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Impact of Electrolysis on the Connection of Distributed Generation

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Abstract

The rapid increase in renewable generation will necessitate significant electricity network reinforcement or generation curtailment unless alternative approaches can be found to bypass electricity network constraints. This paper describes the problems of integrating further distributed generation to an electricity distribution network and demonstrates the effectiveness of using electrolysis to alleviate these problems. Power flow analysis was used to run half hourly simulations over the period of one year. This analysis focuses on network thermal limits and network voltage limits. Four case studies were considered with different levels of generation and control strategies for the distributed energy resources connected to the network.

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1. Introduction

In recent years, many countries move towards decarbonizing their energy sector. The United Kingdom's (UK) goal is to ensure that 15% of the energy demand is met from renewable sources by 2020, in the most cost effective way [1]. Ambition is equally strong across all areas of the UK, and many investors are now ready to invest on PV solar farms and on-shore wind farms at the medium voltage level. However, a large penetration of renewable generation will require significant network reinforcement or generation curtailment when their production level would otherwise endanger the operational security of the system. The distribution network operator (DNO) will charge the reinforcement cost of the network from the owners of distributed generation (DG) otherwise the energy production of the DG will be

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curtailed. This might discourage the investor, and therefore alternative approaches should be found to bypass the electricity network constraints in a cost effective way [2, 3].

Wind based water electrolysis was found to be a viable option in producing hydrogen which can be used in either transportation or other industrial applications [4]. Effectiveness of introducing an electrolyser in a wind farm site, to eliminate above issues is discussed in this paper. A case study was completed based on an actual distribution network in the UK.

The area, where the selected distribution network is located, has one of the highest average annual wind speed and solar radiation in the UK. An increasing number of on-shore wind farms and PV solar farms are being connected each year in this area. The selected distribution network, with the layout illustrated in Fig. 1, consists of a ring feeder which connects a 132/33kV substation to two 33/11kV substations. One of the feeders leaving from Busbar2 connects a 5 MW wind farm (A) and a 3 MW solar farm (C) through a 33/33 \pm 10% voltage regulator, which is located between Busbar6 and Busbar13 in Fig. 1. The voltage regulator uses Line Drop Compensation to control the voltage at the generation connection point.

There are four operational renewable farms (A,B,C,D) currently being connected to the network and another four in the application process (E,F,G,H). Furthermore, it has been decided to increase the capacity of the existing renewable farm (A). Therefore the network might become highly constrained. The major concerns related to the connection of new distributed generators to this part of the network, covered by this study, are the thermal ratings of the voltage regulator, thermal ratings of the line between Busbar1 and Busbar2, and the voltage rise at Busbar2 and new wind farm H connection point. The network parameters, demand and generation values used in the simulation are taken from the measurements of an actual network, and cover a period of one year, from 1st of April 2012 to 31st of March 2013. The output of the future generators was scaled from existing measurements to match their capacity.

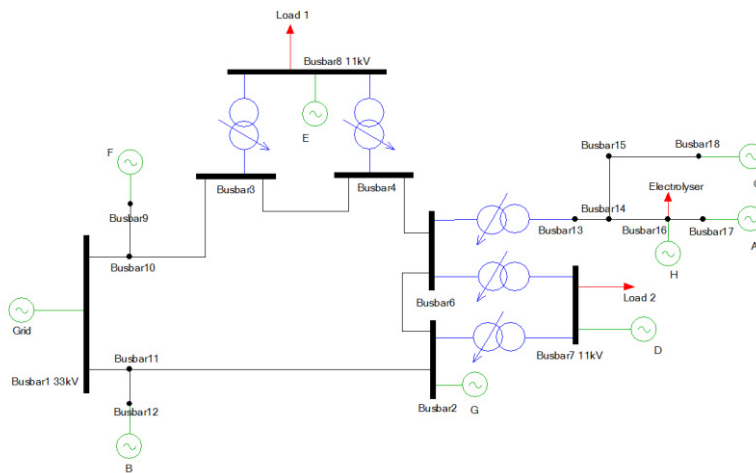


Fig. 1. Distribution test system

2. Methodology

The analysis of the distribution network was structured in four case studies according to the distributed energy resources connected to the network, summarized in Table 1. The data flowchart of the simulation used in the analysis is shown in Fig. 2. The simulation started by reading the load and generation data at time t (number of half hours) = 0. Then it ran power flow analysis to obtain the equipment loading and

voltage profiles. In case studies *a* and *b* these steps were repeatedly executed for the each half hour, throughout the year until $t = t_{end}$. Here the network constraints were not taken into consideration. For case study *c*, if the network limits are exceeded the generation is curtailed until the network parameters are below their ratings. In case study *d*, an electrolyser was activated to bypass the electricity network constraints before curtailing the generation. Half hourly simulations were carried out throughout the year as previous. The four case studies are explained in detail in the following sections.

Table 1. Case studies considering different levels of DG connection and control strategies

Case Study	<i>a</i> .Existing DG	<i>b</i> .Future DG	<i>c</i> . Future DG with active power generation curtailment	<i>d</i> . Future DG with active power generation curtailment and electrolyser
DER Name	Capacity (MW)	Capacity (MW)	Capacity (MW)	Capacity (MW)
A / WF	5	12	12	12
B / SF	4.4	4.4	4.4	4.4
C / SF	3	3	3	3
D / SF	2	2	2	2
E / SF		5	5	5
F / SF		5	5	5
G / SF		5	5	5
H / WF		6	<6	<6
Electrolyser				1

Note: WF - wind farm, SF – solar farm

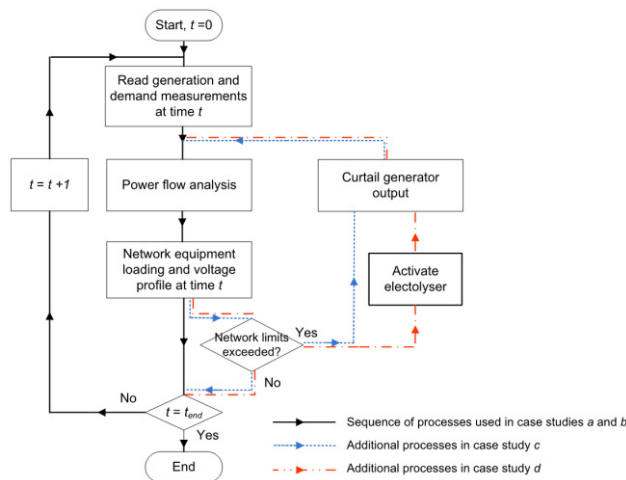


Fig. 2. Data flowchart of the simulation

2.1 Case study *a* - Existing DERs

In case study *a*, recent measurements from the existing distributed generation plants and loads were used to assess the current available headroom of the voltage regulator and line connecting Busbar1 and

Busbar2. The maximum loading recorded at the voltage regulator and line connecting Busbar1 and Busbar2, during a day resulted from half hourly simulations are shown in Fig. 3(a) and Fig. 3(b) respectively. A peak is shaped in the middle of the day in Fig. 3(a), due to the high solar farm generation. According to Fig. 3(a) and Fig. 3(b) the minimum available headroom of the voltage regulator and line connecting Busbar1 and Busbar2 are 10.5 MVA and 13.6 MVA respectively. Therefore it can be seen that, this network can accept new generation sites to be connected at this level.



Fig. 3. Maximum loading at: (a) Voltage regulator; (b) Line between Busbar1 and Busbar2

2.2 Case study b- Future DERs

In this case study, it was considered that all the new generation were connected with a firm access to the network. Three new solar farms (E,F,G), each with a 5MW capacity and one new wind farm (H) with a 6 MW capacity were connected to the network while the existing wind farm capacity was increased up to 12 MW. The maximum loading recorded at voltage regulator and line connecting Busbar1 and Busbar2 are shown in Fig. 4(a) and Fig. 4(b). There are certain hours where the voltage regulator rating was exceeded, especially at times of high solar radiations. The maximum loading on the line connecting Busbar1 and Busbar2 surpasses its line ratings in the summer.

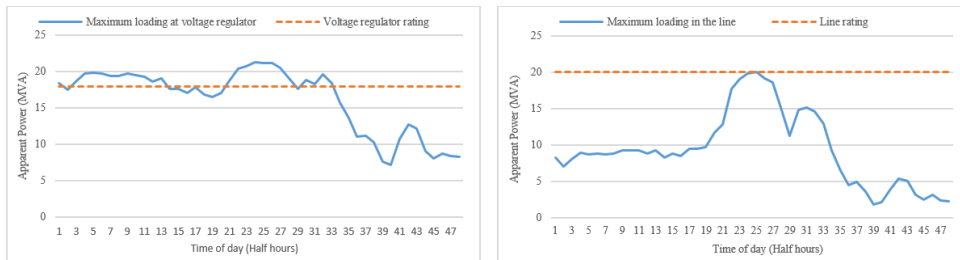


Fig. 4. Maximum loading at: (a) Voltage regulator; (b) Line between Busbar1 and Busbar2

The main concern related to voltage in the context of integrating large scale DGs on the distribution network is the voltage rise effect [5]. For this study only a part of the entire 33 kV network was modelled. An assumption was made on the voltage at 33kV Busbar1 that it is controlled by the grid supply generator (Grid in Fig. 1). In reality there are two 132/33 kV Grid Transformers with On-Load Tap Changers (OLTC) which control the voltage on the 33 kV Busbar1. In the simulation, the voltage at 33 kV Busbar1 was changing for each 30 minutes interval according to the measurements taken from the actual network. Although different case studies were considered, the voltage value for Busbar1 was held constant for the same time interval.

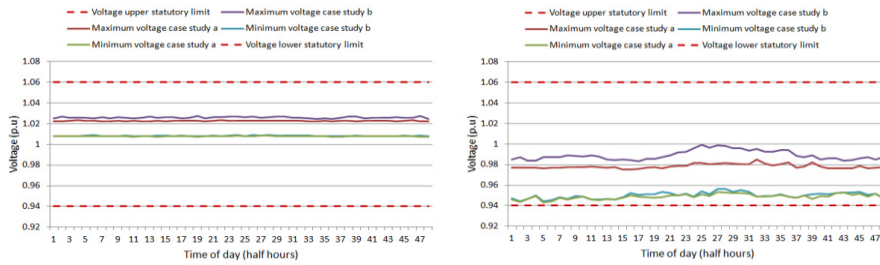


Fig. 5. Maximum and minimum voltages recorded at (a) Busbar2; (b) Wind farm H connection point

The maximum and minimum voltages at the Busbar2 are plotted in Fig. 5(a) for case studies *a* and *b*. The case study *b* was chosen because it represents the worst scenario, where no generation curtailment or electrolysis was employed. The integration of the new DGs will trigger an increase in the maximum voltage. However, because the voltage was kept below 1pu by the Grid Transformers (GT) at Busbar1, there were no threats of the voltage surpassing the upper limit. The voltage at the connection point of the new wind farm H, was controlled by the voltage regulator, which keeps the voltage rise due to new DGs (case study *b*) within moderate values. The maximum and minimum voltages are plotted in Fig. 5(b).

2.3 Case study *c* - Future DERs with active power generation curtailment.

In this case study, one of the generators connected through the voltage regulator will accept curtailment of its active power output for limited periods to keep the loading on the voltage regulator below its rating. A Last in First Out (LIFO) principle of access was considered [6]. Therefore, the output at wind farm H was controlled to keep the loading at the voltage regulator below the rating. The control can be done by stopping one or more wind turbines in the wind farm or controlling the pitch angle in all the wind turbines. The curtailed energy reached 193.5 MWh over the period of one year considered, as shown in Fig. 6. For this case study the maximum loadings, of both the voltage regulator and the line between the Busbar1 and Busbar2, did not exceed the equipment’s ratings.

2.4 Case study *d*- Future DERs with active power generation curtailment and electrolyser

In this case study a large scale 1MW electrolysis element connected at the site of wind farm H, transforms the electricity into hydrogen which was injected into the gas network at times when generation exceeds the equipment rating. For this scenario the energy that needs to be curtailed was reduced from 193.5 MWh to 44.35 MWh. Fig. 6(a) shows a comparison between case study *c* and case study *d*.

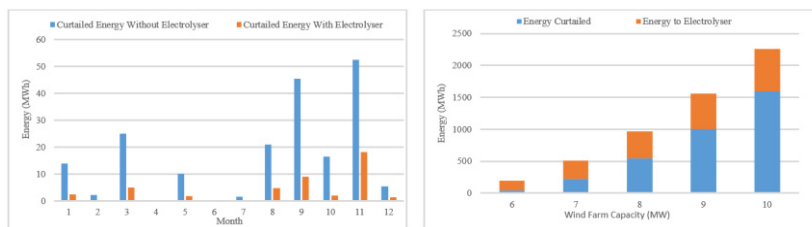


Fig. 6. (a) Curtailed energy due to voltage regulator rating; (b) Excess energy due to the network constraint imposed by the voltage regulator rating for different values of wind farm H capacity

2.5 Energy curtailed at wind farm H for different values of generation capacity

For this simulation a range of values were considered for the generation capacity of wind farm H. Fig. 6(b) presents the values of excess energy and the amount utilized by the electrolyser and the amount curtailed by active power generation curtailment. The electrolyser with 1MW capacity was efficient in capturing the excess energy from the DGs (A,C,H). However the efficiency was decreasing if higher generation capacities were considered, e.g. for the wind farm (H) as shown in Fig. 6(b).

3. Conclusion

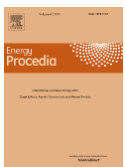
The connection of all the DGs that are currently in the application process may overload the voltage regulator and the line between Busbar1 and Busbar2 for the considered distribution network. Connecting only the 1MW electrolyser was able to keep the loading on the line below its rating. For the voltage regulator, in spite of reducing the duration of operating in overload conditions, active power curtailment still has to be employed. In this study the electrolyser was able capture most of the excess energy, 149 out of 193 MWh, thus it can be a valuable asset in the integration of intermittent generation from renewable sources. Future work includes a financial analysis to quantify the benefits of this application.

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Biography

Jianzhong Wu is a Reader in Institute of Energy, Cardiff University. Prior to this, he was a Research Fellow at the University of Manchester from 2006 to 2008. He received his PhD in 2004 from Tianjin University, China. His research activities are focused on Energy Infrastructure and Smart Grids.