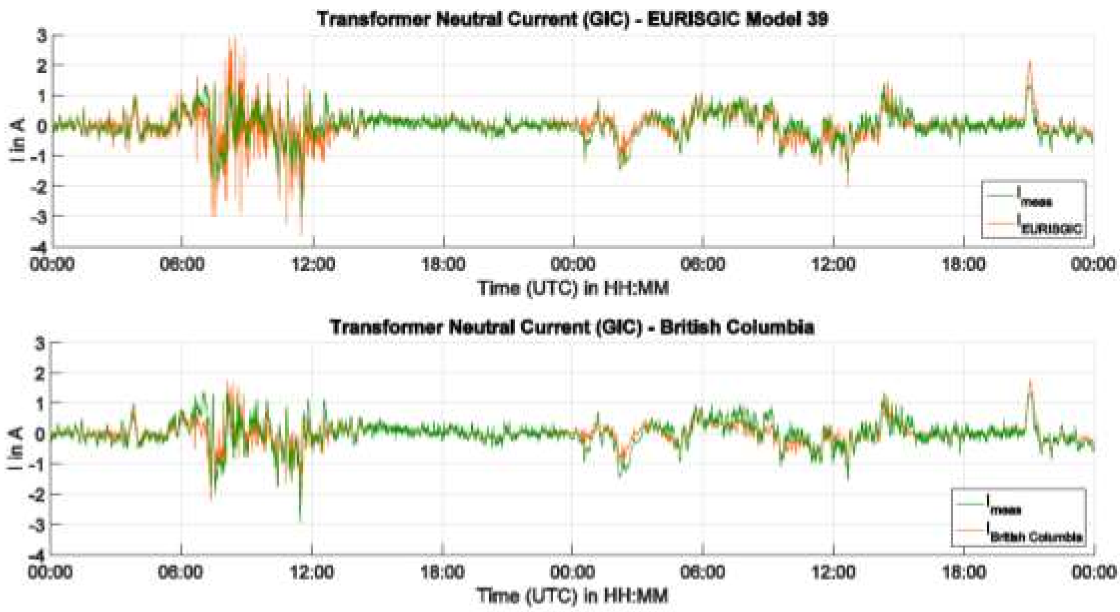

Figure (9): Transformer neutral currents (GIC) on 22-23 March 2015. The measured (rectified) current is in green, the simulated GIC for different earth models are in orange [2].

Two different earth conductivity models were applied and the resulting currents were compared with according measurements, showing satisfying consistence in figure (9).

BIBLIOGRAPHY

[1] M.Weixelbraun "Hydro Governor as Damping Device", 2013

[2] T. Halbedl et al, "Analysis of the Impact of Geomagnetic Disturbances on the Austrian Transmission Grid",