DEMAND SIDE MANAGEMENT USING ALKALINE ELECTROLYSERS WITHIN THE UKGDS SIMULATION NETWORK

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ABSTRACT

Due to the problem of pollution from fossil fuels, there has been an effort to diversify our energy supply especially in the transportation sector and to use cleaner fuels. The interest in a hydrogen energy economy has been increasing recently. One of the Hydrogen production methods is to use an electrolyser. Hydrogen can help the transition from energy infrastructure available today into an energy world with a growing renewable electricity supply. As the number of time varying renewable power generators increases in the electrical power system, the usage of demand side management tools will become more important. Electrolysers could be used as a significant new demand side management tool in these networks to improve the quality of their operation.

The UKGDS High Voltage Underground Network has been modelled with electrolysers and wind farms added to four different buses to investigate the impact of electrolysers on this network. The electrolysers are assumed to be able to consume variable power (within their maximum and minimum limits) from the network. The impact of adding electrolysers on the network voltages and transmission losses has been investigated through modelling. Despite the fact that electrolysers behave like additional load on the system, the transmission losses were decreased by 2.91% while the electrolysers were added to the electrical grid. This reduction in transmission loss is achieved as a result of the proper selection of the location and size of electrolysers with respect to the location and size of the wind farms and also the control strategy which is used to run the electrolysers with respect to the power output from the wind farms.

Keywords: Alkaline Electrolyser, UKGDS Network, Demand Side Management

INTRODUCTION

Carbon dioxide emissions could be reduced using clean energy resources. Hydrogen could be used as a major energy carrier in a future clean energy economy, and it could be produced from many different feed stocks [1]. The development of new hydrogen technologies could increase energy and economic security. A successful transition to a hydrogen economy needs a fuelling infrastructure and a proper strategy for utilisation of available renewable power. The electrolysis of water is one of the main processes for hydrogen production. An electrolyser uses a DC electric current to split water into oxygen and hydrogen. An introduction to different types of electrolysers and a comparison between them can be found in [1]. Hydrogen could be used in Fuel Cell Vehicles (FCVs) which have no direct harmful emission and have efficiencies about twice that of conventional internal combustion engine vehicles.

Onsite Hydrogen production by electrolysers has the following advantages:

- If the power for running the electrolysers comes from renewable resources then the hydrogen production process will not produce any carbon dioxide or other pollutants.
- Hydrogen does not need to be shipped in tankers if it is produced locally in fuel stations, so the cost of the transportation of hydrogen will be eliminated. If the cost of natural gas increases in future, then production of hydrogen from renewable energy might become cheaper than hydrogen production from natural gas.
- Electrolysers could be used to consume the excess wind or solar energy in the electrical system, and they can also use the excess power in the system during off-peak times. The response of electrolysers to the fluctuations in wind or solar power or consumer demand can help improve the performance and stabilisation of the electrical system especially in the case where the penetration of wind power is very high [1].

The United Kingdom Generic Distribution System (UKGDS) is a resource for the purpose of simulation and analysis of the impact of distributed generation on the United Kingdom distribution system. It contains some network models which are representative of the UK networks. These networks are studied for the purpose of test and evaluation of new concepts. The UKGDS networks are split into Extra High Voltage (EHV) and High Voltage (HV) models. There are six EHV models and seven HV models [2].

MODELLING METHOD

In this paper a UKGDS High Voltage, Underground Network is considered having two electrolysers and two wind farms added to four different buses. The electrolysers are assumed to be able to follow the power available from wind farms [3]. In other words, their electricity consumption is adjusted to follow changes in the renewable power generation in the power system. Software was developed using MATLAB and MATPOWER [4] to simulate the network model. The parameters for the simulation of the UKGDS power system are taken from [2].

The efficiency of Alkaline electrolysers is considered to be constant and equal to 53.5 (KWh/kg of H_2) [5]. This efficiency is considered based on the efficiency of an array of type 5040 electrolysers from StatOil Hydro's Hydrogen Technologies which is suitable for large-scale hydrogen production [6]. It is also assumed that the electrolysers do not produce any hydrogen during standby condition. In this study electrolysers are considered to be able to consume only active power with a maximum rate of 1MW per unit.

Figure 1 shows the UKGDS HV UG model [2] with two electrolysers and two wind farms which is simulated in this study. Electrolysers are added on two buses (bus 1158 and 1169), and the wind farms are also added at bus 1156 and 1157 of the UKGDS model.

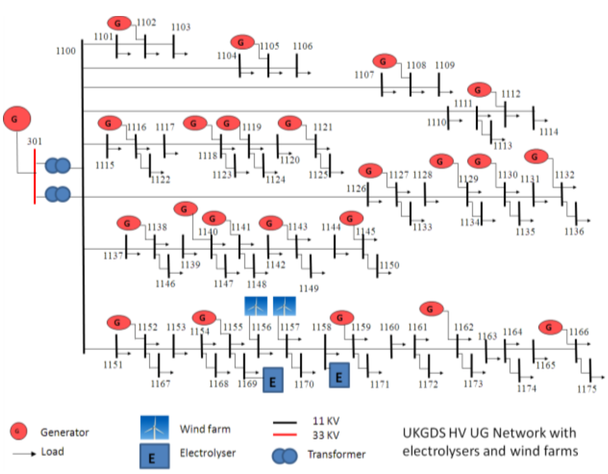

Figure 1: UKGDS HV UG network with 2 wind turbines and 2 electrolysers added to 4 different nodes

The electricity demand profile of the United Kingdom on 10th of January 2010 [7] is scaled down to match to the load profile of this UKGDS system, and then it is used in the simulation process. This demand profile is available with a resolution of 30 minutes, so the electrical demand in the system without electrolysers changes only once in 30 minutes. Figure 2 shows the total demand profile which was applied to the UKGDS model. The amount of load on different system nodes is equal to the proportion of loads defined in the UKGDS load profile. The active power generated from each generator in UKGDS model is scaled down with respect to the change in UK load demand profile [2]. The share of the active power from each generator is equal to the proportion of active power generation defined in the UKGDS standard model.

In this study, it is assumed that it is possible to forecast the amount of wind power generation from wind farms at least for the next hour before each decision is made about the state of electrolysers. The authors have not worked further on this persistence forecasting issue yet, but it is assumed that this data is available with adequate precision. The electrolysers are considered to be able to absorb variable input power within their maximum and minimum limit, and if the available power is less than the minimum power then the electrolysers will go into standby condition. Standby power of electrolysers is assumed to be equal to 6% of nominal power, and the Minimum power of electrolysers is assumed to be about 20% of their nominal power [3].

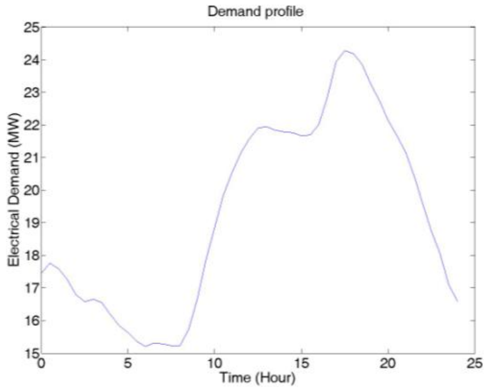

Figure 2: The demand profile for the whole UK, scaled down to adapt to the UKGDS demand scale

A data set with a resolution of 10 minute power output from an actual UK wind farm was used for modelling the active power profile of the wind farms over a period of one day. The wind turbines which the data are taken from have the maximum output power of 600KW. This value is multiplied by a factor of 2.5 to scale to the UKGDS model. This factor (2.5) was selected in a way that the size of wind farms would match the size of electrolysers, so the number of times that electrolysers go into standby mode would be minimised. The strategy which has been used for injecting power to the electrolysers is described below.

If the available wind power in the system is greater than or equal to 0.26 MW (20%+6% of 1MW), then the first electrolyser will work in normal mode and the second electrolyser would be in standby mode. If this wind power is greater than 1.2MW (100%+20% of 1MW) then both of the electrolysers will work in normal mode. In this study, the size of electrolysers is selected in a way that they would work in a normal condition most of the time, and the number of times that the electrolysers go into standby mode would be minimised. In practical condition, a large scale electrolyser would not go into normal operation mode or standby mode for a short period of time, so an additional restriction that each electrolyser should remain in its status (hydrogen production or standby mode) for at least one hour has been implemented by the authors. It is assumed that the electrolysers are never switched off, and they will go into standby condition in the case that there is not sufficient wind power. In addition, the converter losses are not considered in this study, but they could be easily added to the system by adding a dynamic coefficient, which represents the efficiency of the rectifier, to the simulation program.

The software which is used for modelling purposes is using the following algorithm, and variable defined as:

W_1: The output power from the first wind farm (MW)

W_2: The output power from the second wind farm (MW)

1. If $W_1 + W_2 \geq 1.2MW$ for at least half an hour (three 10 minute intervals) in one hour analysis then both of the electrolysers will work in normal operational mode during that hour. The reason that we used 10 minute intervals was that the data from wind farms were available over this timescale. The first electrolyser will work with full power and the second electrolyser will consume the rest of the available power from wind farms (note that the maximum and minimum power limits of the electrolysers are active during their operation).
2. If $0.26MW \leq W_1 + W_2 < 1.2MW$ for at least half an hour in one hour analysis, then only the first electrolyser is working normally during that hour, and the second electrolyser is working in standby condition. The first electrolyser will absorb the available power from the wind farms, after subtraction of the power used by the second electrolyser which is in standby condition.
3. If $W_1 + W_2 < 0.26MW$ both of the electrolysers are in standby condition during the forthcoming hour.
4. End of algorithm.

A 24 hour period of operation of the system was simulated using a simulation time step of 10 minutes. For the purpose of power flow analysis, it is necessary to assume that the output from the wind farms and the load demand in the system are constant during each 10 minute interval. Figure 3 shows the active power from the wind farms and also the power used by each electrolyser in the simulation period. The second electrolyser is in standby condition in the first five hours of the day due to lack of wind power available from wind farms.

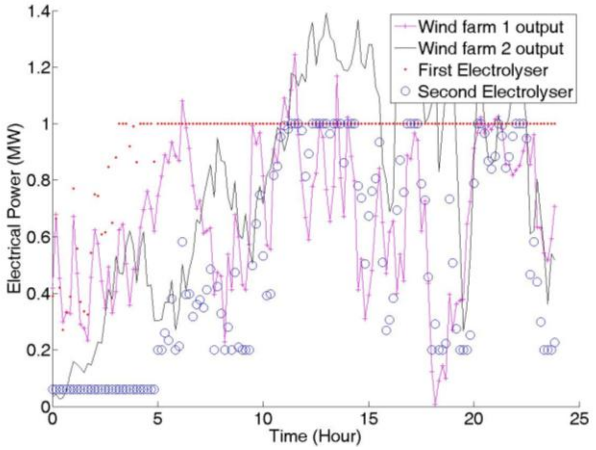

Figure 3: The power output of wind farms and the power demand from electrolyser

SIMULATION RESULTS AND DISCUSSIONS

The total amount of wind power absorbed by the electrical system during a day is shown in Figure 4. The difference between the amounts of wind power absorbed by the network and the amount of power used by electrolysers is shown in this figure as well, which is due to the limitation on the electrolyser to stay in its operational mode for at least one hour and the existence of the maximum and minimum power limits for electrolysers. Hence, these electrolysers cannot absorb all of the renewable power which is injected to the grid.

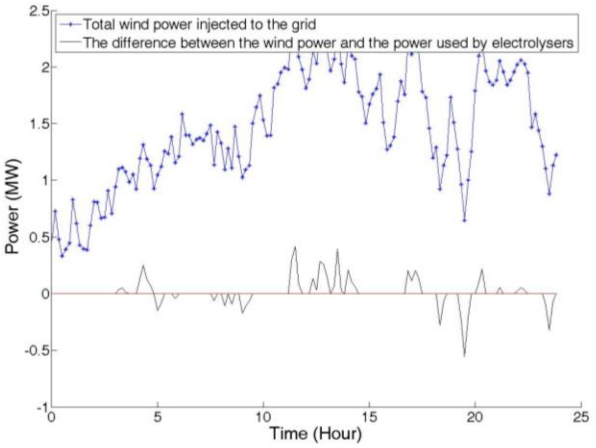

Figure 4: The total amount of wind power absorbed by the grid, and the residual of the renewable power which is not absorbed by electrolysers.

It is obvious from this figure that by using the defined algorithm, the electrolysers are able to absorb most of the available renewable power. However, there is still some amount of renewable power which is not used by electrolysers. This residual power has some small sharp peaks and troughs. During some short period of times, when this residual power is negative, other generators in the network must provide the energy needed for electrolysers. This also raises the argument that if hydrogen is produced from non renewable power, then the amount of carbon gas emission might exceed the amount of carbon dioxide emissions from the conventional fossil fuel transport sector. In this work this residual power is negative only for very short periods of times due to the algorithm implemented in this study and also the proper sizing of electrolysers and wind farms.

The amount of wind power generated and injected to the grid by the wind farms during one day is equal to 34.7MWh. The total amount of power consumed by electrolysers during the same period of time is equal to 34.4MWh. About 0.29 MWh of this amount is lost as the result of standby losses, and the rest of that is used for hydrogen production. By considering the efficiency of the electrolyser, the amount of hydrogen produced in the network would be equal to 638.33kg during the course of this day.

Using electrolysers in the electrical grid can have an impact on the voltages at different nodes in the system. Figure 5 shows the impact of using the electrolysers on the voltage of bus 1158 which is connected to the second electrolyser. The nominal voltage of this bus is 11KV. The voltage is decreased on this bus as a result of the operation of electrolysers.

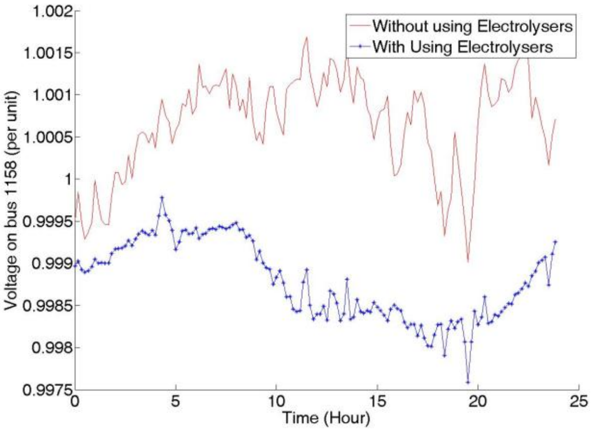

Figure 5: The voltage on bus 1158 before and after adding electrolysers to the system

Figure 6 shows the impact of using electrolysers on the total transmission loss in the network. Despite the fact that the electrolysers act as additional load on the electrical network, they could reduce the transmission losses in this study. In one day, running the electrolysers decreased the amount of transmission losses on the network by 0.23MWh. This accounts for 2.91% of the total transmission loss within the system. This reduction could be as the result of the fact that electrolysers are located near wind farms and their sizes are selected properly with respect to the size of the wind farms.

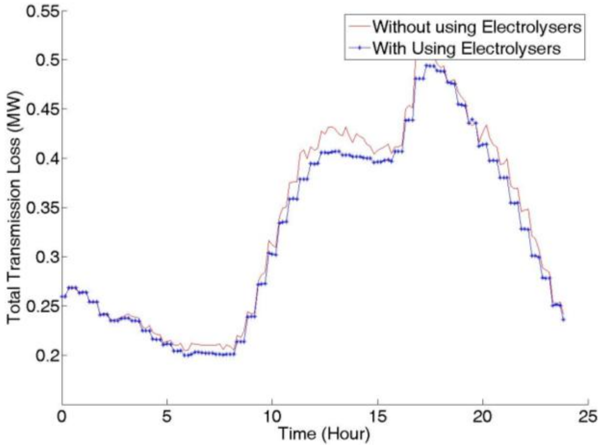

Figure 6: The total Transmission loss in the HV UG UKGDS grid before and after adding two electrolysers

CONCLUSION AND FUTURE WORK

Electrolysers and wind farms have been introduced to a UKGDS model, and a simulation program was developed using MATLAB and MATPOWER to investigate the impact of electrolysers on voltages and transmission losses of this generic distribution network. Utilisation of two electrolysers on two different buses of this network could reduce the transmission losses by 2.91%.

Electrolysers could be used not only for the purpose of hydrogen production, but also as responsive loads and demand side management tools in electrical grids to absorb the excess power from renewable resources.

High resolution data from wind farms is going to be used in future by the authors to analyse the system within a millisecond time frame. The effect of variable input power on the efficiency of electrolysers is not considered in this paper, and the maximum derivative of injected power (maximum change in the power) which is acceptable by electrolysers is not considered either, however they will be considered in future work.

Acknowledgments

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