AN ENHANCED VIRTUAL POWER PLANT FOR FLEXIBILTY SERVICES INTO A LOCAL AREA (INCLUDING EV'S)

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ABSTRACT

Aggregation by Virtual Power Plants to provide flexibility to distribution and transmission networks is seen as an important element in the transition to Net-zero. This paper presents work carried out in the SIES 2022 ERA-Net project, which is investigating in detail the possible provision of flexibility by different technologies, including EVs, but thorough a lens of different business models. Thus, presented work relies on the real use cases. The focus of this work is on the construction of grid representations to guide bidding in potential flexibility markets. It shows that without an appropriate level of detail on the wider grid connections, these bidding strategies, and therefore associated asset optimization schedules, could lead to errors. A methodology that derives EV price response curves is highlighted, with an aim to use such curves in sophisticated optimization scheduling module for further work in management of EV integration.

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INTRODUCTION

Virtual Power Plants (VPP) will form an important element in the development of a future low carbon power systems and markets, as they will ease the interactions of system operators with thousands of potential customers. Exactly how these sources of flexibility will be managed, and the economic impact on the players, is still unclear. The challenge of employing flexibility from generation, consumption and storage in the context of a VPP depends on the appropriate optimization of market access, asset characteristics and an understanding of the constraints on the wider distribution system.

One of the partners in the SIES 2022 ERA-Net consortium is the Engineering Technical Centre in Central Scotland (ETC), which has been set up to deliver a technology demonstrator system to manage energy pools using VPP software as well as to investigate how this VPP could operate using a variety of assets in a realistic setting. ETC has interests in two energy pools which are available for immediate deployment in the project:

- ETC's own premises and the wider Scottish Enterprise Technology Park energy infrastructure
- A test area at the Myres Hill wind turbine site

The sites include both electrical and thermal loads, that can be used for flexibility as well as other consumers, including a EV charging point, in the area. The paper will outline development of a wider distribution grid model around the use-case site to identify dynamic export and import limits that can affect the ability of the site to provide flexibility to both the local area and beyond. The paper will focus on the grid associated with the technology park, although in the longer-term grid models with multiple sites will be considered. The addition of a new charging station close to the use case site is also considered.

Furthermore, access to appropriate markets to generate revenues is important to a successful EV integration and implementation. In that sense, consideration of dynamic nodal prices within the simulation allows a more realistic and sophisticated modelling of the interaction of assets with the wider market, whilst respecting distribution system constraints. The most relevant simulation results are reported for the ETC use-case (technology park), using two representations of the same site, with one having more detail than the other. Finally, using the more detailed representation of the associated grid, bidding price response curves for a potential EV fleet are derived.

CREATING A DIGITAL TWIN MODEL OF THE ETC ASSETS

While there are many papers detailing the optimization of markets, demand side response etc., few take account of the limitations and the interaction between the power grids to which they are connected. Reference [1] recognises that is important to model such constraints and interactions and uses a co-simulation environment (PandaPower (PP) [2] and Modelica [3]) to model the connection of a hydrogen plant to a nearby grid. PandaPower is used to model the grid and Modelica to model the electrolyser plant dynamics. The grid model in [1] is a relatively simple one, while other work detailing EV optimisation strategies use IEEE test cases. It is known from other work that issues at one location can affect another many miles away, with this impact location and time-of-year dependant since embedded renewable generation/demand in the area will be variable.

In the case of the SIES 2022 project use-case studies associated with ETC, the distribution network around these locations is highly congested. This represents both an opportunity and a threat. Conventionally, the Distribution Network Operator (DNO) keeps it systems secure by imposing "worst case" limitations on export volumes. However, by managing and coordinating loads and generation using a Virtual Power Plant (VPP), value can be extracted by overcoming issues with congestion in these areas. Additionally, the distribution company and the Transmission System Operator (TSO) may be willing to pay for system support resulting in either a delay or the negation of transmission/distribution upgrades, or replacement of ancillary services provided at the transmission level.

As part of the SIES 2022 project a digital twin-of the power grid has, therefore, been constructed to enable the team to simulate the use-case grid connections and its impact on the wider network. In addition, it allows us to better understand the ability of the use-case to extract value using VPP concepts. This has necessitated the collection of several of pieces of data including but not limited to the following:

- Distribution Connections, including Transformers, lines loads, Cable data and, in this instance, embedded generation at the 33/11 KV levels. In other areas different voltage levels may be required.
- Use-case asset details including active and reactive power, max/ min short circuit currents etc.
- Cost data where appropriate. This is required so that an Optimal Power Flow (OPF) calculation can be carried out, as discussed below. This process also included verification and validation.

Approach to Distribution Grid Modelling (Digital Twin)

Model of the local area grid network has been developed using PandaPower [2], so that it can be linked to other models associated with the analysis of the use-cases, so to ascertain the value of a VPP, while considering constraints on the electrical system. Initially a simplified model of the ETC use-case assuming infinite Grid Supply Points (GSP's) was created using a combination of data from heat maps and data specification sheets, together with the graphical user interface in the GridCal software [4] (as shown in Figure 1). This included the modelling of 11 KV connections using generic cable data.

AC Optimal Power Flow (OPF)

Although a power flow calculation can be run on a model of a network negating the need for cost data on generation and demands, differences in line and transformer loadings can be significantly different in a real dispatch world. In the case of the power flow methodology, flows occur to reduce losses, but OPF, looks to minimise system costs under power flow constraints. In the Australian and some of the USA power markets e.g. PJM, centralised dispatch uses OPF (includes generators bids, volumes and price, etc.) to dispatch generation and demand to minimise costs. Although the UK wholesale markets now uses a system of self-dispatch, application of an AC OPF calculation at the distribution level can be useful if determining an accurate calculation of distribution power flow loadings is required, and operational and coordination decisions for devices providing flexibility needs to include network constraints.

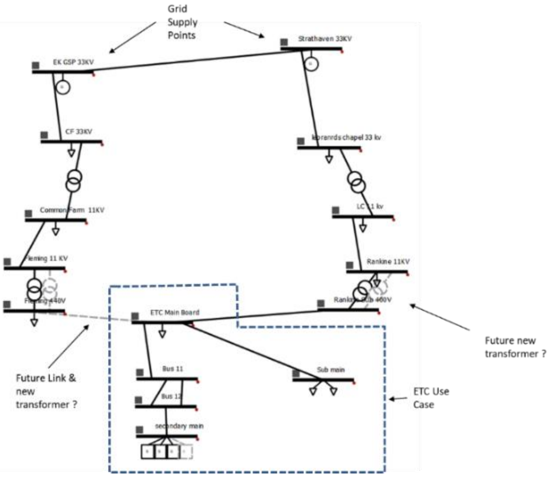


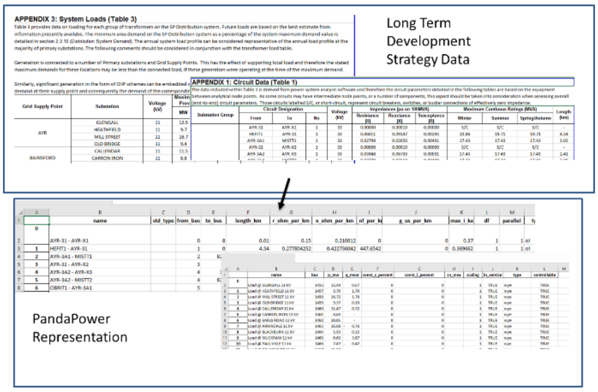
Figure 1: Simple grid model of ETC at Scottish Enterprise Technology Park

DATA REQUIREMENTS FOR MORE SOPHISTICATED GRID MODEL

To perform an accurate simulation through time so that export/import limits (and nodal prices) can be determined, hour by hour data on loads, generation and costs must be provided. Some of this is available and others must be derived from a multitude of sources.

DNO Long-Term Development Strategy Document (LTDS)

UK DNO's are required to provide a long-term development strategy document, as well as associated data that provides forecasts of loads (maximum and minimum levels), details on embedded generation (single value), line data and transformers on their network. Data on substations, circuits etc. provided in such spreadsheets have been translated and prepared for input formats that can be import to the PandaPower software (Figure 2).


APPENDIX 3: System Loads (Table 3)

APPENDIX 1: Circuit Data (Table 1)

Figure 2: Conversion of Long Term Development Strategy (LTDS) data into PandaPower format

Fuel Cost Data: A Driver of Marginal Prices

In general, to simulate a market clearing using an OPF formulation which includes grid constraints and seeks to minimize cost of operation, requires estimates of the so called fuel cost curves, which typically uses a quadratic formulation. Using historical construction cost data and other databases (IEA [5] and NREL [6]), costs for different types of generic power generation units can be found. Analysis of such data allows us to formulate regression equations that take account of the costs of the unit by size. Operating costs as a function of CPX or load factor have also been developed. These costs are typically quoted in real terms for a particular year e.g. 2022. Costs of unit constructed in 2010 are typically more expensive than those constructed later so all costs are adjusted into real 2022 terms using inflation indices.

Load Data at Substations

A methodology has been constructed to estimate load variability through time using a variety of databases based on postcodes by volume, by customer type. Using typical profiles for customer types and min/max volumes in the LTDS documents at substations, allows us to estimate sub-station profiles using a linear optimisation technique to fit data to known data points.

Embedded Generation Profiles

Embedded generation is typically renewable based and therefore generation output will be location dependent and stochastic. The LTDS documents provide the max output values from each of the embedded generation assets but do not provide hourly profiles. Fortunately, databases like Renewables Ninja [7] provide specific locational power output data. Data can be download for specific locations for different asset types and can be sized for the asset. Fuel cost curves are estimated for the associated embedded generation using the same method described above. Discrete data from 2019 is currently being used in the modelling but the databases would allow for an analysis on a stochastic basis. By combining such data with LTDS data it has been possible to synthesize embedded generation profiles through time.

COMPLEX AND SIMPLE REPRESNTATIONS OF THE ETC GRID

Figure 3 and Table 1 summarise the representation of ETC (Technology Park) under a simple and a more detailed or complex representation. The output from a PandaPower power flow has been used to represent the grid structure (line loadings. are graded using colouring). Note that the Grid Supply Points in the simpler representation are connected to a large generator representing the UK transmission grid.

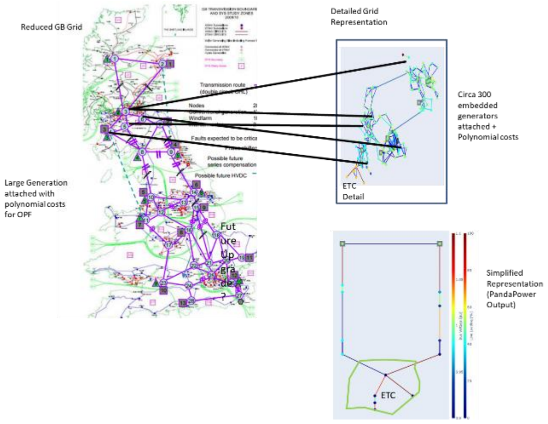


Figure 3: PandaPower representations at two levels of detail

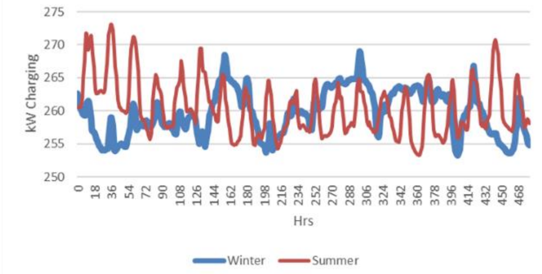
	Loads	Gens	Lines	Trafo	Buses
Complex	31	22	68	48	94
“Simple”	21	5	18	11	28

Table 1: ETC grid characteristics. Number of elements

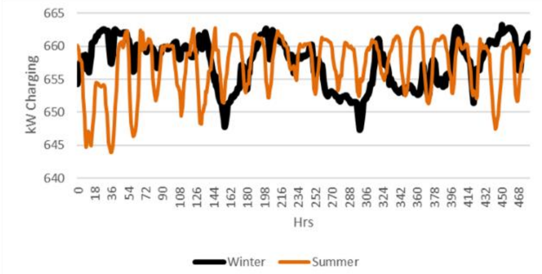
In the case of the more complex network, additional detail is provided as it includes more embedded generation and loads modelled. In addition, use of the “reduced” GB transmission model originally developed in the University of Strathclyde [8] has been connected to the distribution grid in the complex model at the appropriate points. These networks are used in the simulations presented below.

DYNAMIC LIMITS

The creation of a network model for the use-case assets using controllable EV assets and optimising generation levels allows for the estimation of maximum export and import levels (discharging/charging) to the ETC site for EV use. Figure 4 shows these levels for 20 days (480 hours) for days in January(winter) and June (summer).



(a) Maximum Charging Capacity



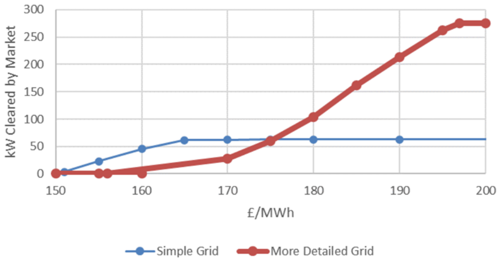
(b) Maximum Discharge Capacity

Figure 4: Max import and export power flows for EV Fleet

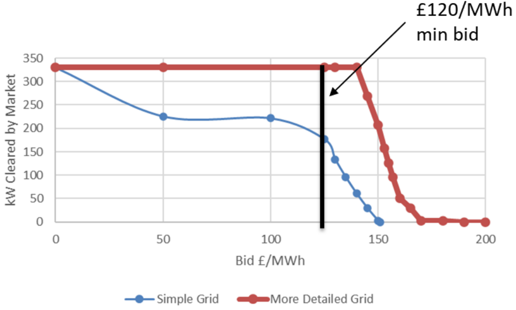
This provides an important input into any optimal scheduling algorithm to be used by a VPP, but this does not tell the whole story, as EV bid prices are ignored.

EV BID STRATGEY

Work in [9] provides an analysis of the effects of forecasting day ahead prices in a flexibility balancing market using DC optimal flow on an IEEE 30 bus. Their work shows how discharge patterns change with bid prices based on different market price forecasts for one day, however, that analysis does not highlight in detail how bid price affects cleared EV volumes (bid response). We have extended this work using a minimum price of £120/MWh for battery replacement and, as a first step, used nodal prices as a surrogate for market prices. EV's are represented as pseudo generators (discharge) and loads (charge). EV bid prices are represented in the model as a fixed £/Mwh value. Figure 5 shows the results from a one period simulation using maximum generation values and load values as provided for in the LTDS document. It also illustrates for a variety of bid prices for a charging/ discharging case for the two representations of the grid. Energy Volumes (MW) are limited by constraints at the ETC site and beyond.



(a) Accepted volumes Vs bid-price curve -charging

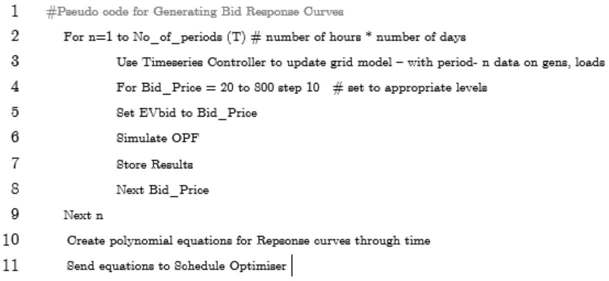


(b) Accepted volumes Vs bid-price curve -discharging

Figure 5: EV price response curves for two grid representations of the ETC use-case

It is clear from Figure 5 that even though the two grid models represent what is essentially the same site, the price response curves are very different. The key question then is to what level of detail should one model the wider area grid.

By extending the analysis to include price bids through time (see Figure 6) it would be possible to create price response functions that could then be passed to a more detailed optimisation routine.



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#Pseudo code for Generating Bid Response Curves
    For n=1 to No_of_periods (T) # number of hours * number of days
            Use Timeseries Controller to update grid model – with period- n data on gens, loads
            For Bid_Price = 20 to 800 step 10   # set to appropriate levels
            Set EVbid to Bid_Price
            Simulate OPF
            Store Results
            Next Bid_Price
    Next n
    Create polynomial equations for Repsonse curves through time
    Send equations to Schedule Optimiser
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Figure 6: Pseudo code; Price response curves through time

Essentially price response curves like those shown in Figure 7 would be created.

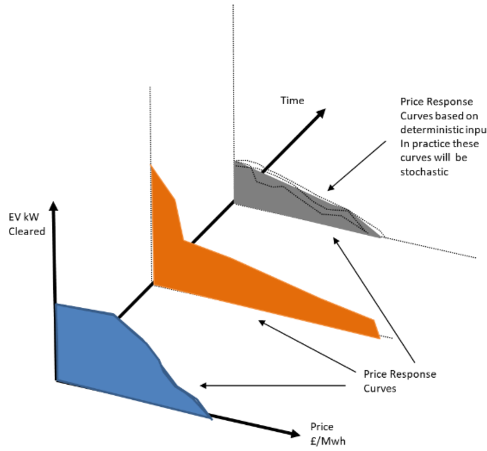

Figure 7: Hypothetical price response curves through time

Although bid price has been used to optimise EV dispatch, the AC OPF methodology allows the EV loads to be fixed and will produce marginal prices at the appropriate buses. This would be representative of a case where EV fleet schedules are fixed. In this case the simulation of nodal prices would represent the price at which a bid would be made to achieve such volumes. For brevity only the discharge curve is shown. Figure 8 shows simulation results for 20 days during summer and winter conditions at ETC for various discharge outputs.

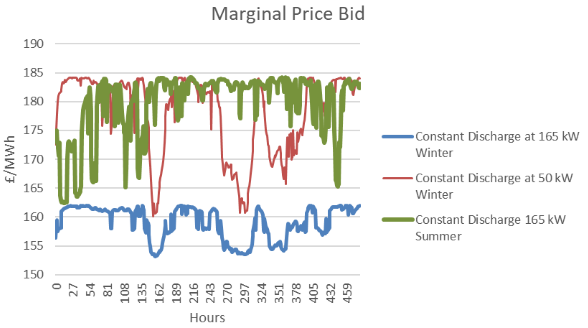

Figure 8: Nodal price at EV bus under different conditions

It is important to note that as a first step, the analysis is based on nodal prices using theoretical marginal generation costs. The current UK market is not nodal so an important next step in the work is to reconcile actual market bidding behaviour, with the simulated outcomes, and to calibrate the model as necessary. Flexibility providers are also able to provide flexibility to transmission operators or to the DSO, and here presented models created allow us to analyse the impacts on the DSO and transmission operator.

CONCLUSIONS

Using a learning by doing approach, an AC OPF, simulation of assets connected to a real distribution network has been constructed with the aim of using the said digital twin in the optimisation and scheduling of assets (demand side response, EV charging and discharging, thermal loads and generation). This has required the creation or synthesis of appropriate data sets.

Using different representations of the grid an investigation into the bidding response (price vs cleared volumes) has been carried out and will be used in detailed optimisation schedule algorithms for the assets. It is clear that simpler representations of the grid could result in large errors in simulations of price values and volumes cleared.

Acknowledgments

The SIES 2022 project has received funding from the ERA Learn /European Union’s Horizon 2020 research and innovation program under grant agreement No 811171.

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