OPTIMISING VIRTUAL POWER PLANT RESPONSE TO GRID SERVICE REQUESTS AT NEWCASTLE SCIENCE CENTRAL BY COORDINATING MULTIPLE FLEXIBLE ASSETS

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ABSTRACT

Newcastle Science Central is introduced; a 24 acre city centre site being developed as an exemplar sustainable urban environment encompassing Smart Grid technologies throughout. A real time energy management algorithm is proposed to maximise the power availability of the site's flexible electrical assets; all of which have different operating characteristics. Each asset is considered in an equivalent form similar to energy storage, allowing it to be compared on a like-for-like basis through a virtual state of charge. The new Enhanced Frequency Response service offered by National Grid is used as a case study to demonstrate that through intelligent energy management, the site operated as a virtual power plant, can deliver greater value than the sum of the constituent assets operating individually to the same overall control signal.

INTRODUCTION

The UK is targeting reduced carbon emissions of 80% of 1990 levels by 2050 [1]. The electrical generation industry has responded by transitioning to renewables, which accounts for 77% of all new power plant installations in Europe [2]. Distributed renewable generation typically has a variable output and is connected at lower voltages closer to the load than traditional dispatchable centralized generation. At high penetrations, the variability of these renewables can cause network issues that must be managed [3] and microgrids have been suggested as a facilitating technology to help integrate many small distributed generators into electrical networks [4].

This paper describes the services that could be delivered to the grid by a microgrid operating as a Virtual Power Plant (VPP) [5]. An exemplar microgrid, Science Central, being built in Newcastle city centre, UK, is introduced, before a control scheme designed to maximize the availability for providing services is described and demonstrated.

VIRTUAL POWER PLANT SERVICES

A VPP can deliver different services to the grid including; peak shaving or capacity management [6], voltage support [7], Enhanced Frequency Response (EFR) and Firm Frequency Response (FFR) [8], Short-Term Operating Reserve (STOR) [8], capacity market [9] and tolling [10]. This paper considers a VPP response to the EFR service. EFR is a new market to help maintain system frequency and will start operating Winter 2017/18. The required response is dependent upon system frequency, as shown in Figure 1. The service will allow an envelope of deviation from the set point curve, widening around the normal operating frequency. This is designed to enable State Of Charge (SOC) management, however the magnitude of this range is still to be determined by National Grid. The output must be delivered within 1 s of being called, and support the grid for at least 9 s until the primary FFR service can take over.

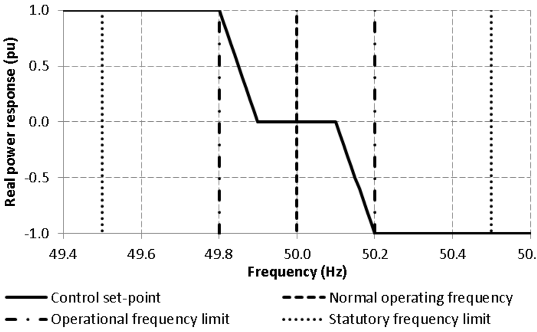

Figure 1: Service requirements for Enhanced Frequency Response [8]

PLANT DESCRIPTION : SCIENCE CENTRAL

Newcastle University and Newcastle City Council, are collaborating to redevelop a 24 acre city centre brownfield site to be an exemplar sustainable urban environment encompassing Smart Grid technologies throughout [11]. Electrically, the site will contain an Energy Storage System (ESS) [12], an Electric Vehicle (EV) charging station, a Combined Heat and Power (CHP) plant, Photovoltaic (PV) generation and both residential and commercial buildings with the potential to provide Demand Side Response DSR [11]. The proposed electrical distribution of the site is shown in Figure 2.

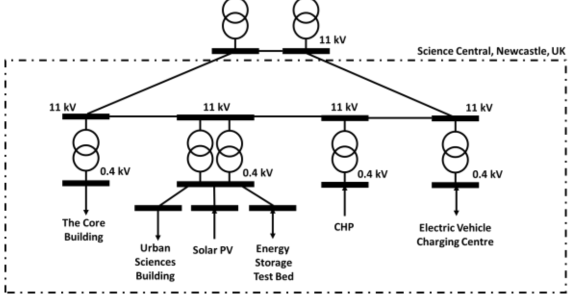

Figure 2: Proposed electrical distribution of phase 1 of Science Central, Newcastle, UK

There is considerable choice in how to control each of these flexible assets in order to provide services to the grid at the point of connection whilst also providing value to the various stakeholders on the site. The characteristics of each is described below and summarized in Table 1.

Energy storage

The ESS will be built to allow different cell chemistries to be evaluated in response to real grid disturbances and new control algorithms. The inverter is rated at 360 kVA, and is assumed to have a storage capacity of 100 kWh.

Combined Heat and Power

A gas turbine CHP plant will be built with an electrical rating of 2000 kW and heat rating of 6000 kW. Since the gas will be supplied via the national gas networks, it is assumed that this power can be supplied at all times. The heat generated will supply a heat network on the site which is not the subject of this paper.

Electric vehicle charging station

The site is to have six rapid EV chargers, and it is possible that adjacent to these will be a smart EV charging station. For the purpose of this study, it is assumed that an average of 45 EVs arrive for smart charging each day with a standard deviation of 3 cars. The EVs arrive at 09:00 and leave at 18:00 with a standard deviation of 1.2 hours. Each charge point is rated for 7 kW demand, and 3 kW vehicle to grid. The EVs are assumed to each have a battery of 24 kWh, which arrives with an average SOC of 53% with a standard distribution of 15% [13]. On departure the vehicles are assumed to leave with a SOC of between 80% and 100%. Using these statistical distributions, a Monte-Carlo study was undertaken to find the maximum aggregate power and energy limits that could be realised from the smart charging EV fleet. Using the ideas presented in [14], [15] and [16], it is assumed that an algorithm could exist to allow full flexibility within the aggregate power and energy curves presented in Figure 3, which is based on the 5th and 95th percentiles for maximum and minimum curves respectively. The EVs in aggregate can therefore be imagined similar to an ESS with dynamic power and energy ratings.

Building demand side management

As the site progresses, numerous commercial and residential buildings will be erected to include Heating, Ventilation and Air Conditioning (HVAC) DSR capabilities. The first building already on site is The Core, and the second building currently under construction is the Urban Sciences Building (USB).

Both buildings are to be heated using electrical pumps and the site heat network. A MATLAB Simulink model has been built for both buildings allowing the temperature feedback from DSR calls to be estimated. It was assumed the air condition deteriation takes place at the same rate as the heat energy dissipates to the external atmophere.

For the purposes of this study, it was assumed that the Core needs 31 kW and the USB needs 240 kW to maintain a constant temperature and air condition, based on an engineering judgement that HVAC DSR can achieve up to 33% reduction in a buildings demand [17]. The minimum power for each building was set to 0 kW (representing an effective generating power of 31 kW and 240 kW respectively). The maximum power demand was set to 70 kW for the Core and 500 kW for the USB. For an allowable temperature variation of 4°C, the model estimated the Core and USB to have an effective storage capacity of 9 kWh and 23 kWh respectively.

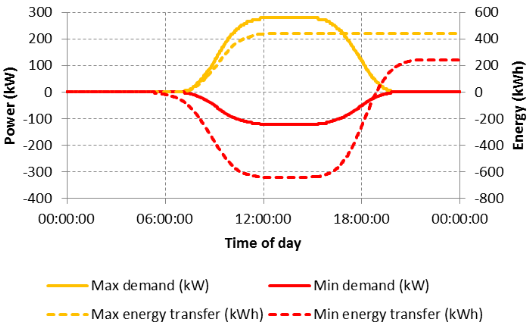

Figure 3: Dynamic time of day Power and Energy ratings of a smart EV charging station

Table 1 Summary of flexible asset characteristics

	POWER (kW)			ENERGY CAPACITY (kWh)	TIME TO CHARGE 0% TO 100% SOC (Minutes)
	Min	Power to maintain constant VSOC	Max		
Energy storage	-360	0	360	100	17
CHP	0	-	2000	-	-
EV Charging (at 12.00)	-120	0	280	1077	231
The Core DSR	0	31	70	9	14
USB DSR	0	240	500	69	16
Aggregation of whole site (at 12.00)	-480	271	3210	1255	-

SKOLTECH CAMPUS [18]

The Skolkovo Institute of Science and Technology (Skoltech), Russia, are also developing a new campus similar to Science Central, hence the collaboration between Newcastle and Skoltech for this paper. The new campus is expected to accomodate 2,772 people over 133,000 m^2 of floor space by 2020.

PLANT CONTROL

The EFR service requires full requested output to be delivered for at least 9 seconds with just one second of notice. Despite this short duration, National Grid's initial analysis of frequency data indicates that the optimal battery capacity is that which corresponds to a 45 minute duration (0%-100%)[8]. It can be seen in Table 1 that only the EVs, which are not available at all times, have a duration above this. All the other assets have a duration significantly below 45 minutes. A control scheme has been developed to combine the high power ratings of the DSR and ESS with the high energy rating of the EVs, through intelligent energy management to ensure that the aggregate maximum power of the site is realisable, with little to no notice. The control scheme is designed to be scalable such that any flexible asset can be utilised. Each asset is considered in a form similar to ESS and the equivelent Virtual State of Charge (VSOC) is used as a common currency across the different types of assets with varying characteristics, that could otherwise be difficult to compare like for like.

In order to realise a power request, an asset must have energy available within its storage. By targeting 50% VSOC, an asset without any prior knowledge of the service can maximise the amount of time a power request can be delivered for. During the service however, the VSOC will deviate from 50% at varying rates for each asset dependent upon their power and energy ratings. To maximise the power availability, all assets should approach their energy capacity limits at the same time. To implement these ideas, the time each asset can deliver maximum (positive or negative) power for is considered. The asset that can deliver for the longest period of time is used primarily for its energy and no target VSOC is set. All other assets are used primarily for their power and assigned a 50% VSOC target, unless the energy asset is approaching its VSOC limits in which case the energy of these assets is needed. In this situation, the power assets are assigned a VSOC target that would result in reaching their VSOC limit at the same time as the energy asset.

A single fuzzy logic control surface is used mulitple times, once for each asset as shown in the block diagram of Figure 4. Fuzzy logic allows multiple variables to be considered at once, similarly to human thinking, and an intelligent decision to be made [19]. In this implementation, it ensures the overall requested microgrid power is delivered whilst managing the internal energy of individual assets to be as close as possible to their respective SOC targets. Each controller has three inputs :

- **Output power** – the output of the asset's fuzzy logic controller is fed back as a reference signal to be increased or decreased based on the error and SOC difference.
- **Error** – the power outputs of all assets are summated and compared against the total microgrid desired power output. The resulting error is fed into all fuzzy logic controllers.
- **SOC difference** – the difference between an assets SOC and its target SOC.

Fuzzy logic rules were created to prioritise the reduction of the error so the correct power output is delivered. At high power requests the error is picked up faster or slower depending on the SOC difference. When the power request and error are both low, the rules try to reduce the SOC difference. Therefore, a secondary control brings all assets towards their target VSOC if possible. The 4-dimensional control surface, with axes in per unit, is shown in the three 3-dimensional figures of Figure 5.

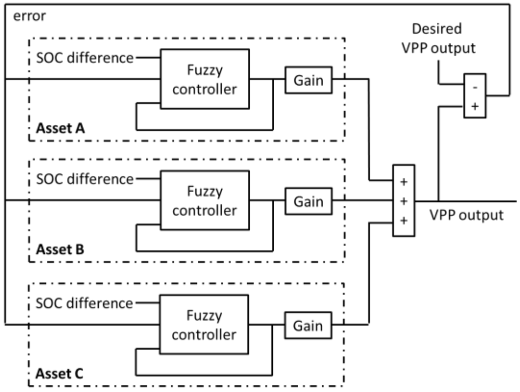

Figure 4: Block diagram of the scalable fuzzy logic based control

CASE STUDY RESULTS AND DISCUSSION

In order for potential EFR providers to demonstrate their offering, National Grid has published system frequency data at a one second resolution. One representative day has been simulated using this data, in conjunction with Figure 1 and the proposed control algorithm.

The distribution of the VPPs real power output dependent upon frequency, one second after each control set-point is given, is shown in Figure 6.

The aggregate load of the VPPs flexible assets is shown in Figure 7 along with each assets VSOC. The same study was undertaken without managing the VSOC of the assets, shown in Figure 8. During the day of simulation there was 11 minutes when a service could not be realised, during which the service was requested for 5 minutes. The deadband of Figure 1 could have been used to ensure VSOC when the assets are operating individually and without coordination, however with the proposed algorithm this is not required meaning the deadband could be used to layer other commercial services, thus increasing revenues. Furthermore, it can be observed in Figure 7 that the VSOC for the ESS, Core and USB remain close to

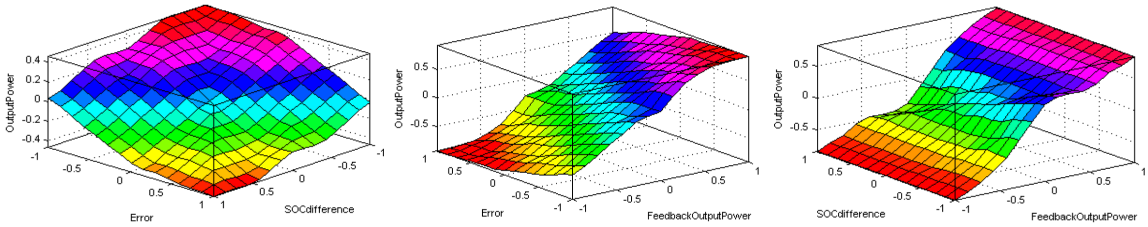

Figure 5: Fuzzy logic control surface (all axes per unit)

50% with a relatively large headroom of storage capacity unutilised. This suggests that by using the proposed control algorithm either; the storage capacities could be minimised reducing initial capital expenditure, or power ratings increased maximising potential EFR revenues.

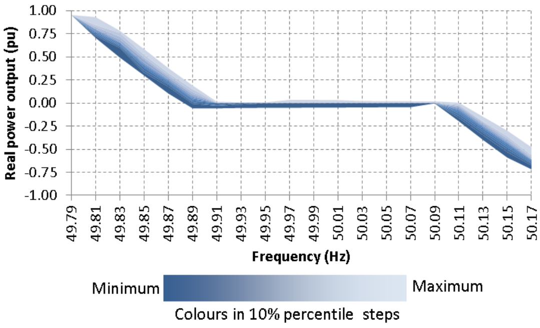

Figure 6: Distribution of realized service delivery one second after its request, dependent upon frequency, for the simulation day

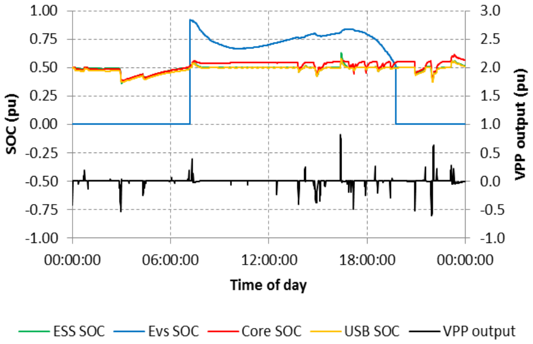

Figure 7: Aggregate load of the VPPs flexible assets and their SOC

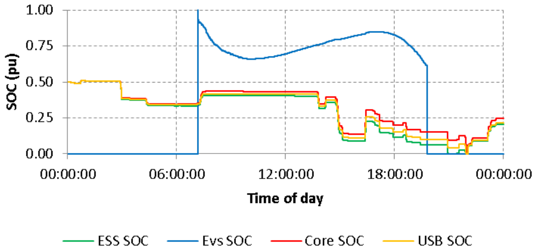

Figure 8: SOC of assets delivering the service without coordination

The proposed algorithm successfully maximizes power availability, however it does this without considering the economical or environmental costs associated with the use of each of the assets. Incorporating these attributes to find a good compromise between availability, economic and environmental cost is the subject of future work.

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