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VPP implementations: different types of services developed, experiences and platforms

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Abstract

Aggregation by Virtual Power Plants (VPP's) 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. Thus, presented work will be based on real use cases.

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, battery storage that can be used for flexibility as well as other consumers in the area.

The VPP design includes the use of cloud-based third-party software for communication, hardware interfaces and an additional pilot VPP software platform providing enhanced services such as optimization scheduling and forecasting amongst other things. Devices from many manufacturers have been incorporated into the demonstrator plant.

The integration of these components and development of the VPP software has proceeded on a learning-by-doing approach. The paper will discuss the design, development of the VPP platform (hardware and software) including a review of the various other platforms that could have been be used in the pilot, In particular, the paper will discuss the challenges with the implementation of the various components and present results on the performance of the design in the context of supplying flexibility services to a TSO/DSO. The VPP software has been running for over a year now and has allowed us to investigate issues with its operation such as reliability, forecasting (Machine learning), optimization (Stochastic and Deterministic) and its potential reuse and design for other projects. Lessons learned and how such a design could be adapted to other potential types of users will also be discussed.

1. Introduction

Virtual Power Plants (VPP) will form an important element in the development of a future low carbon power market, 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 in generation, consumption and storage in the context of a VPP depends on the appropriate optimization of market access, assets and an understanding of the constraints on the wider distribution system. The SIES 2022 project aimed to develop a digital energy utility management service (VPP) capable of managing local and regional energy systems and markets using a number of energy pools & use cases. Although flexibility markets it considered are mainly UK based, the approach can be extended for analysis in other countries.

The project (Fig. 1) focused on the technological and business related barriers and opportunities of how VPPs can function in flexibility markets to help local communities better manage their assets (power, heat, gas). Although it was focused on smaller locally based assets, the lessons learned from the project can be equally applied to larger and/or smaller projects. The majority of the assets were based at Engineering Technology Center (ETC) in East Kilbride, Scotland. Further details can be found at the project web site www.sies-project.com.

The VPP design includes the use of cloud-based third-party software for data storage, communication between certain assets, hardware interfaces and an additional pilot VPP software platform providing enhanced services such as optimization scheduling and forecasting amongst other things. Devices from various manufacturers have been incorporated into the demonstrator system, requiring appropriate integration procedures and settings. The integration of these components and development of the VPP software has proceeded on a learning by doing approach.

In summary the project consists of:

- Multiple Energy Pools (FindHorn, ETC demonstrator site (EK), Myres Hill) were used.
- Various technologies: Heat pumps, thermal stores, an auxiliary gas system, electrical load (up to 80kW), PV (12kW), wind (10kW+220kW) and different types of battery storage (178kWh) and an EV charger.
- Aimed to connect different types of assets, to maximize profits and provide support to an already congested grid.
- Was used for testing & developing algorithms/asset types and concepts

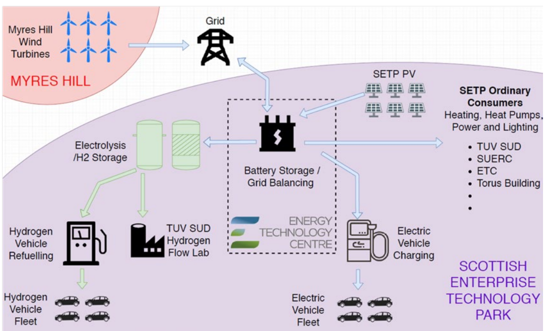

Figure 1: SIES Project Overview

The project also has access to data from the Findhorn Eco Village in Moray, Scotland which provides data from 3 wind turbines, a shared thermal store heat pump, domestic heat and hot water usage in several houses. Four community-owned wind turbines, which have a total capacity of 750kW, supply more than 100% of the community's electricity needs. The system is unusual in that the community owns its own private electricity grid. The electricity produced by the turbines is sent to a substation that meters the flows, alters the transmission voltages and acts as a switching station. Normally output is used on-site, but If production exceeds demand the surplus is exported to the grid and generates revenues. If there is no wind output the site imports from the grid. Overall Findhorn are net exporters of electricity.

Many lessons have been learnt during the development of the VPP platform in the SIES Project. These are summarized in Fig. 2 below.

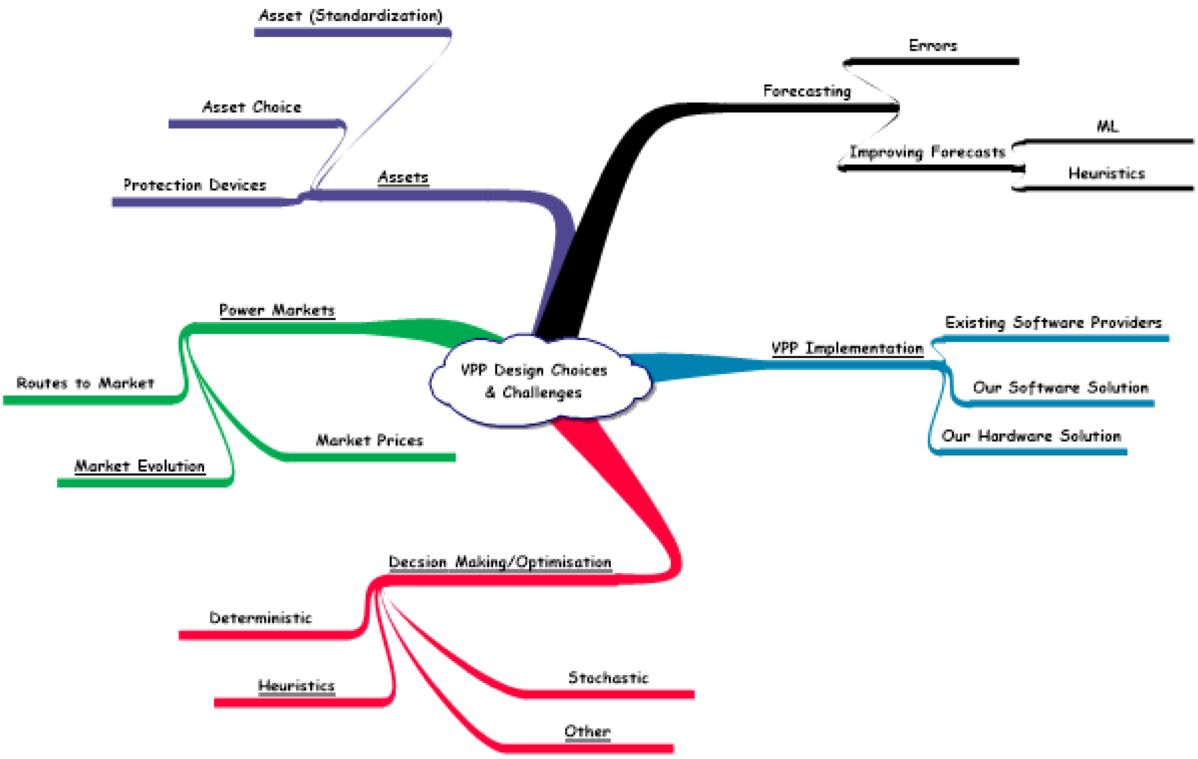

Figure 2: VPP Challenges and Choices

In the remainder of the paper we will discuss each of the points shown in Fig. 2, highlighting experiences, success stories, and challenges. The paper will begin with an outline of the design, development of the VPP platform (Hardware and Software) including an overview of existing suppliers and asset integration issues. This is followed by a discussion of Power markets, decision making algorithms and forecasting.

2. VPP Implementation

A VPP platform utilizing assets at a pilot plant and two other locations has been built and has been operating for over a year. Learning lessons have been extracted and a better view of how and why one would develop a VPP business has been developed.

The operation of the VPP can be thought of as a series of steps listed below:

1 (a) Obtain data from equipment
1 (b) Perform checks on data inputs
1 (c) Obtain weather
1 (d) Correct with local weather measurements if available
2 Forecast prices, power outputs and Demand for power heat etc.
3 Optimize make decision about dispatch of assets/flexibility to markets
4 Send control signals to assets
5 Review actions and analyse data

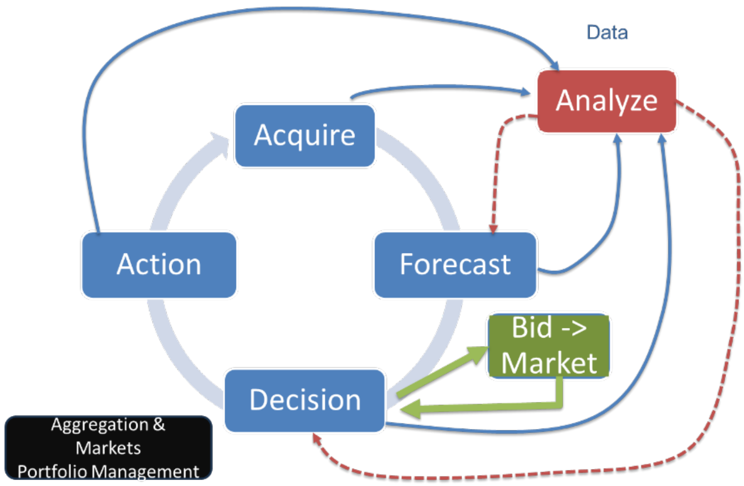

Figure 3: Actions Required by VPP

The VPP could be operated on a purely technical basis, without regard to markets, or as Commercial business, and our work focused on the commercial nature of a VPP.

This has important implications for the DSO as actions by a commercial VPP entity may not be in line with what a DSO wants.

Hardware Design

There are two key components to the design: (i) A VPP platform hosted on server on or off site (currently offsite); (ii) An Energy Management Control System (EMCS) that comprises of an Energy Asset Server, local asset network (Modbus RS485) and utilizes a cloud base AWS to store data from assets.The EMCS is used to provide a control and data logging interface between the Virtual Power Plant (VPP) application and the various energy assets and meters installed at the energy pools. The ECMS gathers operational data from assets at the various energy pools and interfaces with AWS database & provides logging of instantaneous data from assets. Assets at the SIES project site are connected to a Modbus network which communicates with the ECMS.

AWS is used to host a cloud server which forms the central hub for EMCS data and interaction with separate VPP application. The VPP uses API's to send and retrieve data via a bounce server.

The Local assets uses VLAN over LAN (Energy Asset Network [EAN]), while EAN uses a Modbus Gateway and RTU's (TCP - RS485), and essentially forms a Modbus network. Modbus gateways are used to interface to the various existing Modbus RTU (RS485) devices to Modbus TCP, and to interface with the EMCS server.

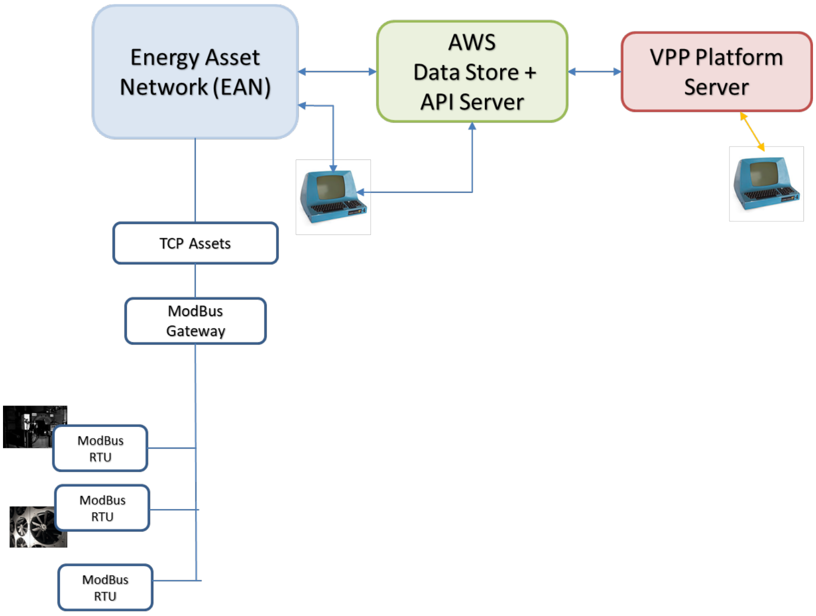

Figure 4: ECMS System

Software Design
Initially the project was to use a commercial version of VPP software, so an assessment at the time (circa 2021) was made of the potential suppliers shown here in Table 1 (for details see https://sies-project.com/fff02_files/existingproviders.html). At the time, few Vendors provided us with the appropriate decision making software that we required, although this has now become more prevalent. Some providers provided access to weather and forecasting services for a fee. Currently there are vendors that will provide users with AI/ML forecasting/decision models with their systems. We cannot comment on their accuracy or efficacy. There are many differences between VPP Software providers. Some provide software only with little support. Some focus only on one or two assets types, e.g. batteries only. In recent years some Open Source offerings have also become available (see [1]).

An Existing Framework PyEMLab-AGG [2] was developed as a Python object orientated simulator to model the interactions of aggregators (VPP owners and associated actions), domestic and industrial customers in a future flexibility market. The PyEMLab-AGG framework has been rebuilt to communicate in real time every half hour with assets at a number of locations including the SIES Project sites. The current architecture for the software framework is shown in Figure 5. Those modules marked with an asterix* are for future development. A key role of the model is to communicate with the assets in the field. This is achieved using API's, some of which have had to be developed for this project. Data is collected and stored for later use, but those that are needed for immediate use are also stored into in-memory storage in the repository object described earlier. The software uses a rolling time horizon to forecast prices and demand, and is used in the decision/Optimisation module. The optimiser, or decision model, looks to maximise revenues to the project and formulates schedules, which are then sent via the communication module to the various assets via AWS and the ECMS.

The original PyEMLab – Agg framework was designed as simulation software but this architecture has dual functionality (real time and simulation). This has proved invaluable for a number of reasons. Firstly, some of the assets have not been available to the project so the use of digital twins allows us to test software functionality and to try out new algorithms.

	NEXT Kraftwerke	Smarter Grid Solutions	Moixa Grid Share	Limejump	Kiwi	gridIMP	Open Energi	Origami	Electric Imp	AutoGrid	AMPX
Elements											
Individual Asset SCADA	Next Box	'Integration Services'?	yes	LJ Smart Devices	Kiwi Fruit (Energy Imp supplied)	No?	No	No	Yes		
Decentralised Control Hub		Element Flex	yes			ImpHub			Yes		Yes
Centralised SCADA	N/A		?	N/A	N/A	N/A					
Cloud Optimisation Platform	NEMOCs	Cirrus Flex	?	'The Cloud'	Kiwi Core	N/A	Dynamic Demand 2.0	Flex, Storage	No	"AutoGrid Flex" uses "GridSight"	Yes including advanced AI and ML capability. Also Asset mangment
Market Trading	NEXTRA		?	'Ops and Trading Platform'		ImpHub				Yes; Under guise of Renewables Trading	?
EV charging Integration			yes incl VtoG							Yes	Yes
DSM/DSR Integration			yes							Yes	Yes
Features											
UK-based	No, Germany	Yes, Glasgow	Yes, Manchester	Yes, London	Yes, London	Yes, Somerset	Yes, London	Yes, Cambridge	UK office, US HQ	No, USA ,India, Amsterdam, Japan	Yes Edinburgh Prauge and Toronto Affiliated with Amp energy which has offices in spain Japan India -
Owner Direct Asset Control	Yes	Yes	Yes	Yes	Yes	Yes	?	?	N/A	?	?
Owner Generated Schedules	?	?	?	?	?	?	?	?	N/A	?	?
Suitable for kW and MW assets	Yes	Yes	Yes	kW?	kW?	MW?	Yes	?	Yes	Yes	Yes
Other comments	2nd in Gartner /Nexant Studies. Now Owned by Shell	Recently acuired by Mitibishi	They started as Smart Battery Co but have platform to allow other assets to be utilised as battery type assets.	Limejump has been a wholly owned subsidiary of Shell since 2019, and is a part of Shell's Trading and Supply team.			BP acquired in 2021	Owned 14% by Aggrekko. Power Rental company		Market leader according to Gartner and Nexant. Appears to have largest number of installations completed. Owned by Schnider	Grid Edge solution. AMP X was supported by Energy Catapult to develop said system https://es.catapult.org.uk/impact/projects/amp-x/
Web link	https://www.next-kraftwerke.com/	https://www.smartergridsolutions.com/	https://moixa.com/business-services/	https://www.limejump.com/	https://www.kiwipowered.com/	https://gridimp.com/	https://openenergi.com/	https://www.origamienergy.com/	https://www.electricimp.com/	www.auto-grid.com	www.ampx.energy
Testimonials	https://www.next-kraftwerke.com/vpp/case-studies	https://www.smartergridsolutions.com/media-center/case-studies	https://moixa.com/case-studies/	https://www.limejump.com/knowledge-hub/ssdc-opium-power-case-study/	https://www.youtube.com/watch?v=euDBYjITYdU	https://gridimp.com/case-studies	https://openenergi.com/case-studies			https://www.auto-grid.com/case-studies/	https://www.youtube.com/watch?v=eSADLBFl1_o

Table 1: Overview of Potential Vendors

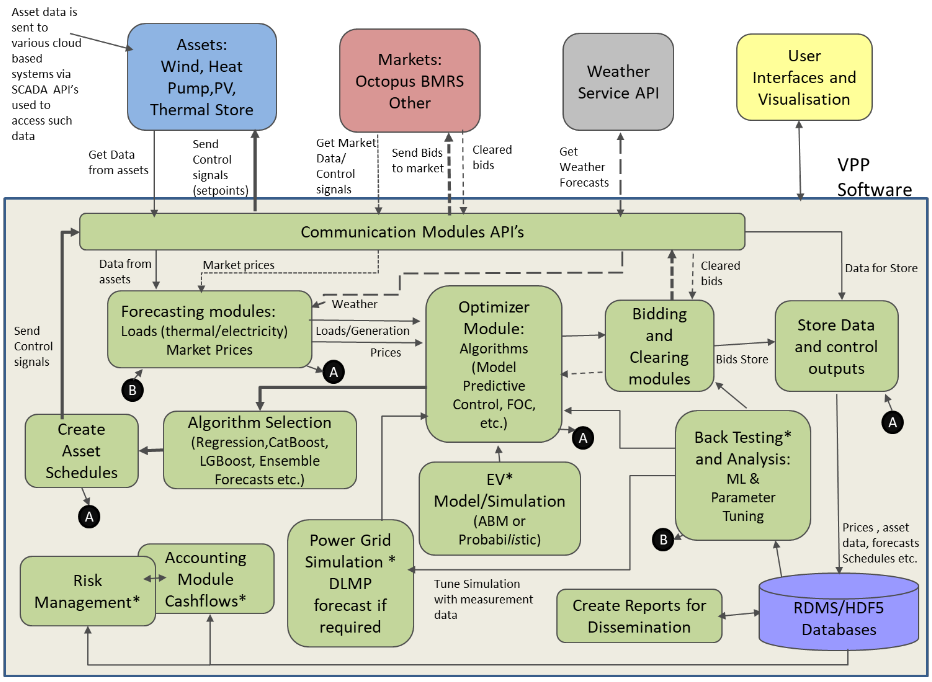

Figure 5: Current VPP Software Architecture; Block diagram

Secondly, the current demonstrator cannot gain access to some of the markets so a simulation environment allows to simulate these markets in the presence of real assets and their data. Using the experience gained form the VPP development we estimate that a fully blown commercial VPP platform is likely to cost in the region of £0.5 - £1Million pounds to develop, and would include risk management, cyber security and accounting modules amongst other things.

3. Asset Challenges /Choice

The SIES project uses a mix of new and legacy assets from different manufacturers, some of which are over 10 years old. Integrating these assets into a VPP platform has proved to be time consuming process and more difficult than a simple plug and play. Defining communication channels and measurement specifications has also been challenging, especially as some of these measurements are not currently sourced.

The data captured during project operation has been used to value different business models for the pilot project [3]. The SIES project itself is relatively small (provision of ~ 70-80kW of flexibility). Scaling the values shown in [3] to 1 MW indicates that depending on routes/access to market, and asset combinations could provide a revenue benefit of up to ~£350,000 per year per MW of flexibility. An analysis using the tool presented at https://sies-project.com/fff02_files/evaluationtool.html, indicates that if the assets already exist, a Commercial VPP might make sense for assets sizes greater than about 0.3 MW. Where asset investments are required, this figure rises to around 0.5 MW. Of course, this depends on the assumptions and costs assumed for the VPP service. Note that this tool assumes the use of one market i.e. Piclo distribution flexibility but ability to participate in different markets and revenue stacking would be expected to increase this value.

4. Power Markets

A key element to any assessment for any commercial Virtual Power Plant (VPP) is the prices that one would expect to achieve in the various markets. There are a number of markets that a potential VPP can sell into or buy from and in the future would include:

- Longer term Storage/Flexibility Markets associated with Transmission (currently exists under the UK STOR" arrangements)
- Longer term Storage/Flexibility Markets associated with Distribution (Evolving trial systems set up – e.g. see Piclo flex (https://picloflex.com)
- Day ahead and real time sales of Power between producers/consumers (wholesale EPEX and N2EX trading market places are currently available)
- Real time flexibility market at distribution or local level (future market)
- Frequency response services (e.g. FFR) and other ancillary services
- Bilateral markets between participants (current PPAs)
- Peer to Peer (P2P) markets (future markets)

The current markets are evolving at pace and regulators like the UK's Ofgem are looking to make market access for flexibility services easier to access. Historically balancing markets have been focussed on providing flexibility or imbalance services via the transmission network. but Flexibility at the distribution market level is still evolving with several pilot markets such as Piclo Flex being made available. Real time markets at the distribution level do not currently exist, but it is anticipated that they will.

Ultimately, a commercial VPP owner will be required to access these various markets to monetize its assets and generate revenues. This will require contractual arrangements as well as communication technologies to transfer data to the appropriate parties. VPP owners can communicate with the markets and the system operator (National Grid ESO in the UK).

VPP owners can connect with these markets and system operator directly or indirectly (via Energy/Supplier/Retailers or Aggregators) through a variety of mechanisms.

Deciding how to sell, and selecting the right route to market, is essential to the success of any VPP product or service. Different routes to market will suit different kinds of assets producing different products/services. In the case of a Virtual Power Plant (VPP) it is not a simple case of picking one market over another, but to understand that having ability to switch between markets may be more valuable than any one market. There are costs (financial and other resources) to joining a marketplace and this needs an assessment of whether having access to additional markets is worth the cost of joining them. This can be likened to having an option. If the cost of the option far outweighs its value, then the market should not be accessed.

Assessment of the VPP value will take account of the value of these markets, the costs of access and will eventually enable us to determine the best setup for a particular use-case.

5. Forecasting

Forecasting is a key element of the VPP functionality and is described and discussed in reference [4] . The key take way from our work is the following:

- There are many algorithms one can use to forecast wind/solar output, including Machine learning algorithms such as CatBoost, LG Boost and stochastic models for price forecasting.
- Sometimes, (perhaps surprisingly) the simpler methods e.g. a simple logistic equation to estimate power output from renewables is more accurate than the more" sophisticated method
- Overall, operating errors of around 12% have been seen in operating the current VPP unit. This results in large discrepancies between expected and actual volumes exported to/from the grid for about 15% of the time!
- We believe that we can reduce this error to ~ 5% with the use of ensemble modelling techniques.
- We are developing ML algorithms to correct for the discrepancies in dispatch volumes. This has proved to be difficult, but are still working on this.

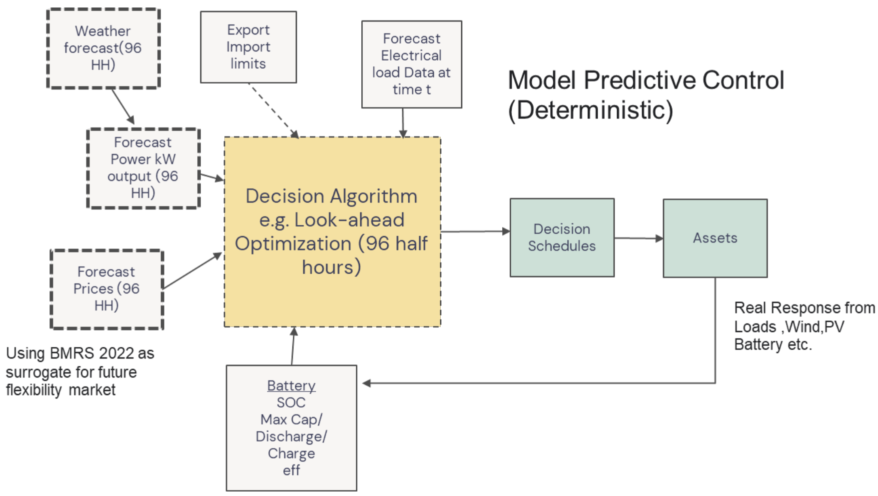

Figure 6: Forecasting Modules and Approach

6. Decision Making (Optimization)

A “deterministic” based decision optimization model, based on the work in reference [5] was originally included, but has been adapted to include battery degradation costs, import/export limits and carbon prices. It uses the Pyomo [6] modelling language and an open source GPLK MILP optimiser. This has been further adapted to include some elements of the current UK flexibility and wholesale markets, as well as contract structure selection, but this brings another level of complexity to the problem to be solved. Adding contract structure has increased solution times by a factor 150 – 1000. The optimizer, or decision model, looks to maximize revenues to the VPP and formulates schedules which are then sent via the communication module to the various assets.

Discrete, Stochastic or Heuristics
An important part of the commercial VPP operation is to bring financial benefits to its operations. This essentially means the optimization of decisions, such as Discharge/Charge profiles on battery, thermal and other innovative storage technology, EV and Demand scheduling and market participation optimization with bidding. The inherent uncertainty associated with this problem in what is a complex system, and will become even more so with domestic customer involvement (added human behaviour dimension in future evolutions of the market). Experiments with stochastic solvers indicate that solution times for “relatively” simple problems can take many hours to solve. However, a future environment that could require bidding times of less than 5 minutes tends to suggest that other solutions need to be considered and/or found for this problem.

Linearizing and solving deterministically can help, but our recent experience on a problem which bids into real imbalance and flexibility markets shows the solution times can be excessive.
Our current incarnation of the assets uses a forward looking horizon deterministic optimization method. It solves relatively quickly, but does not account for the stochastic nature of the real problem. Essentially, we have a speed vs accuracy challenge, which is dependent upon the bidding timeframes e.g. potentially as short as 5 minute bid. Although AI/ML will prove to be a useful tool to forecast and, more generally operate VPP’s, i.e. make decisions on asset dispatch, it is but one tool. AI is useful if data is stationary, as it can predict based on past patterns relatively fast. Unfortunately, markets are not stationary in the longer term and the addition of Human Behaviour (Domestic Consumers) into the flexibility mix will test their ability to forecast. Additionally, some form of heuristic might prove to be useful, albeit using a combination of models is thought to be a better approach and one that we have been pursuing.

7. Added Values/Conclusion

Although the development of a VPP pilot plant was meant to use commercially available software – it has turned out that for a variety of reasons that a “homegrown” development has occurred. This enabled us to learn more about the process of developing a VPP project from the ground up, and afforded us a better understanding of the benefits and challenges associated with such projects.

The integration of existing legacy hardware has proved to be a problem – lack of standardization, difficulty in obtaining manuals for older equipment and so on. Most importantly, the collection of, and use of, data to simulate future VPP configurations has proved to be a bonus. The software architecture can be used to run simulations, hardware in the loop or to operate as a real time VPP engine.

Thus, this development of the VPP software tool has provided a number of benefits:
1. Allowed us to use data in simulations for, asset combinations that we do not currently have access to
2. Enabled us to easily incorporate and try out new algorithms
3. Provided us with the ability to perform hardware in the loop simulations.
4. Provided opportunity to value alternative business models and, most importantly, to put a value of flexibility on those combinations.

References

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