Electrification as a Solution to Carbon Neutral Society

Yrjö Majanne, Tomas Björkqvist and Matti Vilkko

March 23, 2021

Yrjö Majanne*, Tomas Björkqvist, Matti Vilkko

Electrification as a Solution to Carbon Neutral Society

Abstract: This study demonstrates how various power system engaged part-solutions can be combined as a functional, operable, and climate neutral electric power system. This is a simulation study taking the Finnish electric energy system as a case study. A chief aim here is to study how investments e.g. in wind and solar power production, heat pumps on a large scale, and increased number of chargeable electric vehicles influences the other components and operability of the existing power system. In this way we can obtain new insights on how different part-solutions function together and how they imply on energy prices and emissions.

Keywords: power system modelling, renewable energy

*Corresponding Author: Yrjö Majanne: Tampere University, E-mail: yrjo.majanne@tuni.fi

Second Authors: Tampere University, E-mail: tomas.bjorkqvist@tuni.fi, matti.vilkko@tuni.fi

1 Extended Abstract

1.1 Introduction

The theme of this paper is to assess the effects of alternative structures of the future energy system regarding the functionality and operability of the national power system. From this perspective the main requirement is the momentary balance between the production and consumption in power system, because electricity cannot be stored in large amounts cost efficiently. The paper presents four scenarios consisting of alternative options regarding types and capacities of the generation structure as well as profiles, flexibility, and capacities of the consumption. The scenarios combine possible production and consumption resources of the future power systems.

There is a strong consensus that the amount of weather dependent wind and solar power generation will be increased remarkably in next few decades. The increased share of variable renewable energy (VRE) generation will push out controllable thermal generation from the generation portfolio, which will further hamper the balancing of generation and consumption in the power system. Finnish energy companies also plan to increase nuclear power generation for base load generation that will make the control of the power system balance even more difficult. Thus, it is evident that to be able to operate the national power system, additional transmission capacity between neighboring countries, energy storages, and high amount of flexible loads i.e. demand side management will be needed.

In systems with a relatively small amount of controllable power generation available, the needed flexibility must be produced by controllable loads and energy storages. With current Battery Energy Storages (BES) technology, storing of electric energy is expensive, and this technology is not expected to be feasible for a long-term seasonal storing of energy. Instead, they will be increasingly used as daily storages and for fast balancing of power systems i.e. primary level frequency control. Also, storage capacities of controllable loads in industry, commercial buildings, and residential buildings are enough only for intraday rescheduling and smoothing of power consumption.

On the heating side there are plans and even already some realizations of medium- and long-term heat energy storages. Heat storages enable temporal decoupling of heat production and consumption introducing additional flexibility also to the electric power generation. In case of combined heat and power (CHP) generation, heat storages enable the electric power generation according to the needs of electric power system instead of a temporal heat load.

A possible technical solution to medium- and long term storing of energy is power-to-X-to-power technology (P2X2P), where hydrogen is produced by electrolysis and together with carbon it is converted to ammonia, methane or some other storable medium to be reconverted back to electric energy when needed. The challenges of this technology are high electric energy consumption, high costs, and poor efficiency.

The focus of this paper is to illustrate what kind of effects different scenarios would have to the operation and functionality of the national power system. The discussed subjects amongst other things are demand for controllable generation capacity, storage capacity, and needs for flexible consumption. The goal of this study is to illustrate the systemic effects of different possible development paths to the operation of the national energy system. The analysis results should help the decision makers to understand the effects of different development paths supported by political decision making.

1.2 Power System Model

The modelling and simulation tool applied in this study is FlexTool, a free software provided by the International Renewable Energy Agency IRENA [1]. The FlexTool model is a so-called data-based model. Characteristic behavior of different sub-systems like consumption profiles and weather dependent power generation by wind and solar PV power plants are characterized by time series of data. The applied power system model is a linear aggregated model combining all similar type generation and consumption units as single units having the total capacities and common characteristics of each unit types. The model also contains energy storages to introduce dynamic behavior to the system. With storages it is possible to replace the fixed coupling of the balance between generation and consumption sides with dynamic decoupling thereby producing flexibility to the dispatching of the generation.

Fig. 1 presents the principled structure of the FlexTool model. The model consists of different grids, e.g. electric grid, heat grid, and gas grid. The grids can be connected to each other by energy conversion units. The grid consists of nodes consisting further of different power generation and consumption units. The grid can be composed of several nodes connected with transfer units.

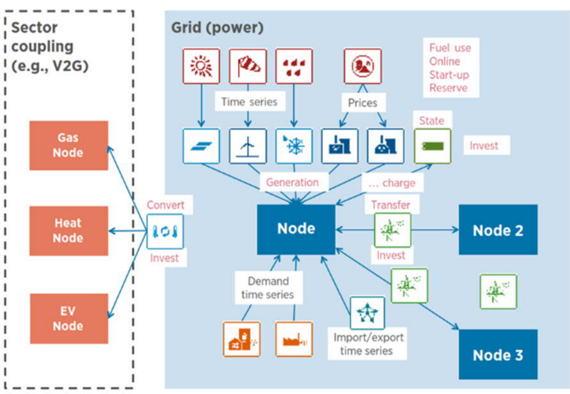

Fig. 1. The structure of the FlexTool model consisting of different grids and nodes inside the grids, aggregated generation units, consumption, and transmission between nodes.

The model of the Finnish national power system consists of two main grids, electric and heat grids, and two assisting grids, pulp grid and hydrogen grid. The two assisting grids are applied to model industrial demand response characteristics in the model. The operation and validity of the power system model was evaluated by comparing the actual year 2018 data with the data computed by the reference model. Results computed by the model compared with information from energy statistics is shown in figure 2.

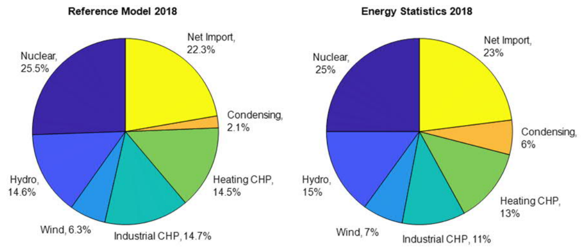

Fig. 2. Shares of different power generation sources on 2018 calculated by the validated reference model 2018 and obtained from energy statistics.

1.3 Scenarios for Future Power System

The scenario study includes four scenarios. The base scenario for 2030 is based on the reference model supplemented with already decided and financed investments to model the power system existing by the end of year 2022. [2] This model is further supplemented with non-radical evolution to achieve the Base Scenario for 2030. Scenario 1 for 2030 includes increased electrification and VRE generation without separate investments for flexibility. Scenario 2 for 2030 is the same as Scenario 1 but includes separate investments for flexibility and energy storages. Scenario 3 is for year 2050, where the amount of nuclear generation is reduced from 2030 situation, number of electric vehicles has increased to 2 000 000, wind and solar power capacity has doubled from year 2030, and in heat generation CHP is replaced to a large extent by heat pumps and geothermal heat.

The operability and the functionality of scenarios is analyzed by looking the duration curves and ramp rates of residual loads and how much of momentary importing and exporting of electric energy is needed to run the system. The residual load is the difference between the electric load and VRE generation describing how much additional energy in addition to momentary wind, solar and run of the river type hydro power generation is needed to balance the power system.

1.3 Results

The results show that even if in the scenarios the annual net amount of market power is small compared e.g. to the reference situation on 2018, big amounts of imported and exported energy is momentarily needed to balance the system. The increased share of VRE generation increases the ramp rates of residual load, which means the increased need of control capacity provided by storages or flexible loads. The increased capacity of energy storages reduces especially the need to export energy. With increased storage capacity it is very important to analyze the strategy, how to charge the storages without causing excessive disturbances in the system.

1.5 Conclusions

Transition to carbon neutral energy system requires thorough systemic analysis about the effects of changed generation structure and consumption characteristics. If the transition is carried out by increasing nuclear generation or by variable renewable generation, changes in generation structure effect on the needed control dynamics and capacity. The feasibility of the system cannot be evaluated according to annual amounts of produced and consumed energy, but the operation has to analyzed hour by hour, or even second by second.

Development of the Finnish national power system is not only a question about our own national system structure, but also the development in neighboring countries must be included in the system planning. This is because the operability of our national system is strongly connected with the Nordic energy market. If the transition of energy systems in our neighboring countries is also going to rely more and more variable renewable generation, we cannot rely so much on balancing our national system by importing/exporting energy with our neighbors.

Power systems are very complex having strong and dynamically fast interactions between all the subsystems the wholeness is built up. Touching one part of the system effects the operation of the whole system. That's why when modifying the system, a thorough analysis and planning is need. The transition of the system must be based on total optimization instead of looking some individual sub systems.

This study is a part of the research project "Transition to a resource efficient and climate neutral electricity system", EL-TRAN [3], financed by The Strategic Research Council of Academy of Finland.

References

[1] IRENA FlexTool methodology, 2018. Power System Flexibility for the Energy Transition, Part II, ISBN 978-92-9260-090-7, https://www.irena.org/ publications/2018/Nov/ Power-system-flexibility-for-the-energy-transition (March 15, 2021)

[2] Finnish Wind Power Association, 2021. Projects under construction 13.1.2021. https://tuulivoimayhdistys.fi/media/rakenteilla_2021_2023_olevat_hankkeet-13.1.2021.xlsx (January 16, 2021)

[3] https://el-tran.fi/ (March 15, 2021)