EPPL INSIGHTS

VIRTUAL POWER PLANT CONCEPT

ENERGY PLATFORM LIVING LAB

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VIRTUAL POWER PLANT

EPLL's view on
Virtual Power Plant

July 2024

Report can be found at: epll.eu/insights

Introduction to Virtual Power Plant

Problems like the "unmanageability" of the system can be overcome by directing two-way energy flows, including prosumers and advanced storage systems. Aggregating production allows for a more stable electricity supply, and a new player, the aggregator, manages a group of facilities within a certain area. The aggregator, as a collaborative commons, actively manages demand.

> A Virtual Power Plant (VPP) is an innovative model that connects various energy sources, such as solar panels, wind turbines, and fuel cells, to create a controlled and efficient unit.

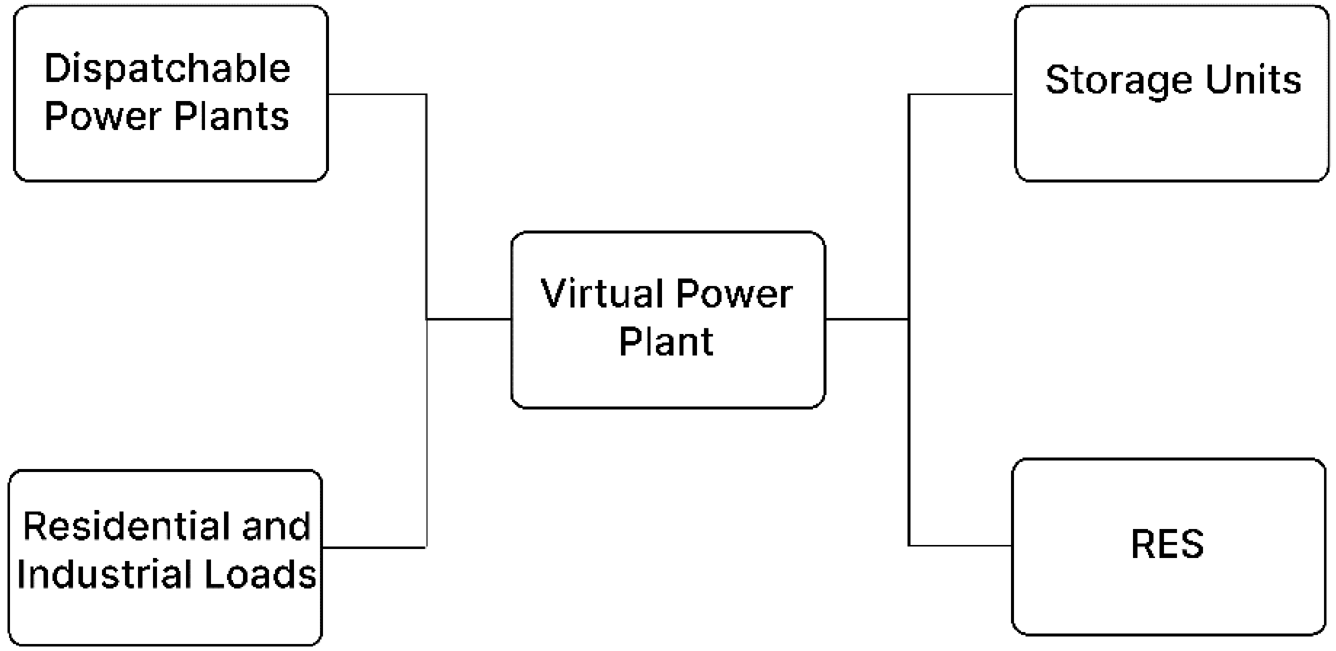
This concept allows for local energy production without the need for long-distance transmission and is supported by a computer system managed by the distribution system operator. Participants in this system play an active role in the energy system, enabling their strong involvement.

VPP's have proven to be flexible elements in the energy system, and there are successful projects worldwide using them. The use of renewable energy sources is increasing globally, and VPP's play a key role in optimizing the performance of different sources and solving challenges faced by grid operators.

Figure 1 shows the various units that can be included in a Virtual Power Plant. The sources covered by a VPP can include micro-CHP, wind turbines, solar photovoltaic energy, small hydropower plants, small hydropower plants without storage, biomass plants, diesel generators, or battery energy storage systems.

Distributed energy resources (DER) can solve peak electricity demands and generate extra energy during periods of low demand. This energy can be sold on the electricity market. DER's can be grouped and managed from a single central unit, making them visible in the energy market. This approach is open to all types of energy production technologies.

In addition to distributed energy resources, a Virtual Power Plant also consists of sensors and measuring devices that collect data on energy production and consumption. This data is then processed and analyzed to enable optimal management of energy production and consumption in the virtual power plant.



> "Virtual Power Plants reduce costs for all energy consumers by decreasing the need for massive investments in poles and wires while eliminating the need for distant, expensive and polluting fossil fuel plants."
>
> Lynn Jurich

VPPs can manage units that are far apart using a hierarchical control strategy that virtually combines the capacities and flexibilities of various Distributed Energy Resources (DERs) within the VPP. This improves the operation of the power system. By optimizing the use of renewable energy sources, VPPs help balance supply and demand, making the grid more stable and reliable.

They also enable small energy producers to participate, empowering consumers and promoting local energy generation. VPPs play a vital role in the green energy transition by enabling better integration of renewable energy, reducing greenhouse gas emissions, and supporting new technologies for a sustainable energy sector. Overall, they offer a new way to manage energy, helping to meet climate goals and support sustainable economic growth.

The main focuses in VPP research are:

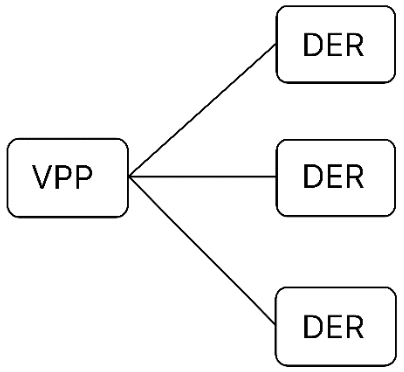
1. **Feasibility of DER participation in the market**
2. **Optimization of VPP control and coordination**
3. **Design of VPP and the electrical system**

Concept of VPP

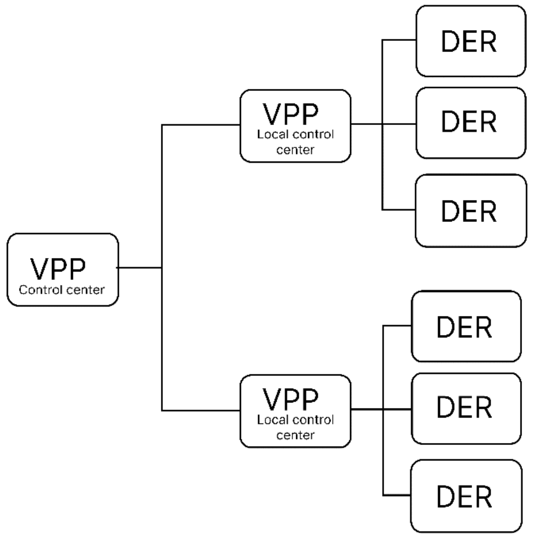
Architecture of a Virtual Power Plant

The architecture of a Virtual Power Plant (VPP) is designed to integrate different distributed energy resources (DER) into a single, coherent system that can be managed centrally or in a distributed manner. There are several ways to classify VPP's, one is based on the control method used:

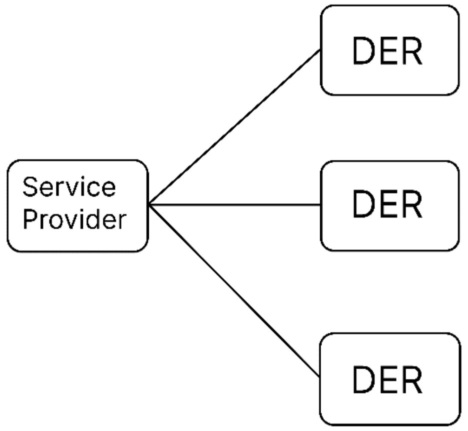
1. A Centralized Controlled VPP is a type of virtual power plant managed by a single central control unit. This unit coordinates the activities of all individual production devices (such as solar panels, wind turbines, energy storage batteries, etc.) to ensure the VPP operates optimally according to the needs of the power system. For example, if the demand for electricity is high and solar panel production is not enough, the system can automatically activate other distributed energy sources to increase total electricity production. Similarly, if production from distributed energy sources exceeds demand, the system can store the extra energy in batteries for later use. This system provides flexibility in electricity production and consumption. It helps reduce greenhouse gas emissions, improves the efficiency of the power grid, and reduces dependence on fossil fuels.



2.A Distributed Controlled VPP uses distributed control logic based on collaboration and coordination among DER's within a group. In this type of VPP, distributed energy resources share information and make decisions together, allowing for better optimization of production and load management according to current demand. This type of VPP provides greater flexibility and adaptability and better utilization of available resources. Examples of distributed Virtual Power Plants include rooftop solar panels on private houses, wind turbines in fields, or hydropower plants on rivers, which can be connected and coordinated through an energy management system to ensure a stable and sustainable energy supply.



3.A Fully Distributed VPP means that system management and energy production coordination decisions are distributed among the DER's. Each DER in the Virtual Power Plant acts independently and has some autonomy in deciding its production. However, to achieve coordination, DER's communicate and exchange information about their capacities and needs. An example of a fully distributed VPP is smart homes using solar energy to produce electricity and store excess energy in home battery systems. These battery systems can be connected via software and communication technologies to create a fully distributed VPP. Each home has its own energy production and storage system, but when one home produces excess energy, it can share that energy with other homes in need, reducing the overall energy consumption from the grid.



VPP's can be flexible, use more renewable energy, and **help cut down emission of CO2**.

Management objectives of a VPP

Another classification of VPP's includes two categories: **Technical Virtual Power Plant (TVPP) and Commercial Virtual Power Plant (CVPP).**

A Technical Virtual Power Plant consists of distributed energy resources located within a specific geographic area and collaborates in managing local power systems for the distribution system operator. It also provides system balancing and ancillary services for the transmission system operator. The TVPP is responsible for facilitating the management of local network constraints. Together with the distribution system operator, the technical VPP represents an active distribution network, enhancing reliability by allowing distributed energy resources to operate under various conditions. Some defined functions of the TVPP include:

- Visibility of DER's to the system operator
- Contribution of DER's to system management
- Optimal use of DER's

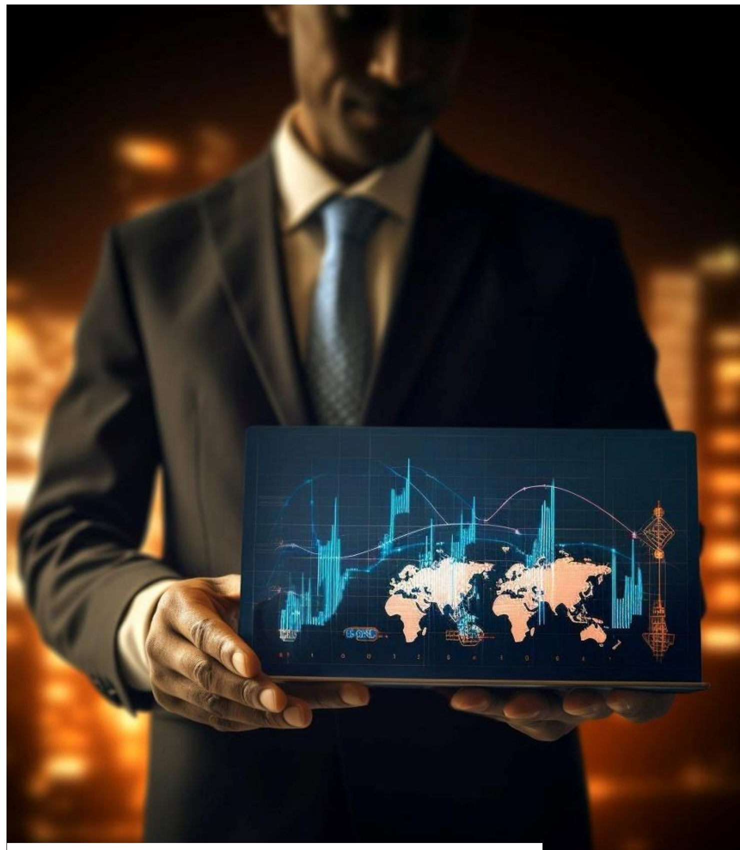
The TVPP collects data and models the characteristics of the energy system, which includes distributed sources, controllable loads, and networks within a specific region. It represents a unified entity that encompasses the entire local network. The technical characteristics of the TVPP align with those applied by the transmission system operator to traditional power plants connected to the transmission network. Its role is to manage the local network and define the characteristics of the local distribution network. Through collaboration with the Commercial Virtual Power Plant, the technical VPP obtains information about all distributed sources in the network, which is then used alongside detailed data about the network itself, such as topology and constraints, to assess the contribution of the distribution network to the transmission network.

The Commercial Virtual Power Plant (CVPP) primarily focuses on the costs and operational characteristics of its distributed energy units. The CVPP actively participates in energy markets, whether through trading or providing services, and enables smaller energy sources to access the market. The main goal of the CVPP is the aggregation of entities for commercial benefits rather than system stability. Unlike the Technical Virtual Power Plant, the commercial one can include participants from a wider geographic area.

An important feature of the CVPP is its ability to optimize production scheduling based on predicted demand and available production capacity. Some of its key functions include:

- Managing the characteristics of DER's
- Forecasting production and consumption, along with optimized production allocation
- Assisting individual DER units in participating in energy markets through bids and sales
- Predicting production and demand

To sum up, Technical Virtual Power Plant is responsible for the stability of the power system and the Commercial Virtual Power Plant aggregates distributed energy sources to create a portfolio for participation in energy markets.

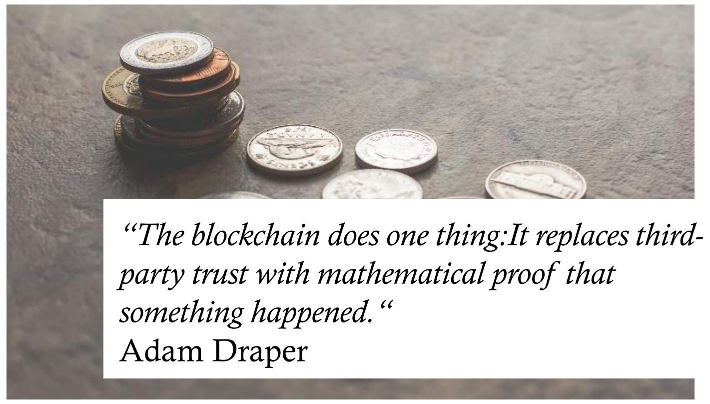


Power to (and from) the people thanks to Virtual Power Plants

Decentralized Energy Management System

Operators like Virtual Power Plants aggregate Distributed Energy Resources (DER's) to behave like traditional power plants with standard attributes such as minimum/maximum capacity, ramp-up rate, and ramp-down rate. They participate in markets to sell electricity or provide ancillary services. The aggregator controls a central information system in which data related to weather forecasts, wholesale electricity prices, and general trends in electricity supply and consumption are processed to optimize the operation of the DER's included in the Virtual Power Plant.

DEMS acts as a bridge that connects the energy park with the distribution and transmission networks, ensuring transparency and synchronization of data.



"The blockchain does one thing:It replaces third-party trust with mathematical proof that something happened."
Adam Draper

Based on these previously defined requirements, a software package for decentralized energy management called DEMS has been developed. The DEMS system is not a replacement for the automation equipment needed to manage the components of the energy park. At least local automation devices must be available to ensure the basic functioning of decentralized energy units and to ensure safety for components and personnel in the absence of the DEMS system. The central point of the VPP's operation is the energy management system. A key component of DEMS is its connection to the distribution network management system and the transmission network management system. This connection allows for the exchange of important information about the state of the grid and the capabilities of the VPP. DEMS acts as a bridge that connects the energy park with the distribution and transmission networks, ensuring transparency and synchronization of data. This information about the grid's state enables optimal management and utilization of the Virtual Power Plant's potential in accordance with the requirements of the energy system. The functions of DEMS can be divided into planning functions and control functions. The relevant planning functions include weather forecasting, load forecasting, generation forecasting, and unit commitment. Control functions include generation and load management, exchange monitoring, as well as online optimization and coordination.

Planning functions consider a time period of one to seven days, with time resolution depending on the billing periods for energy buying and selling, e.g., 15, 30, or 60 minutes. Planning functions are triggered cyclically (once a day or more frequently), by demand, and spontaneously.

Challenges of Virtual Power Plants

Once Virtual Power Plants (VPP) are established and distributed energy resources (DER) are activated, energy management must be executed to ensure grid stability and maximize energy production. However, managing the energy of Virtual Power Plants presents a series of challenges. One of the main challenges is the diversity of characteristics and capabilities of individual DER's, which can lead to difficulties in controlling their operation and achieving expected results. This can be addressed by employing various algorithms and methods to control each DER within the VPP. However, using different algorithms to control each element in the VPP can negatively impact other resources, potentially leading to undesirable outcomes. To overcome these challenges, it is essential to ensure that the control system incorporates various elements and capabilities of DER's and allows for interaction with the power grid. It is also important to ensure that the control system has different capabilities for energy management over various time frames and for providing different services to support the main system.

Data security is also one of the biggest challenges in Virtual Power Plants, as large amounts of data are exchanged between different devices and platforms, relying on internet connectivity. Some of the key challenges related to data security in Virtual Power Plants include increased vulnerability, as the large volume of data exchanged between various devices and platforms heightens susceptibility to various security threats, such as hacking, malware attacks, or unauthorized data access. Data security may be compromised if the infrastructure or system is unavailable, which can lead to data loss or disruptions in energy supply. Integrating different devices and platforms within a Virtual Power Plant can be challenging, especially if various types of technologies and protocols that do not communicate well with each other are used.

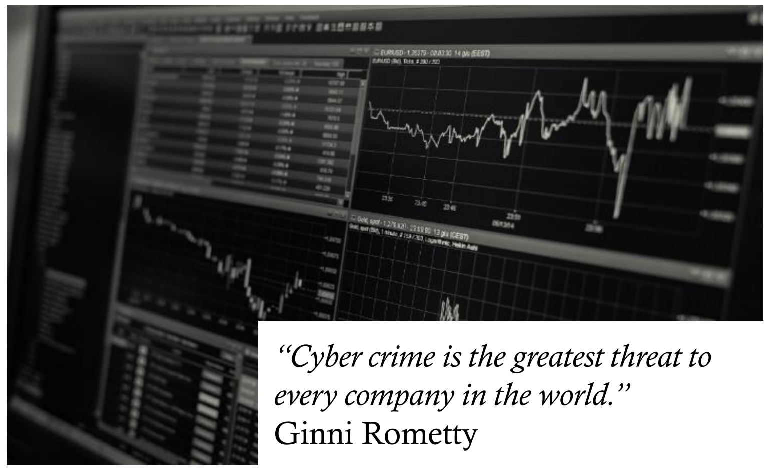
Virtual power Plants utilize data on energy consumption and other information gathered from diverse sources, which may pose a risk to data privacy. Finally, it is important to note that managing data security in Virtual Power Plants can be challenging due to the complexity of the systems, the variety of technologies and protocols, and the fact that data is collected and processed in real-time.

Blockchain in the energy industry

Blockchain, also known as distributed ledger technology, has attracted the attention of companies in the energy industry. Companies in the energy sector and software companies are partnering with governments and universities to use blockchain technology for energy storage. The convergence of blockchain and energy is undoubtedly one of the most exciting technological developments in recent history.

Stakeholders are using blockchain technology to create a virtual network that facilitates energy transactions on a distribution or wholesale basis. Consumers can exchange goods and services among their own devices and resources, as well as with neighbors and the grid. The entire process can be automated using smart contracts. One of the most interesting examples of blockchain in energy is its use in P2P energy trading. The flow of blockchain-based energy trading involves various elements, including financing, community resilience, and the growth of renewable energy. Owners of renewable energy resources (e.g., individuals or organizations with solar panels) can exchange surplus energy with neighbors if they operate within a closely connected geographic group or community.

Automated transaction resolution is an important concept in the implementation of blockchain in the financial sector.



"Cyber crime is the greatest threat to every company in the world."
Ginni Rometty

Application of Vehicle-to-Grid (V2G) technology through VPP's

Electric vehicles (EVs) are distributed energy resources in future smart grids. The main difference between EVs and other distributed units is mobility. EVs can connect to different parts of the grid and still use the same quality of service. The integration of electric vehicles and other DER units into energy systems under the principle of "convenience and entertainment" is not efficient for the safe and reliable operation of energy networks. Different electricity and DER suppliers can come together to meet the necessary load. A Virtual Power Plant (VPP) is responsible for load management and resource planning. It sources energy from distributed energy resources and contracts with consumers to power electric vehicles and their household loads. This creates savings on a scale in a completely new way. Virtual Power Plants minimize the overall cost, ensuring efficient use of energy produced by distributed energy resources. They do not require large and complex infrastructure and can communicate with the smallest DERs with greater efficiency and flexibility. This new technology is commonly referred to as the "energy internet." The terms "VPP" and "microgrid" are usually used interchangeably, except that a microgrid can "disconnect from the grid" from the grid, while a virtual power plant must be connected to the grid.

An aggregator centrally manages the distribution of energy for a group of consumers with TE (time-elastic) and TIE (time-inelastic) loads. Cooling or heating, must be met as soon as requested, while the former, such as EVs, can be scheduled arbitrarily during the connection time. For example, an EV owner connects the vehicle to the power grid after returning from work at night and needs a fully charged battery by morning. If necessary, the aggregator can discharge energy from the EV at any time during the night, provided the battery reaches the required level by morning.

The development of renewable energy sources and the rational use of energy are changing the role of the power grid, especially the distribution network. The distribution network is currently the main interface for renewable energy sources. This fundamentally changes the task of this system, which is increasingly responsible for the operation of the interconnection between distributed generation systems and the end user. The rapid growth of distributed generation and changes in the time and space of energy production and consumption are too complex to manage with the models used today. This will necessitate the implementation of a new energy management model. One such network is the smart grid, which is defined as a modern grid that uses advanced communication and control technologies to generate and distribute electricity in a more efficient, economical, and secure manner. These structures represent the backbone of virtual power plants and require the widespread presence of energy storage systems.

Electric vehicles (EVs), particularly their energy storage equipment, are one of the most interesting technical solutions for the implementation of these models. There are several models that describe the future impact of electric vehicles on the performance and economics of power grids. One of them proposes the "vehicle-to-grid" (V2G) technology as a possible solution to the impact on the stability of the grid developed by distributed generation. In such a model, electric vehicles are considered both a means of transportation and an energy storage system. Electric vehicles can be used for multiple grid services to stabilize the grid and support the utilization of renewable energy sources. These considerations are based on the analysis of the number of cars per capita, the distribution of the space and time of car use, the average utilization coefficient, and the correlation between the time and place of electricity usage and car use.

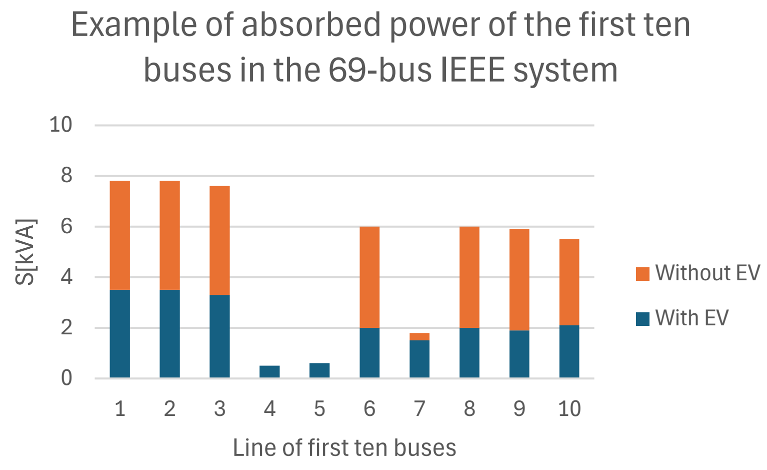
Vehicles are typically parked 90% of the time and represent an unused electrochemical source that can absorb energy to or from the grid when connected.

This is the basic concept of the so-called "vehicle-to-grid" technology, in which electric vehicles must have three or more elements to provide such services. First and foremost, they must have a bidirectional interface for powering or absorbing energy. The second essential element is the energy management system (EMS). Such an element must manage and measure energy flows between the battery pack and the grid. Finally, a communication protocol is needed between the grid operator and the electric vehicle owner to transmit all useful information to the EMS and assess the cost and revenue of the service.

Optimizing electric vehicle charging using renewable energy and Virtual Power Plants

Imagine a situation where we have two electric vehicles charging at two different charging stations. One of them has been charging for some time and its battery is nearly full, while the other has just arrived and needs to charge quickly to continue on its way. To utilize as much renewable energy as possible, the virtual power plant decides to use the remaining energy from Station 1 to charge the battery of the second vehicle at Station 2 more rapidly. In this way, Station 1 releases some of the available energy, while Station 2 uses this additional energy to accelerate the charging of the second electric vehicle's battery.

Assuming the electric vehicles are connected to high-voltage lines, the amount of electrical energy flowing through the lines connecting different grids and consumers is calculated and displayed in figure 5. These diagrams illustrate the quantity of electrical energy absorbed by the same lines during the connection and charging of the electric vehicles. In this case, the amount of electrical energy absorbed by each line has significantly decreased, indicating that the electric vehicles could provide excess electrical energy to the system without compromising grid stability.



The conclusion is that a virtual power plant, which manages the distribution system, can utilize the remaining energy from one charging station to charge the battery of another electric vehicle that has just connected to a different station more quickly. This reduces the consumption of conventional energy while increasing the use of renewable energy sources. The characteristics of voltage and current waves through the charging stations help better distribute the load from various renewable energy sources, improving the stability and reliability of the entire system. By integrating electric vehicles into the distribution system connected to high-voltage lines, it is possible to decrease conventional energy consumption and increase the utilization of renewable energy sources without jeopardizing grid stability.

"In order to have clean air in cities, you have to go electric."
Elon Musk

A new era is here, and we must embrace Virtual Power Plants

Virtual Power Plants represent a new and innovative concept in the energy sector, enabling the connection and management of a large number of decentralized energy sources. Their implementation achieves greater flexibility, efficiency, and sustainability in electricity production and management. One of the advantages of Virtual Power Plants is their ability to integrate various types of renewable energy sources such as solar panels, wind turbines, biomass, etc. This integration allows better utilization of available resources, reduces greenhouse gas emissions, and decreases dependence on traditional fossil fuels.

The introduction of Virtual Power Plants has a significant impact on the energy system. They contribute to decentralizing energy production, reducing the need for large centralized power plants. This results in greater security and resilience of the energy system, as the risk of failures or interruptions is reduced. Additionally, VPP provide the opportunity to participate in the electricity market. Due to their flexibility, they can adapt to market demands and provide various services such as load balancing, participation in energy reserves, and electricity trading. This opens up new business models and opportunities for integrated energy systems.

However, the implementation of VPP faces many obstacles and challenges. It is necessary to establish an appropriate regulatory framework, legal conditions, and market support to ensure their long-term sustainability. Advanced technologies for monitoring, management, and communication within virtual power plants also need to be developed.

"The best way to predict the futere is to design it."
Abraham Lincoln

In conclusion, VPP have a positive impact on the energy system by providing a sustainable and flexible alternative to traditional energy production methods. Their implementation can contribute to achieving energy goals, reducing greenhouse gas emissions, and creating a more sustainable energy sector.

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Energy Platform Living Lab
Unska 3, 10000 Zagreb

epll.eu
epll@epll.eu