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Open Data in Power Grid Modelling: New Approaches Towards Transparent Grid Models

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ABSTRACT

In order to analyse the mid- and long-term impacts of energy related policies, different modelling approaches can be derived. However, the results of even the best energy system model will highly depend on the underlying input data. First, in this contribution the importance and availability issues of grid data in the context of energy system modelling are highlighted. Second, this paper focuses on power grid modelling based on open and publicly available data from OpenStreetMap using open source software tools. Two recent approaches developed to build electrical transmission network models using openly available data sources are presented and discussed. The proposed methods provide transparent assumptions, simplifications and documentation of grid modelling. This results in the ability of scientists and other stakeholders to validate, discuss or reproduce the results of energy system models. Thus the new open approaches offer a unique opportunity to increase transparency, comparability and reproducibility of results in energy system modelling.

1. Introduction

The constant increase of the renewable energy source shares in the European energy mix implies a transformation of the energy system structure and operation. This transformation is directly induced by the shift from central to de-central energy production and from unidirectional to bidirectional energy flows. In Germany, the goals of the energy transition are a share of 40%–50% of renewable energy production until 2025 and a share of 50%–60% in 2035.[1] For Europe, the objectives is to have a 86% share of renewable in electricity production.[2] Those ambitious goals require a strong and modern electricity grid implying the modernisation and expansion of the current grid (Nikoletatos and Tselepis, 2015; EnerNex Corporation, 2011; Sims et al., 2011; American Physical Society, 2010). The EU scenarios assume investments of more than 50 billion EUR in the transmission grid infrastructure implying fundamental changes in the electricity grid.

The progress of the electrical grid expansion has direct political, economical, socio-cultural and environmental impacts. On the medium and long term, it may also influence investment decisions in current and future generation facilities. Due to these factors, electrical grid extension additionally requires public acceptance (Roland Berger Strategy Consultants, 2015). As a basis for political and strategic decisions, different studies on the impacts of renewable energy sources on the future design of energy systems were commissioned (RESTORE2050, 2014; Bode, 2010; EmployRES Project Consortium, 2009; European Commission, 2007). In addition, the funding of research projects addressing this particular topic increased significantly (Bundesministerium, 2015; RWTH Aachen University, 2014; BMU, 2010).

The process of expanding transmission systems (including but not limited to: grid operation, stability, control, congestion management and integration studies) heavily relies on modelling. Moreover, public acceptance of such expansion depends on the transparency of the underlying strategies and decisions (Ciupuliga and Cuppen, 2013). Those factors added to the emergence of wholesale electricity markets imply an increasing importance of energy system modelling tools in general and electricity market

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1 Federal Ministry for Economic Affairs and Energy.

2 EU Commission: Energy Roadmap 2050.

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modelling tools in particular. These tools involve a representation, or a model, of the electrical grid. However, all grid models rely on the quality and availability of the electrical grid data they represent.

In this contribution, we present and discuss recent efforts towards developing open grid models and using open data in electrical grid modelling. In Section 2, a general introduction to grid models, their relevance and use in load flow calculations and energy system models are presented. An overview on the data requirements for grid models and grid data availability are also introduced. The current status of open grid models and data are discussed in Section 3. Section 4 introduces OpenStreetMap and the power data available in its database. Two approaches used to derive grid models from OpenStreetMap data are also presented: a deterministic and heuristic approach including their key features. The comparison of the two approaches, as well as their advantages and limitations are discussed. Finally, in Section 5 conclusions are presented.

2. Grid models and their input data

2.1. Grid modelling

Energy system models analyse energy systems or a number of sub-systems (e.g. power system). These models became increasingly relevant for decisions in energy acquisition and trading. According to Hoffman and Wood (1976), "Energy system models are formulated using theoretical and analytical methods from several disciplines including engineering, economics, operations research and management science". Multiple solution methods involving "mathematical programming (especially linear programming), econometrics and related methods of statistical analysis and network analysis" are used to solve the models equations (Hoffman and Wood, 1976). Energy system modelling involves modelling the transmission grid in an appropriate way using grid models.

In general, grid models are developed and used for different purposes and can have many focuses. In this paper, the authors differentiate between two applications where grid models are used, namely *grid simulation models* and *electricity system models*. The focus of grid simulation models lies on the technical and physical behaviour of electric grids. Electricity system models are tools used to manage, plan and extend electricity systems, manage electricity demand as well as electricity trading. They model the physical behaviours of the underlying grids as well as market mechanisms.

Grid models are in general classified in four different types (Pfluger, 2014; Ventosa et al., 2005; Villasana et al., 1985). The simplest grid model is *the single-node model*, also known as *the copper plate approach* (Tande et al., 2008; Schaffner and Mihalic, 2005). This simple approach assumes an unconstrained electrical grid, and is mostly used in economical models. The second type of grid models is *the transshipment model* (Nygard et al., 2011), where a various number of *nodes* or *regions* are defined. Between the defined regions an exchange of power is possible and is constrained by the net transfer capacity. This model neglects the existence of the physical power flow principles. A more sophisticated model is the (linear) *DC model* (Schavemaker and Sluis, 2008), where a network of several nodes and interconnections (or power lines) is defined. Using Kirchhoff's law, active power flows can be determined, which depend on the resistance and the maximal capacity of the power lines. A more realistic way to model AC grids is to consider an *AC power flow model* (Schavemaker and Sluis, 2008). In this approach the active and reactive power flows are modelled. Therefore, the reactance of the power lines is highly relevant and both capacitive and inductive behaviour of the power lines are considered. However, the increase of detail and accuracy is usually accompanied with an increased complexity resulting in longer simulation times. An overview of the characteristics and level of details of the grid data needed for the above cited models is presented in the following section.

2.2. Data requirements of grid simulation models

The input data needed by grid models (called grid data) and their requirements highly differ depending on the type of the grid model used. In *single-node models*, active power data of generation and demand are needed. Information about grid topology and its electric parameters are neglected. *Transshipment models* require an abstract grid topology using nodes, power lines and regions. The only electrical parameters considered are the net transfer capacities of power lines connecting the different regions considered. Active power of demand and generation are considered spatially differentiating between the defined nodes or regions. Losses can be addressed to each line as an assumed percentage (Wiese, 2015). In *DC models* in addition to topological information of the grid, electric parameters of power lines have to be defined. These parameters, which are essential to perform DC load flow analysis are the resistance (R [Ω]) and thermal limit current (I_{th} [A]) of each power line.

The *AC power flow model* requires by far most input data in the scope of the relevant grid model types defined in this paper. Global frequencies (f [Hz]) and nominal voltage levels (V_n [kV]) are set. Each node needs to be defined either as a *PQ* or as a *PV* bus which states whether reactive power (Q [var]) or voltage (V [kV]) are known (Rendel, 2015; Milano, 2010) at this bus. Demand and generation data have to be additionally specified by their reactive power or voltage behaviour. The power lines, apart from their active resistance, are defined by their reactive behaviour, hence information of their reactance (X[Ω]) is necessary. Specifying this behaviour either the capacitance (C [nF]) or inductance (L [H]) have to be defined as well (Agricola et al., 2012). The thermal limit currents are also crucial for determining utilisation rates of power lines. In order to simulate multiple voltage levels at once, transformer data are also needed. Apart from the normal line characteristic (R, X, C), additional parameters define the transformer's behaviour allowing to modify the magnitude and the phase angle of the voltages at the nodes being connected. Most importantly the primary and secondary voltage rating, iron losses, tap ratio and phase shifts have to be additionally provided for transformers (Milano, 2010).

2.3. Grid data availability

After highlighting the requirements for grid data in the previous section we discuss here its availability for scientific and technical studies. Energy systems modelling accuracy and results depend of the input data available. In the case of grid modelling, this data includes in general the structure and electrical properties of the grid, called *grid data* commonly generated using a *grid model*. Other data are necessary in energy systems modelling including electricity generation capacities, electrical loads estimation and electricity price data. Note that, the details and scale of the required data depends on the modelling temporal and spatial scales. Generally, neither grid models nor grid data are publicly available. Moreover, the details and derivation of grid data used in modelling are not accessible. However, data is an important resource in energy system modelling as models are only of use if they are provided with valid input data. How can the quality of energy system modelling be evaluated if there are no or few information about input data, its quality, and the assumptions and simplification considered in their derivation (Egerer et al., 2014; Wiese et al., 2014)? How can the results of simulations be verified,