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THE MULTI-OBJECTIVE OPTIMISATION OF ELECTRICAL THERMAL STORAGE TO COMPENSATE FOR THE INTERMITTENCY AND VARIABILITY OF RENEWABLE GENERATION IN DISTRIBUTION NETWORKS

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ABSTRACT

In order for the UK to successfully meet its renewable generation targets and carbon emissions reductions, identifying and utilising an effective means of energy storage is a key developmental step. One such means of energy storage is Electrical Thermal Storage (ETS). Incorporating smart ETS devices at a residential level to act as a responsive demand could greatly benefit the network.

This paper presents a methodology to optimise the size and location of ETS devices in distribution networks by using a multiple objective optimisation technique.

INTRODUCTION

The UK Government is committed to providing 15% of its energy from renewable sources by 2020 and to reducing carbon emissions by 80% by 2050 [1-2]. These commitments raise serious issues for the electrical grid. Whilst the continued connection of renewable energy technologies will assist in reaching the Government's aims, these technologies are being connected to an electrical grid that is already saturated. It is for this reason that decentralised generation has become an area of interest in solving this problem. This would see local generation connected to distribution networks to supply local loads and offer wider grid support when required.

The increased connection for renewable energy also presents a requirement for adequate energy storage technologies. Renewable generation, especially wind generation, is intermittent and variable, however energy storage would allow for situations where generation does not meet demand. This research project is investigating Electrical Thermal Storage (ETS) as a possible means of addressing this issue. The electrification of the UK's heat demand is one step being considered in an effort to make heating as low-carbon as possible [3-4].

Advantages and Disadvantages of Storage

There are many benefits that can arise from the connection of energy storage to distribution networks. These benefits can be summarised as [5]:

- Electric energy time shift
- Increase capacity
- Load following
- Area regulation
- Reserve capacity
- Voltage support
- Deferral of transmission upgrade costs

- Demand charge management
- Reliability
- Power quality
- Wind generation grid integration

There are also detrimental effects that the distribution networks may experience due to the addition of energy storage. These include voltage rise, increase in line losses, reverse power flows and the need to reinforce the network [6].

Optimal Integration of Storage

Distribution networks currently employ a "fit and forget" approach which means they are essentially passive networks. In order to accommodate the ever increasing connections of renewable generation, and developing storage technologies, distribution networks will be compelled to become more active with some demands becoming responsive and controllable [7].

In order to successfully add ETS, and all storage technologies, to distribution networks it is essential to determine the optimal integration of these devices.

However, there are also various stakeholder points of view to consider in the optimisation process. The network operator will be concerned with issues such as minimising outgoing cost, which could include network upgrading, and maximising revenue. The consumer will be concerned with quality and security of supply. Aside from this there are also network constraints, such as thermal limits and voltage limits and environmental concerns to be considered.

This problem requires a multiple objective approach to optimisation as there are many different and conflicting objectives to be taken into account in conjunction with the network constraints.

Multiple Objective Optimisation

It is possible to achieve multiple objective optimisation through a number of methods; a popular approach to take is that of a Genetic Algorithm.

The move to heuristic approaches to optimisation was the result of the inability to apply the methods used in single objective optimisation to the more complex multiple objective optimisation problems. There are several approaches available which include: simulated annealing, tabu search, ant colony search, neural networks, fuzzy programming, hybrid techniques and evolutionary algorithms [8]. Genetic algorithms have proved popular in power engineering with them being applied to many different problems and especially

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network planning problems [9-11].

Electrical Thermal Storage

In the domestic setting ETS can be in the form of space heating or hot water storage. This is one of the most cost effective means for storing energy, however it is limited in its application to areas where the devices' natural dissipation of heat can be of use. It is envisioned that the aggregated effect of domestic ETS devices in the network will allow for energy to be stored when there is an abundance of renewable generation, and at times where generation does not meet demand, the electric heating and hot water loads can be switched off from the network [7].

Hot Water Tank Model

A model of an electric hot water storage tank was created in Matlab. It was created to model the temperature inside a tank over the course of 24 hours and to show the power consumption over the course of that period. The hot water tank modelled by Elamari et al was used as a point of reference [12]. A hot water draw profile representing the average domestic daily water draw in the UK. Figure 1 shows the water draw profile [13].



Figure 1 - Average daily domestic water draw

The diagrams in Figures 2 and 3 show the temperature and power consumption characteristics over a 24 hour period respectively.



Figure 2 - Temperature of hot water tank over 24 hours



Figure 3 - Power consumption of hot water tank over 24 hours

This hot water demand model is integrated into a power network optimisation framework for evaluation.

THE MODERNE FRAMEWORK

This research project is making use of the Multiple Objective Distributed Energy Resources and Network Evaluation (MODERNE) framework. This framework was originally developed to optimise the size, type and location of distributed energy resources (DER) in distribution networks [14]. This research project has been focused around modifying the MODERNE framework in order to optimise the size and location of ETS devices. Figure 4 illustrates the main processes of the MODERNE framework and how they interact.



Figure 4 - Flowchart of MODERNE processes

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The inputs that MODERNE requires are:

- A distribution network model with loads and load profiles
- An ETS device with costs and production profiles
- A set of planning objectives such as minimise carbon emissions or minimise penetration of ETS
- A set of planning constraints such as voltage and thermal limits

The framework is modified and extended to optimise the connection and operation of ETS devices.

Case Study

To demonstrate the functionality of the MODERNE framework, two UK distribution networks were chosen for comparison: Orkney and Shetland. This provides an interesting contrast as Orkney is interconnected to the mainland, whereas the Shetland Isles are isolated. The objectives that were applied in this instance were to:

- minimise emissions
- minimise line losses
- minimise the penetration of ETS devices
- minimise imported energy

The constraints for this simulation were to stay within the network's operating thermal and voltage limits, and to reduce the overload probability of the voltage and thermal limits.

The genetic algorithm was run for 150 generations with a crossover probability of 1, mutation probability of 0.01, an initial population size of 150 and an archive size of 150. The results generated by the MODERNE framework for the Orkney and Shetland networks are displayed in Figures 5 and 6 respectively.



Figure 5 - MODERNE results for Orkney network



Figure 6 - MODERNE results for Shetland network

It can be seen from Figure 5 that in the situation of Orkney that:

- As imported energy decreases the emissions in the network decrease as more locally connected renewable energy is used
- As the penetration of ETS increases the imported energy is still varied. A new load has been introduced to the network and with the variability of renewable energy, there is still a clear requirement for interconnection to the grid
- The emissions factor is also varied as depending on the solution implemented, the more energy that is imported, the higher the emissions will be

The case for the Shetland Isles, in Figure 5, is a little different as this network is not connected to the mainland grid. Instead of minimising imported energy, the MODERNE framework aims to reduce the energy generated from fossil fuel plants. As the penetration of ETS increases the emissions reduce and the requirement for fossil fuel generation decreases.

MODERNE then assesses the renewable generation it had available and displays how ETS charging can be altered to suit the generation profile. Figure 7 illustrates an example of how the power consumed by the hot water tank can be changed to meet renewable availability.



Figure 7 - Graph showing wind dependent power consumption

Figure 7 shows the power consumed by the hot water tank, both uncontrolled and wind dependent, over a 24 hour period. When there is an abundance of wind energy the hot water tanks receive more power, and when wind is not available the tanks do not receive power. For the example 24 hours given, the times of low wind are early in the morning, in the early evening and later in the evening. The largest variation in Figure 7 is between approximately 1900 and 2200. If the hot water tank is left uncontrolled, there is a large spike in the graph. In this example there is no power available from wind generation so the power to the tank drops off.

CONCLUSION

Electrical Thermal Storage does have the potential to benefit distribution networks and renewable generation and emissions targets. It can be seen from the results generated that emissions and imported energy can be reduced by introducing ETS.

The multiple objective optimisation approach being taken is an appropriate method of assessing the impact that Electrical Thermal Storage will have on distribution networks. Multiple objectives and specific network constraints are able to be considered simultaneously ensuring that the solutions found are the most optimal.

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