Vehicle-to-Grid Power in Danish Electric Power Systems

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1. Interest of the work

Renewable energy plays a vital role in ensuring global energy and environmental sustainability. To meet the environmental standards set up in the Kyoto Protocol, many countries have proposed specific targets for the share of renewable energy. Denmark has always promoted the use of renewable energy and is one of the pioneers in producing electricity from renewables like wind energy. The share of wind in electricity generation in Denmark is more than 20%, which is one the largest in the world. As part of the future Danish energy policy, it is planned to integrate 30% of energy consumption from renewable energy by 2025 and a 50% wind production share of the electricity generation by 2030 [1].

However, it is obvious that the renewable energy sources are intermittent in nature. For example, the electricity from wind energy is produced only when the wind blows, not when the power is demanded. During high winds, the electricity generation may be more than the electricity demand. In that case, so far the surplus electricity is either exported to the neighbouring countries or the generation is reduced by curtailing the conventional generator supply. Similarly during low winds, the energy imbalance due to the deficit of power supply will be compensated by increasing the power supply from other generators or by imports. This power imbalance is highly challenging for a power system operation and control point of view. It is estimated that, for every 10% wind penetration, a balancing power from other generation sources equivalent to 2-4 % of the installed wind capacity is always required for a stable power system operation. So, with more penetration of intermittent renewable energy like wind power, the system operation will be more complex and it will require additional balancing power. Installation of new conventional generators and dependence on more power exchanges with neighbouring countries may be limited by the promotion and substitution of conventional generation by renewable energy in Denmark as well as across its borders. One of the viable solutions for the energy balance is thus the energy storage technologies which is complementary to the stochastic nature of the renewables. The energy storages can store energy during low demand period and supply when power is required.

The storage systems of electric vehicles are one of the emerging technologies, which can act as a load reacting to the change in power supply. The concept of environmental-friendly vehicles has encouraged many car manufacturers to develop clean vehicles, especially vehicles powered from electricity. Electric vehicles when coupled to an electricity network (Vehicle-to-grid (V2G)) can act as a controllable load and energy storage in power systems with high penetration of renewable energy sources. The reliability of the renewable electricity will be enhanced with the vast untapped storage of electric vehicle fleets when connected to the grid. With fleets of electric vehicles, the balance between the supply and demand could be achieved by the load reacting to change in generation. Vehicle-to-grid power could provide back up electricity storage as well as quick response generation to the changes in power balance of the electricity grid. V2G systems uses the electric vehicles to transfer power with the grid when they are parked and plugged in to the charging stations at parking lots, at offices or at homes and they will have bidirectional power transfer capability. The electricity supplied by the V2G will reach the consumers through the grid connection and in return, any surplus energy in the grid could be stored in the electric vehicles. The Transmission System Operator (TSO) could request for a power transfer with an individual vehicle or fleet of vehicles in a parking lot through control signals in the form of a power line carrier, radio signal, internet connection or mobile phone network [2].

In general, the utilisation factor of vehicles is less than 10%, compared to an average 40-50% utilisation of central power plants. The light motor vehicles are idle almost 90% of the time or for a period 20-22 hours a day

[4]. The average daily vehicle miles travelled in Denmark is 36km/day. Thus, if the 2 million light motor vehicles (less than 2 tons) in Denmark supply an average power of 15kW each, they could provide 30GW of electricity. This implies that the power capacity of 13% of the above vehicle fleet is equivalent to the total average power requirement of 4GW in Denmark. Many models of electric cars are now commercially available in the market operating with highly efficient lithium-ion batteries. The 2008 model battery electric vehicle, Tesla Roadster has a vehicle efficiency of 5.65 miles/kWh and energy storage capacity of 53kWh. From a calculation based on equation (3) in the reference article [2], the net energy available in the battery after the daily driving requirements by this battery electric vehicle in the Danish context is approximately 45kWh.

2. Objective

The objective of this work is to analyse the use of battery electric vehicles as a provider of ancillary services (regulation and manual reserves) to support large-scale integration of renewables in Danish electric power systems.

3. Main Contribution

A. Ancillary services from V2G

A battery electrical vehicle with power capacity similar to Tesla Roadster providing ancillary services (regulation and manual reserves) could possibly provide significant annual payments to the electric vehicle owner. The earnings which are achievable from the regulation services are higher than the manual reserves. This is because; the regulation services are used quite often in a day to match the grid fluctuations and are offered a higher capacity price. The total earnings from the vehicle storage are dependent on the total plug-in time, state of charge, power line capacity, and hourly market prices. The calculations are based on the assumptions that the vehicles are plugged-in 20 hours a day, daily utilisation for regulation as 10% and the average costs as presented in the article. Also from the results, it is evident that the revenue is increased for the V2G service with a higher power line connection.

B. V2G for renewable energy support

The vehicle-to-grid power using battery electric vehicles are analysed in this article for the ancillary service operation in Denmark to incorporate a larger penetration of wind energy and solar photovoltaic (PV) [3]. The V2G vehicles supporting 10% grid-solar PV integration for peak load management is realised by storing power from the solar peak and supply to the system peak. This could be realised with 8.7% of the current vehicle fleet available in Denmark. To utilise 50% wind energy production in Denmark, 3.8% of the current vehicles under V2G could support regulation power services and with 6.8% of the vehicles, V2G power could generate sufficient manual reserve requirements.

From these results, it is obvious that the vehicle-to-grid power could play a major role in providing ancillary services to power systems integrated with 50% of renewable power generation in Denmark. This is achievable by an amount of V2G based electric vehicles less than 10% of the total vehicle need in Denmark. The rapid development of high storage capacity batteries will increase the net power capacity of the electric vehicles rendering V2G power in the future. This will in turn demands less number of electric vehicles to provide ancillary services for such large-scale grid integration of renewable energy.

The modelling of generic battery energy storage and a suitable dispatch strategy of utilizing the electric vehicles for power balancing in a typical Danish power system network are currently being investigated as part of this research work. In a real situation, the ancillary services supplied by the electric vehicles will be a mix of large number of small different units. To analyse the performance of such units in a power system network, aggregate models of vehicle storages are designed which will reduce the complexity and computation time of the evaluation.

Key References

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