BUSINESS MODELS FOR VIRTUAL POWER PLANTS AND THEIR IMPACT ON ECONOMIC OPERATION

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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 but thorough a lens of different business models. Thus, presented work relies on the real use cases and associated data. The focus of this work is on the value of different business models associated with a demonstrator plant in East Kilbride Scotland. Using an adapted business model structure with three strategic dimensions, along with a risk/reward portfolio framework, an illustrative case study is used to highlight the business model choices available to a small VPP owner.

INTRODUCTION

One of the partners in the SIES 2022 ERA-Net consortium is the Engineering Technology Centre in Central Scotland (ETC), which has been set up to deliver a technology demonstrator system to manage energy pools using Virtual Power Plant (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 loads in nearby buildings, and includes a 178kWh Delta battery, solar (PV), wind turbines and is connected to the distribution network. The paper proposes a framework for assessing business models using "strategic dimensions" and provides an illustrated case study using this framework for some combinations of assets and markets at ETC.

BUSINESS MODELS

The Cambridge dictionary defines a business model as "a description of the different parts of a business or organization showing how they will work together successfully to make money". Zott, Amit and Massa [1] review business model approaches and find that there is a multitude of approaches using methods such textual, verbal, and ad-hoc graphical representations. There are a multitude of definitions of what a business model is and the term "business model is used with different meanings ... partly because of the absence of consensus on the definition of a business model and partly because of the different contexts in which the term is used" [2]. A common formulation of the term is as a description of the way a firm does business at the strategic level [3](p. 14)".

Value chain analysis is still a sound model for identifying market opportunities and competitive differentiation. Originally developed by Porter [4] in 1985, it is still widely used in many corporate settings although Porters original framework has been modified or are used in conjunction with other methods. Osterwalder [5, 6], developed a comprehensive template on which to construct business models. The nine-part "business model canvas" is essentially a way to lay out assumptions on key resources and key activities in the value chain of the business, but includes customer relationships, channels, customer segments, cost structures, business partners, revenue streams and the value proposition.

It is important to recognize that value will ebb and flow over time, it will move from one part of the value chain to another. How fast it moves will depend upon competition between entities and the dynamics present in the market. Different business models will fare better than others at different times as the dynamics of the market change both in terms of customer mix, volumes and prices [7]. Johnson [8], like many authors in this research area, provides a list of analogies based on experiences [7]. Slywotzky and Morrison [9] analyse profitable companies and also look for patterns in those companies and the industries they operate in. They develop 22 profitability models that they characterise using three dimensions (strategic, operational and organizational) with many more sub dimensions below each dimension category.

Current aggregation/VPP business models [10-12] in the sector are relatively straightforward typically using a margin based fee model, however, it is reasonable to expect that business models will inevitably evolve over time.

VPP BUSINESS MODELLING APPROACHES

Although there is a multitude of different business model approaches, they each provide a different set of lenses in which to view a particular Industry. Using a combination of these approaches, a multidimensional model (Figure 1a) based on exhibit A1.2 in [9] has been derived to consider the types of business model that an aggregator/VPP business model could follow.

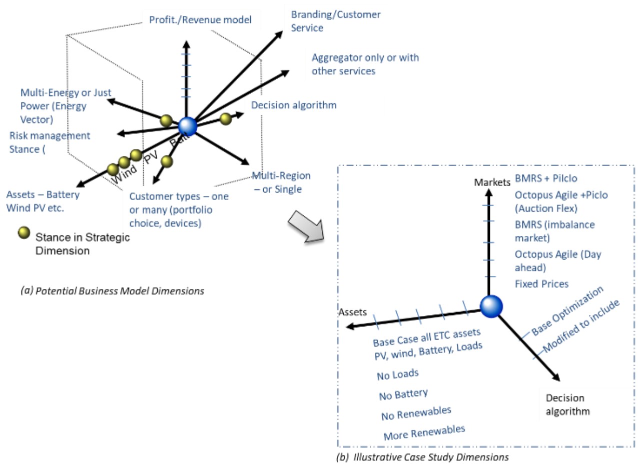

Figure 1: Multi-dimensional business model framework

The model dimensions include:

- Geography (aggregators may operate across different geographical location)
- Energy vectors (selling across power, gas and heat sectors)
- Optimization algorithms, simple myopic or heuristic approach
- Different revenue generation models (which would include contract types, price levels, contract lengths and so on)
- Risk management stance – e.g. fully hedged to minimize downside risks or with no risk management at all.

The selection of elements along the various strategic dimensions constitutes what defines a business model. The use cases on the SIES project will fit along many of these axes, although the current ETC demonstrator and the illustrative case study that is presented later focusses on just three dimensions (Figure 1b). The SIES 2022 project does include assets in different geographical locations, but these will be ignored in the analysis. Ultimately asset choice, the contract structure, the decision algorithm and available route to market will affect the value proposition and enable a comparison between different business models.

The ETC demonstrator site has many different assets including a flow battery, a 178kWh Delta Li-ion Battery charger, a heat pump, thermal store, and variable electrical loads. For this illustrative case study we are going to concentrate on the interactions with the Li-Ion battery, the small Wind and PV units and the loads at two industrial buildings (one is associated with ETC; see Figure 2). The wind (10kW) and PV (12 kW) units can be used to supply the loads (min: 1.5kW, max: 59 kW, with additional spikes of 80kW), charge the battery or can be exported to the grid. Imports from the grid can also be used to charge the battery and supply the loads. Lastly, the battery can be used to supply the loads or export to the grid.

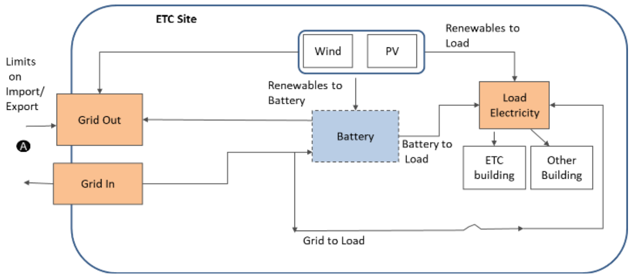

Figure 2: Illustrative case study using assets in ETC

SIMULATION APPROACH

Using an approach set out in references[13,14], a Pyomo [15] optimisation model of Figure 2 has been constructed in Python. A VPP simulator built for the project based on the PyEMLab framework/EMLab [16, 17] has been used to generate the results and includes the Pyomo model as well as other decision-making algorithms. This case study will focus on the results with just one base algorithm; a modified model predictive control algorithm presented in [13]. This a look-ahead optimisation of the various assets assuming perfect foresight. In practice, inputs would be stochastic so an approach using stochastic programming would be preferred, but would increase computational complexity. The simulation process is shown in Figure 3.

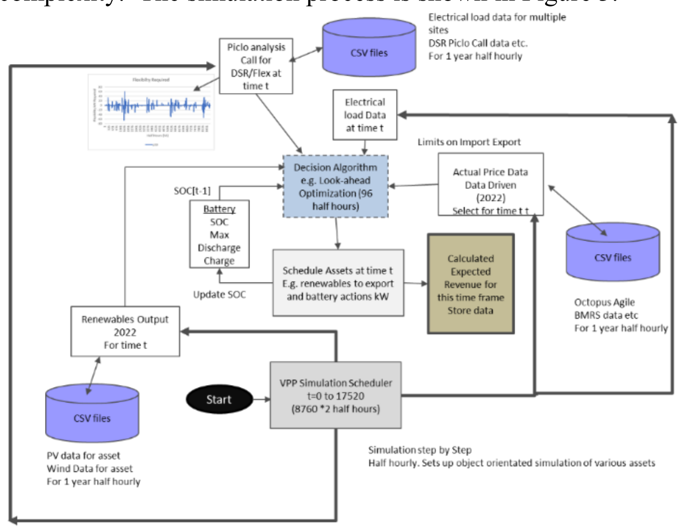

Figure 3: Simulation process

Actual data from assets have been used in the simulation along with prices from various UK flexibility markets in 2022. The market data is stored in CSV files in half hours. The VPP simulator uses a scheduler to step through the half hours, running it for one year data. It takes relevant prices from a variety of markets. A battery digital twin model is included in the simulation that allows for the state of charge of the battery to be passed to the optimisation module step by step. The module uses these inputs with a look-ahead horizon of 96 half-hours. The optimisation algorithm therefore takes account of the impact of decisions made now, on future decisions. The optimisation maximises the net revenues seen by the case. Net revenues are defined as:

$$Net\,Revenues = \sum_{t=0}^{horizon} (Sellprice_t * \text{Export}_t - Buyprice_t * import_t) \qquad 1$$

Where horizon in this instance = 96 half hours

Results for the immediate half-hour are stored and have been used to generate the graphical results seen in the portfolio approach section below.

ROUTES TO MARKET

The UK provides many routes to market for the sale and import of electricity. The currently envisaged markets are summarised in Table 1. It should be noted that these flexibility markets are currently evolving. It is expected that future markets for flexibility would become more localized and potentially more volatile. One interesting development in the UK is the Piclo auction for DNO flexibility (see entry in Table 1). Auctions are carried out half yearly/yearly for flexibility at certain locations on the grid. ETC is currently not participating in this market, as there are no such markets available for this part of the network. Making some assumptions about future EV use and grid demand, we have used the grid based digital twin discussed in reference [18] to model potential calls for flexibility response, and modified the optimisation model to dispatch energy to the DSO as required. This reduces the potential exports/imports to the grid. Hypothetical calls by the DNO on the ETC site to provide flexibility via a Piclo auction type contact are shown in Figure 4.

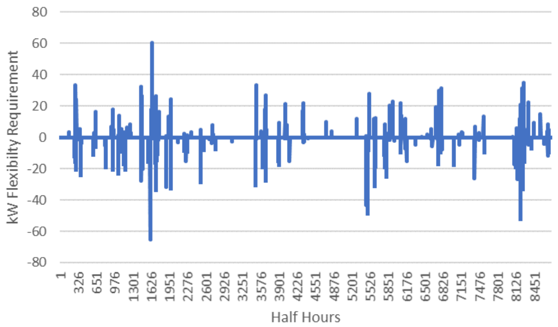

Figure 4: DNO Call for Flexibility

Market	Type	Comment	Reference
Fixed Price PPA	Fixed Prices	Typically agreed contract price for sales and imports. Fixed price over year	
Octopus GO	Off Peak On Peak Pricing		[20]
Octopus Agile	Dynamic Tariff eg based on Day ahead wholesale prices		[21]
BMRS	Imbalance market price -UK wide	UK wide market	[22]
Piclo	Flexibility Auctions usually for flexibiloty at bthe distribution level	DNO/DSO Calls for agreed standby services at price set during one of Piclo's competetions	[23]
Firm Frquency Response FFR	Short term dispatch or reduction of power to stabilise overall system frequency. UK ISO provides dispatch signals to providers	Provision to wider UK grid	[24]

Table 1: Summary of routes to market in UK

VPP owners would be able to mix and match output to these various markets, but this is not considered in this paper. In practice, many of these markets would not be available to VPP owners. ETC for example cannot currently sell to the BMRS imbalance market because its output is too small. However, the BMRS does provide one of the few sources of real data on the price movements of a potential flexibility market and has therefore been used in this capacity. We are ignoring this commercial constraint in this illustrative case study.

PORTFOLIO APPROACH

In 1959, Harry Markowitz developed his mean variance risk framework [19] for portfolio selection. In this work, Markowitz developed the concept of the efficient frontier to develop the idea that investors could combine different assets in different ways to produce a risk reward curve that represented the greatest value or reward for the some set risk level; or for a set reward what is the portfolio that provides lowest risk.

Portfolio analysis provides a useful methodology on which to view the rewards and associated risks with different business models estimated in the simulation. Although the model is set up to calculate risk metrics using Monte-Carlo techniques, time constraints precluded the calculation of risk value metrics so qualitative risk scores based on the authors experience in the risk management field have been used.

Using the ETC demonstrator as an illustrative case study – we have calculated the net revenues to the project half-

hour by half-hour over a period of a year.
The results are shown in Figure 5 below. Graphs are for the renewables output at the actual rates at ETC. Spheres of the same colour have the same routes to market.

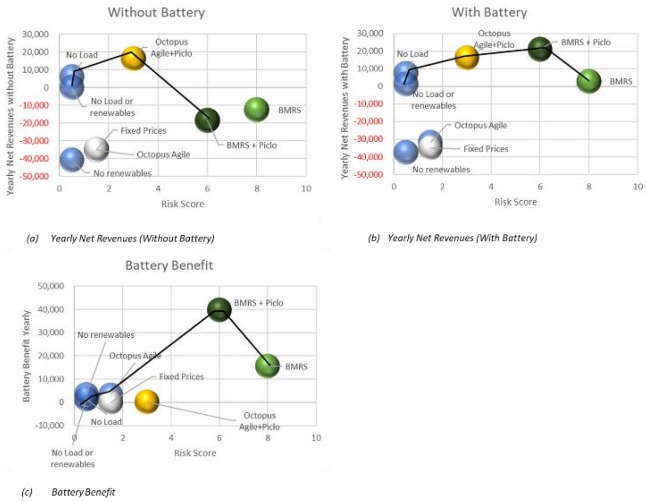

Figure 5: Simulation results using a risk reward framework

For every level of risk there is a business model that provides the greatest reward. E.g. Business model "No load" (Figure 5.a) is preferred over "No renewables", which have the same risk. The black lines represent the best selection at each risk point (the efficient frontier). Whether an enterprise prefers one business model over another is a matter of personal choice and risk preference e.g. As in the case of "Octopus agile" and "BMRS+Piclo".
In the "without battery business model" where all options are available to a VPP owner, it is clear from fig 5.a that an ETC demonstrator set up with an octopus agile tariff and a Piclo contract to provide DSR support would provide the best return for a risk neutral investor. That is, one who does not worry about risk. In the case where risk is considered, the choice between a solution involving an investment with "octopus agile at ETC with no load" or the investment with the "loads and octopus agile + Piclo markets" lie on the efficient frontier has to be made. That is, is the investor willing to take on the additional risk for the extra reward by moving right on the diagrams above Note, no well-informed investor would invest in a business model utilizing BMRS as a route to market, as it provides lower returns with more risk.
A slightly different view evolves in the with battery case, where an investment in a route to the BMRS market with a Piclo contract might be preferred, depending on risk tolerance. Considerably greater risk is taken on for a £4000-£5000 gain, however, a risk averse investor might not be willing to take this additional risk. It is clear that different business outcomes would be preferred depending upon risk tolerance and asset choice e.g. battery or no battery.

CONCLUSIONS AND FUTURE WORK

A VPP business model framework has been proposed that uses a number of strategic dimensions. The selection of elements along the various strategic dimensions constitutes what defines a business model. Using the ETC VPP demonstrator project as a case study, three of these dimensions have been studied using a real data driven simulation approach based on 2022. Simulated values are shown against a qualitative risk value score (reward vs risk).
Under the strategic dimension approach of reference [9] there are still many other different combinations of assets, contracts, algorithms, locations and markets etc. that need to be considered. Future work will generate risk values and consider the effect of risk management on the outcomes. In addition, the stochastic nature of many of the inputs need to be included.
Most importantly, the data generated from such simulations will help us develop heuristic rules about which business model (combinations of strategic dimensions) will be best under which circumstances.

Acknowledgments

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