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Utilisation of alkaline electrolysers in existing distribution networks to increase the amount of integrated wind capacity

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A B S T R A C T

Hydrogen could become a significant fuel in the future especially within the transportation sector. Alkaline electrolysers supplied with power from renewable energy sources could be utilised to provide carbon free hydrogen for future hydrogen filling stations supplying Hydrogen Fuel Cell Vehicles (HFCV), or Internal Combustion Engines (ICEs) modified to burn hydrogen. However, there is a need to develop and use appropriate strategies such that the technology delivers greater economic and environmental benefits.

In this work, the use of alkaline electrolysers to increase the capacity of integrated wind power in existing radial distribution networks is explored. A novel optimisation approach for sizing, placement and controlling electrolysers has been introduced, and its performance is assessed through modelling using a United Kingdom Generic Distribution System (*UKGDS)* case study. The controller objective is to dispatch alkaline electrolysers appropriately to maximise the total amount of profit from selling hydrogen and reduce the losses within the network while considering the realistic characteristics of pressurised alkaline electrolysis plants and satisfying the power system constraints. The impacts of increasing wind power capacity or the initial size of hydrogen filling stations on the results have been investigated and discussed.

1. Introduction

There is a need to decarbonise the road transportation sector, and there are a number of primary alternatives, such as battery electric vehicles or hydrogen fuel cell vehicles (HFCVs), available for our clean future transport, which can replace the conventional petrol or diesel Internal Combustion Engine (ICE) vehicles. Alkaline electrolysers can be used to produce 'green' hydrogen for HFCVs from electricity generated by renewable power resources [2].

On the other hand, the global capacity to generate wind power is continuously increasing [3], and the main issue arising from this increase is that the power systems might not be able to absorb the renewable power generated at all times due to lack of demand or breach of power network constraints. Transmission networks are already operating close to their capacity constraints, and adding renewable power generators at transmission level would require upgrading these networks with significant investment, so connecting generation to distribution networks has become more popular. As a result, there is a need to rethink about how to optimally arrange and operate the assets and devices on the distribution networks [4–6].

Distributed Energy Resources (DER) are generation technologies (typically renewable generation), energy storage technologies and flexible demand located at distribution level [4]. Current distribution networks have been designed on a 'fit and forget' basis, so some technical issues could arise due to adding more distributed renewable generation within the network. Such issues include voltage rises due to the connection of generators or reverse power flows, which could result in the violation of network constraints [7]. Therefore, there is a need to make distribution networks active by inclusion of responsive DER [8].

Active Network Management (ANM) techniques operate the network closer to its constraints by real time monitoring and controlling of the network parameters, such as currents, voltages, Distributed Generator (DG) outputs and responsive or non-responsive load demands, and therefore their utilisation will allow more renewable power resources to be connected to the existing distribution networks while maximising the utilisation of

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Nomenclature

θ^k	The $n_b \times 1$ vector of voltage angles at the time interval of 'k'
ANM	Active Network Management
ASDL	Aggregate Station Demand Limit (MW)
B	The set of bus numbers within the network
C_i	Cost function coefficients
Capital	The capital cost of an electrolyser in £/MW
D_i^k	The amount of demand (excluding the demand of electrolysers) in MW on bus 'i' of the last feeder (from bus 53 to bus 77) at the current time step '*k*'
ΔE_{Loss} %	The percentage reduction in the total energy loss on the distribution network during the simulation
DER	Distributed Energy Resources
DG	Distributed Generator
DNO	Distribution Network Operator
DSM	Demand Side Management
E_{HHV}	The Higher Heating Value (HHV) of hydrogen (39 kWh/kg, [1]).
E_{Loss}	Total energy loss during the simulation (MWh)
E_{Loss}^{With}	The total energy loss on the distribution network in the system with electrolysers (MWh)
$E_{Loss}^{Without}$	The total energy loss on the distribution network in the system without electrolysers (MWh)
E_{St}	The total energy delivered to all of the stations during the simulation (MWh)
ELD_{ij}^k	The demand (MW) of 'i'th active electrolyser located at 'j'th active filling station at the current time step '*k*'
GA	Genetic Algorithm
$H2P_{ij}^k$	Hydrogen produced by 'i'th active electrolyser located at 'j'th active hydrogen filling station (kg)
HFCV	Hydrogen Fuel Cell Vehicle
$\|I_{ij}^k\|$	The magnitude of current (A) flowing between bus 'i' and 'j' of the power system in the time interval of '*k*'
$\|I_{ij}^{Lim}\|$	The limit for the current magnitude (A) flowing between bus 'i' and 'j' of the power system
ICE	Internal Combustion Engine
k	The current time interval number in the simulations
Life	The lifetime of an electrolyser in years
n_b	The number of buses within the network
N_{El}^{EST}	The number of electrolysers at each station
$NAEL_j^k$	The number of active electrolysers at active filling station 'j' at each time interval '*k*'
NAS^k	The number of active stations at the current time interval of '*k*'
NB	The number of branches on the power system
NDP	The number of data points during the simulation (e.g. if the simulation is carried out for a duration of 24 h with time interval of 1 h, then NDP = 24)
NS	The total number of filling stations
η_{ij}^k %	The efficiency of the 'i'th active electrolyser in the 'j'th active station in percentage
NW	The total number of wind farms placed within the network
OM	The annual operational and maintenance cost of an electrolyser in £/MW/year
OPF	Optimal Power Flow
OSZ_i	The optimal size of station 'i' in MW
P_g^k	The active power (MW) from slack bus at the time interval of 'k'
$P_{Loss_i}^k$	The amount of power loss (MW) on branch 'i' of the power system at the time interval '*k*'
$P_{Min.El}$	The minimum demand from an electrolyser to stay in active hydrogen production mode, and it is equal to the minimum demand of a station (MW)
$P_{N.El}$	The size (nominal demand) of each electrolysis unit located at each filling station (assumed to be 2 MW here)
Q_g^k	The reactive power (Mvar) from slack bus at the time interval of 'k'
S_{ij}^k	The complex power flow (MVA) between bus 'i' and 'j' of the network in the current time interval of '*k*'
$\|S_{ij}^k\|$	The apparent power (MVA) between bus 'i' and 'j' of the power system in the current time interval of '*k*'
$\|S_{ij}^{Lim}\|$	The apparent power limit (MVA) between bus 'i' and 'j' of the power system
SD_i^k	The demand (MW) from station 'i' during the current time interval of '*k*'
$\mathbf{SD}^k$	The $NS \times 1$ vector of the demand (MW) from stations during the time interval of 'k'
S_{St}	The initial size of each station (MW)
Surplus(*k*)	The surplus wind generation (MW)
S_W^i	Size of ith wind farm (MW)
t	Metric tonne
T	The simulation time interval in hours (In this work T = 1 h)
TH2P	The total hydrogen produced in metric tonne (**t**)
TLB_{Prob} %	The probability of thermal limit violations (%)
TLB_k	The function indicating whether there has been any thermal limit violation within the grid at time interval 'k'
$\mathbf{V}_m^k$	The $n_b \times 1$ vector of voltage magnitudes at the time interval of 'k'
$\|V_i^k\|$	The magnitude of voltage on bus 'i' of the power system in pu in the current time interval of '*k*'
$\|V_i^{Min}\|$	The minimum limit for the voltage magnitude on bus 'i' of the power system (pu)
$\|V_i^{Max}\|$	The maximum limit for the voltage magnitude on bus 'i' of the power system (pu)
VB_{Prob} %	The probability of voltage constraint violation (%)
VB_k	The function that indicates whether there has been any voltage violation within the grid at time interval '*k*'
W_i^k	The output of wind farm 'i' in MW at the current time step '*k*'
$\mathbf{x^k}$	The optimisation vector at the time step '*k*'

network assets [9]. The current ANM techniques are listed in [9], which also includes load control and energy storage techniques to support increasing renewable power generation.

Different storage devices have been explained and compared in details in [10–12], and their applications, advantages and drawbacks are explained in details. The benefits of energy storage devices from the Distribution Network Operator (DNO) point of view are listed below [13].

- Voltage support
- Distribution losses reduction
- Capacity support and deferral of distribution investment