Ensure A Stable Power Grid When Using Renewable Energy

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***Abstract*— How can we ensure that we do not overload the power grid as we use more renewable energy sources, charging more electric vehicles and using more home electronics? In this paper we will investigate the limitations in the power grid, the consequence of using more renewable energy and charging more electric vehicles. We will also look into ways that smart home technology can make the grid more efficient, and reduce the need for infrastructure upgrades.**

Keywords- Systems Thinking; Systemigram; Power Grid; Smart Electricity; Sustainability; Renewable Energy; Electric Vehicle; Smart Charging; Smart Home Technology

I. INTRODUCTION

The Nordic Transmission System Operators (TSOs) Svenska kraftnät, Statnett, Fingrid and Energinet.dk has identified the following challenges for the Nordic power system: climate change, development of more Renewable Energy Sources (RES), technological development, and a common European framework for markets, operation and planning [1].

Before we continue, renewable energy is according to U.S. Energy Information Administration [2]: energy from sources that are naturally replenishing but flow-limited: renewable resources are virtually inexhaustible in duration, but limited in the amount of energy that is available per unit of time. The major types of renewable energy sources are:

- Biomass
  - Wood and wood waste
  - Municipal solid waste
  - Landfill gas and biomass
  - Ethanol
  - Biodiesel
- Hydropower
- Geothermal
- Wind
- Solar

The Nordic power system have experienced trouble during cold winter days with high consumption and limited generation and transmission capacity. It is easy to predict when these conditions will occur, and to implement corrective actions. In addition to days with high consumption, the power grid may also have hours with low load and high wind production. The power system (illustrated in Figure 1) needs to keep production at the same level as consumption at all times. To be able to do this, flexibility is required. This can be used to change the input or output for balancing purposes. Irregular renewable production is a main driver to increase the flexibility compared to today. Flexibility can be achieved through utilizing transmission capacity more efficient, utilize information from Automatic Metering System (AMS) to further develop demand response and new technology. As the world shifts for more renewable energy production, a new problem emerges. With some green energy, comes more unreliable production and with the increasingly bi-directional flow of power, there is a need to update the infrastructure. With the emerging number of prosumers (households and Electric Vehicles (EV) that consume power from the grid, but also produce electricity from their rooftop solar panels or wind turbine) installation of smart technology will be required to ensure flexibility [3].

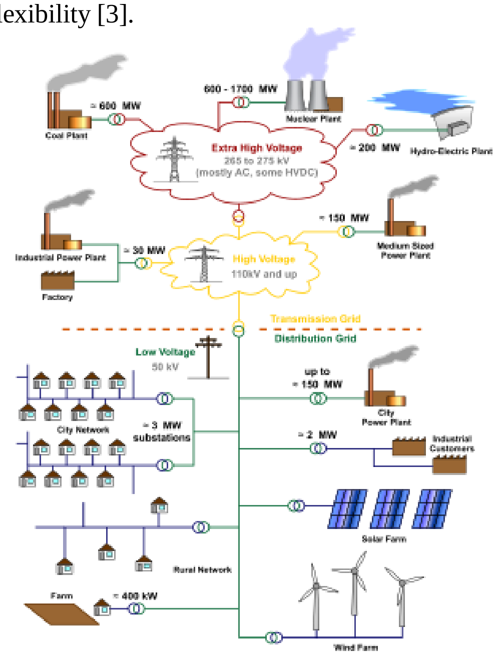

Figure 1. Example of electrical grid [15]

In this paper we will investigate the limitations in the power grid, the consequence of using more renewable energy and charging more electric vehicles.

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The reminder of this paper is organized as follows, Section II investigates the current limitations in the power grid. Section III investigates the consequences of using more renewable energy. Section IV investigates how agents can be applied. Section V investigates in to how we can achieve a holistic view of challenges. Section VI looks into how smart technology can be used for grid efficiency.

II. CURRENT LIMITATIONS IN THE POWER GRID

Most of the Norwegian transmission grid is built from 1950 – 1980 and the last part of the transmission grid connecting northern Norway with southern Norway was finished in 1994 (see Figure 2). Large parts of the power production happens in western Norway and in norther Norway, but eastern Norway has the highest consumption with limited local production. This is reflected in the transmission grid, where the flow of power basically flows from west to east and north to south (Figure 3). The government sees a need to modernize, restructure and expand the capacity in the transmission grid. This is to increase the security of supply in some areas, more RES, higher consumption in industry and rural areas with population growth [4].

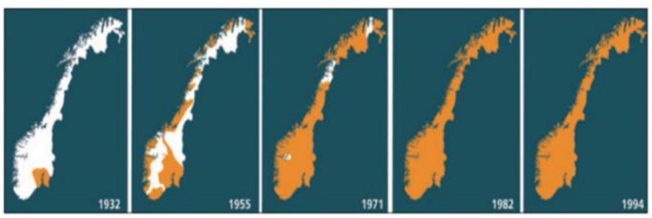

Figure 2. Development of the Norwegian transmission grid.

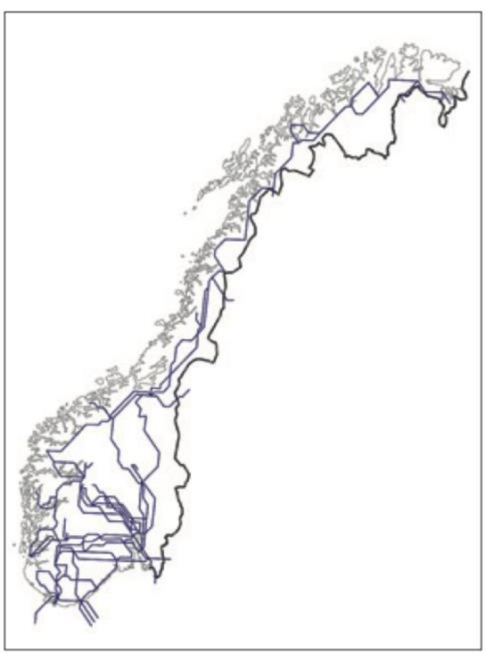

Figure 3. Overview of the Norwegian transmission grid [4].

III. CONSEQUENCE OF USING MORE RENEWABLE ENERGY

To be able to reduce initial infrastructure cost its recommended to exploit the current transmission grid in relation to available transmission capacity, so that renewable energy production is localized in areas with low capacity or areas in need of more capacity. This may mean a more geographical distributed development.

Renewable energy draw power from natural sources; solar, wind, ocean, hydroelectric and geothermal. This means that it is affected by environmental, seasonal and daily cycles that can limit their efficiency. This means that production will vary during all hours of the day and be less predictable. Because of this there is a need to store the energy, *grid energy storage.* There are multiple ways to store energy depending on the source; dammed hydroelectricity, batteries, thermal energy storage and mechanical energy storage. Dammed hydroelectricity is the largest way to store energy, using both conventional hydroelectricity generation and pumped storage hydroelectricity. Recent years the research and development of battery storage technology has enabled commercially viable projects to store energy during periods with low consumption and high production. Thermal energy storage is another way to store renewable energy using liquids or solid materials to store and release thermal energy. Water tanks in buildings are a simple example of thermal energy storage systems. Storage of energy may give the TSOs and grid operators the flexibility and ability to maintain security of supply.

As a consequence of high electricity bills, lower cost for solar panels and the security of supply more and more consumers become prosumers. Not only do they consume power, they also generate their own (Figure 4).

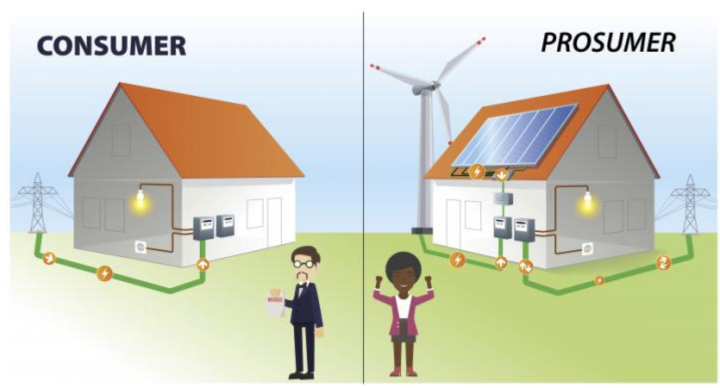

Figure 4. Consumer vs. Prosumer [3].

The increase in electrical appliances and charging of EVs is making some cities experiencing higher peak loads. Increasing peak loads will lead to grid enhancements and increased cost. Some of this cost may be reduced if local generation, batteries or other *demand flexibility resources* reduce the required capacity during peak load hour.

IV. Application of Agents

The problem domain can be viewed as a system containing various agents. The agents and their characteristics can change based on the area that's being researched or analyzed. The Energy Hub [20] has made some good examples of this, they present all consumers and producers of electricity are represented by an agent, connected to a power matching auctioneer agent (Figure 5).

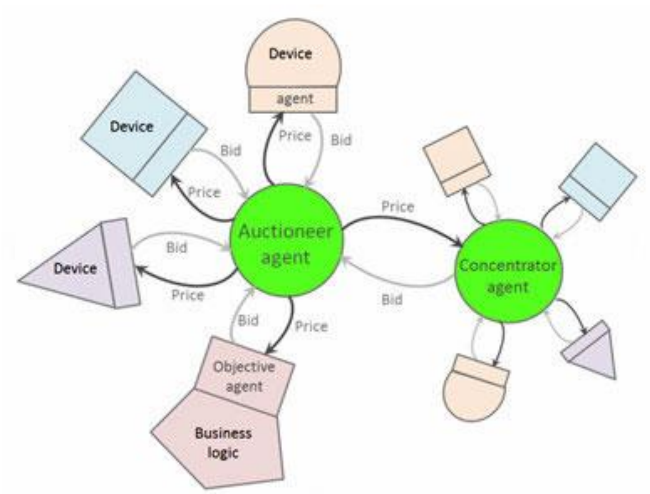

Figure 5. Agents representing devices operating in a market with an auctioneer agent [20].

The report "NIST Framework and Roadmap for Smart Grid Interoperability Standards" written by The National Institute of Standards and Technology (NIST) [16] has useful illustrations showing the agents and domains that could exist in the problem domain. This is a good basis to understand the different stakeholders (Figure 6).

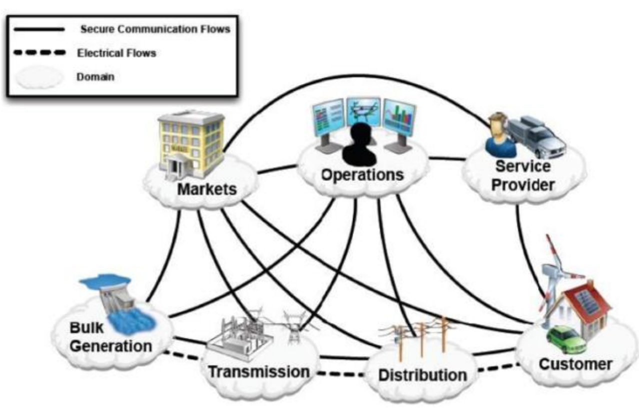

Figure 6. NIST domains and agents for a Smart Grid [17].

V. Achieving a holistic view of the challenges

A central approach in Systems Thinking is the holistic approach, which looks at the interrelationship between the parts in its environment [5]. We want to use this approach, and to get a holistic view, we model the problem domain and its relationship in a Systemigram. The Systemigram can be seen in Figure 7 below, and the full-scale Systemigram can be seen in Figure 8 at the end of this paper. From the Systemigram, we can see that there are many complex and complicated relationships and not individual problems. The Systemigram contains many stories, and every story has an unique color, and the reading direction is appointed by the arrow. By the help of the Systemigram, we get a holistic view of the problem domain. This is helpful because, as stated earlier, new solutions bring new challenges to the table, but with the Systemigram one can get an idea of how the other relationships are affected, so one can take precautions and make a more robust solution. From the Systemigram we can see that there is more than one system in action.

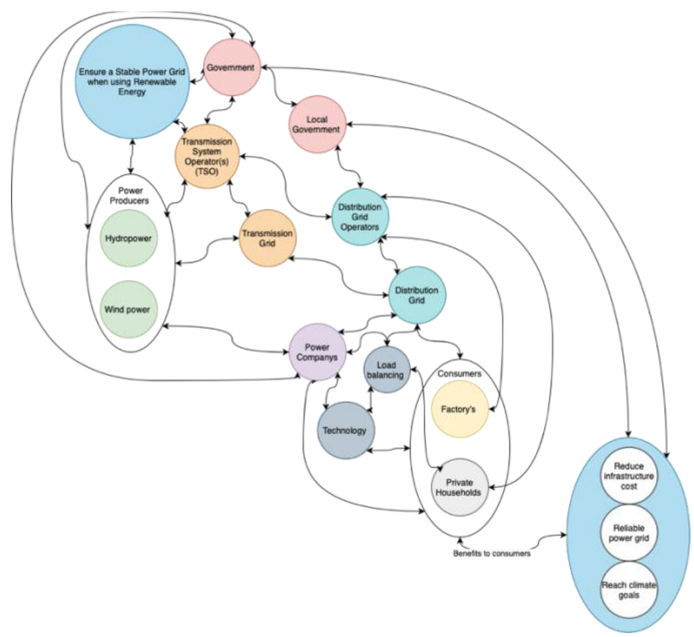

Figure 7. Systemigram of the problem domain.

VI. Using smart technology for grid efficiency

In recent years, there has been multiple research projects focusing on utilizing smart technology for grid efficiency. The focus has been to give TSOs and grid operators the flexibility needed to maintain security of supply and minimizing the impact on the customers. These research projects have been cooperation between different technology companies, grid owners and TSO.

A. *NorFLex*

Cooperation between Agder Energi, Statnett, Glitre Energi, Mørenett and NODES to develop new technological solutions to get a more flexible power consumption [6]. The solutions shall contribute to avoid overload in the power grid. The goal of the project is to find the smart technological solutions for the power grid that smooths out the peak loads over the hole day. One of the technologies used in this project is smart adapters for panel heaters and smart EV chargers connected to Tibber. Tibber then pooled together the flexibility from these two device types in multiple homes and offered this aggregated flexibility to the local grid owner Agder Energi in an automated process.

B. *Electric vehicles and buildings keep the power grid in balance*

This is a cooperation project between Tibber, Entelios and Statnett to use electric vehicles and large buildings to maintain balance between the production and consumption of electric power [7]. Entelios and Tibber are working to deliver flexibility from a wide range of technologies. Tibber has now contributed flexible power consumption from EVs in Greater Oslo, while Enelios has tested automated flexibility from electric central heating boilers in industrial, commercial and public buildings in the eastern part on Norway, according to Statnett. Both research projects conclude that to be able to safeguard the supply of power in the future, there is a need for smart technological solutions.

Tibber is currently using smart chargers for electric vehicles as load balancer in the real power grid in large scale in Sweden as they have moved into the Swedish balancing market for frequency containment reserve (FCR), using the capacity offered by electric vehicles [8] [18].

The U.S. Department of Energy´s Office of Electricity states that [9]: “The Smart Grid is not just about utilities and technologies; it is about giving you the information and tools you need to make choices about your energy use. If you already manage activities such as personal banking from your home computer, imagine managing your electricity in a similar way. A smarter grid will enable an unprecedented level of consumer participation. For example, you will no longer have to wait for your monthly statement to know how much electricity you use. With a smarter grid, you can have a clear and timely picture of it. "Smart meters," and other mechanisms, will allow you to see how much electricity you use, when you use it, and its cost. Combined with real-time pricing, this will allow you to save money by using less power when electricity is most expensive. While the potential benefits of the Smart Grid are usually discussed in terms of economics, national security, and renewable energy goals, the Smart Grid has the potential to help you save money by helping you to manage your electricity use and choose the best times to purchase electricity. And you can save even more by generating your own power.”

VII. Conclusion

Norway is committed to achieving its emission reduction target under the Paris Agreement, which sets a target of reducing emissions by at least 50% and towards 55% below 1990 levels by 2030 [10]. Smart Grids are the digitalized and smart power grids of the future. They are also essential to Norway’s electrification efforts and success with the necessary reduction of greenhouse gas emissions [11].

Norway, the Nordic countries and the EU are all shifting from large, centralized coal- and gas power plants to de-centralized wind- and sun power plants. It is estimated that from 2010 to 2025 the total capacity of wind power is quadrupled to 24.000 megawatt, or 22% in the Nordic. The most important challenges for the TSO and grid operators is to secure a stable power grid. One of the means to ensure this is flexibility; the possibility to get industry or households to reduce their consumption during peak load hours [12].

The Nordic TSOs has published a report “The Way forward – Solutions for a changing Nordic power system” where they summarize the key solutions that are needed to meet the challenges affecting the Nordic power system in the period leading up to 2025. One of the key areas is balancing the power system, with a new Nordic balancing concept called the Modernized Area Control Error (MACE) [13]. Compared to ACE control, MACE control utilizes modern IT solutions and optimization algorithm, automatic reserves and available transmission capacities in order to exchange reserves between zones [14].

There are multiple research projects underway or finished related to the topic we have investigated in this paper. All projects conclude that smart technology, used right, gives the flexibility needed to help balance the power grid as more RES are integrated. Tibber is doing this in Sweden using only smart charges for electric vehicles, this can be expanded to utilize other smart technology to balance the power and to postpone the need for infrastructure updates. The implementation Tibber is doing in the Swedish power grid can easily be expanded to Norway and Germany where Tibber also has established their business [19].

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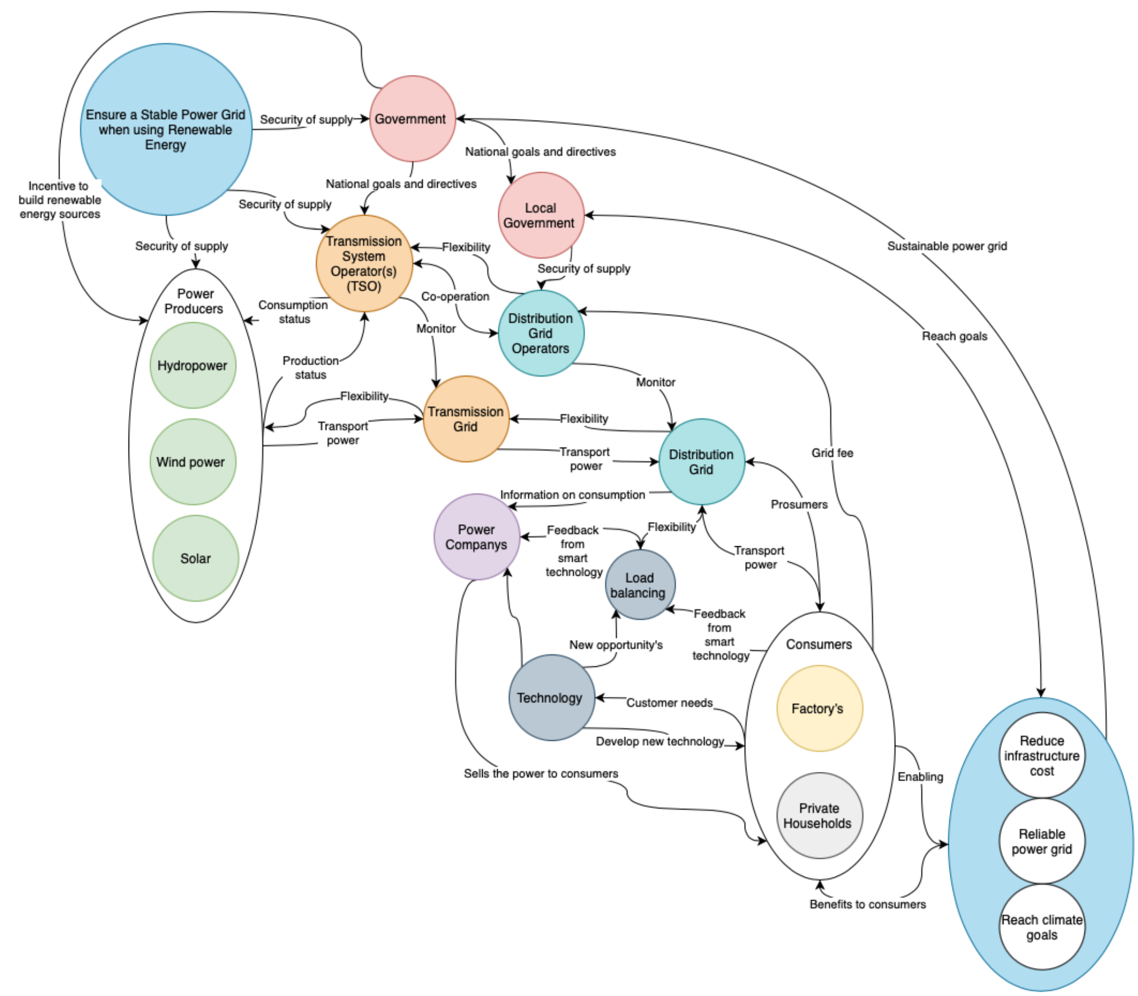

Figure 8. Systemigram of the problem domain.