A European Project Supported by the European Commission within the Sixth Framework Programme for Research and Technological Development

fenix

'… a step towards the future of electricity networks'

Contract Nº: SES6 - 518272

Deliverable 1.4.0

The FENIX vision:
The Virtual Power Plant and system integration of distributed energy resources

Document type:	Deliverable 1.4.0
Main authors:	Danny Pudjianto, Charlotte Ramsay & Goran Strbac
Company:	Imperial College
Address:	Exhibition Road South Kensington London. SW7 2AZ UK
Telephone:	+44 (0) 20 7594 6169
Fax:	
Email:	danny.pudjianto@imperial.ac.uk charlotte.ramsay@imperial.ac.uk goran.strbac@imperial.ac.uk
Further Authors:	

Document information

Document ID:	Deliverable 1.4.0
Date:	21/12/2006
Issued by:	Imperial College
Work Package / task:	WP1
Status:	S2: Pending for Approval
Dissemination level:	CO – Confidential. Consortium only
Distribution:	FENIX Partners

Document history

Version	Date	Modification	Author
1		First version	D. Pudjianto, C. Ramsay, G. Strbac
2		Commented	J. Correra, J. Maire, J. Oyarzabal, F. Gorgette, I. Bel.
3		Second version	D. Pudjianto, C. Ramsay, G. Strbac

Approvals

	Name	Company	Date

Abstract

This paper presents the concept and the overarching structure of the Virtual Power Plant (VPP), the primary vehicle for delivery of the FENIX project aims. It describes the technical and commercial functionality facilitated through the VPP and proposes a new architecture for integration of these concepts into the activities of current market participants and new market entrants. The paper concludes with a description of the functionality and specification of the novel technology underlying the VPP concept.

CONTENTS

1 INTRODUCTION

1.1 The challenge for the future energy system

The current policy of installing distributed energy resources (DER) has been focused on connection rather than integration; typically DER have been installed with a "fit and forget" approach, based on the legacy of a passive distribution network. Under this regime, DER is not visible to the system so whilst it can displace energy produced by centralised generation it cannot displace this capacity. Without active management or representation to the system, DER lack the functionality required for system support and security activities, so centralised generation capacity must be retained to perform this function.

With growing pressure to increase DER penetration, this passive approach will lead to rising costs for investment and operation of the system and ultimately impact the pace of DER adoption. FENIX proposes an alternative to this, whereby DER (including responsive loads) are aggregated into controllable Virtual Power Plants (VPPs). When aggregated, these groups of DER would have system and market visibility, controllability and impact similar to a transmission connected generator.

Through the VPP concept:

- 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.

1.2 The transmission system analogy

The FENIX vision for DER integration through the VPP is analogous to some of the principles for operation established in transmission systems and traditional transmission connected plant.

For participation in transmission system management and current market activities, the VPP represents a portfolio of DER under a single profile. This makes the DER visible to the transmission system operator and presents a resource that can be used in the same way as transmission connected plant.

The same model can be transferred to the distribution networks; under FENIX, distribution network management changes from a passive to an active approach. Distribution networks become a regional version of the transmission network and the VPP provides location specific visibility of DER that allows the local network operator to interface directly with DER units in the network.

1.3 Aims of the FENIX project

To meet this challenge, the aim of FENIX is to conceptualise, design and demonstrate a technical architecture and commercial and regulatory framework that would enable systems based on DER (via VPPs) to become the solution for the future cost efficient, secure and sustainable EU electricity supply system.

The realisation of VPP based integration of DER is also concurrent with the evolution of competitive electricity markets. Through the FENIX long-term aim of greater visibility for DER and efficient use of existing capacity, there are opportunities for the development of markets in system management and the creation of new roles, frameworks and technologies to enable efficient DER system participation.

2 THE VIRTUAL POWER PLANT

2.1 The Virtual Power Plant Concept

The Virtual Power Plant (VPP) is comparable to transmission connected generating plant (Figure 1).

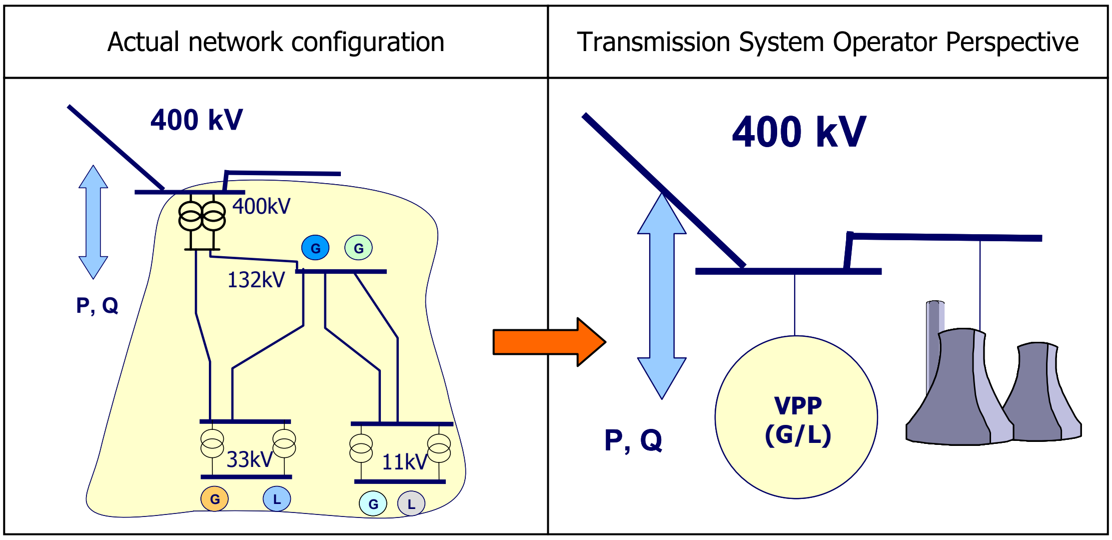

Figure 1: Characterisation of DER as a Virtual Power Plant

Transmission connected plant has a profile of characteristics e.g. schedule of generation, generation limits, operating cost characteristics etc.; using this profile individual plant can interact directly with other market participants to offer services and make contracts. Via direct communication with the transmission system operator or through market based transactions, a transmission connected generating unit can contribute to system management. Generation output and other associated services can be sold through interaction in the wholesale market or direct contact with energy suppliers and other parties.

When operating alone, many DER do not have sufficient capacity, flexibility or controllability to make these system management and market based activities cost effective or technically feasible. However, with the creation of a Virtual Power Plant from a group of DER, these issues can be counteracted.

A Virtual Power Plant is a flexible representation of a portfolio of DER. A VPP not only aggregates the capacity of many diverse DER, it also creates a single operating profile from a composite of the parameters characterising each DER and incorporates spatial (i.e. network) constraints into its description of the capabilities of the portfolio.

The VPP is characterised by parameters usually associated with a traditional transmission connected generator, such as scheduled output, ramp rates, voltage regulation capability, reserve etc). Furthermore, as the VPP will also incorporate controllable demands, and hence the parameters such as demand price elasticity, load recovery patterns will be used for characterisation of VPP. Table 1 outlines some examples of generator and controllable load parameters that can be aggregated and used to characterise the VPP.

Given that the VPP will be composed of a number of DER of various technologies with various patterns, the characteristics of the VPP may vary significantly in time. Furthermore, as the DER that belongs to a VPP will be connected to various points in the distribution network, the network characteristics (network topology, impedances, losses and constraints) will also impact the overall characterisation of the VPP.

Generator parameters	Controllable load parameters
• Schedule or profile of generation • Generation limits • Minimum stable generation output • Firm capacity and maximum capacity • Stand-by capacity • Active and reactive power loading capability • Ramp rate • Frequency response characteristic • Voltage regulating capability • Fault levels • Fault ride through characteristics • Fuel characteristics • Efficiency • Operating cost characteristics	• Schedule or profile of load • Elasticity of load to energy prices • Minimum and maximum load that can be rescheduled • Load recovery pattern

Table 1: Examples of generation and controllable load parameters for aggregation to characterise a Virtual Power Plant

As any transmission connected generator, the VPP can be used to facilitate DER trading in various energy markets (e.g. forward markets and the Power Exchange) and can provide services to support transmission system management (e.g. various types of reserve, frequency and voltage regulation etc). And supplementary to transmission connected generation activity, the VPP can also contribute to active management of distribution systems. In the FENIX project, these activities of market participation and system management and support are described respectively as "commercial" and "technical" activities, which derive two roles of Commercial VPP (CVPP) and Technical (TVPP).

The CVPP is a competitive market actor (e.g. an Energy Supplier). The composition of a CVPP portfolio is not necessarily constrained by location, although for participation in some markets DER may have to be managed by location. DER will contract with a CVPP to optimise their revenue potential and visibility in the energy and system management markets. The CVPP will manage the DER portfolio(s) to make optimal decisions on participation in these markets. A single distribution network area may be occupied by more than one CVPP aggregating the DER in its region. A DER is free to choose which ever CVPP offers them most favourable representation/compensation.

Because of locational requirements in provision of system management services, the TVPP is a monopoly role undertaken by the Distribution System Operator (DSO) as they are the only party with access to the necessary local system information. Therefore, a TVPP will include every DER in a distribution network region and will be able to present an accurate picture of the network at the point of connection with the transmission system, as well as calculating the contribution of each DER taking location and network constraints into consideration.

The TVPP will use DER operating and cost parameters (received via CVPPs operating in the local network) and local network knowledge to manage the local system and to calculate the characteristics of the network at the point of connection between distribution and transmission systems for submission to the transmission system operator to assist with transmission level balancing.

The activities of Commercial and Technical VPPs are described in more detail in sections 2.2 and 2.3, and the interaction between these two activities is outlined in section 2.4.

2.2 Commercial VPP activity

In a commercial context, the VPP provides the following:

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

The commercial VPP is a representation of a portfolio of DER that can be used to participate in energy markets in the same manner as transmission connected generating plant. For DER in the portfolio this approach reduces imbalance risk associated with lone operation in the market and provides the benefits of diversity of resource and increased capacity achieved through aggregation. DER can experience economies of scale in market participation and benefit from intelligence on market participation to maximise revenue opportunities.

2.2.1 CVPP participation in wholesale energy markets

In systems allowing unrestricted access to the wholesale markets (i.e. any system constraints caused by contracts in the market, or other locational issues are not accounted for at the time of contract creation), CVPPs can represent DER from any geographic location in the system. However, in markets where energy resource location is critical the CVPP portfolio will be restricted to include only DER from the same location (e.g. distribution network area or transmission network node). In these instances a CVPP can still represent DER from various locations, but aggregation of resources must occur by location, resulting in a set of DER portfolios defined by geographic location. This scenario is envisaged in, for example; (transmission system) Locational Marginal Pricing based markets and in markets where a zonal approach is taken to participation.

As part of optimising the performance of its DER portfolio, when activity in the wholesale markets is complete the CVPP will submit information on individual DER contract schedules and corresponding bids and offers (marginal cost) to adjust that position, to the TVPP.

2.2.2 CVPP Summary

Figure 2 summarises commercial VPP activity. Each DER that is included in the CVPP portfolio submits information on its operating parameters, marginal cost characteristics etc. These inputs are aggregated to create the single VPP profile representing the combined capacity of every DER in the portfolio. With the addition of market intelligence the CVPP will optimise the revenue potential of the portfolio making contracts in the PX and forward markets, and submitting information on the DER schedule and operating costs to the TVPP.

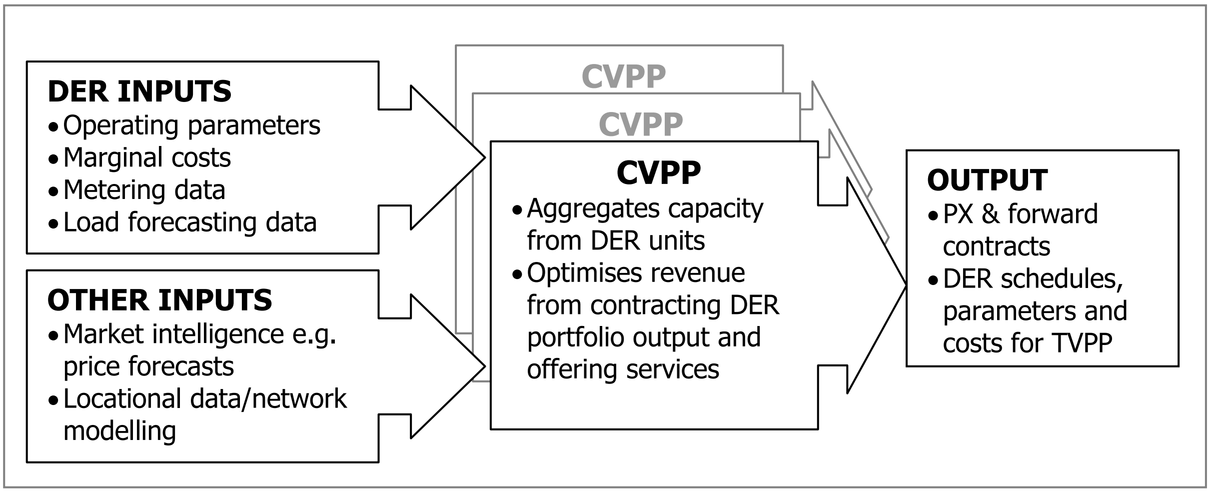

Figure 2: Inputs to- and output from CVPP activity

The CVPP can be composed of any number of DER, one distribution network area may contain many CVPP portfolios. This commercial VPP role can be undertaken by a number of market actors including incumbent Energy Suppliers, third party independents or new market entrants. DER are free to choose a CVPP to represent them in the wholesale market and to the TVPP.

2.3 Technical VPP activity

The Technical VPP provides the following:

- Visibility of DER to the system operator(s)
- DER contribution to system management activities
- Optimal use of DER capacity to provide technically feasible system services incorporating local network constraints

The technical VPP aggregates and models the response characteristics of a system containing DER, controllable loads and networks within a single electric-geographical (grid) area, essentially a description of sub-system operation. A hierarchy of TVPP aggregation may be created to characterise systematically the operation of DER at low, medium and high voltage regions of a local network, but at distribution-transmission network interfaces the TVPP presents a single profile representing the whole local network. This technical characterisation is equivalent to the characterisation that the transmission system operator has of transmission connected generation and corresponding transmission network topology.

2.3.1 TVPP participation in local system management and grid aggregation

The TVPP requires information on each DER within its local network region to facilitate active management of the local network and the technical characterisation/grid aggregation of the network at the transmission level. As described in section 2.2.1, this information is submitted on behalf of the DER by the CVPP. This is comparable to the generating position notification that transmission connected plant provide to the TSO.

In the local distribution network, DER operating positions, parameters and bids and offers collected from the CVPP can be used to improve DER visibility to the DSO and to assist with real-time or close to real-time network management, to provide scheduled ancillary services.

To facilitate DER activity at the transmission level, the TVPP aggregates the operating positions, parameters and cost data from each DER in the network together with detailed network information (topology, constraint information etc); calculating the contribution of each DER in the local system. The TVPP characterises the local network at its point of connection to the transmission system, using the same parameters as transmission connected plant (e.g. as outlined in Table 1). This TVPP grid aggregation profile and marginal cost calculation (reflecting the capabilities of the entire local network) can be evaluated by the TSO along with other bids and offers from transmission connected plant; to provide real time system balancing.

Carrying out TVPP activity requires local network knowledge and network control capabilities; typically the Distribution System Operator (DSO) will be best placed to fulfil this role. With this TVPP capability the DSO role can evolve to include active management of the distribution network, analogous to a transmission system operator. The DSO will continue to be a local monopoly and any additional active management responsibilities would need to be regulated activities.

2.3.2 TVPP interaction with transmission system balancing

At present, to participate in the transmission system balancing market requires market access; typically, this is a role undertaken by competitive, commercial market actors (e.g. Energy Suppliers). However, to characterise correctly the VPP contribution at the point of distribution-transmission connection also requires detailed, dynamic knowledge of the local network and to characterise the contribution of an individual DER to transmission system balancing in the context of the network, also requires a perspective of the resource in the context of the whole local network. Clearly, the DSO is optimally placed to understand how network conditions and constraints will contribute to the TVPP characterisation and individual DER capabilities.

So, to offer the aggregated DER profile created by the TVPP to the transmission system requires both a commercial and technical actor. There are arguments for the TVPP taking this role and participating directly in the market, or for CVPPs to become the transmission market interface (with the TVPP validating proposed CVPP schedules) or another entirely different solution involving new/different market actors. Indeed, there are several options to facilitate this interaction, all of which raise a variety of technical, commercial and regulatory questions that the FENIX project aims to explore.

2.3.3 TVPP Summary

Figure 3 summarises the TVPP activity. TVPP activity involves the management of local network constraints (i.e. active distribution network management) and grid aggregation of a distribution network area to characterise the contribution and characteristics of the local network at its point of connection with the transmission system. TVPPs are composed of all DER from a single distribution network area.

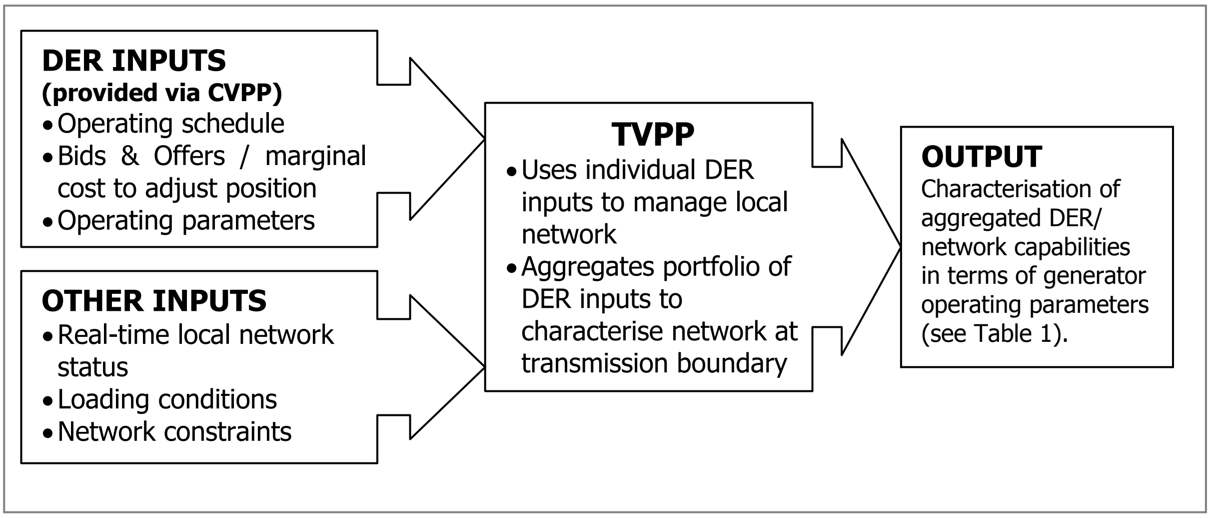

Figure 3: Inputs to-and outputs from TVPP activity

Information on DER in the local network is passed through by the various CVPPs that represent DER in the area. The TVPP will use this information in conjunction with detailed network information e.g. topology, network constraints etc, to characterise the contribution of the distribution network (and associated generation and loads) at the point of connection to the transmission system.

This characterisation can be used at the transmission level to provide DER derived transmission system balancing services. Whether the TVPP, CVPP or another agent will use this characterisation and participate in the transmission system balancing market is a new area for exploration and a matter for the FENIX project to investigate in more detail.

2.4 CVPP & TVPP interaction

Figure 4 illustrates the respective roles of the Commercial and Technical VPPs and their interaction with each other and the wider market. The CVPP is operational in the energy markets, and responsible for passing information on DER through to the TVPP. The TVPP is engaged in system management, and facilitates management of local network constraints as well as aggregating DER with local network parameters for presentation at transmission level.

The CVPP optimises the position of its portfolio with reference to the wholesale markets, and passes DER schedules and operating parameters on to the TVPP. The DSO/TVPP uses input from the CVPPs operating in its area to manage any local network constraints and determine the characteristics of the entire local network at the transmission connection point. This can then be used to offer transmission balancing services which the transmission system operator can evaluate along with bids and offers from transmission connected generation.

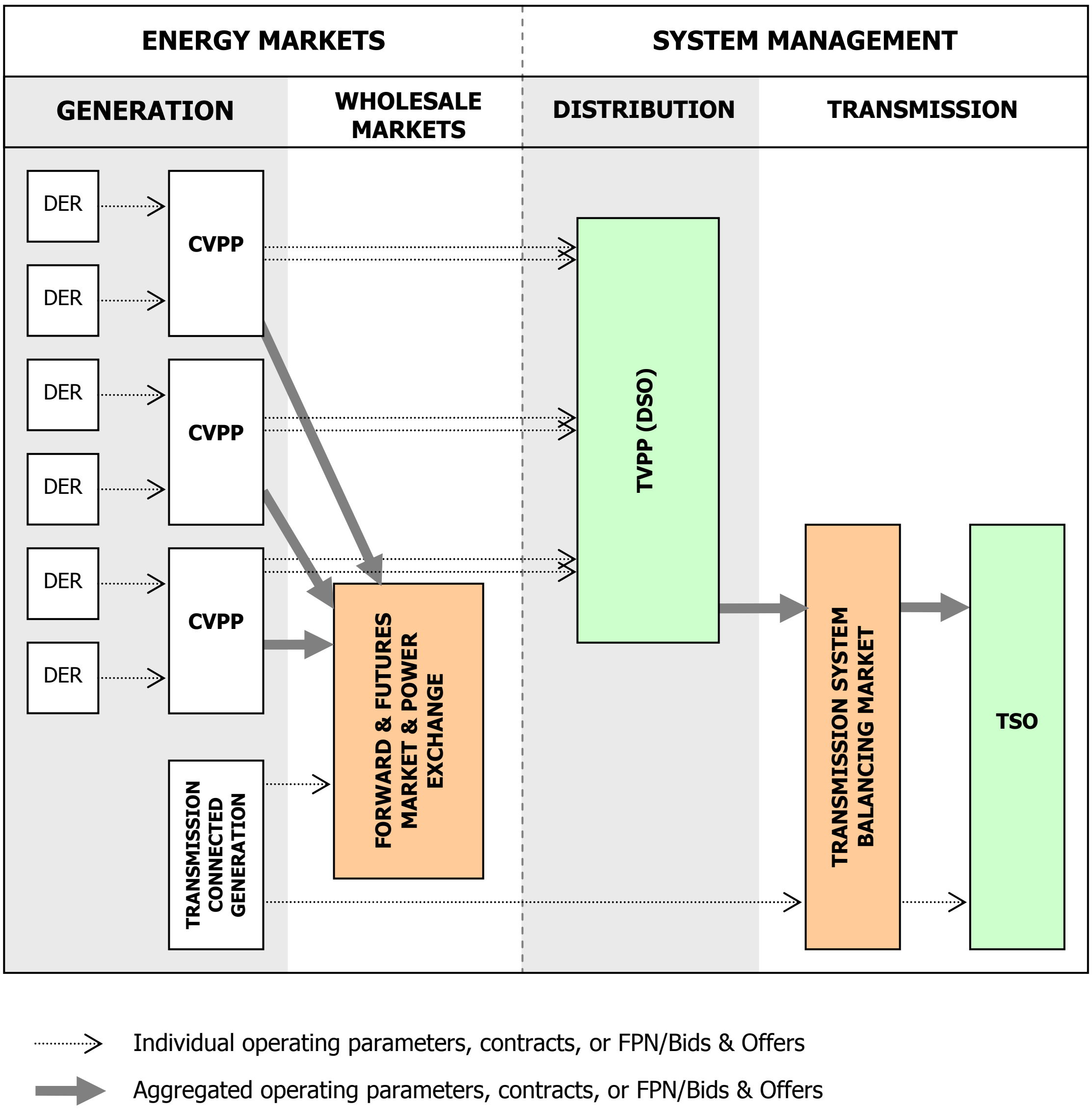

Figure 4: Commercial and Technical VPP activity in energy market and system management context

2.5 FENIX-VPP technology architecture

The architecture of the FENIX technology is based on a hierarchical structure that will allow complete scalability of the concept to incorporate thousands to millions of DER units in a single VPP.

At the DER level, each unit becoming part of the VPP is linked to a "FENIX Box", a low-cost intelligent meter with monitoring and control capabilities capable of sending data and control/operation parameters to- and receiving instruction from the VPP systems.

FENIX enabled DER are linked to the FENIX-VPP via a communication network designed to facilitate progressive concentration of multiple DER data signals; this will ensure the scalability of the FENIX-VPP concept up to potentially millions of units in a single VPP.

The FENIX-VPP itself is a system with unique data management and characterisation functions, that enables it to emulate a transmission connected conventional generator. The FENIX-VPP aggregation algorithms will calculate the composite operating profile and capabilities of the VPP, incorporating the operating parameters and locational constraints of all DER in the portfolio. This composite profile is then used to provide various market and system services.

The FENIX-VPP has dispatch functions that allow communication back to the DER in the portfolio to instruct on dispatch according to contracts made in the markets or necessary for system management.

The FENIX project is investigating novel solutions to facilitate both commercial and technical VPP activities. But, within the FENIX vision there is also scope for alternative software and technology solutions to the FENIX-VPP to be devised by new market entrants or existing providers of similar technologies.

3 THE FENIX FUTURE & VPP IN CONTEXT

At present, several power systems across Europe are near realising aspects of the commercial VPP approach. Low levels of DER have been integrated into some commercial electricity markets and there are several examples of nascent VPP roles developing in the areas of commercial consolidation for wholesale and scheduled ancillary service market access.

As DER penetration increases, the FENIX vision proposes that power markets begin the transition towards an increasingly integrative approach that embraces the technical VPP activity; namely, a system that integrates DER fully in all aspects system management as well as electricity market participation.

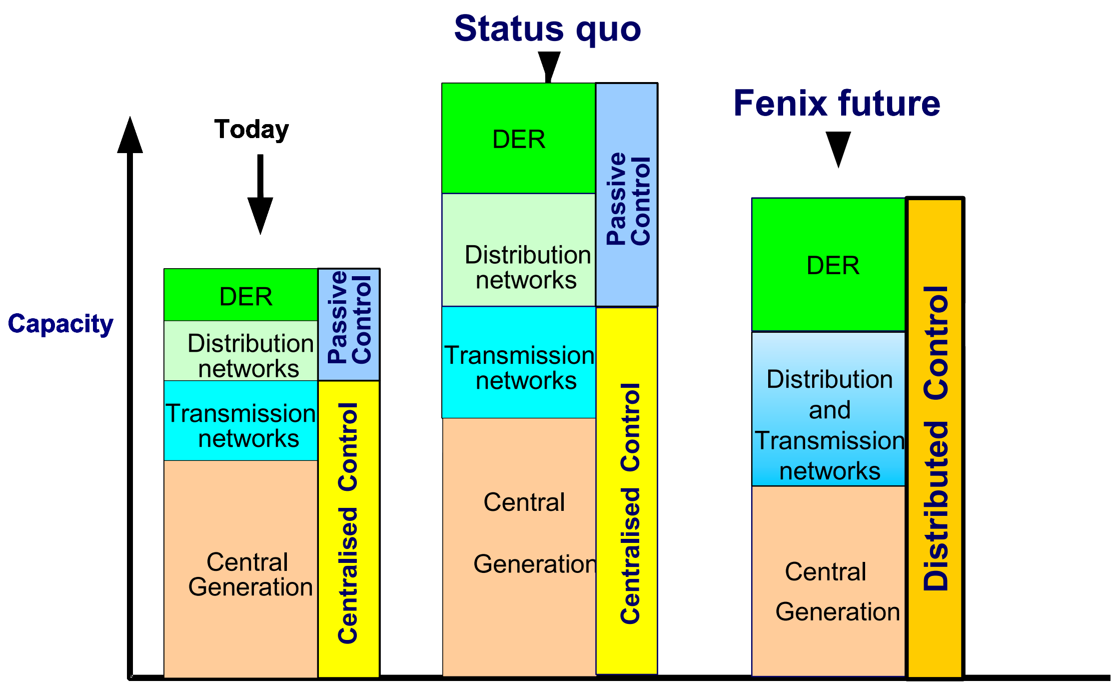

Figure 5: Relative levels of system capacity

Figure 5 shows a schematic representation of the capacities of DER, distribution and transmission networks as well as central generation of today's system and its future development under two alternative scenarios both with increased penetration of DER. "Status quo" Future represents system development under a traditional system operation paradigm characterised by centralised control and passive distribution networks as today. The alternative, FENIX Future, represents the system capacities with DER and the demand side fully integrated into system operation under a decentralised operating paradigm incorporating both commercial and technical VPP activity.

Under the status quo future, it is apparent that without technical integration of DER into the system, large penetration of DER may displace the energy produced by conventional plant. However, conventional generation continues to be necessary for provision of system support services (e.g. load following, frequency and voltage regulation, reserves etc.) required to maintain security and integrity of the system. In addition, given that a significant proportion of DER is likely to be connected to distribution networks, maintaining the traditional passive operation of these networks and centralised control will necessitate increase in capacities of both the transmission and distribution networks, increasing overall system costs and reducing the efficiency of system use.

On the other hand, by fully integrating DER and demand side into network operation, using the VPP approach, DER and the demand side will take the responsibility for delivery of system support services taking over the role of central generation. In this case DER will be able to displace not only energy produced by central generation but also its controllability reducing the capacity of central generation as in shown in the figure. To achieve the distribution networks operating practice will need to change from passive to active necessitating a shift from traditional central control philosophy to a new distributed control paradigm, including significant contribution of demand side necessary to enhance the control capability of the system.

This transition towards full integration of DER through the commercial and technical VPP will cause:

1) An increase in system complexity, and
2) An increase in system value.

System management in the across the networks will become more complex. For example, as the transition towards active networks is made and commercial, technical and regulatory frameworks are put in place to allow DER representation and participation in system operation. The energy markets and interaction with market participants will become more complex as the associated regulatory frameworks, contractual arrangements, metering and billing requirements across the system adapt to represent fully integrated DER and deal with a dramatic increase in volume of transactions.

However, this necessary increase in complexity to deal with large numbers of small scale distributed resources will also facilitate realisation of the true value of DER in the system. It will improve DER access to energy and system management markets, optimising the utilisation of system capacity and the efficiency of operation.

To realise this future of system integration of DER via the VPP, FENIX is addressing three key areas of research:

1. Requirements and design of VPP: What can DER can offer? What can be resolved by DER? How can DER portfolios be characterised as VPPs? What services and activities can the VPP provide? (Work Package 1: Trading functions and system solutions for DER and demand response integration)
2. System control: What new Distribution Management System / Energy Management System applications are required to make use of DER and VPP based services? (Work Package 2: Electrical and ICT system architecture)
3. Commercial and regulatory framework: What is the commercial and regulatory framework required to support integration based on VPPs? (Work Package 3: Commercial and Regulatory framework for VPPs)

Key features of the developed Fenix VPP concept, software and technology will be also demonstrated (Work Package 4: Northern and Southern Scenario Demonstrations of VPP activity).

4 GLOSSARY

Virtual Power Plant (VPP)
A Virtual Power Plant is a flexible representation of a portfolio of DER. A VPP not only aggregates the capacity of many diverse DER, it also creates a single operating profile from a composite of the parameters characterising each DER and incorporates spatial (i.e. network) constraints into its description of the capabilities of the portfolio.

Commercial Virtual Power Plant (CVPP)
A VPP that is used to make contracts for DER output in the wholesale energy markets.
A market actor using a CVPP to aggregate DER facilitates:

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

Technical Virtual Power Plant (TVPP)
A VPP that is used to offer DER system management services to the system operator
An actor using a TVPP to aggregate DER facilitates:

- Visibility of DER to the system operator(s)
- DER contribution to system management activities
- Optimal use of DER capacity to provide technically feasible system services incorporating local network constraints

Distributed Energy Resources (DER)
Distributed Energy Resources are generation units and/or controllable loads, connected to the distribution network.