Virtual Power Plants in Real Applications

Pilot Demonstrations in Spain and England as part of the European project FENIX

Martin Braun
Institut für Solare Energieversorgungstechnik (ISET) e.V., Königstor 59, 34119 Kassel, Germany
mbraun@iset.uni-kassel.de, +49(561)7294-118

Abstract

The concept of Virtual Power Plants (i.e. aggregation of distributed generators through a centralised control architecture) was further developed in the European project FENIX and tested in real networks, namely with Iberdrola in Spain and EDF Energy in the UK. The potential for active participation in power markets and distribution network operation is demonstrated.

1 Introduction

Greenhouse gas emissions and the dependency of many industrialised countries on fossil energy imports can be reduced by using local Renewable Energy Sources (RES) and Distributed Energy Resources (DER). Distributed generation can increase the efficiency and the security of the power supply system.

According to related political aims, incentives are offered in some countries that boost DER and RES. In the past, the main objective was to feed in maximum active power, but in future the need for active participation of DER units by supporting power system operation will increase. With high shares of DER units they should in principle also cover similar control tasks compared to conventional power plants. DER should not only be connected to the network but also be integrated into system operation.

Distribution networks were formerly designed for a predominantly passive operation because their task was mainly to distribute electricity with unidirectional power flow from the transmission level down to the consumer. In the future the distribution system should be more actively controllable in order to utilise both the network and the DER/RES units more efficiently.

In practice, current policy of connecting DER units is generally based on a so-called 'fit and forget' approach. This policy is consistent with historic passive distribution network operation and leads to inefficient and costly investment in distribution infrastructure. Moreover, the lack of controllability of DER units implies that system control and security must continue to be provided by central generation. We are now entering an era where this approach is beginning to:

- Adversely impact the deployment rates of DER and RES,
- Increase the costs of investment and operation of the electric power system, and
- Impact integrity and security of the system.

In order to address these problems, DER units must take over the responsibilities from large conventional power plants and provide the flexibility and controllability necessary to support secure system operation. Transmission System Operators (TSOs) have historically been responsible for the security of the electric power system. With the integration of DER, Distribution System Operators (DSOs) also need to evolve to perform more active network operation. This represents a shift from the traditional central control philosophy used to control hundreds of generators, to a new distributed control paradigm applicable for operating hundreds of thousands of generators and controllable loads.

Figure 1 shows a schematic representation of the capacities of DER units, distribution and transmission networks, as well as central generation in today's system. It also includes the future development under two alternative scenarios, both with increasing shares of DER units. The "Status quo Future"-Scenario shows the continuation of the traditional system operation characterised by centralised control and passive distribution networks. The "FENIX Future"-Scenario represents the system capacities of integrated DER units with the FENIX concept of virtual power plants under a decentralised operating paradigm. DER units will provide system services sharing the role of central generation and substituting significant central generation capacity. In addition, active distribution network operation using services from DER units will share roles with the transmission network and reduce necessary network capacities for DER integration.

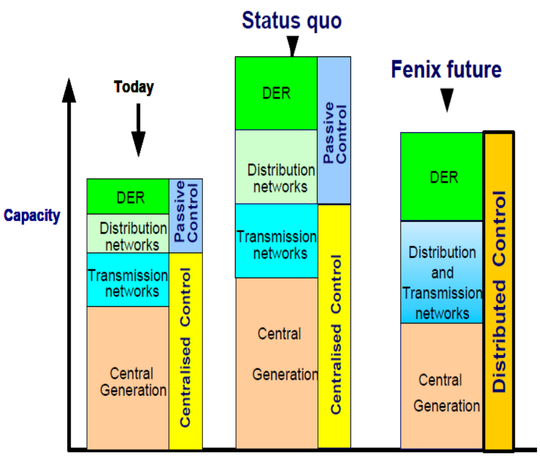

Figure 1: FENIX objective [1]

In late 2005 a consortium of 20 different partners (see Figure 2) from research and industry launched an integrated research project named FENIX [www.fenix-project.org]. The FENIX project meets the challenge of DER integration.

Figure 2: FENIX Consortium

The objective of FENIX is to conceptualise, design and demonstrate both technical architecture and a commercial and regulatory framework that would enable DER units to become the solution for the future: a cost-efficient, secure and sustainable EU electricity supply system.

DER units are too small and too numerous to be visible or manageable on an individual basis. The Virtual Power Plant (VPP) counteracts this problem by aggregating these individual characteristics of DER units so that they can now be used in a manner similar to transmission connected generation. The VPP concept was further developed and tested in FENIX to allow large-scale technical and commercial aggregation of DER units. The VPP can then be used to provide technical and commercial services to system operators and actors in the energy market.

This article introduces the FENIX concept (section 2) and presents the results of the pilot demonstrations in Spain and England (section 3).

2 FENIX Virtual Power Plant Concept

The basic component, the DER unit, must first be defined. 'Distributed energy resources' (DER) are defined in IEEE 1547.3 to "include both generation and energy storage technologies". It is also important to define the term 'distributed': "distributed generation is an electric power source connected directly to the distribution network or on the customer site of the meter" [5]. Thus, DER units include distributed generators and distributed bidirectional storage units.
The term DER does not include distributed loads because they are not resources as discussed in [3] and according to IEEE 1547.3. However, for simplification, the definitions in FENIX follow the definition of [5] that also includes demand-side resources in the term DER.

Numerous definitions of Virtual Power Plants (VPP) exist [3], for example, a "Virtual Power Plant" is an "aggregation of DER units dispersed among the network, but controllable as a whole generating system" [4].
Since a harmonised definition of VPP does not exist in literature, FENIX first had to define the project-specific meaning of VPP. According to [2] and [9] and with reference to Figure 3:
"A Virtual Power Plant (VPP) aggregates the capacity of many diverse Distributed Energy Resources (DER). It creates a single operating profile from a composite of parameters characterizing each DER unit and can incorporate the impact of the network on aggregate DER output. A VPP is a flexible representation of a portfolio of DER that can be used to make contracts in the wholesale market and to offer services to the system operator. There are two types of VPP, the Commercial VPP (CVPP) and the Technical VPP (TVPP). DER can simultaneously be part of both a CVPP and a TVPP" [2].

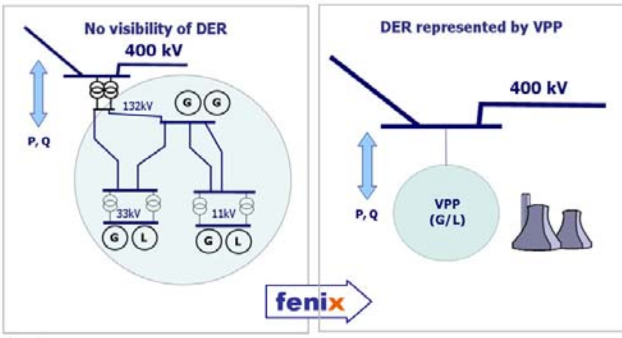

Figure 3: Virtual Power Plant concept in FENIX [2]

Technical VPP:
"A Technical VPP is a type of VPP. The TVPP consists of DER from the same geographic location. The TVPP includes the real-time influence of the local network on DER aggregated profile as well as representing the cost and operating characteristics of the portfolio. Services and functions from a TVPP include local system management for Distribution System Operator (DSO), as well as providing Transmission System Operator (TSO) system balancing and ancillary services. The operator of a TVPP requires detailed information on the local network; typically this will be the DSO" [2].

The TVPP enables:

- Visibility of DER units to the system operator(s)
- Contribution of DER units to system management activities
- Optimal use of the capacity of DER units to provide ancillary services incorporating local network constraints

This allows small units to provide ancillary services and reduces unavailability risks by diversifying portfolios and capacity compared to stand-alone DER units.
A comprehensive overview of the technological control

capabilities of distributed generators and the resulting possibilities of providing ancillary services are analysed in [6] and [7]. The technological potential is investigated by application of a new assessment approach that considers the grid-coupling converter separately with its particular capabilities. An enormous technological potential is identified.
DSOs that use the TVPP concept can also be considered as Active Distribution Network (ADN) operators [3]. An ADN operator can use ancillary services offered by DER units to optimise their network operation. On the other hand, an ADN operator can also provide ancillary services to other system operators. A hierarchical or parallel structure of ADNs may exist where the TVPP concept is applied, for instance according to different voltage levels or different network regions. Many examples of ADNs can be found in the Active Network Deployment Register [8].

Commercial VPP:

"A Commercial VPP is a type of VPP. A CVPP has an aggregated profile and output which represents the cost and operating characteristics for the DER portfolio. The impact of the distribution network is not considered in the aggregated CVPP profile. Services or functions from a CVPP include trading in the wholesale energy market, balancing of trading portfolios and provision of services (through submission of bids and offers) to the [transmission] system operator. The operator of a CVPP can be any third party aggregator or a Balancing Responsible Party (BRP) with market access; e.g. an energy supplier" [2].

The CVPP enables:

- Visibility of DER units in energy markets
- Participation of DER units in the energy markets
- Maximisation of value from participation of DER units in the energy markets

This allows market access of small units and reduces the risk of imbalance by portfolio diversity and capacity compared to stand-alone DER units.

CVPPs perform commercial aggregation and do not take into consideration any network operation aspects that active distribution networks have to consider for stable operation [3]. The aggregated DER units are not necessarily constrained by location but can be distributed throughout different distribution and transmission grids. Hence, a single distribution network region may have more than one CVPP aggregating DER units in its region.

Context of CVPP and TVPP:

Figure 4 illustrates the system and market context of CVPPs and TVPPs. The CVPP aggregates the DER units on a commercial basis and maximizes the benefit of their market participation by portfolio optimization. It also provides information to the TVPP that needs location-specific information of the DER units in its distribution grid. Consequently, the CVPP disaggregates the portfolio of DER units to pass the relevant information to the TVPP. The TVPP is active in system management on distribution level by, for example, considering local constraints such as voltage. It further aggregates DER units to the transmission level to, for example, access balancing markets of the TSO.
Offering the aggregated profile of the DER units to the transmission system requires both a commercial and technical actor. There are arguments for the TVPP as well as for the CVPP (with the TVPP validating proposed CVPP schedules) to become the transmission market interface. A new actor can also be considered.

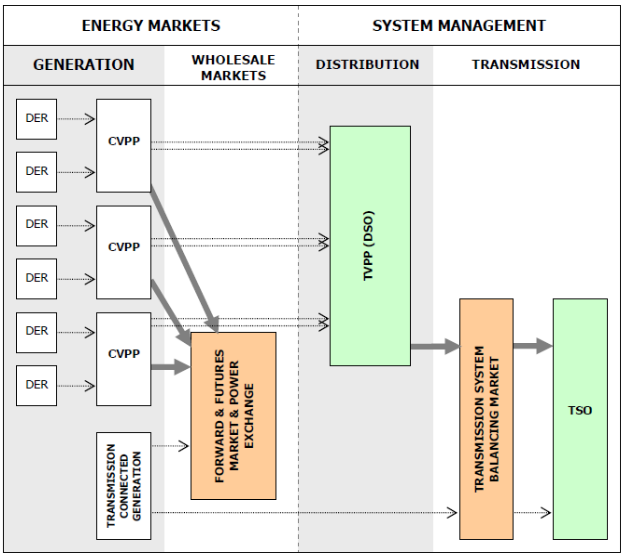

Figure 4: Commercial VPP (CVPP) and Technical VPP (TVPP) in system and market context [9]

3 FENIX Information and Communication Architecture

The objective is to include thousands to millions of DER units in a single VPP. Thus, the architecture has a hierarchical structure to allow complete scalability. At the DER unit a standard communication interface is required that enables exchanging monitoring data and control signals between the DER unit and the VPP system. This communication interface is called the "FENIX Box" (FB) in the FENIX project [14]. It can also aggregate several DER units. All FENIX Boxes are linked to the dedicated FENIX-VPP system via standard communication networks. The FENIX-VPP system itself is a system with unique data management and aggregation functionalities. This can be the CVPP system for energy traders or the TVPP system for DSOs in their Distribution Management System (DMS).
Three pieces of equipment have been developed [14] in FENIX as given in **Figure 5**:

- FENIX Box server
- CVPP server
- TVPP in the DMS Server

The CVPP system includes functions such as [10]:

- Maintenance and submission of static physical characteristics of DER units
- Administration of availability and outages

- Forecasting of generation and demand
- Real-time day-to-day optimisation and re-balancing
- Participation in markets with the available portfolio (management of physical trades, risk management, metering etc.)

The TVPP system is part of the SCADA/DMS of the network control system and includes functions such as [10]:

- Validation and evaluation of schedules
- Optimisation in given network constraints, e.g. Voltage Var Control (VVC)

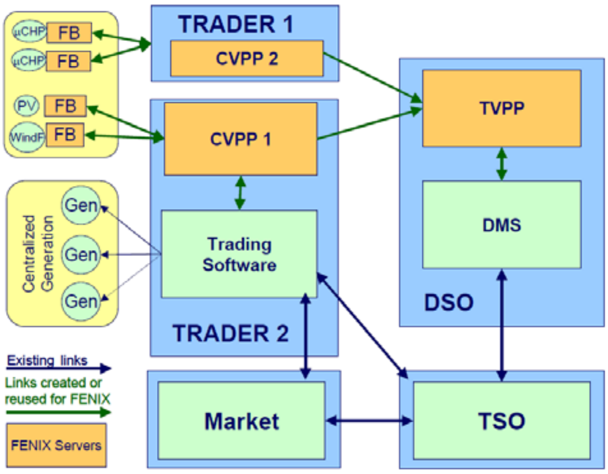

Figure 5: FENIX Architecture [10]

CVPP and TVVP functions have been developed, implemented and tested by AREVA and Siemens in their respective tools e-terra and Spectrum [14].

4 Demonstrations

The developments and functionality of the FENIX concept were demonstrated in the real networks of Iberdrola in Spain (Southern Scenario) and EDF Energy in the UK (Northern Scenario). Laboratory demonstrations and simulations were also performed.

4.1 Northern Scenario

The Northern scenario demonstrates the value of market participation in the Commercial Virtual Power Plant (CVPP) for smaller scale generation such as domestic and community scale CHP and PV connected to low voltage networks [11].

The Northern Scenario demonstration was carried out by a number of FENIX project partners (Areva T&D, ZIV, EDF Energy Networks, National Grid and Imperial College London) working together with Woking Borough Council (WBC) and EDF Energy, to accommodate the VPP concept in a number of test sites.

One challenge for the Northern scenario was to demonstrate the FENIX concept in today's network environment. A cluster of small scale generators linked to a common low voltage network was identified in the privately owned network of Woking Borough Council (WBC). WBC owns a generation portfolio that provides energy to its civic centre, conference centre and other municipal facilities at the Pool in the Park. The portfolio includes small and medium sized CHP units, a fuel cell, PV plants, and loads that can be controlled for short periods of time.

Figure 6 shows the arrangement of the Northern Scenario. The WBC FENIX box provides visibility of actual generation and demand and control flexibility. This information will be sent to the distributed management e-terra system hosted by Areva T&D which provides information to the CVPP on how best to dispatch the generation in its portfolio. As the DER units of WBC are only monitored, an additional FENIX box at Imperial College integrates DER units in their labs in order to analyse the control flexibility. In a FENIX future, with high penetration of DER and active management of distribution networks, the DSO will also be actively involved.

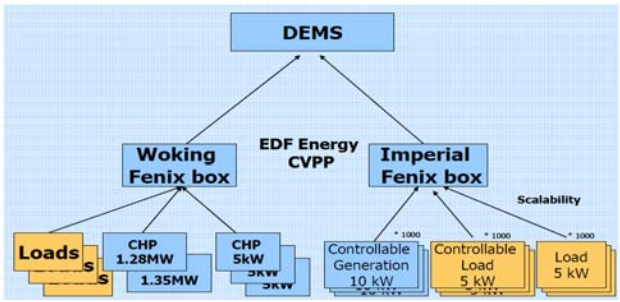

Figure 6: Northern Scenario Arrangement [11]

The study case in the demonstration considers four key market participants:

- National Grid (TSO in the UK)
  - Responsible for system security
  - Procurement of balancing services
- EDF Energy (energy supplier in the UK)
  - Participation in energy market
  - Reduction of imbalances
  - Operation of CVPP
- EDF Energy Networks (DSO in the UK)
  - Operation of the distribution network
  - Management of network constraints
  - Operation of TVPP
- Woking Borough Council (DER unit operator)
  - Operation of DER units
  - Maximisation of revenues by service delivery to the system through CVPP

The main value of the demonstrated business case is the near real-time visibility of generation and demand as well as the visibility of their flexibility.

4.2 Southern Scenario

The Southern scenario demonstrates the opportunities for distributed generation connected to medium voltage networks to deliver ancillary services to TSOs and DSOs. The Alava distribution network of Iberdrola was selected as the demonstration site (see **Figure 7**). It provides service to 169,000 low voltage customers from which 70% are urban, 12% sub-urban and 17% rural, in 30 kV or 13 kV. Although the design for the 30kV sub-transmission network is meshed, it is operated radially with several open circuit breakers. The Alava network has an installed DER capacity of 170 MVA. This is about 35% of the transformer capacity linking transmission and distribution networks [12].

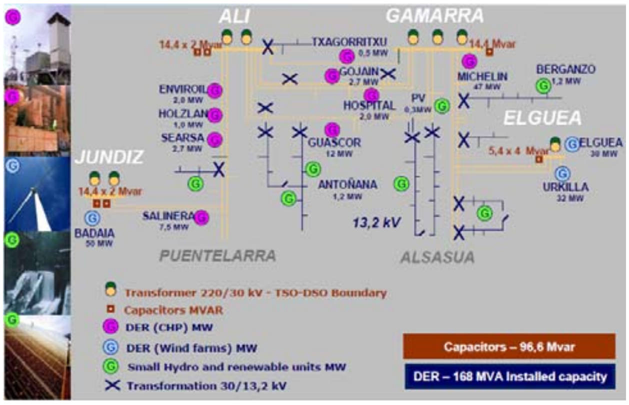

Figure 7: Alava network [13]

This FENIX architecture was adapted and deployed in Spain (see **Figure 8**) as a parallel control system (FENIX control system) in Iberdrola's DSO control centre, so as not to interfere with real operations. It uses real-time SCADA values of the Alava network region. The Distributed Energy Management System (DEMS) of Siemens, acting as Virtual Power Plant (CVPP), communicates with the FENIX Boxes over a GPRS network using IEC 104 and OPC protocols.

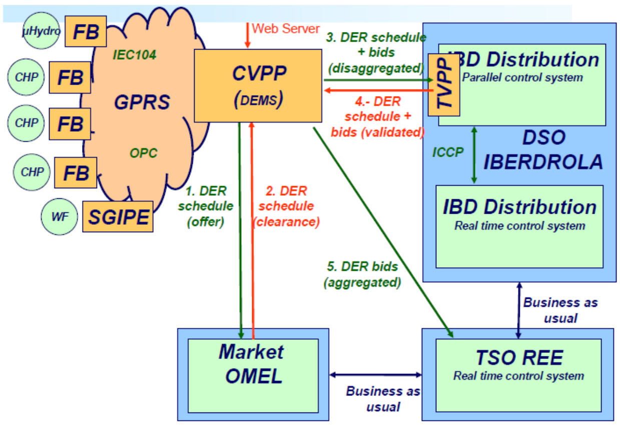

Figure 8: Southern Scenario Architecture [13]

To prove FENIX concepts, the following different use cases were defined and partly demonstrated in real Spanish networks [12]:

- Participation in the Day Ahead Energy Market
- Providing Tertiary Reserve
- Voltage Control
- Network Contingencies

Participation in the Day Ahead Energy Market:
Each DER unit communicates its position to the CVPP. The CVPP aggregates all bids into a single one and submits it to the Spanish Market (OMEL). After market clearance the CVPP disaggregates and informs the DSO (using TVPP) of the assigned output for each unit. The DSO validates the scheduled output and rejects or accepts each bid depending on its technical feasibility. After this validation by the DSO, the CVPP aggregates the modified bids and communicates them to the TSO for final validation. This process is also given in **Figure 8**.

Voltage Control:
DER units can support maintaining a certain voltage level at substation high voltage bus bars by providing reactive power. For that purpose a DMS tool called Volt Var Control (VVC) has been further developed by Siemens. It is an OPF based algorithm considering three possible actions: changing the reactive power output of DER units, changing transformer taps, or switching capacitor banks. It optimizes the use of these actions and calculates the needed reactive power for each DER unit [14].

4.3 Laboratory demonstrations

In addition to field demonstrations, laboratory demonstrations were also performed in FENIX. They took place in the laboratories of ISET in Germany and IDEA in France. IDEA demonstrated the local and co-ordinated real-time Volt Var Control (VVC) with real-time hardware equipment and network simulations. ISET demonstrates more generally the technological control capabilities of distributed generators and loads to provide ancillary services. Different types of demonstrations were performed at ISET's DeMoTec laboratory, including:

- optimised reactive power supply by distributed generators with the objective to minimise network congestion and operational costs,
- Voltage control, and
- Frequency control.

These laboratory demonstrations complement the field demonstrations in real networks.

6 Conclusion

The concept of Virtual Power Plants (i.e. aggregation of distributed generators in a centralized control architecture) was further developed in the European project FENIX and tested in real networks, namely with Iberdrola in Spain and EDF Energy in UK. The potential for active participation in power markets and distribution network operation was demonstrated.
Through the VPP concept [9]:

- Individual DER can gain access and visibility across all energy markets, and benefit from VPP market intelligence to optimise their position and maximise revenue opportunities.
- System operation can benefit from optimal use of all available capacity and increased efficiency of operation.

Benefits from the Virtual Power Plant concept of FENIX have been identified for different stakeholders:

Main benefits for owners of DER units:

- Capture the value of flexibility
- Increasing value of assets through the markets
- Reduced financial risk through aggregation
- Improved ability to negotiate commercial conditions

Main benefits for DSOs and TSOs:

- Increased visibility of DER units for consideration in network operation
- Using control flexibility of DER units for network management
- Improved use of grid investments
- Improved co-ordination between DSO and TSO
- Mitigate the complexity of operation caused by the growth of inflexible distributed generation

Main benefits for Policy Makers:

- Cost effective large-scale integration of renewable energies while maintaining system security
- Open the energy markets to small-scale participants
- Increasing the global efficiency of the electrical power system by capturing flexibility of DER units
- Facilitate the targets for renewable energy deployment and reduction of CO_2 emissions
- Improve consumer choice
- New employment opportunities

Main benefits for suppliers and aggregators

- New offers for consumers and DER units
- Mitigating commercial risk
- New business opportunities

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Martin Braun is a senior researcher at ISET, Kassel. He manages the group 'Decentralized Ancillary Services' in the R&D division 'Systems Engineering and Grid Integration'. Martin Braun studied Electrical Engineering and Economics at the University of Stuttgart, Germany. He received his Ph.D. at the University of Kassel with a thesis on the provision of ancillary services by distributed generators. His research activities focus on grid integration of distributed generators, storage and loads with special focus on applying them for optimized grid operation.