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Empowering residential energy resources through virtual power plants aggregation: The TRUST-PV proposal

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Abstract

Electricity production from renewable energy sources (RES) is characterized by its distributed nature and geographical dispersion of production facilities. Recently, energy storage has become both feasible and economically viable for residential installations. The ways the residential energy production and storage systems can be best exploited for the benefit of their owners and the community are to subject of on-going research. A recent proposal involves commercial aggregation of the dispatchable electricity via the integration of the residential storage into a distributed virtual power plant (VPP). In this paper we report on work conducted in the context of the TRUST-PV H2020 research project, discussing specifically the modelling, creation, and eventually pilot implementation of a virtual power plant -based on rooftop PV and residential batteries-, under a fine-grain control scheme. Residential production/storage resources are shared by their owners with a centrally managed/distributed controlled VPP. INACCESS's state-of-art UNITY RES asset management platform is used for the management of the VPP, interacting with the residential power assets through custom and lightweight residential power controllers (RPCs). We present the control architecture, the business actors' involvement, and the proposed service offerings.

1. Introduction

An effective management strategy for a residential energy system that comprises renewable generation with storage assets requires to consider a set of objectives, limitations and specific conditions. Strategy implementation is distributed between on-site (edge) controllers and central (cloud) management. The aim of this work is to define applicable business cases and couple them with effective control strategies. Firstly, the research background of the study is outlined including a literature review of control strategies on residential VPPs as well as technology control and monitoring tools, such as the Unity platform. Secondly, the residential VPP context as explored in Trust-PV H2020 is presented together with the pilot site that will serve as a validation testbed. Finally, the applied control strategies are presented and the resulting conceptual architecture of a residential VPP platform that could facilitate the intra-VPP operations and serve as a tool of a third-party aggregator or an energy community.

Nomenclature

BESS Battery Energy Storage System
CMS Central Monitoring Platform
DER Distributed Energy Resource
ESS Energy Storage System
EV Electric Vehicle
HMI Human-Machine Interface
PoI Point of Interconnection
PPA Power Purchase Agreement
PPC Power Plant Controller
PV Photovoltaic
REC Renewable Energy Community
RES Renewable Energy Sources
RTU Remote Terminal Unit
SCADA Supervisory Control And Data Acquisition
VPP Virtual power Plant

2. Technology Background

The self-consumption maximization context is to utilize the energy generated from local RES for load coverage primarily at the time of production and secondarily through time shifting from the battery. The batteries in general improve self-consumption rate, limiting the interactions with the grid (concerning both grid imports and feed-in power). This strategy can be applied at an individual household (through a local controller) and is also valid at community and/or portfolio level (with distributed control). “Collective self-consumption” or “Community Energy Balancing” business cases are usually applied with reference to a substation that is the Point of Interconnection (PoI) with the upstream network.

In the work of Matthias Resch [1] the above scenario is described with the addition of reactive power compensation using cosϕ(P) control.

Another ESS strategy is to schedule the battery charging during specific hours of the day in order to keep the feed-in power under a specific limit. In other words, this strategy maintains the amount of energy exported but distributes it to a predefined time period in order to keep the exported power under specific thresholds. In the works of J. Struth [2] and Y. Ueda, 2007 [3] the typical time shifting strategy was introduced upon a specific time schedule.

The batteries play an important role in the residential flexibility portfolio and can be utilised in several different manners. In the work of (Hossain, Pota, & Moreno [4] the battery cannot provide energy to the grid but only to the domestic load based on operational cost efficiency rules. However, it can be charged from both the residential PV and the Grid.

In Worthmann et al [5] four different control strategies are studied in a comparative manner in a test case that addresses reserve power flow elimination and voltage constraints management in an LV distribution grid. Only the local control scheme comprises simple rule-based logic. All other approaches are based on load and RES generation forecasts as inputs in an economic Model Predictive Control (MPC) problem. The "Centralised Model Predictive Control" algorithm in [5] is used to reduce the aggregated variation in energy usage across the network. In the "Decentralised Model Predictive Control" algorithm each individual entity implements their own local control logic. The main advantages of this approach are the reduced communication overhead and computational complexity as well as the consequent scalability. However, such an approach is considered by Karl Worthmann, as unlikely to achieve optimal overall behaviour at global level. Finally, the work of Ranaweera [6] combines the local and central control as first and second level decision making into a unified "distributed" concept which seems a promising option.

The Trust-PV research framework attempts to connect the control strategies applied at simulation level will a real-life living lab that will provide significant feedback with regards to model applicability as well as user acceptance.

2.1 Unity Platform

Unity is a state-of-the-art Hybrid SCADA and real-time big data platform for RES power plants, integrating modern technologies and concepts to maximize capacity and speed, minimize latency and optimize the operation of all controllable assets. The platform provides monitoring, control, grid, and market integration for solar, wind, battery, microgrid, and hybrid assets, allowing capabilities and services that unlock new revenue streams and value.

Deployed locally and centrally, Unity offers unparalleled flexibility and a uniform approach for the operation of RES power plants. The local (edge) suite includes the field and plant SCADA, the Power Plant Controller (PPC) and the Grid Integration RTU. It effectively implements extensive controls for seamless grid integration and efficient market participation and offering all the necessary tools for the asset's operation, performance evaluation and optimization. Centralized in the cloud or on-premises, Unity offers remote access to multiple asset classes, integrating events, alarms, and operations control center HMIs into a single platform for ease of operations and real-time responsiveness [7].

Within the Trust-PV research framework, a customized Unity platform will evolve into a useful tool suite for the aggregator facilitating portfolio monitoring and application of complex control strategies to multiple assets.

2.2 VPP as part of INACCESS service offering

A Virtual Power Plant (VPP) comprises a set of diverse technology assets combining variable RES (either PV or Wind) with dispatchable storage and/or generation assets that enhance its overall flexibility. Inaccess Unity portfolio of leading renewable energy and battery storage control as well as hybrid plant grid integration, accommodates Virtual Power Plants offering three key interfaces, namely with:

- The electricity market operator, which produces pricing and demand signals as well as capacity requests.
- The distributed asset owners and operators, which relay information about the readiness of assets with regards to the market requests.

- The grid operator, which ensures compliance with grid codes and operational constraints [8].

Figure 1: Schematic diagram of the Inaccess integrated VPP platform [8]

The grid operator interface requires field and plant SCADAs, for device-level data acquisition and plant-level control respectively, which are standard in any renewable energy plant. Additionally, there are additional requirements for a VPP to be able to participate in balancing markets: the infrastructure must be equipped with a power plant controller (PPC) and a remote terminal unit (RTU) acting as a grid interface.

Furthermore, there is a need for a central management system (CMS) and asset management platform to enable VPP communication with the distributed assets under its control. And to work in response to market signals, the VPP must have an integration platform that is capable of forecasting, energy management (particularly for VPPs incorporating battery storage), physical optimization, day-ahead and intraday bidding, settlement and daily, weekly or monthly reporting [8].

Inaccess offers a full suite of technologies required for VPP development, from SCADAs and PPCs to analytics, reporting and market integration platforms. These products have been developed in partnership with utilities, oil and gas firms, developers, investors, engineering, procurement and construction (EPC) contractors, operations and maintenance teams and asset managers, and tested across an installed base of more than 32 GW of capacity.

3. VPP in the Residential Context

As a concept, the residential VPP represents the aggregation potential and combined management of prosumer-owned, residential energy resources.

A residential VPP requires:

i. A portfolio of prosumers that have buildings with small-scale PVs and storage systems.

ii. A VPP Platform for the management of the distributed energy resources as an aggregated flexibility portfolio.

iii. Rules and processes for the management of pooled resources.

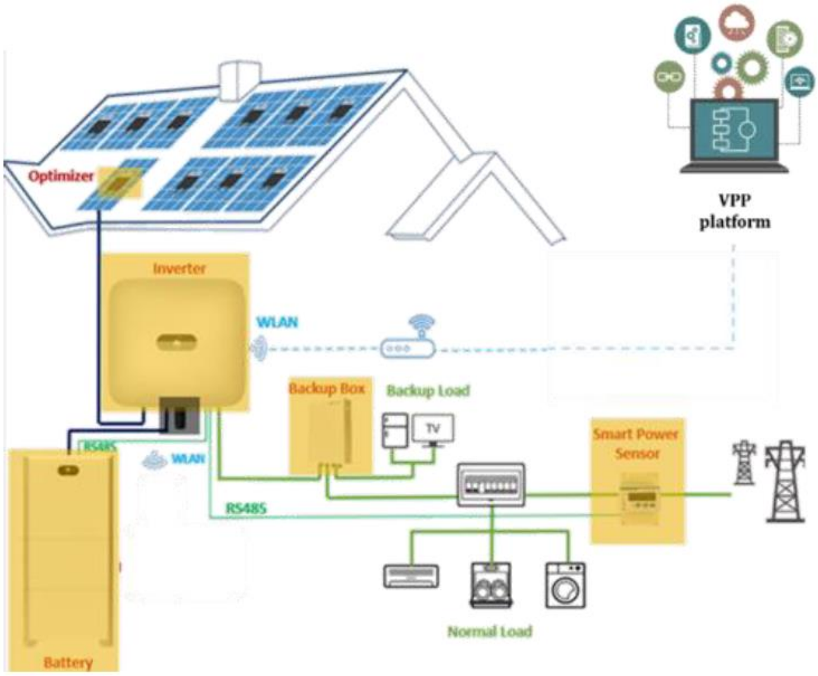

Figure 2: Pilot site set-up design

An appealing business case for a VPP whose available assets are in geographical proximity, which could in other words qualify as a Renewable Energy Community (REC), is the "optimization of community energy profile" or otherwise "collective self-balancing". This constitutes the utilization of local distributed energy storage resources in order to increase self-sufficiency based on locally produced renewable electricity generation.

Such an application can be supported by a business model based on a price mechanism (e.g., difference in grid-supplied electricity costs and the feed-in tariff, etc.) [9].

Another business model that applies to VPP portfolio -with fewer restrictions in terms of geographical proximity- is the flexibility aggregation from the combination of RES, storage and controllable demand in order to create revenues from market participation. The service offerings may vary between:

- Frequency-related services in ancillary markets
- Optimized price-based dispatch in wholesale markets

Besides the market-based interactions, another feasible business scenario includes a Purchase Power Agreement (PPA) between the VPP and an Energy Producer (e.g. PV+BESS generator).

There are already indicative pilot installations, such as the Tesla VPP of 50MW in California. The incentive mechanism is promising, valorizing the offered flexibility provided during grid emergency with a high unit price, namely 2$/kWh. However, the concept is considered to be immature and the business model "fluid" showing significant issues to be resolved [10].

At prosumer level, the flexible resources could also include Electric Vehicles (EVs) through controllable charging and demand response besides a rooftop PV coupled with a battery. Smart metering is also required in order to provide feedback with respect to the energy inflows and outflows from/to the upstream network. Finally, a local energy management system is essential to facilitate the applications of prosumer-level control strategies, such as scheduled import/ export energy, self-consumption maximization, etc.

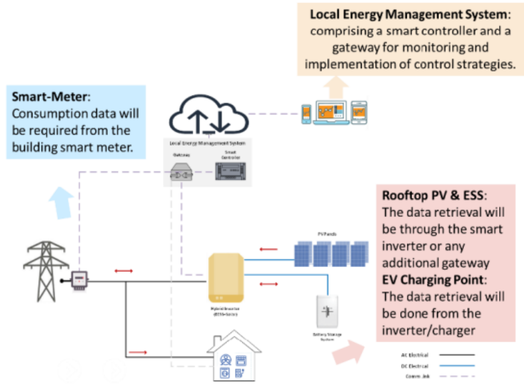

Figure 3: Domestic flexibility resources

4. Ex-ante Analysis & Control Strategies

A set of ex-ante simulations have been performed by the project partner EURAC, to test a model-based different Renewable Energy Community business models, such as “collective self-sufficiency” or utility PPA schemes, realized through “peer-2-peer” energy sharing.

With reference to the outcome of the calculations, relevant control strategies will be applied at the TRUST-PV living lab in Netherlands in order to check applicability beyond model feasibility.

According to the preliminary study on the applicable control strategies of residential ESS, two building-level control strategies have been selected as means to apply the aggregated resource optimization:

i. **Building-level self-consumption maximization while preserving grid constraints management:** The objective is to achieve maximum utilization of locally produced renewable energy to directly cover the load. In case that the PV is lower or higher than the load requirement, the battery contributes through charging/ discharging based on its electrochemical limitations. The grid interactions constitute the last and least preferable choice which is employed when the PV production and storage flexibility do not meet the exact load requirements. Some basic rules of this operation mode are presented as follows:

Battery Discharging:

$$P_{PV}(t) < P_{load}(t) \ \& \ SOC_{battery} > SOC_{low}$$

Battery Charging from PV:

$$P_{PV}(t) > P_{load}(t) \ \& \ SOC_{battery} < SOC_{high}$$

PV feed-in to Grid:

$$P_{PV}(t) > P_{load}(t) \ \& \ SOC_{battery} \geq SOC_{high}$$

Load fed from Grid:

$$\text{If } P_{PV}(t) < P_{load}(t) \ \& \ SOC_{battery} < SOC_{low}$$

The advantage of such a business model at community level is the independence of each prosumer in terms of system sizing and financial investment. Each household can independently decide the energy resources and level of self-consumption since there is no shared community asset. The additional community-level control that could be employed is mainly focused at reactive power control for proper grid constraints management. If there is a need to adjust the reactive power to the household with high grid feed-in flows.

$$\mathbf{P_{PV}(t) < P_{feed-in_{max}}} \text{ then } \mathbf{Q_{PV} \rightarrow 0}$$

$$\mathbf{P_{PV}(t) \geq P_{feed-in_{max}}} \text{ then } \mathbf{Q_{PV}(t) \rightarrow Q_{Feed-in}}$$

ii. **Collective self-sufficiency through scheduled power sharing during specific time slots:** The objective is self-sufficiency at aggregated level. As per the global optimization, a schedule is created for feed-in time intervals from the household to the grid. The battery will keep charging only locally from the PV.

During feed-in intervals, the PV feeds the Grid regardless of the battery State of Charge:

If $P_{PV}(t) > P_{load}(t)$ then $P_{residual} \rightarrow P_{Feed-in}$

During charging slot starts then Battery Charging is permitted considering the State of Charge:

If $P_{PV}(t) > P_{load}(t)$ && $SOC_{battery} < SOC_{high}$ then $P_{residual} \rightarrow P_{battery}$ until SOC_{high}

If $P_{PV}(t) > P_{load}(t)$ && $SOC_{battery} = SOC_{high}$ then $P_{residual} \rightarrow P_{Feed-in}$

5. VPP Platform Architecture

At the aggregated/ portfolio/ community level, the research objective is the definition of a SW architecture for the Residential VPP-platform and the distribution of functions between the local residential controller and the central VPP management entity.

In terms of essential functionalities, such a platform shall be able to:

i. Provide performance analytics and performance guarantee monitoring for BESS (in case of a centralized solution).

ii. Provide web-based remote user interfaces for power control and performance finetuning.

iii. Receive weather forecasts from third-party providers and VPP power dispatch signals from the grid operator, when applicable.

iv. Dispatch setpoints and/or schedules to household ESSs.

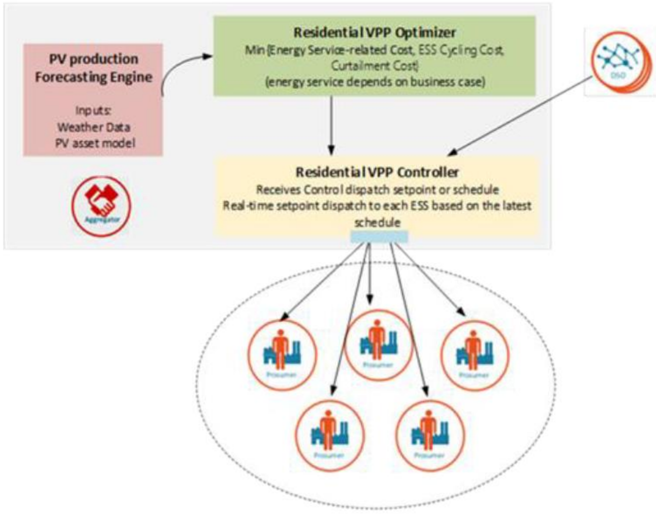

Figure 4: Residential VPP platform architecture.

The optimization-based scheduling algorithm requires to:

1. Model the technical and business constraints on community/ portfolio level.
2. Model the technical and business constraints on building/prosumer level.
3. Model the storage assets' "physical" constraints (SoC, max/min power/energy limits, etc.)

The objective function should be cost minimization considering cost of penalties, asset life cycle costs, as well as opportunity costs of various types (e.g., PV curtailment, etc.).

6. Conclusions

In the present work the applicable business models and control strategies have been presented in terms of the ex-ante pilot analysis. After the pilot completion and the testing validation procedures, more conclusions will be available which will serve as basis for an overall ex-post feasibility analysis.

On top of this technoeconomic study, incentive schemes could be evaluated for both cases of shared community assets or implicit demand response business models. Through the presence of a living lab, this analysis could be accompanied by user engagement evaluation which will provide useful outcomes to take into account in the design of service offerings given that a sound scalability analysis takes place.

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