MULTI-OBJECTIVE NETWORK PLANNING TOOL FOR THE OPTIMAL INTEGRATION OF ELECTRIC VEHICLES AS RESPONSIVE DEMAND AND DISPATCHABLE STORAGE

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ABSTRACT

The integration of distributed energy resources (DER) into power systems presents substantial challenges to network planners. Assessing accurately the impact that installed DER will have is critical in areas such as: control of the network within statutory and operational limits; quality of supply; losses; and financial objectives. In particular, identifying the optimal placement, capacity and operational envelope for electric vehicles (EVs) when used as a responsive demand and dispatchable storage in distribution networks is desirable for network planners. The precise operation and scheduling of one or more EVs, particularly when used as a responsive demand can have a substantial impact on the network but can also offer many benefits to multiple stakeholders and this also must be accounted for in planning and operational decisions. This work investigates the effect that the inclusion of Electric Vehicles (EVs) will have on the distribution network when used as a responsive demand and dispatchable storage. The ultimate aim of this planning approach is to offer distribution network planners low cost solutions to multi-objective problems relating to EV integration.

INTRODUCTION

Currently, the electricity industry has to meet substantial challenges in utilising the potential of renewable energy. Meeting these challenges and receiving the optimal benefit from these resources will be a significant step towards cutting carbon emissions and also in meeting the target of 15 percent of energy generated from renewables by 2020. This target is equivalent to a seven-fold increase in UK renewable energy generation from 2008 levels: the most challenging target of any EU Member State [1]. The Supergen Highly Distributed Energy Future (HiDEF) research programme seeks to address these challenges and in particular those associated with Distributed Energy Resources (DER).

To maximise benefits and minimise costs associated with the integration of DER, analysis based planning tools are required to indicate exactly where on the network controllable DER should be placed and how it should be operated. A modular and flexible planning methodology is required. This planning methodology should take into account the stochastic nature of power systems such as the fluctuations in DER production and electricity demand.

BACKGROUND

This paper presents the extension of an existing planning tool for distribution networks [2] and shows that it can analyse and inform the decision maker on the optimal integration of electric vehicles (EVs).

An extra module is added incorporating both the stochastic and controllable nature of the electricity storage capacity of electric vehicles. Influencing and managing the placement on the network of EVs will be crucial in receiving optimal benefits whilst minimising the effects that the inclusion of EVs will have at Low Voltage (LV) and Medium Voltage (MV) levels. Network configurations are represented within the outer loop investment optimisation problem to allow various network architectures to be selected to complement the DER portfolio.

Electric vehicles are added to the distribution network so that the optimisation of the siting and sizing (and scheduling in operation) of one or more EVs when used as dispatchable storage and a responsive demand can be conducted while addressing the impact on the network. This paper presents the discussion regarding how a multi-objective planning tool can analyse the integration of EV into the distribution network at LV and MV when it is used as a flexible and controllable source of storage and also as a responsive demand.

A planning model of the EV storage device, definition of operational rules and the development of the objective function are incorporated into the existing distribution network planning tool. This offers decision makers with options relating to the optimal siting, sizing and operational management of electric vehicles. Underpinning this research is a methodology based upon a multi-objective distribution planning tool that analyses and optimises the integration of EVs into the distribution network.

PROJECT MOTIVATION

The depletion of oil reserves and the increase of CO2 emissions associated with traditional combustion engines have sparked interest in the potential use of EVs as an alternative to internal combustion engines. Incentivising the use of EVs is widely seen as one of the key policy instruments to enable shifting transport energy demand from fossil fuels to the electricity sector which has greater potential to deliver low carbon energy. Electric vehicle

growth can also, consequently, assist in increasing the penetration of electricity generated from renewable sources, which is by nature intermittent and therefore challenging to power system operation.
Rising energy costs and the move towards a low-carbon economy act as drivers to develop an effective and innovative means of storing renewable energy - viable energy storage systems will lower energy prices and assist in meeting renewable energy targets. By 2015 it is estimated that 240,000 EVs will be in use in the United Kingdom; this figure is forecast to rise to 1.7million EVs on the road by 2020 [3]. The managed charging of electric vehicles and the storage capacity of EV batteries can be harnessed to counteract the problem of intermittency of certain types of renewable energy and to fully utilise and store renewable energy at times of high output.
If EVs network connection can be managed appropriately, this could actually be seen as an asset for the electricity system at distribution level. Electrical load can be shifted in time to manage the loading of the network, and stored EV battery energy could be fed back into the network under certain conditions. In addition the stored battery energy could provide backup during periods of peak energy demand, and also provide reserve, constraint management and other frequency and voltage regulation services when connected to the wider grid.

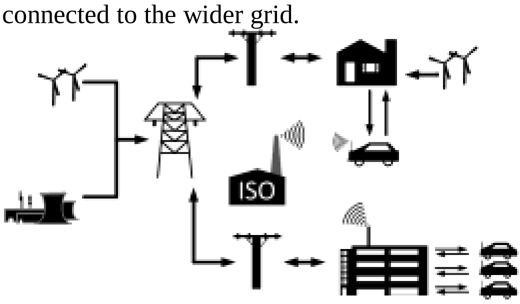

Figure 1 Future grid with V2G technology

To maximise the benefits and minimise the costs associated with the integration of EVs as a responsive demand and dispatchable storage, planning tools are required to indicate exactly where on the network this controllable EV DER should be placed and how it should be operated. This planning methodology should take into account the stochastic nature of power systems such as the fluctuations in DER production, storage and electricity demand across time periods (with timescales of hours to days being of particular interest).
The integration of EV technology on the distribution network will have dual benefits. The use of EV batteries when used as storage technique can be exploited to meet grid requirements at times of high energy consumption or other system stress. The system operator will benefit when the availability of EVs as a source of dispatchable energy storage is concurrent with times of high demand as this will enable additional load to be absorbed by coordinated control of EVs. When smart EV charging strategies are undertaken, peaks in the demand profile can be avoided and managed charging can assist in ensuring that, for example, wind energy is utilised at times of high power output.
With appropriate communication technologies delivering price signals, consumers can be informed as to time of day charge. Avoiding "dumb" charging where the EV is plugged in and fully charged at return from work – when the network peak demand is experienced currently – will also ensure that marginal plant which is fuel inefficient will not be used for generation.

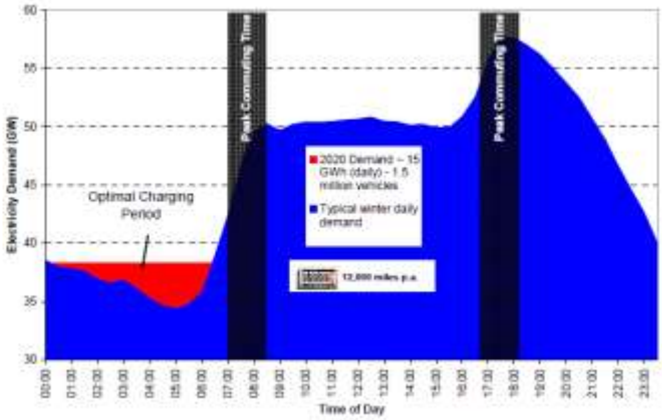

Figure 2 Matching EV charging to the current electricity demand profile [4]

NETWORK PLANNING

Network planning is essential for the optimal integration of the increasing penetration of renewable and distributed generation. As energy generation from DER increases, benefits to the network have been identified [5]:

- Improvement of voltage profile
- Reduction of distribution losses
- Reduction of transmissions losses
- Increased reliability
- Reduction of peak loads
- Reduction of carbon emissions
- Investment deferral

However, challenges presented to the network planning process as DER penetration increases can include [6]:

- Voltage rise
- Increase of line losses
- Reverse power flows, which might exceed
- Thermal limits of equipment
- Need for grid reinforcements

An effective means of energy storage will assist in mitigating the intermittency of renewable sources of generation (specifically wind) and to take advantage of responsive demands such as scheduled electric vehicle charging. There are costs associated with increased cycling of the batteries (e.g. reduced battery life and round trip efficiencies) but this cost could well be lower than the benefits from enhanced electricity usage from renewables or when electricity is sold back to the grid at times of peak demand (and therefore higher prices) [7].

Integrating high penetrations of renewable energy into the distribution network presents challenges to network operators. However, an increasing uptake of domestic electric vehicles - when used as dispatchable storage and a responsive demand – will assist in providing flexibility to the power system through the use of the inherent storage capacity and smart charging of electric vehicles. When EV operation and charging is managed correctly and scheduled smartly there are substantial benefits for multiple stakeholders including the network operator and the consumer.

PLANNING METHODOLOGY

When analysing distribution networks at LV and MV, network analysts have to take into account different stakeholder viewpoints and also the multiple and conflicting objectives that have to be reconciled (e.g. minimise costs while maximising revenue and network access) all within a set of constraints.

An effective way to approach complex, non-linear optimisation problems is to use Genetic Algorithms (GA). A Genetic Algorithm is a search method based on the principles of evolutionary theory and is the most popularly used Evolutionary Algorithm [8]. Genetic Algorithms can be used with non-differentiable objective and constraint functions and non-convex objective functions.

Strength Pareto Evolutionary Algorithm (SPEA2) is the selected technique for DER planning from the family of Multi Objective Evolutionary Algorithms (MOEA) and is based upon the principles of Genetic Algorithms. These techniques have the ability to find several solutions of the Pareto set simultaneously. MOEA are able to analyse complex objective functions and offer a "true" multi-objective approach where each objective of interest is analysed and optimised with respect to every other objective.

SPEA2 is an elitist technique that preserves good solutions by making use of a novel fitness assignment where the fitness of each individual solution is modified according to the distance to its neighbours. In doing this the technique ensures that as much of the search space as possible is explored and also that 'good' solutions are not lost but rather stored until the next iteration (generation). The focus on elitism in the SPEA2 algorithm (along with some other modifications) eliminates some of the limitations that had been recognised in SPEA [7].

It has been shown that SPEA2 is more accurate, computationally faster and outperforms other MOEA techniques in both theoretical and practical applications and is the most efficient, even in a small number of generations [9].

RESPONSIVE EV CHARGING

Responsive EV charging can meet multiple stakeholder objectives. This hypothesis will be tested by using an optimisation tool with different EV charging/scheduling methods in tandem with a generic distribution network model.

Coordinated control of EVs within a microgrid or other managed segment of the grid (e.g. control zone or cell) would provide an opportunity to optimise energy management while satisfying grid constraints [10]. The size of the desired capacity and location of storage must be optimised by evaluating cost and benefits [11]. Using appropriate communication technologies it will be possible to control EVs as storage units and to optimise charge and discharge schedules.

The current planning tool which is based upon the SPEA2 algorithm will be adapted and used to mange and schedule the (smart) charging of electric vehicles on the LV distribution network. EVs are added (to the simulated test network in blocks of ten to each node) so that the optimisation of the scheduling in operation and siting and sizing can be conducted while addressing the overall impact on the network whilst being limited by thermal and voltage constraints and also a fixed battery capacity. The precise formulation of the network planning problem can offer network planners low cost solutions to diverse planning problems that may include;

- Minimise network investment costs (by managing constraints and capping peaks in demand)
- Maximise wind energy utilisation
- Minimise losses
- Maximise renewable DER network access

The inner operational optimisation is used for every network configuration considered and at every evaluation step of the outer loop 'investment' GA to evaluate and optimise the operational parameters such as the scheduling and management of the charging process.

Different configurations of numbers and size of EVs when managed as a responsive load are represented within the outer loop investment optimisation problem to allow various network architectures to be selected to complement the decentralised energy resource portfolio. The penetration of renewable wind energy will be maximised (in balance with the other optimization objectives) with the use of electric vehicles as a responsive load in this method.

EXPECTED RESULTS

With the increased penetration of many types of DER (e.g. EV as dispatchable generation and responsive demand) network planners have to ensure that a structured and flexible planning framework is in place which is able to deal with multiple objectives and constraints which will also offer the decision maker a number of possible feasible and optimal solutions to a specific problem. The problem of integrating EVs into the distribution network and optimally scheduling the managed charging of these will be approached by extending a network planning tool that uses SPEA2 to size and site EVs on the simulated distribution network. A multi-objective planning method will obtain a set of Pareto Optimal DER and EV integrations and network configurations. For example, the existing framework will give similar result to the output below when the objectives are set to maximise DER Penetration and minimise C02 emissions. The results, shown below illustrate that the higher the level of local DER, the lower the CO2 emissions.

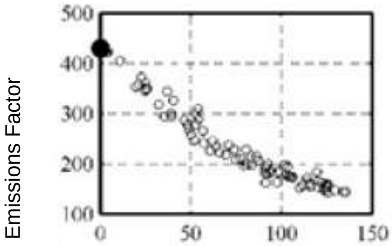

Figure 3 Output from planning tool [12]

The best charging strategies will be identified and correlations with EV availability for scheduled charging and times of high penetration of renewables will be shown and results similar to those above will be presented.

CONCLUSIONS AND FURTHER WORK

Coordinated smart charging of electric vehicles can assist in managing peaks in the demand curve and also increasing the uptake of intermittent renewables. Unmanaged EV charging at peak times will cause capacity constraints in the distribution network requiring significant investments in the capacity of the local network. If EV charging is concentrated in periods when demand would otherwise be lower then this effect on the local distribution network would be reduced. The optimal time for charging electric vehicles (dependent on the chosen objectives) may be identified and correlated to times at when wind generation availability is at its maximum and also when the demand curve is at its lowest. The use of the presented network planning tool will identify smart charging strategies of electric vehicles (based on the chosen multi objectives and with respect to constraints) which will assist in mitigating the intermittency of wind, and the accompanying benefits that this will provide. EV charging has the potential to place a significant burden on the grid unless it is managed with scheduled charging. This will assist the distribution network operator to balance demand with generation more effectively and provide the consumer with the most cost effective energy, whilst increasing the uptake of energy generated from renewable sources. The identified optimal EV charging and storage control is expected to be pushed towards test in a managed network demonstration.

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