Distributed Generation and Virtual Power Plants: Barriers and Solutions

Master Thesis Sustainable Development – Energy and Resources

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Abstract

This research focuses on the applicability of the Virtual Power Plant (VPP) concept as a solution to overcome integration barriers for distributed generation (DG) into the grid, with a focus on the situation in the Netherlands. As the amount of DG is expected to steadily increase, the current technological and regulatory system needs to adapt to the shift from large, centralised generation by fossil fuel fired power plants towards small scale, distributed generation in combined heat and power (CHP) and renewable generation units. The current grid system forms technological and regulatory barriers to this transition. Additionally, energy economics at this moment do not favour DG, as the market is concentrated merely around large-scale generation.

For the Netherlands, a scenario is sketched for the year 2020, in which particularly the amount of PV solar and wind are expected to increase. In the field of CHP, growth is expected for conventional CHP as well as a rise in micro-CHP, which is currently not yet widely employed.

The technological barriers that have been identified consist of system reliability and power quality issues. System reliability is affected by reverse power flows that are caused by energy sources connected to distribution networks. Power quality issues include a variety of factors, amongst which voltage and frequency reliability appear to be the most relevant. Economic barriers include pricing and metering of DG, access to wholesale markets for DG, connection charges for DG, allocation of network investment costs, and the intermittent nature of DG. Regulatory barriers comprise the allocation of network losses costs where DG is involved, and the provision of ancillary services by DG to network operators.

The VPP concept is subsequently defined and broken down into different layers. The base is formed by distributed energy resources (DER), which include DG, demand response (DR) and energy storage. These are connected with smart grid technology to an energy management system (EMS), which puts forward schedules and dispatches DER according to geographical, technological, financial or other criteria. The EMS itself communicates with and participates in energy wholesale markets and markets for ancillary services. This structure redefines the current energy system drastically.

Literature and practical experience with several kinds of VPPs shows that all barriers can be overcome, with the exception of the economic unfeasibility of DG power sales, which cannot be guaranteed by sales into wholesale markets. Adaptions of the regulatory system remain necessary, but the conditions on which these adoptions can take place are greatly improved when VPPs are in place. As a recommendation for further research, particularly the focus on other countries, the trade-off between storage, DR and DG and longer-term energy systems are recommended.

1. Introduction

The background and motivation of the research are introduced in 1.1. An overview of literature on relevant research on the subject is given in 1.2. Through this research overview, research possibilities are identified, which lead to the problem statement and research objective, described in 1.3. In 1.4 the research framework is outlined, and in 1.5 the research questions are presented. In 1.6, an outline of the thesis is presented.

1.1 Background

The transition from conventional to renewable energy sources is on-going. In 2008, the EU heads of state and government set a target of 20% of the EU energy consumptions to come from renewable resources by the year 2020 (EU, 2008). In the Netherlands, individual targets have been set for energy efficiency (20% improvement), greenhouse gas reduction (30%) and renewable energy share (20%) in 2020. A major part of these targets is expected to be accomplished by increasing the share of renewable energy sources and combined heat and power (CHP) in the energy market.

Opposed to conventional, centralised power plant, these renewable energy resources and CHP units often appear as distributed generation (DG). To facilitate this transition, the way the electricity transmission and distribution system (the electricity grid) is laid out will have to change. Instead of one-way, single-level provision of electricity from power plants to end users, smart grids will emerge, either grid-connected or stand-alone. The electro-infrastructural situation is different in every country; the focus will be on the situation in the Netherlands in this research.

Conventional power generation occurs in highly centralized power plants, fired mostly by coal or natural gas. Technologies exist to produce clean electricity in a centralized way: hydropower, possibly nuclear power and concentrated solar power are centralized energy production methods. Many renewable energy resources however, such as wind power, PV solar power, fuel cells and biofuel CHP, are commonly produced in a dispersed setting. Therefore, decentralized power generation is an inevitable aspect of the production of clean and renewable energy. The existing electricity grid is designed for conventional, centralized power generation, which limits the transition to renewable energy production.

A magnitude of research has been done on the question how to integrate distributed resources into existing electricity grids. Various issues pose a challenge to wide-spread integration. It appears from the literature that these issues are mostly technological, commercial (economic) and regulatory (political) in nature. A comprehensive method to address all these issues may be found in the transition from conventional power plants to so-called Virtual Power Plants (VPP). A VPP consists of a cluster of distributed generation (DG) units which are centrally driven by a control system. An ideal VPP has the ability to solve technical barriers (e.g. by maintaining grid stability through applying load management), commercial barriers (e.g. by providing economic efficiency by energy trading), and regulatory barriers (e.g. by allocating costs and benefits of power consumption and production to various players involved).

1.2 Literature overview

Literature has partially focused on the technological potential of VPPs. Braun (2009) categorizes the VPP into a commercial and technical variant and provides an in-depth view on two VPP European pilot projects. Also in this study, the potential of network voltage control through aggregation in a VPP is shown, and compared to the potential to other approaches. Bosman et al. (2009) models VPP too and finds an optimal method for distributed production planning of a group of micro-CHP units in the Netherlands. Dimas (2007) tries to find an architecture for optimal and effective control of a VPP, including several case studies. The agent-based control system is found to be a suitable solution, however no other architectures are considered. Setiawan (2007) also seeks to find an optimal control system for a VPP, by modelling different VPP components. An optimal control method is found that minimalizes power exchange with the superior grid and optimizes efficiency of DG. Furthermore, the potential for voltage control is modelled and shown to be vast. Mutale (2010) provides an overview of the mathematical modelling of the VPP, demonstrating the guidelines for creating a user-friendly VPP control tool.

Another research area is the economic viability of VPPs. NREL (2004) demonstrates the technical and economic viability of aggregation of DG resources through a pilot project in New York. Power reliability is improved through intensive quality control. Economic efficiency is shown by an annual profit of the system operation of $1.5 million. Wille-Hausmann et al. (2009) shows that a high economic potential exists for cost savings by operating CHP plants through a VPP. Additionally, this study shows the potential of balancing fluctuating generation with CHP by a VPP. Kok (2009) analyses optimal bidding strategies for VPP delivering real-time balancing services. It is found that a bidding strategy spectrum exists: On one end of the spectrum, bidding strategies are based straightforwardly on true marginal cost or benefit. Further along the spectrum, optimal bidding strategies become less dependent on marginal cost levels and more on the price dynamics in the VPP market context.

Research conducted has generally focused on one aspect of VPP, particularly technical, economic or regulatory; the interrelation between these aspects has been little explored. Exceptionally, Werner and Remberg (2008) combine these three aspects and present an overview of the ICT and software requirements for a VPP, possible economic purposes of a VPP and give an overview of the regulatory problems in the German power system.

Most studies that have been performed have comprised only one form of VPP architecture, without comparing other forms of architectures; other studies focus on one specific type of generation (commonly CHP). You et al. (2008) does compare two alternatives for VPP, a general bidding scenario and a price signal control scenario. However, no other DG resource then micro-CHP is studied here.

There is no known work in which case studies from different experimental regions have been compared. Additionally, no research has specifically focused on the specific Dutch technical and regulatory environment.

1.3 Problem statement and research objective

1.3.1 Problem statement

The share of DG units in the energy system will need to increase in order to reach the targets set for energy efficiency, greenhouse gas emission reduction and renewable energy share that have been committed to. However, integration of DG is hampered by various barriers that are inherent to the energy system, and can be technical, economic or regulatory in nature. The combination of DG into a VPP is expected to represent a system change that can overcome a multitude of these barriers.

It can be seen in the literature overview that it is yet uncertain what the potential and the benefit of implementing VPP in the Netherlands is, and what will be the best form for the Dutch technological and regulatory environment.

1.3.2 Research objective

The aim of this research is to determine how and to what extent VPP can overcome the technological, economic and regulatory barriers to DG integration, with a focus on the situation and regulatory environment of the Netherlands.

1.4 Research framework

Firstly, an analysis is performed of the nature and amount of DG resources, and a prospect is given about growth potential of these resources. The relevant aspects of the Dutch electricity grids are summarized in order to put the situation into a domestic perspective.

Secondly, the current and potential technological barriers that may prohibit growth towards the set targets are summed up. The same is done for regulatory and economic barriers. The amount to which these specific barriers actually prohibit growth in the Netherlands is evaluated.

Thirdly, different concepts (partially) designed to support DG integration are specified. The VPP concept will be defined and clearly distinguished from other concepts and terminology. Within the VPP definition, the concept is decomposed into elements and several sub-definitions are highlighted, in order to get an overview of different forms and interpretations of VPP currently in practice.

Finally, the potential of the VPP concept to overcome barriers to DG integration is determined, and the relevance and shortcomings of different VPP forms for the Dutch situation is evaluated.

The practice of conducting the research comprises two stages. The first stage consists of literature research, in which the issue of DG integration, prospects of DG integration and possible future grid concepts are derived from existing literature. In the second stage, relevant stakeholders in the transition towards future DG-friendly grid architecture are consulted. This stage consists of a critical investigation of the experiences and views of people and organizations that have interest in this kind of power system transitions.

- The first objective of this research is to identify all the major economic, technological and regulatory barriers that play a role in the integration of DG resources into the electricity grid in the Netherlands. The method to achieve this objective is by literature research and stakeholder consultation.
- The second objective is to define the VPP concept and to compare it to other possible future architectures that may accommodate the smart grid. This objective is achieved by literature research and by conducting interviews with relevant stakeholders in the power industry.
- The third and final objective is to determine what the VPP's potential is to reduce barriers to DG integration in the Netherlands, and how this potential compares to the potential of other possible future architectures.

1.5 Research questions

The main research question is:

"How and to what extent can VPP overcome the technological, economic and regulatory barriers to DG integration, within situation and regulatory environment of the Netherlands?"

The main research question is divided into several sub-questions, which are each split up into specific sub-questions.

A. *What is the state of integration of DG in the Netherlands, how is the physical and regulatory environment organised, and what are the prospects for DG growth?*

- *What is the nature and amount of DG currently installed?*
- *What will be the nature and amount of DG installed in 2020?*
- *Who are the stakeholders for DG integration?*
- *What is the physical state of the electricity network, with respect do DG?*
- *How is the regulatory environment organised?*

These questions will be answered by desk research and a limited amount of interviews with research institutes.

B. *Which are the current and potential barriers to further DG integration in the Netherlands, and to what extent do they prohibit DG growth?*

- *Which are the current and possible technological barriers to DG growth?*
- *Which are the current and possible economic barriers to DG growth?*
- *Which are the current and possible regulatory barriers to DG growth?*
- *To what extent to technological barriers prohibit further DG integration?*
- *To what extent to economic barriers prohibit further DG integration?*
- *To what extent to regulatory barriers prohibit further DG integration?*

The answers to the first three questions can be found in literature previously done on the topic of DG integration. The latter three questions will be answered by desk research and interviews with stakeholders.

C. *How does the VPP model compare to other possible grid architectures, and what categories of VPP can be distinguished?*

- *Which are the possible grid architectures that may facilitate DG integration?*
- *What is a VPP and what are its characteristics?*
- *What categories of VPP exist and what are their characteristics?*

The answers to these three questions can be found in literature on Smart Grid technologies and market analysis.

D. *To what extent can the VPP model overcome barriers to DG integration, and which are the relevancies and shortcomings of different VPP forms?*

- *Which barriers to DG integration can be addressed by VPP?*
- *What VPP forms are currently in practice?*
- *What are the results from VPP projects currently in practice?*
- *To what extent do the results of current VPP projects meet the requirements for facilitating DG integration?*
- *What uncertainties remain for the implementation of a VPP in the Netherlands?*

The answers to the first question can be found by linking the results found in B to the results found in C. The answers to the second question can be found by market analysis. The answer to the third question can be found by research of case studies and interviews with stakeholders involved. The answers to the latter two questions can be found by desk research and by linking the previously found results together.

1.6 Thesis outline

Firstly, a general introduction to this thesis, including the research background, framework, and research questions, is given in chapter 1. In chapter 2, the nature and amount of DG in the Netherlands is evaluated, the technical and regulatory environment is outlined and the relevant stakeholders are identified. Subsequently, in chapter 3, the actual and potential economic, technological and regulatory barriers to DG integration are identified and their respective potential to prohibit DG growth is analysed. Chapter 4 continues with an overview of smart grid-architectures that can be identified in theory and practice, and may help overcome barriers mentioned in the previous chapter. Also in this chapter, the VPP concept is described and various categories are distinguished. In chapter 5, the results from chapter 3 and 4 are linked to find which barriers to DG integration can be addressed by VPP. Also, results from case studies conducted at operating VPP projects are analysed, and it is determined to what extent these project have the potential to facilitate DG integration. Finally, a reflection upon the research and recommendations for further research are given in chapter 6.

2 DG in the Netherlands

In this chapter, the technical and regulatory situation for DG in the Netherlands is outlined. This enables putting the DG integration question into a national perspective. In 2.1, the amount and nature of DG in the Netherlands is summed up and a scenario is created for DG capacity growth until 2020. In 2.2, the technical environment, consisting of the national transmission and distribution systems, is dealt with. The emphasis is on aspects that are relevant to DG integration. Finally, section 2.3 deals with the regulatory environment for DG. Here, the Dutch regulatory system is put in an international perspective and relevant stakeholders in the DG field are identified.

2.1 Definition of distributed generation

The benefits of distributed generation are well-documented. Increasing the number of generation stations and distributing them over a larger geographic area decreases transmission distances, reducing energy loss and lowering pressure on the energy grid. Distributed generation can increase energy supply security by spreading the load between multiple energy sources, decreasing the likelihood of brownouts or blackouts as a result of the failure of a single energy source (Pepermans et al, 2005; Willis & Scott, 2000). Furthermore, the transition towards an efficient and sustainable energy supply requires making use of distributed energy resources, as generation used based on renewable energy resources and CHP units often appear as distributed generation units. Distributed generation requires some deregulation of the energy sector, allowing energy generation by those other than the major utilities.

Several definitions and interpretations exist of the concept of distributed generation. Commonly, there is a maximum limit to the size of the DG generation unit in the range of 50-100 MW. The Gas Research Institute (GRI) defines distributed generation as "generation smaller than 25 MW" (GRI, 1998), whereas the International Council on Large Electricity Systems (CIGRE) sets this limit at 50-100 MW, with the notion that DG is "usually connected to the distribution network (CIRED, 1999). The International Energy Agency (IEA) sets no capacity limit, but instead defines DG as "power generation equipment and system used generally at distribution level and where the power is used locally on site" (IEA, 2002).

In this research, all power generation that is connected to the distribution network (as opposed to being connected to the transmission network) is considered distributed generation (DG). Distributed generation can be broken down into two main categories: renewable energy sources (RES) and combined heat and power (CHP). CHP plants are not renewable power sources, but they are assumed to play a large role in achieving CO_2-emission reduction targets set by the Dutch government (30% reduction in CO_2-emission in 2020, compared to 1990). CHP will therefore be included as a topic of interest in this research. However, not all RES and CHP can be considered distributed energy sources, e.g. large hydropower dams and geothermal energy plants are RES but not DG. In table 2.1 it is shown which types of generation are considered DG in this research, and which are not. Hydropower dams are considered "large" when their capacity exceeds 10 MWe. Micro CHP refers to units <3 kW, industrial CHP refers to units > 50

MW. In table 1, different generation resources that are found in the Netherlands are divided in categories, with large-scale generation vs. DG on the one hand and CHP vs. RES on the other.

	Large-scale generation	Distributed generation (DG)
CHP	District heating Industrial CHP	CHP (remaining) Micro CHP
RES	Large hydropower dams Geothermal energy Offshore wind power	Small hydropower PV Solar power On-shore wind power Bio-CHP Fuel cells

Table 1 - Division of DG resources over categories CHP/RES and large scale/DG

In section 2.1.1-2.1.5, all resources that fit within the DG category according to Table 1 will be described and their expected growth is estimated. Results of this estimation are listed in Table 2.

2.1.1 CHP

The majority of installed DG capacity in the Netherlands currently consists of CHP plants. In 2009, the total amount of CHP capacity amounts to over 12,000 MWe (COGEN, 2009), producing 40-50% of the total electricity consumption in the Netherlands . More than half of this capacity is taken up by industrial-scale CHP, which is not considered DG. The share of distributed CHP, including mini-CHP (<100 kW), is approximately 40%. A considerable share (2,500 MWe) of the gas engine CHP plants is located in horticultural areas, providing power to the grid and heat to greenhouses. Horticultural CHP has also been the responsible party for the overall growth in CHP capacity over the last years (COGEN, 2009). The share of biomass and biomass co-firing in the total electricity production being approximately 2.5% (IEA, 2004), it is estimated that 5-6% of DG CHP is made up by biomass.

Presently, a negligible amount of micro-CHP units (MWe < 3 kW) is present in Dutch households (Cogen, 2005). Recently, several field-test have been conducted, in which the operation of micro-CHP in households has been studied. In 2008, 100 micro-CHPs were tested in households; in 2009, 200 units were tested (MicroWKK, 2010). Currently, the test phase is considered accomplished and the market is ready to grow (MicroWKK, 2010). Prospects for micro-CHP are sizable, as within current policy the 2020 target for micro-CHP units in Dutch households is 1.6 million (SenterNovem, 2010).

2.1.2 Small hydropower

The use of hydropower in the Netherlands is limited, as no major changes of altitude occur in the Dutch landscape, limiting the options for the construction of dams. Nevertheless, approximately 38 MW of conventional hydropower capacity has been installed so far. The major part of this consists of three over 10 MW hydropower plants. Some extra capacity is generated by a number of small-scale traditional watermills at <100 kW (MHP, 2008). The Dutch government has set the target for hydropower to 100 MW in 2020 (Boonstoppel, 2007).

2.1.3 PV solar power

The installed capacity of photovoltaic (PV) solar power in the Netherlands is approximately 60 MW (CBS Statline, 2010), representing a very small share of the country's total DG and renewable energy resources. Future forecasts of growth in capacity are highly dependent on the assumed policy. Holland Solar (2005) provides a scenario of PV solar growth in the Netherlands in the case of a favourable policy. Estimates are made for 2015 (500 MW) and 2030 (6 GW). This growth curve gives 2,000 MW as the installed capacity prospect for PV in 2020.

2.1.4 On-shore wind power

Currently, the total installed wind power capacity in the Netherlands amounts to 2.2 GW, including on- and offshore wind turbines (GWEC, 2010). As off-shore turbines are typically integrated into the transmission grid, while on-shore wind turbines deliver power to regional distribution grids, only the on-shore share is included as DG. The total capacity of installed on-shore turbines is currently approximately 2,0 GW (WSH, 2010). Wind power is expected to contribute majorly to the governments 2020 targets of 20% renewable energy production, but growth is mostly planned in the off-shore branch.

The Dutch Wind Power Association strives for an installed capacity of 6,000 MW of on-shore wind energy in 2020 (NWEA, 2007). Besides large-scale wind turbines, growth is also expected in the microturbine domain. The estimates for microturbine capacity in 2020 vary between 60 MW and 517 MW (IEE, 2007). A high estimate of 500 MW is used here, however it must be noted that this is uncertain and highly dependent on technological innovation in the microturbine field. This additional capacity sets the total projected on-shore wind power capacity to 6.5 GW in 2020.

2.1.5 Fuel Cells

At the time of writing, no significant amount of fuel cells is used for energy production in the Netherlands. Growth projections are uncertain and strongly dependent on unknown variables, e.g. innovation, technological development and research funding. Therefore, no assumptions are made on fuel cell growth up to 2020.

In table 2, the current installed capacity is listed per DG category, along with the expected capacity in 2020. It can be seen that the total amount of DG is 8,308 MW as of 2010, which is approximately one third of total generation capacity, which is displayed in the extrapolated data from EIA (2010) below. In 2020, DG will amount to 16,900, which is roughly half of the expected total generation capacity. It has to be noted that these numbers are highly dependent on factors influencing growth, such as energy prices, policy incentives and various barriers to growth.

Year	**2007**	**2008**	**2009**	**2010**	**2011**	**###**	**2020**
Total generating capacity	24 GW	25 GW	25 GW	26 GW	27 GW	###	34 GW

DG type	Generating capacity 2010	Generating capacity 2020
Micro CHP (<3 kW)		1,600 MW
CHP (< 50 MW)	4,200 MW	6,700 MW
Small hydropower	38 MW	100 MW
PV Solar power	60 MW	2,000 MW
On-shore wind turbines	2,000 MW	6,500 MW
Total	**8,308 MW**	**16,900 MW**

Table 2 – Total and DG generation capacity growth 2010 – 2020

It can be seen that, within the boundaries of uncertainty of the used growth prospects, DG capacity will be likely to double in the upcoming decade. Besides this, the composition of the DG group will likely change; the CHP-dominated DG market will evolve into a more equally mixed one, where large shares are also taken up by wind power, PV solar power and micro-CHP. This development can be seen in figure 1.

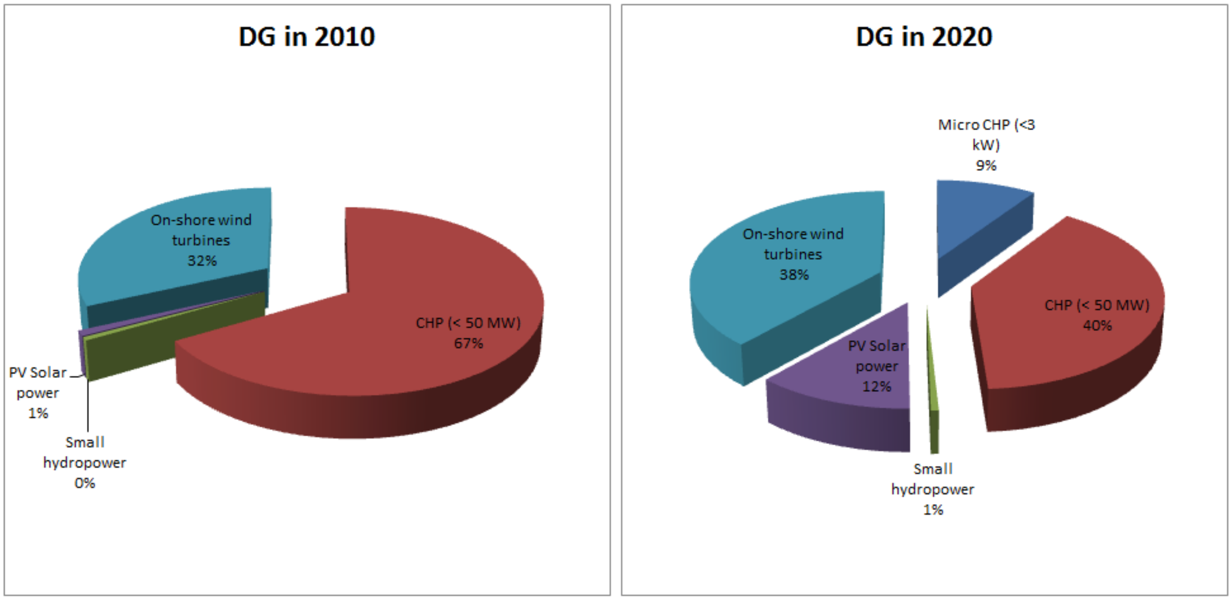

Figure 1 - DG resource division in 2009 – 2020

2.2 Technical environment

In the Netherlands, the standardized voltage levels are divided into three categories: low voltage level (LV), medium voltage level (MV) and high voltage level (HV). These categories are defined as follows:

- *Low voltage (LV) level* is defined as voltage levels with phase-to-phase voltages up to and including 1000 V (AC) or up to including 1500 V (DC). The low-voltage distribution grid is typically at 230/400 V.
- *Medium voltage (MV) level* is defined as a voltage level with phase-to-phase voltages higher than 1000 V and up to 110 kV AC. The urban distribution grid *(Stedelijk Distributienetwerk)* typically operates at 10 kW medium voltage level. The urban transport grid *(Stedelijk Transportnetwerk)* operates at levels of 10 and 50 kV. Grids with voltages up to 50 kV form the Dutch distribution grid.
- *High voltage (HV) level* is defined as a voltage level with phase-to-phase voltages higher than 110 kV. The provincial and national transmission grid *(Provinciaal* and *Landelijk Koppelnet)* operate at HV levels of 110 up to 380 kV AC.

The Dutch electricity transmission system is managed and operated by the national *Transmission System Operator* (TSO) TenneT, which is legally separated from electricity companies. TenneT was established in 1998 and has the monopoly on the operation of the transmission grid, ensuring reliability and continuity of power supply and also has as its task to balance supply and demand on a nation-wide level. This TSO is a member of the European Network of Transmission System Operators (ENTSO-E), and works according to the principles that apply for its member states. As can be seen in Figure 2, the transmission system is interconnected with the neighbouring countries of Germany, Norway and Belgium.

Figure 2 - Power transmission system

The TenneT transmission system in 2008 comprises 2,032 km of 380 kV lines, 653 km of 220 kV and 532 km of 150 kV lines. The voltages are transformed in 21 substations at 380 kV, 12 substations at 220 kV, and 19 substations at 150 kV. The system is depicted in Figure 3. Besides the onshore lines, TenneT operates a 290 km long 450 kV DC submarine power cable, connecting the Norwegian and Dutch power system (TenneT, 2009). Outside the Netherlands, TenneT operates in the Belgian, French and German electricity markets, both as a TSO and owner of HV grids.

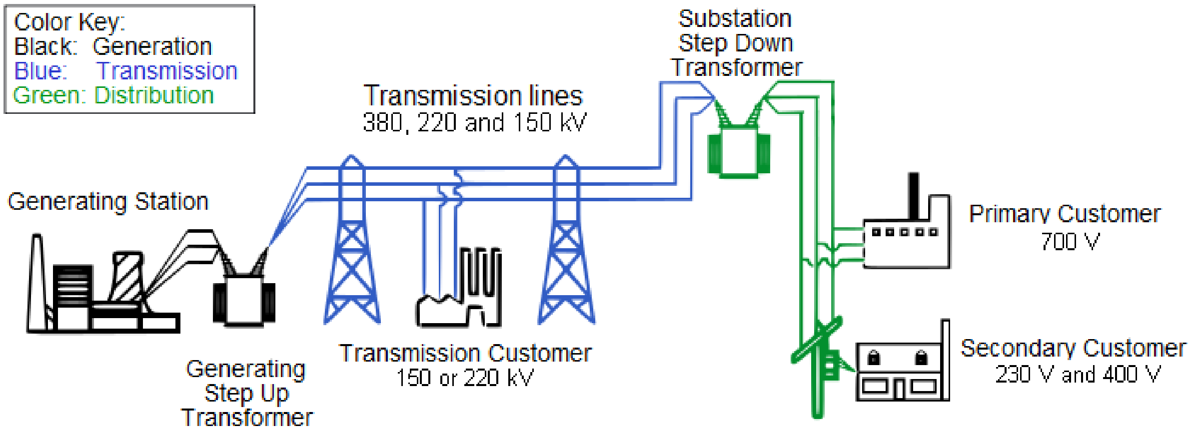

Figure 3 – Power transmission and distribution system scheme

The distribution grids are connected to the transmission grid via the aforementioned substations. The operation of the distribution network is in the hands of various Distribution System Operators (DSOs), dependent on the region. DSOs are responsible for operation and maintenance of the distribution grids, as well as the connection of households to these grids. In 2008, new legislation was approved by the Dutch government that required energy companied to be legally unbundled before 1 January 2010. This means that DSOs can no longer be part of holdings with commercial interests in the energy sector, e.g. power production or supply.

As in most developed countries, a balance between power load and supply is safeguarded by the TSO on a national level. All major power plants participate in commitments to increase or reduce the produced power, whenever this is necessary. Regional DSOs can expect to receive high-quality power from the transmission lines, and controllers are not widely used in distribution grids, except for some tap changers ion major substations. The overall outlook of the Dutch electricity grid is currently that of a centrally regulated, active HV-transmission network, feeding a practically unregulated, passive LV-distribution network.

2.3 Regulatory environment

The regulatory environment for DG consists of laws and regulations that have been developed by the governments to exert control over DG business practices. This regulatory environment strongly influences the interactions between different stakeholders, and thereby the potential for DG growth. The stakeholder group consists of all parties that are believed to have a certain interest in technological and economic topics surrounding the integration of DG. In 2.3.1, the different stakeholders for DG integration are summed up and their roles and interactions are described. In 2.3.2, the Dutch regulation system is put in an international perspective.

2.3.1 Stakeholders

For a transition towards a new model of energy infrastructure, various stakeholders need to play a role. Bayod-Rújula (2009) gives an overview of all the relevant stakeholders in this process: Government agencies, DSOs, TSOs, power utilities, electricity consumers, DG operators and owners, and communication technology (ICT) providers.

Government agencies

Public authorities comprise the institutions that are involved in regulation of the electricity grid. They set up the framework for DSOs and TSOs. In the Netherlands, the following organisations play a role in this process:

- **EK:** Energy Chamber *(EnergieKamer),* previously known as DTe: Institution for Execution and Supervision Energy *(Dienst Uitvoering en Toezicht Energie, DTe).* EK is an entity part of the NMA. This regulating body lists how the costs of electricity grids are divided amongst different stakeholders through the Tariff Code *(Tarievencode)* since 1998.
- **NMA:** Netherlands Competition Authority *(Nederlandse Mededingings Autoriteit)* is the competition regulator in the Netherlands. This government agency regulates and enforces competition laws, which are not confined to the energy sector.
- **Ministry of Economic Affairs, Agriculture and Innovation:** This ministry *(Economische Zaken, Landbouw en Innovatie)* is as a lawmaking agency responsible for setting the necessary conditions for renewable energy targets through regulation and policy.

Public authorities play a key role in reducing regulatory barriers, as well as in creating a socio-economic environment in which barriers to DG are minimal.

Distribution system operators

Distribution system operators are responsible for the physical transport of electricity through the distribution grids. According to Dutch law, every region has its own monopolist DSO, each functioning as a public utility. Nationwide, the DSOs include *Cogas, Delta, Enexis, Liander, NRE, Rendo, Stedin* and *Westland Infra.* According to the Law for Independent Energy Supervision *(Wet Onafhankelijk Energiebeheer),* a utility cannot function as a DSO, leading to a split between DSO and utilities that used to be under the same umbrella corporation.

DSOs receive connection charges from electricity consumers and DG operators. Further income comes from government agencies through performance-based network regulation

Transport system operators

The nation-wide transport system operator is called *TenneT.* TenneT was established in 1998 and has the monopoly on the operation of the transmission grid, ensuring reliability and continuity of power supply and also has as its task to balance supply and demand on a nation-wide level. This balancing task means that the TSO is the party that is involved in the balancing market.

Electric utilities

Electric utilities are companies that are engaged in the generation, supply and trade of energy. Since the unbundling of the energy market, utilities can legally not be engaged in the operation of transport and distribution networks. Main producers and suppliers include *ENECO, Anode, Cogas, Delta, Energie:direct, Essent, Greenchoice, NEM, NUON, Oxxio, Rendo,* and *Windunie.*

Electricity consumers

Electricity consumers, or loads, purchase their energy from utilities on the energy market. Their cost consists of a tariff paid to the utility and use-of-system charges paid to the local DSO. Their stakes are paying as little costs as possible and receiving optimal power quality.

DG operators

The majority of DG operators and owners in the Netherlands consists of CHP plant owners. This group is various in nature and includes electric utilities, greenhouse enterprises, private housing foundations and LDEBs (local sustainable energy companies, usually co-operations between civilians, companies and local public authorities). Often the structure of ownership is complicated, e.g. in situations where separate foundations are established to maintain, exploit and/or own the CHP-plants. The majority of the owners of PV solar panels is made up by households. Hydropower installations are owned and exploited by a total number of 17 different parties, which equals the number of installations (CertiQ, 2010).

DG operators receive financial support from government agencies through various support schemes, most commonly a price-premium scheme. They are able to sell their produced power back to utilities or, in the case of CHP, to sell it directly on the wholesale market. Furthermore, DG operators pay charges for the DSO for the connection to and use of the network

2.3.2 International perspective

A good regulatory strategy is vital in creating an electricity market and network structure that creates a level playing field between centralised generation and DG, in order to facilitate the integration of electricity from DG. In this section, the current Dutch regulatory strategy is put in an international perspective. This will accommodate the adaptation of results from VPPs in other states to the Dutch situation in chapter 5.

In order to put the Dutch regulatory system in an international perspective, it is useful to review those aspects of the system that are relevant to DG integration. Connor et al. (2002) showed the considerable differences in the contexts and frameworks in which DG has to operate, and identified a variety of factors that can impinge on its successful to distribution networks. These are shown to be:

- Governance system - what is the hierarchy of legislative power in relation to DG outcomes
- Connection charging
- Use of system charging
- Macro incentives and extent to which performance based regulation is in place
- Dispatch - how electricity is sold
- How DG benefits are valued
- Political will to promote DG

A useful tool to benchmark a country's regulation towards DG has been developed by Boccard (2004). The relevant regulatory issues are here divided in those related to network regulation and those related to market access for DG. Regulatory practices are gathered into four groups, one for market access and three for network regulation, altogether making up the following list:

1. Market access for DG (e.g. support mechanisms, wholesale/ancillary market)
2. Regulatory framework for DG (e.g., DG authorization procedures, ancillary services, metering)
3. DG-DSO financial relationship (e.g. connection charges, use-of-system charges)
4. Regulatory framework for DSOs (e.g. supply/generation unbundling, performance standards)

For each group, the questions in Appendix III are answered per country. Best practice is assigned 1 point, any practice deemed to have the opposite effect is assigned –1 point and whenever the practice is considered neutral it scores 0. The evaluation method used is based on three normative valuation grids, depending on the stage of market presence of DG in the specific countries: Low, intermediate or high. The result of the benchmarking exercise can be seen in Table 3. A higher score indicates a regulatory system that better facilitates DG integration.
It can be seen that at the time of benchmarking, the Netherlands scored relatively high on market access (3) and regulatory framework for DG (3). Lower scores are obtained for DG-DSO financial relationship (-1) and regulatory framework for DSOs (-1). However, most other countries in the benchmark score even lower here. It is also important to note that when DG presence rises, a level of high market presence may be reached where standards are higher, which will cause the score do drop, such as in Denmark.

Country	Market Presence	Market Access	Network Regulation • Regulatory framework for DG	• DG-DSO financial relationship	• Regulatory framework for DSOs
Denmark	High	-2	-1	-1	-2
Czech Republic	Med.	-1	4	2	-3
Germany	Med.	-1	3	-3	-5
The Netherlands	Med.	3	3	-1	-1
Poland	Med.	1	-1	-1	-3
Slovakia	Med.	1	-1	-3	-1
Hungary	Low	0	4	2	-1
Italy	Low	1	-1	0	-5
United Kingdom	Low	1	0	-3	-1

Table 3 - Boccard benchmark EU 2004

In this research, the benchmark has been performed for the Netherlands, using as the input the regulatory environment in 2010. The answers to the questions are shown in Appendix III. It can be seen that the score for market access has increased to 4, regulatory framework for DG stayed equal, DG-DSO financial relationship dropped to -3, and regulatory framework for DSOs increased to 3. Therefore, a focus on the DG-DSO financial relationship will be necessary in order to facilitate further DG integration in the Netherlands, compared to other EU countries. This issue is further elaborated in sections 3.2 and 3.3.

Scheepers (2004) developed a "regulatory roadmap" guide to get to an optimal regulatory environment for DG. The use of this model allows for a stipulation of plans that can be made to create a beneficial regulatory regime. A visualisation of this roadmap is given in figure 4.

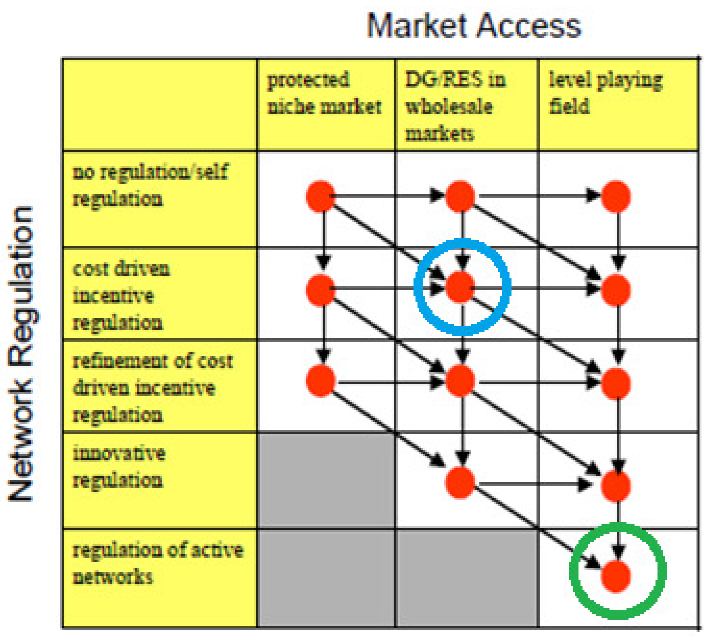

Figure 4 - Regulatory roadmap scheme with current situation (blue circle) and aim (green circle)

The ultimate goal is to get to *"Regulation of active networks"* in a *"Level playing field".* Regulation of active network networks entails a holistic, active approach in which DG is an integrated part of the regulatory model and the market is fully unbundled. A level playing field implies that DG participates in demand and supply side of markets, and DG has a direct effect on prices through markets. (Scheepers, 2004).

Given that the Netherlands are currently in *Cost driven incentive regulation/DG RES in wholesale market* (green circle in , there are a number of steps that are needed to be taken to get to *Regulation of active networks/Level playing field*. In the following chapter, the issues are identified and the amount to which they form a barrier is determined. In chapter 3, the Roadmap model indicators are used as a source from which DG integration barriers are derived. In chapter 4 and 5, it is used to determine the potential of the VPP to overcome regulatory barriers to DG integration.

3 Barriers to DG integration

The integration of DG into power distribution systems is hampered by technological, economic and regulatory barriers. In 3.1, technological issues, grouped into system reliability and power quality issues will be elaborated and an overview of the current state of scientific knowledge on these matters is presented. Economic barriers are elaborated in 3.2, categorised into pricing and metering, wholesale market access, connection charges for DG, allocation of network investment costs due to and, intermittent nature of DG. Finally, in 3.3 regulatory issues are specified: Ancillary services and network losses legislation.

3.1 Technological barriers

In this section, technological barriers to DG integration are grouped into two categories. In 3.1.1, it is explained how system reliability is affected. Integrating DG into the distribution net will create a multidirectional power flow in parts of the distribution networks, which were not originally designed for this mode of operation. Various researches have been done on this effect and the implications it has for the integration of DG. Secondly, there is the issue of power quality, which can be affected by the integration of DG, e.g. grid stability. Grid stability is reached by balancing voltage and frequency on the grid, and can be affected by the addition of decentralized power generation into a power grid. This issue is elaborated in 3.2.1.

3.1.1 System reliability

Electric system reliability has two components: *Security* and *adequacy* (USDE, 2007). Security is affected by DG because of a fundamental difference between a traditional distribution grid and a grid that comprises DG: Power flow. Traditionally, power travels one-way, from the power plant via the transmission substation and transmission lines, downstream to end users via distribution substations and the distribution grid. When DG is integrated into distribution grids, power will travel from connection points into the distribution grid, and possibly via substations into the transmission grid. The flow is therefore unidirectional in traditional distribution networks, and bidirectional in DG-integrated grids.

The major issue concerning bi-directional power flow is the state of protection schemes at the different voltage levels (HV and MV/LV). The purpose of these protection schemes is to protect the power system from faults, which in this case mainly refer to short circuit. A protection scheme usually does so by isolating faulted parts of the system from the rest of the grid, and typically comprises the following five components: Transformers, relays, circuit breakers, batteries and communication channels. The distribution network in the Netherlands is basically composed of radial feeders, designed for unidirectional power flow. Protection of the distribution network against faults is provided by impedance relays. These devices continually monitor the power system, with input from voltage and current transducers. A relay compares the input it gets to defined relay settings; when the difference exceeds a certain level, this means a fault exists in the system. DG affects this operating procedure. Geidl (2005) provides a comprehensive overview of issues concerning grid protection and integration of DG. It is stated that DG affects the functioning of protection schemes in various ways:

- The amplitude, direction and duration of fault currents are affected, causing protective relays to not or not properly trigger fault currents.
- The reach of distance relays may be reduced due to DG power infeed.
- When utility supply to a distribution network is disconnected, e.g. because of a fault in the network, DG will keep delivering power with an uncontrolled voltage and frequency. This may e.g. lead to a dangerous situation for the repair personnel coming to remedy the fault.

Adequacy is the "ability of the electric system to supply to aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and unscheduled outages of system facilities" (USDE, 2007) . The degree of adequacy may be measured by the frequency as the trend in system frequency is a measure of mismatch between demand and generation. Adequacy can be too high or too low, which is referred to as imbalance. Whenever imbalance occurs in a power system, the frequency will start deviating from its nominal value. In a conventional power system, this activates control mechanisms. These control mechanisms stabilise frequency variations and restore the frequency to its nominal value by dispatching generators. Reserve capacity is necessary to perform this task. Primary, secondary and tertiary reserves can be distinguished: The primary reserve can be activated very quickly (within 0 to 30 seconds) and is used to maintain constant frequency; the secondary reserve can be activated quickly (30 seconds-15 minutes) and alleviates typical imbalances; and the tertiary reserve can be activated (15 minutes) in the event of major imbalances.

When integrated into a distribution network in a plug-and-play fashion, distributed generators do not participate in control. Balance is restored only by conventional generators. As the share of DG in production increases, this mechanism will no longer be sufficient and DG participation in balance management will become necessary (Kapetanovic et al, 2008). Renewable DG types are technically poorly capable of fully participating in the balancing market as they usually operate in maximum capacity, disabling them to increase power output. Decreasing power output is always possible, however not economically efficient. This issue is further dealt with in in 3.3.2.

In the Netherlands, the major DG market share is for CHP, which is technically fully capable of power balancing, if controlled by electricity-driven control system instead of heat demand. Growth is expected for PV, wind and micro-CHP. The first two require financial incentives to participate (3.3.2), and all three require aggregation to increase the significance of their impact on net frequency.

3.1.2 Power quality

Electrical power is a product that is sold by a utility to a customer, and like any other product, has to satisfy descent quality requirements. Most of the equipment used in households and buildings today has a need for good power quality. Power quality can be affected by the integration of DG into a LV or MV-grid. Power quality is defined as the ability to deliver a clean signal without variations in the nominal voltage or current characteristics (Dugan et al, 2004). Whenever deviations in voltage, current or frequency occur, power quality is reduced, resulting in failure or malfunction of connected equipment. Ideally, voltage on a grid has the characteristics of a sinusoidal wave, of which the frequency and amplitude are set by (inter)national standards. The ideal impedance is zero Ohm at every possible frequency. However, no real power source or grid has the characteristics of an ideal voltage. The European standard EN50160 describes the voltage characteristics of the power that is supplied by public distribution systems. In this standard, statistical limits are put, which means that a system is allowed to exceed these limits by a small amount within certain limits.

According to EN20160, voltage quality parameters can be sub-grouped into three different categories: Parameters with limiting values, parameters with indicative values and parameters without any given values. A clean signal can be polluted by the following power quality parameters with limiting values: *slow voltage variation*, *fast voltage variation, flicker, harmonics, unbalance* and *signaling voltages*. Parameters with indicative values include *voltage dips* and *short and long interruptions of supply voltage.* Parameters without given values include *temporary and transient overvoltages* and *interharmonics* (EN 50160, 1994).

Slow voltage variations are the aggregate effect of the magnitudes of generating facilities and network loads (Dugan et al, 2004). Typically, the voltage at a node in a distribution grid is required to lie within ±5% of the nominal voltage. Integration of DG into a distribution network may distort the balance between load and generation, and consequently cause the voltage at network nodes to exceed the 5% limits. *Fast voltage variations* occur on a time scale of 10 ms and a few seconds. They can be caused by switching operations in the DG installation or by the variability of the output power of DG during normal operation, e.g. varying wind turbine output due to changes in wind speed (Papathanassiou, 2007). When the voltage exceeds the nominal voltage by more than 10%, this is referred to as a “swell”, when the voltage drops below the nominal voltage it is referred to as a “sag”. Rapid continuous voltage variations are referred to as *flicker.* Especially for the case of wind power, fast voltage variations may result in flicker emissions.

Bi-directional power flows and complicated reactive power flows, associated with the integration of DG into a distribution grid, may cause instability of the voltage profile when insufficient control is introduced (Hird et al, 2004). Voltage control in distribution and transmission networks is partially performed by inserting or absorbing reactive power. Voltage control through reactive power is performed by TSOs and DSOs using devices e.g. synchronous condensers, static compensators and shunt reactors and capacitors. In the Netherlands, the TSO can use additional reactive power from large-scale generators through bilateral contracts with utilities (Tennet, 2010). However, medium-sized and especially small DG technologies often use asynchronous generators (also known as induction generators), as they are significantly cheaper than synchronous generators. These asynchronous generators are not capable of providing reactive power. They require reactive power from the grid during the start-up process and operation. A growing rate of DG in the total power supply thus leads to a loss of voltage support to network operators (Ackermann, 2001).

Currently, different technical options exist to overcome the disadvantage, in the form of power electronic converters (Pepermans, 2003). Power electronics can add to the reactive power control capability of the system. In the Netherlands, no criteria are imposed for generators with a capacity lower than 5 MW, but it is mandatory for DG with a capacity higher than that to be able to contribute to voltage control by providing reactive power (NMA, 2009). However, the Dutch TSO prefers to control the voltage by themselves without contract with utilities, as reactive power supply is a highly regional issue which facilitates monopolist behaviour by power suppliers (DTE, 2005).

Voltage instability as a technical issue can be overcome. However, some reactive power issues still exist. Firstly, there is a question of how to manage reactive power control: The most convenient method, per-unit control through local droop functions may result in sub-optimal power flows in distribution networks (Braun et al, 2009).

Secondly, DG operators need a financial or regulatory incentive to participate in reactive power supply. Sole generators are too small to participate in reactive power trade. This issue is dealt with in 3.3.2.

Another possible effect of increased use of DG can be the increasing occurrence of *harmonics.* Harmonics are distortions in the waveform shape of supply voltage and current which increase the current level. These distortions are the result of voltages or currents with a frequency that is an integral multiple of the fundamental supply frequency. They are caused by customer loads with electronic power supplies, and have been occurring since the introduction of certain advanced electronic equipment and DC motors with variable speeds in the 1960's. The effects of harmonic distortions include mainly the overheating of induction motor winding, causing loss of life period, and the malfunction of certain equipment, such as dimmers and seam welders (Dugan et al, 2004). A different type is *interharmonics,* where the frequency is a non-integral multiple of the supply frequency. Some distributed generation technologies (PV, fuel cells) produce direct current. These units must be harmonized with the grid via a DC–AC inverter, which may contribute to higher harmonics. Special technologies are also required for systems producing a variable frequency AC voltage. Such power electronic interfaces have the disadvantage that they have virtually no 'inertia', which can be regarded as a small energy buffer capable to match fast changes in the power balance. Similar problems arise with variable wind speed machines (Ackermann et al, 2001). Harmonics caused by DG have been considered a bottleneck to DG integration by DSos in the Netherlands (DTE, 2004).

Voltage unbalance is the term generally used to describe the situation in which the voltage between the three phases is not equal (or not balanced). This will cause the current in the motor windings to increase substantially if allowed to continue. Voltage unbalance is not a major hazard for households, as most household equipment in the Netherlands (and internationally) runs on single-phase electric power, in which unbalance cannot occur. Voltage unbalance particularly causes damage to three-phase electric induction motors, commonly used in industrial facilities (Dugan et al, 2004). High amounts of DG units connected to a distribution network could potentially cause voltage unbalance outside of the legal limits as the export power could be unevenly distributed across the phases (PB Power, 2007).

The effects of voltage quality are various in type and magnitude. Studies performed previously for DSOs in the Netherlands have shown that the Dutch LV networks are technically capable of accepting up to 100% of DG (KEMA, 2003), (Boxum et al., 2000). Currently, the effects of harmonics, power supply reliability, voltage dips and electromagnetic compatibility are reported as being the most important power quality issues in European countries (Bhattacharyya et al, 2007). However, Darrow et al. (2005) finds no significant impact of distributed generation on the power quality parameters harmonics, flicker, unbalance, and frequency. In their study, the DG voltage increase effect is mentioned as "the main technical barrier for the connection of DG." Additionally, Schneider et al. (2003) reports: "Due to the use of self-commutated converters instead of current-controlled converters for DG, problems of flicker and harmonics are not of major relevance anymore."

3.2 Socio-economic barriers

Economic barriers to distributed generation rise, when e.g. distribution system operators are repelled by higher costs caused by the growing penetration levels of distributed generation. Besides economic barriers, integration of DG can also provide economic incentives, e.g. reduced transmission losses when electricity is produced on a dispersed level. Centralized generation requires the installation and maintenance of considerable transmission infrastructure which, in addition to being expensive to install and maintain, results in loss of energy due to transmission over long distances. Transmission losses in the Netherlands amounted to 120 million kWh (CIA, 2008) to a total consumption of 4.6 billion kWh (World Bank, 2008), accounting for 3.6% of electricity consumption. DG has a great potential to reduce these losses. However, the focus of this chapter is to lay out the possible friction between the current socio-economic system and DG integration, recognizing the benefits.

It is hard to make a clear distinction between socio-economic and regulatory barriers, as socio-economic issues often involve policy measures, e.g. mandatory maximums to connection charges for DG operators. In this research, the following issues are considered economic barriers and will be elaborated in this order:

- Pricing and metering (3.2.1)
- Wholesale market access (3.2.2)
- Connection charges for DG (3.3.3)
- Allocation of network investment costs due to DG (3.2.4)
- Intermittent nature of DG (3.2.5)

3.2.1 Pricing and metering

A first and highly visible issue for grid integration of DG is the metering system that is used. This issue can form a barrier to DG operators that are also electricity end-users. In net metering, electricity flow from and to consumers with DG is metered through a bi-directional meter, instead of using a two meter system. Generally, net metering is regarded beneficial for DG as compared to a two-meter system, as utilities typically set buy-back rates lower than retail rates (Dondi et al, 2002). Besides the higher tariff, net metering favours integration of DG in other ways: it's long-term nature differs it from short-term tax incentives on DG investments, the burden is carried by utility companies as opposed to the government, and corrects a feeling of social injustice that may be felt by DG operators when they are paid low buy-back rates

(Stoutenborough & Beverlin, 2008). On the utility side, net metering will lower the profits from retail sales, and legislation is necessary to oblige utilities to allow and facilitate net metering.

An alternative to net metering that may potentially provide a higher incentive to DG integration is a feed-in system. In a feed-in tariff system, a two meter system is used and an obligatory buy-back rate is imposed to utility companies by the authorities. It typically involves long-term contracts for the electricity produced and purchase prices that are methodologically based on the cost of renewable energy generation and tend towards grid parity (Mendonca, 2007).

Under current legislation, a variation of the feed-in tariff called "price premium" is in place in the Netherlands. Net metering is allowed up to a maximum of 5,000 kWh/yr. This practice was introduced with the introduction of the Changed Electricity Law *(Gewijzigde Energiewet)* in 2004. Above 5,000 kWh, the incentive for feeding power into the grid may decrease, as the remainder needs to be sold back to a utility who may only charge the avoided costs of production, which are typically much lower than retail rates. This tariff is supplemented by a premium tariff that is determined on an annual basis and is meant to cover the gap between the payback rate and the investment and costs.

Initially, confusion was widespread regarding amongst others variable rate meters, meters with a detent to run backwards and other issues. DSOs, which were charged with the administration of electricity consumption and billing, proved incapable of dealing with negative consumption and refunding additional costs like VAT to customers with double meters (PolderPV, 2010). In 2007, administrative tasks were transferred to utility companies, and in 2008 the maximum electricity delivered was raised to 5,000 kWh (BODE, 2006).

Where net metering and feed-in tariffs provides a ready market for DG to operators, there are some significant drawbacks to end-users, TSOs and DSOs. Network investment and other costs for system operators are included in retail prices; when DG-operating end-users avoids paying retail prices by producing net-metered power which is in the case in net metering, these costs will be shifted to other end-users, increasing retail prices. This phenomenon is referred to as "uneconomic bypass" (Starrs, 1996), and applies to both net metering and feed-in tariffs. Furthermore, as a net metered operator faces a constant retail price, meaning that there is no incentive to operate at times when demand is high, thereby hampering DSOs and TSOs in balancing the grid.

3.2.2 Wholesale market

When selling to the retail market, the most profitable schemes for the generator are feed-in tariffs and net metering, as long as penetration levels of DG are low. With rising DG penetration levels, the barriers seen above (uneconomic bypass, no adjustment to demand) become of greater magnitude and different solutions need to be sought (Ragwitz et al, 2007). In the Netherlands, a DG operator has the option to sell power on the wholesale market, instead of on the retail market. This situation has started with the liberalisation of the energy market in the end of the last century. In the process of liberalisation, the energy market that was dominated by vertically integrated utilities transformed into a more complex and competitive market. The opportunity of selling power on the wholesale market has the potential of removing the imbalance between supply and demand, because the price received will depend on the demand. However, only larger CHP plants sell their power on this wholesale market so-far, because of risks, investment in metering and administrative costs involved. About two-thirds of the 3000 MW of horticultural CHP units in the Netherlands are integrated into power markets. The remaining one-third consists mainly of smaller CHP units (<1 MW), often situated in older and smaller greenhouses. Their operators appear to be reluctant to spend the time and effort on actively maximizing the benefits from their heating installations (Nieuwenhout et al, 2010).

3.2.3 Network charges

Users of distribution networks are obliged to pay network charges to the local DSO, in order to compensate for the additional costs caused by their connection. These costs can be paid for by DG operators, the DSO, or can be shared between these two parties. In all cases they form a barrier to smooth DG integration: For the DG operator the investment is rendered less profitable because of the higher costs, for the DSO the costs will be a negative incentive to promote DG. A distinction can be made between connection charges and use-of-system charges. Connection charges represent the initial investment costs of the physical connection and are paid only once. Use-of-system charges are paid periodically as a contribution to grid maintenance. In some cases only end consumers pay these charges, in others DG operators are also charged use-of-system charges. In the Netherlands, DG operators do not pay use-of-system charges (Nieuwenhout et al, 2010)

Connection charges occur in two different types: deep connection charges and shallow connection charges. Deep connection charges are defined as all costs of connection, including upstream network reinforcements. Shallow connection charges only include the direct costs made for the connection. Cossent et al. (2009) proposes a trade-off of incentives here: When deep connection charges are implemented, an economically optimal siting of DG is promoted, but the cost barrier is relatively high for DG operators. Investment costs are lower under shallow connection charges, but an optimal resource siting is not ensured.

In the Netherlands, connection charges are regulated by the Chambre of Energy *Energiekamer),* an entity part of the Netherlands Competition Authority *(Nederlandse* Mededingings Autoriteit, NMA). This regulating body lists how the costs of electricity grids are divided amongst different stakeholders through the Tariff Code (Tarievencode) since 1998. Currently, DG operators do not pay deep network charges yet as long as their installed capacity is below 10 MW (Tarievencode, 2009). When an additional investment is required due to a new connection, the costs are paid for by the DSO.

3.2.4 Network planning

Network investment with respect to adaptation to DG integration is the DSO-side of the discussion mentioned in 3.2.3. These investments represent the operational expenditures. Another part of the discussion is about network planning and related investments, the so-called capital expenditures. In a new-build network, or in an existing network facing load-growth, the DSO may consider the effects of DG in the planned network capacity as the net demand from transmission and distribution grids may be reduced (Cossent et al., 2009, Niesten, 2010). The capacity of a transformer in a substation could for instance be chosen at a lower level, leading to significantly lower investments. Mendez et al. (2006) shows that the magnitude of cost deferral is highly dependent on DG penetration levels, DG location along a network, DG concentration along the feeder and DG technology. PV cells and CHP plants can contribute more to cost deferral than wind power. Willis & Scott (2000) claim that DG as a means to provide the additional electric power needed, as demands continues to grow within an existing distribution system in an established urban area, can offer costs of power that are up to 75% lower than electric system alternatives.

Currently, possible cost deferral as a result of DG integration is not a decision-making factor in network planning by DSOs in the Netherlands, as planning and security criteria that are used by DSOs currently do not take into account the potential benefit of DG.

3.2.5 Intermittent nature of DG

One of the most important economic barriers to the integration of DG into the grid is the additional costs associated with the intermittent nature of DG, particularly wind and solar power. The inflexibility, variability, and relative unpredictability of intermittent energy sources are the most obvious barriers to an easy integration and widespread application of DG (Luickx et al., 2008). The intermittent nature of DG poses a twofold barrier.

- Firstly, operational and capacity back-up power is required for intermittent energy resources. Economic penalties are imposed for grid unbalance caused by unmet output.
- Secondly, intermittent power production can cause cycling losses in conventional generation, when thermal plants operate below their optimum. This occurs during start-ups, shutdowns, and part-load operation. The less accurate the predictions of DG output, the higher these losses are. Costs due to cycling losses have been estimated to reach up to €1/MWh (Smith et al, 2004).

Solar power is highly affected by intermittency, as the amount of power produced by PV panels is dependent on the amount of solar irradiation on the location. Solar irradiation varies throughout the seasons and throughout the days, an important factor of impact being cloud cover. Storage is necessary in order to gain power from solar energy at night time. However, solar irradiation is predictable and the effects can therefore be managed.

Wind is another highly intermittent power source as the amount of electrical power produced by a wind turbine depends on a number of factors, including wind speed and air density. For on-shore wind turbines (which are considered DG), intermittency is higher than for off-shore turbines (which are not considered DG), due to off-shore breezes being more constant than on-shore breezes. At high levels of penetration, wind power can raise costs for regulation and operating reserve capacity.

Costs of variation in wind output have been estimated to reach as high as €4/MWh (Smith et al, 2004). It is estimated that in the Netherlands, high amounts of wind power may lead to constraints in feasibility of connecting wind power to the system starting at around 4,000 MW (Hammons, 2008; Ummels et al., 2006).

3.3 Regulatory barriers

Extensive research has been done in order to identify and tackle regulatory barriers to the integration of DG. These are barriers associated with rules and restrictions, and commonly evolve from and can be targeted by policy measures. In the case of DG, these barriers are typically associated with the control, operation and management of DG power. The question of how to allocate the costs and benefits that arise from integration of DG can also be approached from a regulatory perspective, but is in this research considered an economic barrier. In regulation, the following stakeholders are involved: Distributed system operator (DSOs), DG operators, utilities and governmental agencies. Any expansion of DG also requires that the traditional regulatory framework for conventional energy is adapted: unnecessary regulatory, administrative and planning barriers to the promotion and development of renewable energy need to be avoided. A number of main identified regulatory barriers can be summed up:

- Network losses (3.3.1)
- Ancillary services (3.3.2)

3.3.1 Legislation regarding network losses

When electricity is transported along the grid, network losses take place. DG may reduce these losses, as the generated production can be consumed on the site, reducing the need for power transmission from centralized power stations. Currently, costs for transmission losses to the TSO TenneT amount to €18 million. Without DG (including industrial CHP here), these costs would have been €32 million: Therefore, DG reduces transmission losses by 44%. (DTe, 2004). Besides this, distribution networks experience changes in network losses because of DG. Mendez (2002) finds that in general, for low DG penetration level, losses decrease but for higher penetration level losses marginally increase and even can be higher than losses in base case. The profits for the DSO due to the presence of DG in a distribution network vary between -40% and 9%, dependent on the level of DG penetration (Frías et al, 2008). The change in network losses forms a barrier to DG in two ways: When network losses decrease, the profit created is not shared with the DG operator, thereby offering no financial incentive to DG, whereas if losses increase, the integration of DG will not be favored by the DSO responsible for the network.

DG operators in the Netherlands are not legally obliged to reward DG operators for their contribution to loss reduction in distribution networks, and seldom do so (DTe, 2004). In 2005, the Dutch regulatory authority implemented a regulation in which DG operators with an annual production of 150 MWh or more received a financial compensation for avoided transmission losses. This compensation was determined through the “grid loss savings scheme” *(RUN, Regeling Uitsparing Netverliezen*). However, this payment was cancelled in 2007 and the authorities announced that no new arrangement will be put in place (Plug, 2007). The reasons for the abolishment of the regulation were the objections from several DSOs and the TSO against the administrative and managerial burdens associated (DTe, 2004).

3.3.2 Ancillary services

The required nature and amount of ancillary services in transport and distribution networks is regulated by law. Ancillary services are "*all services required by the transmission or distribution system operator to enable them to maintain the integrity and stability of the transmission or distribution system as well as the power quality*" (Eurelectric, 2004). These ancillary services roughly serve three goals: Maintaining frequency, maintaining voltage, and restoration of supply. In Table 4, ancillary functions are categorized according to their function.

Function	*Maintaining frequency*	*Maintaining voltage*	*Restoration of supply*
Service	• frequency response (balancing market) • reserve power • remote automatic generation control • emergency control actions	• voltage regulation • reactive power control	• black start • temporary islanding

Table 4 - Ancillary service functions (Eurelectric, 2004)

DG units are able to provide different AS and other network services that can lead to a more secure and economic efficient operation of the distribution network (Cossent et al, 2009). For instance, DG can contribute to power reserves and the balancing market. Not every DG type is equally applicable to perform each ancillary service. For instance, renewable DG is characterised by low to zero marginal costs, providing no incentive to participate in the balancing market, as this requires operating below their maximum power. However, considerable potential for various DG types can be in providing the following ancillary services (Mutale, 2005),

- Frequency response to TSO: Wind power, CHP
- Regulating and standing reserve to TSO: Hydropower, CHP, Micro-CHP, PV
- Reactive power to TSO: Wind power, PV
- Security of supply to DSO: Hydropower, CHP, Micro-CHP, PV
- Quality of supply to DSO: Wind power

In most of the European countries, there is still very low contribution of DG to network ancillary services. Not all generators are equipped with the infrastructure necessary to provide ancillary services. Such infrastructure includes governors, automatic voltage regulators, resynchronisation facilities, and appropriate protection, monitoring and communication facilities (Lopes et al. 2006). The main contributions performed by DG in the Netherlands are (Frias et al, 2009):

- Reactive power control: Wind power, CHP
- Participating in the balancing market: CHP
- Providing reserves: CHP

IT can be seen that there is still considerable potential for further integration of DG into ancillary service markets. Micro-CHP, hydropower and PV don't participate in ancillary service markets at all. For micro-CHP, the main barrier is its size; network operators will have to communicate with a multitude of different micro-CHP plants that all contribute only a little to the various ancillary services, highly increasing complexity. Additionally, only units with a capacity of over 5 MW are permitted to provide ancillary services (Lobato et al, 2009). PV systems and hydropower experience the same barriers because of their small scale.

Wind power does not participate yet in reactive power to TSO and quality of supply to DSO, and may participate more in balancing services. CHP does not yet actively contribute to security of supply, and may participate more in the balancing market and reserve services.

4 Innovative grid concepts

To analyze research done so far on the topic of virtual power plants (VPPs), it is first of all essential to have a straight-lined definition of the concept. Currently, there is no universally accepted working definition of a VPP. In literature and common usage, the terms VPPs, smart grids and microgrids are often used interchangeably. In 4.1, the "smart grid" concept is elaborated, and a number of features that are widely believed to be inherent to smart grids is summed up, and the operation of a number of different possible smart grid architectures is described, e.g. integrated energy systems, microgrids and VPP. In 4.2, the microgrid is further specified, as it serves as a starting point for the definition of a VPP. Subsequently, in 4.3.1, definitions of VPP are given and the features are explained. A demarcating definition for VPPs is thus formulated. In 4.3.2, various sub-species of the VPP are analysed.

4.1 Smart grids

The notion of the smart grid has been introduced in the last decade of the 20th century. It's basic characteristic is the transmission and distribution of information in a power grid, as opposed to the exclusive transmission and distribution of power. Brown et al. (2010) sum up the features that, according to present consensus, constitute a smart grid: *"an increase in use of digital control and information technology with real-time availability; dynamic optimization and cyber-security relating to grid operability; inclusion of demand-side response (DSR) and demand-side management (DSM) technologies; integration of distributed energy resources (DER) including renewables and energy storage; and deployment of smart metering, automated metering infrastructure, distribution automation, smart appliances, and customer devices".*

The notion of smart grids is thus broad and aims at solving a magnitude of issues facing out-dated power grids. One of the most prominent aspects of the smart grid is the integration of DG. Those features that aim at promoting the integration of DG, cannot be viewed separately from the other. However, an emphasis on controlling and communication technology and software has been emerging since the beginning of this century. Lund (2005) compares four different technical systems to identify limits and possible solutions of increasing the share of DG in the Danish power supply. Hammons (2008) provides an overview of the current integration of renewable energy into the power systems in Europe. In this paper, Hammons addresses the drivers towards smart grids, smart grids today, and key challenges for smart grids of the future. The need for changes to current control and communication technologies is emphasized. Itchikawa et al. (2002) mentions "virtual utility concepts" as a topic that has to be considered for wide area application of distributed generation, in order to overcome technical barriers. A distinction between possible grid architectures is given in Chicco et al. (2007), where different concepts for distributed multi-generation systems are mentioned: *virtual power plants, microgrids, integrated energy systems, energy hubs* and *smart grids*. As the distinction between these different approaches is not always clear, it is useful to list their respective characteristics. A comparison of these five approaches is listed in Table 5, in which the characteristics are derived from literature.

	VPP	Microgrids	Integrated energy systems	Energy hubs	Smart grids
Focus	Optimized control and operation of DERs	Integration of DER into the grid	Integration of DG with thermally activated technologies	Integration of multiple energy carriers	Refocusing energy infrastructure
Geographical scale	Unrestricted	Small, local	Building	Unrestricted	Unrestricted
Operation	EMS (central and/or local)	Control center, autonomous/grid-connected	Local EMS	Centralised operation	EMS (central and/or local)
Architectural layers	Power flow	Power flow	Power flow	Power flow	Power flow
	ICT infrastructure	ICT infrastructure	ICT infrastructure		ICT infrastructure
	Market				
Time scale	short (<10 years)	short (<10 years)	short (<10 years)	long (>30 years)	short (<10 years)
Approach	Practical application	Practical application	Laboratory applications	Input-output models	Practical application
Core elements	DG resources	DG resources	Energy efficiency	Generators	DG resources
	DR programs	Demand management	Demand management	Direct connections	DR programs
	Storage	Storage	Fuel switching	Converters	Storage
	Software interface		Customer based generation	Storage	Software interface
	Interaction with energy markets				

Table 5 - Innovative grid concepts and their characteristics

Two architectures are not further elaborated as they are beyond the scope of this research: Integrated energy systems and energy hubs. Integrated energy systems is different in its geographical scale i.e. building level, whereas integrated energy systems are different in their time scale. The comparison between different grid concepts in this chapter will therefore be between smart grids, microgrids and VPP.

Smart grids, microgrids and VPPs are all concepts that require active management of the distribution network. Zhang et al. (2009) define active management of the distribution network as the *"real time control and management of DG units and distribution network devices based on real time measurements of primary system parameters (voltage and current).* The function of this network model is to effectively link power sources with consumers' demand. Increased interconnectivity and level of control is higher than in current distribution network. However, solely applying active management, control of multiple DG sources is not yet aggregated, and individual units are operated by grid control centres. As a solution for the aggregation of multiple DG sources and consumers, two possible infrastructures are likely to contribute: Microgrids and VPPs.

4.2 Microgrids

A microgrid is a small-scale power supply network that is designed to provide power for a small community. This community can be in e.g. an urban environment, public community or industrial area. The microgrid concept is based on the assumption of a cluster of electrical and thermal loads, together with small-scale sources of electrical power and heat. In a microgrid concept, multiple power sources will be a mix of DG sources, e.g. PV cells, micro-wind turbines and CHP units. Commonly, energy storage will also be required to deal with the variations in available generation of intermittent power sources, and fluctuating power demand.

The microgrid concept itself is not new. The first power plant ever to be constructed, the Manhattan Pearl Street station in the US in 1882, can be considered a microgrid as a centralized power grid was yet non-existent. This power station was built by Thomas Edison's firm and provided 110V DC power to 59 customers in lower Manhattan (CE, 2009). After an initial phase in which the small-scale concept spread and Edison's company built multiple DC-microgrids, the electric services industry changed into a state-controlled monopoly market and centralised generation became omnipresent.

After aforementioned development urged for a modernisation towards smart grids, the microgrid concept started to regain attention. The word microgrid was first used by Hoff et al. (1997), referring to an *"electrically isolated set of power generators that supplies all of the demand of a group of customers."* As for the drivers for the development of this microgrid, Hoff et al. (1997) mention consumer's demand for reliable power supply and lower costs of electricity, and research initially primarily focused on the economic feasibility of these grids. Regarding reliability, specifically the threat of the Y2K bug in the United States urged many companies and organisations to protect themselves from power cuts by buying standby generators. A cost reduction was to be obtained by lower required investments in transmission systems and lower transmission losses. As the topic of sustainable development gained interest at the end of the previous and the beginning of this generation, the focus on renewable energy and distributed generation increased as well. As DG removes the need for long-range electricity transmission, microgrids obtained another target besides cost reduction and improved reliability: the incorporation of DG into the electricity grid. In addition to the active distribution network, which is an inherent part of the microgrid, the multiple power sources can be regarded as a single aggregated load or generator (Bayod-Rújula, 2009).

4.3 VPP

A review of literature shows that so far, there is no consensus regarding the definition of a VPP. Many researchers and organisations handle different definitions of VPPs, which sometimes exclude and sometimes overlap with each other. Besides this, the term VPP can sometimes be used interchangeably with similar terms, e.g. "virtual utility". The aim of this chapter is to provide an overview of existing literature and projects that involve VPPs, in order to list and compare existing definitions and subsequently demarcate the concept of the VPP to a useable definition for this research.

4.3.1 Definitions

One of the first occurrences of the use of the term VPP was in the "Virtual Fuel Cell Power Plant" project that started in 2002 and was funded by the European Commission. Within this project, the VPP was defined as "*a group of interconnected decentralized residential micro-CHPs, using Fuel Cell technology, installed in multi-family houses, small enterprises, public facilities etc., for individual heating, cooling and electricity production"* (FP5, 2003). Within this project, some aspects of VPPs as they are currently known are lacking. Notably, there is no pluriformity of DG resources as only CHP is included, demand response programs are not included, and there is no link to the wholesale electricity market.

Willems (2005) proposes a definition of VPP that is purely economic in nature. Within this context, a VPP is a form of contract, in which electricity market entrant buys part of the production capacity from an incumbent electricity generator. The main objective of this VPP is to reduce market power of incumbent generators, and increase accessibility for new generators within a liberalized electricity market.

Bayod-Rújula (2009) defines the VPP (which are referred to as *virtual utilities*) as *"a new model of energy infrastructure that consists of integration of different kinds of DG utilities in an energy (electricity and heat) generation network controlled by a central energy management system (EMS)".* In the model of Bayod-Rújula, DG units are combined with heat storage tanks to form clusters, that are controlled by local management stations (LMS). These LMSs have information about the demand for electricity, heat and cold of the end-users, as well as the state of the DG units and the water in the storage tanks. This information is shared with the central EMS, which dispatches the utilities in the clusters. The heat demand in the cluster is the primary driver for DG units, and consumed locally; electricity is generated and distributed in the network. The mentioned advantages of this model are an optimization of the utilization yield of the whole network, increased electricity supply reliability, high integration of RES and DG, and complete system control to achieve a quick response to changes in demands in the system. The key elements of this system include modern ICT technology, advanced power electronics and efficient storage.

Romero (2010) concentrates his demarcation of the virtual power plant concept around the aggregation of demand-side response programs. In this vision, the main function of a VPP is to create order in a chaotic grid with millions of customers with their own demand-side response programs, by grouping large numbers of points in a network in a single entity. This will allow for managing the flows and constraints in the distribution topology.

VPPs rely upon software systems to remotely dispatch DG resources. Asmus (2010) uses the following definition of a VPP: “The ability to aggregate power production from a cluster of grid-connected distributed generation (DG) sources via smart grid technology by a centralized controller, typically a utility, and then harmonize this generation with load profiles of individual customers.” Asmus (2010) estimates a 80% commonality between the concepts of the microgrid and VPP, but suggests the following differences:

- Microgrids can be grid-tied or off-grid, where VPPs are always grid-tied
- Microgrids can “island” themselves from the larger utility grid, where VPP’s do not offer this contingency
- Microgrids typically require some level of storage whereas VPPs may or may not feature storage
- Microgrids are dependent upon hardware innovations such as inverters, whereas VPPs are software dependent
- Microgrids typically only tap resources at the retail distribution level, whereas VPPs can also create a bridge to wholesale markets

It is seen that three different flexible Distributed Energy Resources are included into the VPP: DG, demand response, and energy storage. The integration of these concepts is explained in text box 1. Besides this, it follows from the findings above that a number of aspects distinguish the VPP architecture from microgrids and other smart grid approaches. These can be identified as: Wholesale market participation, ancillary market participation and balancing services, concepts that are explained in text box 2.

Demand response – After DG, demand response (DR) is the second of the three Distributed Energy Resources (DERs) that can be integrated into the VPP. The notion is to connect devices such as air conditioners, heat pumps, water heaters, and dryers via wireless networks so they can be powered down or turned off to save energy, save costs and help curb peak power demands. VPPs allow utilities to aggregate these programs by program type and by location in the distribution topology

Energy storage – After DG and DR, energy storage is the third DER that can be incorporated into the VPP. In order to even out fluctuating output, various storage devices can be deployed, e.g. batteries, flywheels and supercapacitors. Storage elements allow the aggregate system output power to be reliably controlled, including systems with intermittent resources. High-power electricity storage technologies, are applicable for fast-response voltage and power quality management. High-energy storage applications sustain for longer periods and can be used to shift production.

Text box 1 – Distributed energy resources in VPP

Wholesale market participation – Trading in the wholesale energy market is one of the main services provided by a commercial virtual power plant (CVPP). This operation typically involves forecasting demand and/or supply, bidding and scheduling the resources, dispatching of DG and DR, and settling with markets and suppliers.

Ancillary services – Providing ancillary services to the TSO or supplier is a service offered by a technical virtual power plant (TVPP). A TVPP can use ancillary services offered by DER units to optimize the distribution network operation. TVPPs can also provide ancillary services to other system operators. The added value of the TVPP is the aggregation of DER, as a TSO cannot efficiently manage ancillary services provided by thousands of DG units with only a small contribution of each.

Balancing services – Providing balancing services to the TSO or supplier is a service offered by the TVPP. By the aggregation of DER, it is possible to deliver reserve regulating power to the TSO, delivering active network management services to the DSO or minimizing the imbalance costs of a commercial party.

Text box 2 – Distinguishing aspects in VPP

Lukovic et al. (2010) describes a layered structure of the energy markets, splitting up future energy systems in three distinct layers: Market level, ICT structure and Power flow. The market level consists of the financial, economic and regulatory framework, ICT structure is the model and flow of information and control of applications, and power flow includes the physics of the system, such as generators, loads, and storages. VPP can be seen as the ICT structure layer in a power system, which can be seen in table 6.

Layer	**Features**
Market Financial, commercial and legislative framework	Demand Response Programs
	Real-time pricing
	Market actors
	Grid sales
ICT Structure Information model/flow, control	Energy management system
	Smart metering
	Software applications
	Monitoring and control
	Data storing, processing and transfer
Power flow Physics of the system	DG
	Loads
	Storage
	Power lines
	Transformators etc.

Table 6 - VPP in layer system

4.3.2 Categorisation

The variation in definitions of the VPP concept can be narrowed down to two different roles or functionalities of a VPP: First of all, it's role is to ensure that aggregated units of DG are operated in an optimized and secure way, and secondly it's role is to optimize the economic value of the DG units in an open electricity market. Two distinguish between these complementary goals, a difference is proposed by Braun (2009) between technical virtual power plants (TVPPs) and commercial virtual power plants (CVPPs):

- TVPP takes into consideration the operation of the grid and aims to solve technological restrictions and communicates mainly with the distribution network. The TVPP consists of DER from the same geographical location. As such, a TVPP is no different from an Active Distribution Network (ADN). The operator of a TVPP is typically a DSO. Services provided by a TVPP include local management to the DSO, and system balancing and ancillary services to the TSO.
- CVPP provides the services of trading in the wholesale energy market, balancing of trading portfolios, and provision of services to the DSO e.g. submission of bids and offers. TVPPs communicate mainly with energy markets. The operator of a CVPP is typically a third party aggregator or balancing responsible party with market access, e.g. a utility. Goals of a CVPP are to increase market access of DG and reduce the risk of imbalance by portfolio diversity and capacity.

Another categorization of the VPP concept is made in You et al. (2008), dividing VPP into three different categories that differ from each other in control architectures and associated information directions: Centralised controlled VPP (CCVPP), Decentralised Controlled VPP (DCVPP), and Fully Decentralised Controlled VPP (FDCVPP). Functionality and type of integrated resources are not distinguished in these definitions.

- CCVPP: A control center that has complete knowledge of involved DER units and defines every operating set point to meet the varying requirements of the local power system.
- DCVPP: A collection of distributed local controllers, which constitute an overall hierarchical architecture. A central controller is required to it on top of a DCVPP in order to ensure system security and an overall economic optimization.
- FDCVPP: An extension of DCVPP wherein central controllers are replaced by information exchange agents which only provide services e.g. market prices, weather forecasting and data logging to its participants.

Another division is made by Asmus (2010), dividing the VPP into four distinct segments. Where the previous divisions of Braun (2009) and You et al. (2008) are theoretical in nature, this division based on the type of VPPs currently in operation:

- Wholesale auction VPP: Not an aggregation of distributed resources, but an auction form uniquely in Europe. Base-loads and peaking capacity of centralized power plants are auctioned off under short-term and long-term contracts. Examples of this type include

- DR-based VPP: An aggregation of DR programs, mainly found in the USA. Examples of this type include the Ventyx VPP in Xcel Energy's SmartGridCity in Boulder, USA.
- Supply-side VPP: An aggregation of DG resources, mainly found in Germany in the form of R&D pilots. Examples of this type will be given in 5.2.
- Mixed asset VPP: The most complete type of VPP: A combination of DR-based, and supply side VPP, aimed at optimizing resource value.

A visual representation of the most mixed asset VPP type, which consists of a technical & commercial, centralized control mixed asset VPP, is given in Figure 5.

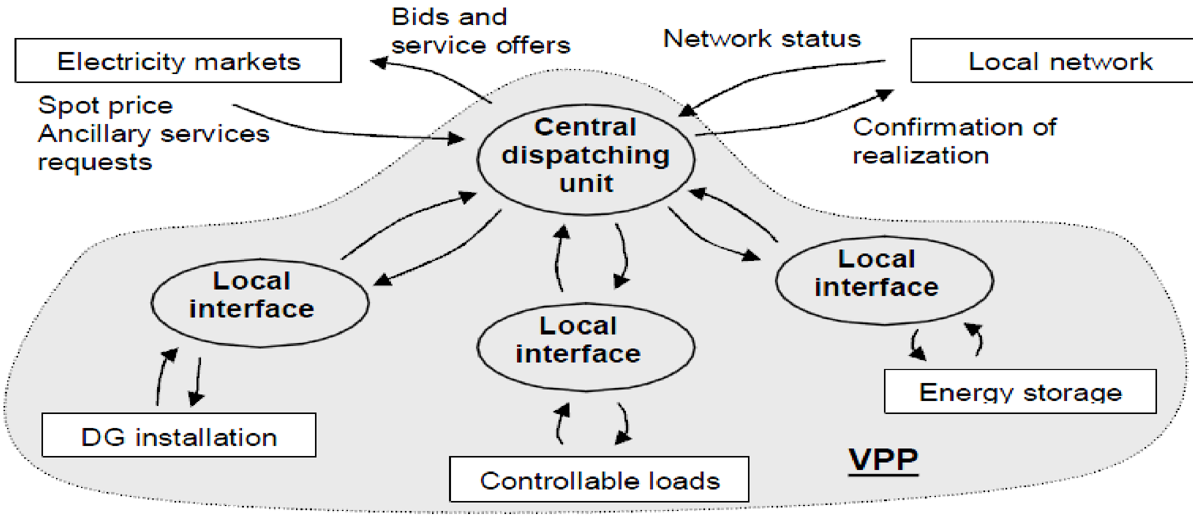

Figure 5 - VPP visualisation (IEA, 2009)

5 VPP performance

The aim of this chapter is to determine to what extent the VPP model can overcome barriers to DG integration, and to identify the relevancies and shortcomings of different VPP forms. In 5.1, a theoretical analysis is performed to determine what barriers from chapter 3 can be addressed by the various VPP forms. In 5.2, the currently known VPP projects in Europe and the US are presented and their results are shown, where available. Finally, in 5.3, an acknowledgment section is provided for the parties that were interviewed and the results of the interviews are discussed.

5.1 Theoretical VPP potential

In this section, barriers will be listed according to category, and possible solutions in the VPP system model are given. It follows from the survey results and literature that not every barrier is addressed in the VPP architecture, nor does every advantage in the VPP architecture apply to a certain barrier as identified earlier in this chapter.

In the tables below, all identified barriers are listed according to category. The current situation is described in chapter 3. The barriers are divided into the different stakeholders involved, and their respective consequences in a VPP situation are listed in the third column.

Technological barrier	Stakeholder	VPP situation
Reliability and protection	DSO	The necessary information flows within a distribution network to control adaptive relays are available to the TVPP operator through the energy management system. The TVPP can also use software to coordinate the relay settings.
Frequency stability	DSO	By controlling DG by demand for power instead of conventionally (e.g. heat demand for CHP or wind speed for wind turbines), system stability losses can be avoided. Furthermore, system stability losses are avoided through the interconnection of power electronics with information and control systems. Aggregation increases the impact of the smallest DG sources to make their impact on net frequency significant. Storage may be used to absorb or inject power when demand shifts and adapting generation output is unfeasible.
voltage stability	TSO	Participation of multiple local generators through aggregation in a VPP will establish competition in the reactive market. Competition will lead to reduced prices to the TSO. Additionally, regional dispatch of reactive supply provides the TSO with more control methods than centralised reactive power from utilities.

	DSO	The TVPP model provides the DSO with insight into the DG reactive supply or demand. This increased visibility enables the VPP to model power flow and thus achieve an optimal voltage profile inside the distribution network.
	DG operator	The DG operator can negotiate a financial compensation for its reactive power supply to the DSO. Additionally, it is aggregated with other DG operators and has access to load forecasts, to be able to provide TSO with reactive supply and reap the benefits.

Table 7 - Technological barriers in a VPP scenario

Economic barrier	**Stakeholder**	**VPP scenario**
Buyback rates	Utility	Utilities no longer buy electricity directly from DG operators, but instead compete with these operators in a wholesale energy market. The economic impact on large utilities/suppliers will be negative.
	DG operator	DG operators receive a variable wholesale market tariff for their electricity production. Although this may be higher than the buy-back tariff received from suppliers, it will not cover the investment costs of renewables and government support will remain necessary. For CHP, which does not currently receive government support, the buyback rate will increase compared to the current situation.
Access to wholesale market	DG operator	DG barriers to access to the wholesale electricity market (APX) are overcome by aggregating DG into a portfolio of multiple units. Aggregation reduces the administrative costs and efforts of participating in wholesale markets for the individual operators.
Allocation of network planning costs	DSO	A DSO that operates as a TVPP will take into account DG as an alternative to adding network capacity. This has the potential of saving high network investment costs to the DSO.
	DG operator	DG will be taken into account when network capacity expansions are considered. Whether or not the savings that evolve from this will be partially allocated to the DG operator will depend on the specific contractual arrangements.
Response to demand fluctuations	DSO	Internal balancing by a TVPP, which is usually operated by the DSO, can handle fluctuations in three ways: DR in the distribution network restores balance from the demand side, dispatching of DG units from the supply side, and storage is used as a buffer when demand drops.
	TSO	By aggregating DG units, A CVPP offers upward or downward balancing services to the TSO, thereby making DG visible and useful for balancing the transmission network. TSO may thus contract their balancing services from a larger number of

		market players, increasing their options.
	Utility	DG will enter the balancing market, providing another competitor to utilities for the provision of balancing services. This is likely to have a negative financial impact on large generators.
	DG operator	DG will be dispatched by the TVPP operator in exchange for financial compensation, or receive price incentives for operating schedules. Both will Additionally, DG will enter the balancing market, which will provide an additional positive financial impact on their profits.
Intermittency of DG power sources	TSO	Aggregation of DG helps to reduce the unpredictability of the output of these resources. Additionally, combining storage with intermittent DG may balance out peaks or droops in power supply by intermittent DG. This reduces economic penalties to the TSO for grid unbalance.
	Utility	As predictability of intermittent DG output can be increased by aggregation and storage, less spinning reserves will be necessary to back-up for fluctuations in the grid. This will reduce efficiency losses for utilities.

Table 8 - Economic barriers in a VPP scenario

Regulatory barrier	**Stakeholder**	**VPP situation**
Network losses legislation	DG operator	TSOs and DSOs will be more tended to reward DG operators for their contributions to loss reduction because of decreased investment and administrative costs to do so. However, operators may also be charged for attributed increases in losses, although optimal dispatch by site will reduce these.
	TSO	Contribution from DG operators to the reduction of transmission network losses can be rewarded as the necessary information for accurate remuneration is already available to the TVPP operator/DSO, reducing administrative costs.
	DSO	Contribution from DG operators to the reduction of distribution network losses can be rewarded as part of the arrangement between DG operators and TVPP operators/DSOs. The necessary information for accurate remuneration and knowledge of the attributing features of the units is already available to the TVPP operator/DSO, reducing investment and administrative costs.
	Public authorities	Objections from DSOs and TSO to obligatory loss compensation will decrease, and laws for compensation can be reinstalled.

Ancillary services	DG operator	By being aggregated into a pool of DG resources, access to ancillary services markets increase. The minimum entrance capacity barrier is overcome, and time and administrative costs per operator are reduced. Information about network ancillary requirements is provided by the VPP.
	Utility	Utilities will have an extra competitor on the ancillary services markets, diminishing the price for these services through auctions. Unless utilities decide to involve in forming CVPPs themselves, they will experience reduced profits because of increased competition.
	TSO	CVPPs provide a flexible and competitive player on the ancillary service markets, allowing more competition in the market and hence lower prices for the TSO.
	DSO	By acting as a TVPP in an active network, DSOs can use ancillary services provided by DG optimally to maintain their network.

Table 9 - Regulatory barriers in a VPP scenario

5.2 Case studies

In this section, several VPP projects in Europe and the US are presented and categorised within one or more of the VPP categories identified in 4.3.2. A description of the projects is given, including the specific goals that were set. Subsequently, the (intermediate) results are presented, as far as they are available.

5.2.1 General

A number of VPPs, in various forms, is currently in operation throughout the world, mostly in Europe and the US. According to Asmus (2010), the VPP capacity worldwide in 2009 was 19,428 MW. The largest segment is wholesale auctions (exclusively in Europe), which represents 51% of the total VPP market. The next largest segment is the DR-based VPPs, which dominate the North America market, with 44% of the total global capacity. The supply and mixed asset segments split the remaining 5% of the VPP market equally. Wholesale auction and DR-based VPPs do not integrate DG and are therefore not considered here. This shows that the number of VPP types in practice that have the potential to reduce DG integration barriers is relatively small (5%). A number of supply side and mixed assets based VPPs are reviewed below.

5.2.2 FENIX project

5.2.2.1 Description[1]

FENIX is a European collaborative project, partly funded by the European Commission within the 6th Framework Program for Research. The project was launched in October 2005 for the duration of 4 years, and consequently ended in October 2009. The primary objective of the Fenix project was "to make the EU electricity supply system cost efficient, secure and sustainable through aggregation into Large Scale Virtual Power Plant (LSVPP) (Jansen et al, 2009). The object of aggregation is not named in the objective, but comprises DG and thermal storage. Electrical storage and DR programs are not included in this project. Therefore, the Fenix project only partially meets the definition of VPP as given in the previous chapter.

The Fenix concept is applied to form both a technical VPP (TVPP) and a commercial VPP (CVPP).

5.2.2.2 Targets

The primary aims of the FENIX project include:

1. Identifying possible DER contribution to networks
2. Investigating aggregation to overcome limitations resulting from the limited size and non-deterministic behavior
3. Revising regulation and contractual relationship between stakeholders
4. Developing the software to facilitate the architecture (FENIX, 2009).

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[1] Data in this section are derived from presentations, seminars and reports that were provided by FENIX, c/o IWES, Königstor 59, 34119 Kassel, Germany; http://www.fenix-project.org/

In the light of this research, it is particularly interesting to review the results from the second and the third target, as the first and the fourth target fall outside the scope of the research. These objectives are specified as follows (FENIX, 2009):

- “In EU countries large DER are able to sell their energy in the day-ahead market, but their production flows through the distribution networks. Typically TSOs validate the schedules for the next day but very seldom DSOs are aware of them. The lack of visibility and controllability of DER make DSOs reluctant to include new DER in their networks.”
- “A major aim of Fenix is to demonstrate that DSO validation and the proposed flow of information between players will lead to a higher penetration of DER, and at the same time to a more secure situation.”
- “In many EU countries, DER are allow to sell energy in the day-ahead market, but they are not considered to provide any ancillary service to the system, even technology today allows them to.”

Another aim of the FENIX project is to demonstrate that DER could provide tertiary reserve in a reliable and controllable manner.

5.2.2.3 Results[2]

The concept was tested in both a Northern (UK) as a Southern scenario (Spain), resulting in two separate try-outs in different regulatory environment.

In the Northern scenario, 4.3 MWe of DG resources are interconnected through a non-public network in Woking Borough. About 2.5 MWe of these resources are flexible and can be dispatched, most of which are CHP plants with gas engines. The Woking Borough network is interconnected to the public distribution network via four points of interconnection. Considering the geographic constraints and the limited capacity, the northern scenario in reference mode can be considered a microgrid. However, in four additional case studies, running the portfolio of DG resources by an aggregator that acts as a CVPP has been tested. The role of aggregator is performed by the DSO in these studies, while utilities are divided into suppliers and lagrhe-scale generators The case studies differ in terms of the amount and nature the services that are offered by the CVPP:

1. *Optimised market participation*: The aggregator takes control over the CHP plants and dispatches the units on the basis of expected wholesale market profitability of running the units.
2. *Balancing services to the TSO*: The same services are provided as in case study 1, with the addition of the option to provide balancing services to the TSO. DG units can thus be

[2] Results in this section are derived from the FENIX deliverable D3.3 Report: *FINANCIAL AND SOCIO-ECONOMIC IMPACTS OF EMBRACING THE FENIX CONCEPT*, available at the World Wide Web: http://fenix2.iset.uni-kassel.de/ifs/files/ifs/webui/jsps/fenix/jsps/documents/doc_download.jsp?doc_name=del_2010_0065

dispatched to help balancing the transmission network, receiving financial compensation from the TSO.

3. *Intra-day adjustment services to the supplier*: Balancing services are offered like in case study 2, however here the services are offered to the DSO instead of to the TSO. For a DSO, this may save costs compared to an imbalance settlement with the TSO.
4. *Tertiary reserve service*: CVPPs are used for the provision of non-automatically activated reserve services.

In the Southern Scenario, 150 MWe of DG resources are interconnected, out of which 50% are flexible CHP plants. Like in scenario 1, four case studies are performed in which the units are aggregated as a VPP. In this scenario, each case is incremental to the previous one in terms of services offered by the VPP.

1. *Commercial aggregation*: The output of the DG units is aggregated to offset imbalances of individual units.
2. *Optimized wholesale market participation:* In addition to scenario 1, the aggregator takes control over the CHP plants and dispatches the units on the basis of expected profitability on the wholesale market of running the units.
3. *Active internal balancing:* In addition to scenario 2, units can modify their output, upon advice of the VPP operator, to reduce the total VPP imbalance.
4. *Balancing services to the TSO:* In addition to scenario 3, units provide balancing services to the TSO.

A cost-benefit analysis was performed in which results are presented as stakeholder and system net benefits. The reference scenario is a fit-and-forget policy, in which all plants are operated independently. Economic results are expressed in €/kW_{flex}/year, where kW_{flex} represents the amount of installed flexible loads. Results for the Northern scenario are as follows:

1. Systems net benefits for case study 1 (optimised wholesale market participation) are shown to reach €24.5 / year / kW_{flex}. DG operators and suppliers gain financially, while CVPP operators and large-scale generators experience negative financial impact.
2. Systems net benefits for case study 2 (balancing services to the TSO) are shown to reach €34.3 / year / kW_{flex}. DG operators and suppliers gain financially, while CVPP operators and large-scale generators again experience negative financial impact.
3. Systems net benefits for case study 3 (intra-day adjustment services to the supplier) are shown to reach €24.0 / year / kW_{flex}. DG operators and suppliers gain financially, while CVPP operators and large-scale generators again experience negative financial impact.
4. Case study (tertiaty reserve services) results in negative profitability, mostly due to the fact that DG is reserved for the reserve market most of the time, and cannot operate in other markets.

Results for the Southern scenario are as follows:

1 - 3. System net benefits are low and incremental, varying between €0.01 – 0.16 / kW_{flex}. Active internal balancing has a negative incremental value, as the benefits do not outweigh the investment.
4. Systems net benefits for case study 4 (balancing services to the TSO) are shown to reach €8.78 / year / kW_{flex}. Benefits go to the DG operators, while large-scale generators experience negative financial impact.

It can be seen that benefits for the DG operators arise from operating at times when electricity prices are highest, and bids for balancing services to the TSO. Lower or no profits are made from offering balancing services to the supplier and offering tertiary reserve services to the TSO. Impact of the VPP on network costs is not included. In the case of wide-spread adaptation of any of the cases, a governmental authority will most likely intervene and transfer part of the profit to the end-users.

Supplementary to the cost-benefit analysis, a qualitative assessment of the impact of FENIX operation on distribution management was performed. It is seen that "adoption of the FENIX concept as such tends to reduce/defer network investments; it falls short of pre-empting the well-known economic "law of diminishing returns" to increased deployment of DG altogether."

5.2.3 RWE Energy/Siemens VPP[3]

5.2.3.1 Description

The RWE Energy/Siemens VPP is a project initiated by RWE in 2008, bringing online a VPP that included nine hydropower facilities in the region of Sauerland, Germany. The total capacity of the system initially amounted to 8.6 MW The development of the plant is currently still in progress and new DG resources are being integrated as the project progresses. The composition of the RWE/Siemens VPP currently includes 10 MW of DG resources, i.e. nine hydropower facilities, CHP plants and back-up generators. At the moment, no intermittent renewables such as wind turbines have been installed yet. Additionally, no thermal or electrical storage, or controllable loads are integrated into the VPP. Therefore, the definition of VPP is only partially met in this project.

The RWE/Siemens VPP operates as a CVPP as well as a TVPP. CVPP services include:

1. The marketing of the generated energy on the wholesale European Energy Power Exchange (EEX) market.
2. Trading reserve capacity through Internet auctions.

TVPP services include:

1. Operating DER and cost parameters (received form CVPPS)
2. Using local network knowledge to manage the local system.

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[3] Data in this section are derived from a case study conducted by Roberta Bigliani and Gaia Gallotti (IDC Energy Insights), on behalf of the Sectorial e-Business Watch. Additional data were obtained by an interview with Dr. Martin Kramer, Anwendungstechnik / Application Technology, RWE Rheinland Westfalen Netz AG

5.2.3.2 Targets

The primary objective of this project is to prove the technical and economic feasibility of the virtual power plant concept and to collect valuable empirical data for other applications. The goal of coordinating the use of distributed generation plants, in addition to the economic benefits, is primarily to help improve their market integration. In order for a supplier to sell its reserve capacity to the German TSO it needs to have an initial offering of 15 MW. The VPP aims to aggregate single unit capacities to fulfil this minimum power limit.

5.2.3.3 Results

The project is accompanied by scientific studies that analyse the results; however these studies were made for internal use only and have not been published yet. Nevertheless, a number of findings have been obtained:

- Below a threshold of 500 kW, the costs relating to the installation of the necessary VPP hardware and operational communication costs to transmit data are currently too high to generate a positive margin when compared to the revenue coming from the limited quantity of energy that can be sold on the market.
- Instead of creating new lines, one area's electric power needs were met by installing distributed, gas-powered, mini-CHP plants with a capacity of < 100 kW. Interconnecting them to form a VPP that delivers electric power and heating made it possible to postpone a major grid investment of €1 million for five years.

5.2.4 DeMoTec VPP[4]

5.2.4.1 Description

In 2009, an experimental test setting was carried out in ISET's DeMoTec (Design Centre for Modular Supply Technology), Germany. The test site is currently no longer active. The setting included a portfolio of DERs:

- Controllable generators providing active and reactive power
- 16 kW PV
- 8 kW wind turbine
- 18 household loads

This portfolio is controlled in a number of scenarios: A reference scenario, A CCVPP, a FDCVPP and a combination of the latter two.

5.2.4.2 Targets

Aim of this pilot was to determine the influence of different VPP control strategies (CCVPP and FDCVPP) on active and reactive voltage control in a distribution network. This pilot distinguished itself from other VPP try-outs, where the focus is usually on economic aspects. Results focus on the voltage change and power flows inside the network.

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[4] Data in this section are derived from a case study performed by M. Braun and J. Ringelstein, ISET e.V., Kassel, Germany, presented on the 6th International Conference on the European Energy Market (EEM 2009), 27-29 May 2009, Leuven, Belgium

5.2.4.3 Results

The results confirm that the voltage can be influenced effectively with both approaches (CCVPP and FDCVPP). One further conclusion is that a combination of both approaches is technically feasible and most effective. CCVPP seems the best option for large controllable distributed energy units that can be controlled directly, such as large CHP units or large loads in industrial processes can be easily integrated in network operation by aggregation in a CCVPP. Small controllable distributed energy units or active customer networks, such as households and household loads, cannot be integrated in the virtual power plant system with acceptable costs or their owners do not want to have them controlled by external parties. In these latter cases, the FDCVPP approach is more effective.

5.2.5 GasUnie Micro-CHP VPP[5]

5.2.5.1 Description

In GasUnie's micro-CHP VPP project, a field test has been conducted in 2007 involving 10 households in the Meerstad area in the North of the Netherlands. These household have been equipped with micro-CHP units, each with a capacity 1 kWe. The units are geographically spread, but all are connected to one virtual sub-station. Measurements of the load on the virtual substation are used to dispatch the micro-CHP units, in order to reduce the load. The substation participated on the APX energy market in order to shift the micro-CHP unit operation to times of high demand.

5.2.5.2 Targets

The aim of the field test was to determine to what extent peak loads on the cables and substations can be reduced, by deploying micro-CHP units. This way, growing power demand in a substation can be met without having to reinforce the network, saving investment costs.

5.2.5.3 Results

It was found that a cluster of 10 households each equipped with a micro-CHP is able to reduce the substation peak load with 30-50% without infringement of the user comfort. However, the field test did not show economically feasible results due to high investment costs, insufficient efficiency of the micro-CHP units, and showed a lack of reliability. The project is considered to have been carried out too early, and innovation in micro-CHP technology is expected to lead to better test results in the future.

5.3 Acknowledgments

Special acknowledgment goes out to the spokesmen of Siemens, RWE, Gasterra (GasUnie) and EPRI who cooperated in the research through the interviews. Although the contribution of the interviews is limited as results from these projects are not accomplished (EPRI), unsuccessful (GasTerra), or available through reports (Siemens/RWE), their cooperation is highly appreciated.

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[5] Data in this section are derived from an interview with Hans Overdiep, Manager Energy Transitions for GasTerra Netherlands, and from ECN (2009).

6 Conclusion

6.1 Conclusion

Aim of the research is to answer the following research question: *"How and to what extent can VPP overcome the technological, economic and regulatory barriers to DG integration, within situation and regulatory environment of the Netherlands?"*

The share of DG in the Dutch power supply is relatively high, mainly due to the large presence of CHP-plants. Growth prospects for DG are large: DG capacity may double between now and 2020. Growth will occur in CHP, a large share of which will be contributed to the rise of micro-CHPs in Dutch households. Other major areas of growth can be found in PV solar power and on-shore wind. Technically, DG is connected to a practically unregulated, passive LV-distribution network. The regulatory system is relatively beneficial to DG when compared to other EU countries; however improvement is possible and necessary. Particularly the financial relationship between DG operators and DSOs does not facilitate DG integration.

Technologically, barriers against DG integration in the Netherlands evolve mainly from a possible decrease in reliability and protection, and a possible reduction in voltage and frequency. The large share of dispatchable CHP in the national DG portfolio makes frequency stability currently not the biggest issue. However, the growth of less dispatchable DG resources will most likely cause a need for more active balancing of distribution networks in order to maintain proper frequency levels. The same is true for voltage regulation, which is influenced by the lack of reactive power generation capacity of most DG resources, particularly renewables. Protection of distribution networks will be jeopardized by the bidirectional power flows caused by electricity injection into the net via distribution networks. Other power quality factors, such as increase in harmonics, appear not to form a barrier anymore.

Economic barriers to DG integration appear more numerous. Firstly, the current pricing and metering system, although it has improved since the last three years, does not provide many incentives to DG and network operators. Energy prices are not related to momentary demand and buyback rates are often insufficient for small DG operators. Larger CHP units do have access to wholesale markets, where prices are established through supply and demand. Secondly, the lack of use-of-system charges for DG operators does not encourage DSOs to take up more DG into their networks. The same is true for connection costs, which are shallow and do not encourage DG operators to contribute to optimising network costs. However, from the DG operator side this current regulation is profitable. Thirdly, contribution of DG is not a decision making factor for new network investment, hence DG is considered a hindrance rather than a cost reduction factor. Fourthly, the intermittency of PV solar and wind turbines increases costs as penalties need to be paid for caused grid unbalances, and more back-up power will be necessary which reduces the efficiency of thermal power plants, when provided by these.

Two main categories of regulatory barriers have been identified. Firstly, network losses legislation does currently not favour DG operators, as their contribution to network loss reduction is not remunerated in anyway. Attempts to change this legislation have been unsuccessful so far. Secondly, contribution of DG to ancillary services provision is so far poor, leaving a potential source of additional income for DG operators unused.

It is found that the concept of VPP is in many ways similar to the microgrid concept. Both use smart grid technology to aggregate a portfolio of distributed energy resources. The main difference found is the VPP ability to enter various energy markets, such as spot markets and balancing markets. The VPP is shown to consists of a portfolio of DERs (which include DG, demand response and storage), smart grid infrastructure, and an energy management systems which dispatches the portfolio and links to the energy markets. Several types of VPP can be identified, that commonly consist of a limited number of parts of a complete VPP.

Theoretically, it is expected that the VPP concept has the ability to overcome to a certain extent all identified barriers to VPP in the Netherlands. However, it can also be seen that at this moment in time, no mixed asset VPP is in operation, making it difficult to verify the actual potential in practice. Types of VPPs can be found mainly in Spain, Germany, the UK and the US, although the type found in the US does not (yet) include DG in its portfolio and is therefore not relevant to the research question. It is found that a number services offered by the VPP have already shown to have a potential for feasibility in VPP projects abroad. Notably, optimised wholesale market participation and the provision of primary and secondary reserve services to TSOs or suppliers are shown to have a positive net monetary value to most of the stakeholders involved. A negative value is seen for large-scale generators or utilities. The potential for active internal balancing (Microgrid) and providing tertiary reserve services to the TSO have not yet been shown to be feasible. Another economic potential is found in the option of delaying network investment by aggregating multiple DG units into a VPP, greatly reducing costs for DSOs. A barrier that cannot be fully solved through VPP is the unfeasible prices that DG operators may receive, and support schemes such as a feed-in system will remain necessary in addition to the VPP infrastructure.

Technically, it has been shown that VPP methods such as centralised and decentralised control of DG are effective in managing active and reactive power flows inside a network, thus steering the voltage level. This confirms the theoretical assumption that VPP is capable of voltage control in a distribution network that comprises DG.

Overall, experiences with VPP seem to show that the concept turns DG integration barriers into opportunities. DG sources are no longer considered an unpredictable hurdle by network operators, but a controllable source of power and services instead. All identified barriers to DG integration can, to a certain extent, be overcome in the VPP concept.

6.2 Discussion and recommendations for further research

This research did not aim at determining the overall feasibility of the VPP concept. The main goal has been to determine the potential of the VPP concept to overcome barriers to DG integration. However, the VPP concept has a broader scope than facilitating integration of DG into the grid. Other purposes exist, such as peak shaving through DR programs, facilitating electric vehicles, and reducing congestion in the transmission network. The extent to which the VPP is a suitable model and which VPP type would serve these respective purposes best, form a relevant field of research. Additionally, in order to practically verify certain theoretical potentials, such as the contribution of storage to frequency regulation in a mixed-asset VPP, will have to be tested in practical settings.

A constraint is formed by the focus on the Dutch physical and regulatory system, as these systems vary highly amongst countries and even within EU member states. In the Dutch situation, there is a relatively large amount of CHP in national power and heat supply, which already participates to a certain extent in energy markets. In other physical and regulatory systems, applicability of the VPP concept may be different. Additionally, with the integration of power markets in the EU and TSOs connecting their networks internationally, a more international approach to VPP may be an interesting topic of research.

Another highly relevant topic for upcoming research on the VPP subject will be in the economically optimal utilization of DG, DR and energy storage in a VPP. Where demand is curtailed, more energy can be stored and/or a different amount generation can be dispatched. The question what strategy is most useful here and how different storage and generation technologies influence this strategy is of utmost importance for the design of a mixed asset VPP, and will thus require further research.

Furthermore, the research did not compare the VPP potential to alternative grid architecture, such as the microgrid. Some research has been done on this, but detailed analyses of both approaches have so far not yet been compared in applicability and feasibility. Additionally, both the VPP and microgrid are relatively short-term solutions, which operate within the current technological framework and without a full replacement of the energy transition and distribution system. On the long term, other approaches such as energy hubs may be the more likely candidate for the next era of the energy system. VPPs may be a "transition phase" between centralized generation and a completely efficient and renewable future energy system. Which options are most interesting on a time scope of >10 years is a highly interesting topic of further research.

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Appendix I - VPP Questionnaire

1. What is the current total electric capacity of the system?

2. What is the maximum electric demand of the users in the system?

3. What are the shares of the different generation technologies (CHP, hydropower, wind turbines, PV solar, biomass) in the total generating capacity?

4. Would you describe the VPP as a "technical virtual power plant", a "commercial virtual power plant", or both? (If these concepts mean nothing to you, skip the question).

5. What is the goal of the VPP?

6. Which of the following services are offered by the VPP:

- Demand response programs / load control / other forms of demand management?
- Energy storage, e.g. flywheels, fuel cells, etc.?
- Balancing services to energy suppliers / transmission system operator?
- Providing ancillary services to the TSO or supplier?
- Reactive power control by the VPP aggregator?
- Forecasting of intermittent energy sources (e.g. solar, wind)?
- Active internal balancing of resources?
- Aggregating of distributed generation to participate in the wholesale energy market (e.g. APX/EEX)?
- If there is participation in the wholesale energy market, does this include forecasting of demand/supply, bidding/scheduling resources, dispatching, and settling with markets/suppliers?

7. Does the VPP improve the security of the electric system and if so, how?

8. Does the VPP improve power quality in the electric system and if so, how?

9. Do DG operators in the VPP receive profitable rates for the power produced by their units?

10. Does the VPP ease access of DG to power markets?

11. Have investments taken place in the network within the VPP, taken into account DG in the planned capacity?
12. Does the VPP reduce back-up power required for intermittent energy sources?
13. Can you mention any further advantages of the VPP?

APPENDIX II – List of interviewed

<u>RWE (Germany), RWE/Siemens VPP:</u>

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Appendix III – Boccard Netherlands 2010

#	cat	Question	Answer NL	med	score
	D	Intermittent electricity incidence (out of #38) (lesser better)	low	*+1*	*0*
40	E	Describe support mechanism for DG	premium tariff, market price plus subsidy on production and tax exemption		*0*
41	E	Duration foreseen by law 10 years 0 0	10 years	*0*	*0*
43	E	Support in % of average market price	50% or more	*0*	*0*
44	E	Wholesale market for energy/electricity ? Yes +1 1	Yes	*+1*	*1*
45	E	DG has access to wholesale market ? practically ? Yes +1 1	Yes	*+1*	*1*
46	E	DG has access to ancillary market ?	Yes	*0*	*1*
47	E	Market form is (related to DG support mechanism)	Bilateral + voluntary power exchange (APX)		*1*
48	E	Concentration in the energy market is ?	medium	*+1*	*0*
				Valuation	***4***

Table 10 - Market access for DG

#	cat	Question	Answer NL	med	score
1	A-I	Has the relevant law been revised to fasten the authorization procedures for building small generating units and connecting them to the distribution network ?	Yes, since 1998	*+1*	*1*
2	A-I	Same Question for CHP (in case there's a difference)	No		*0*
3	A-I	Does the law foresee publication of DSO technical and(connection) cost-sharing rules ?	Yes (national law set rules)	*+1*	*1*
4	A-I	Does the law mention the non discriminating of RES and/or CHP with respect to the provision of ancillary services ?	No	*+1*	*-1*
5	A-II	Who provides ancillary services ? (DSO, TSO) related to market participation	TSO	*TSO=+1*	*1*
7	A-II	Is there any project for two-way metering installation ? Yes +1 1	Yes	*+1*	*1*
				Valuation	***3***

Table 11 - Regulatory framework for DG

#	cat	Question	Answer NL	med	score
8	B-I	How long has been Regulated TPA in force ?	1998	*sooner = better*	*1*
9	B-I	Does the law address the first-comer problem for RES ?	No	*+1*	*-1*
10	B-I	Same for CHP (in case there's a difference)	No	*0*	*0*
11	B-I	Connection charge is ?	Shallow or negotiated	*0*	*1*
12	B-I	If #11 is shallow: Is the DSO compensated for the difference (deep-shallow)?	No	*+1*	*-1*
13	B-II	Structure of UoS: capacity and/or energy component ?	HV on capacity, LV on energy.	*many drivers 1*	*-1*
14	B-II	UoS is initially set by a national authority (e.g., Regulator) or negotiated by association of DSOs and DG operators ?	DSOs with regulator approval	*Reg = 1*	*0*
15	B-II	Is there some leeway for DSO in the application of the UoS ?	No	*Yes = -1*	*1*
16	B-II	Who pays UoS charges ? (ability to discriminate sources and sinks)	Mostly end-users (load)	*User=-1*	*-1*
17	B-II	Is there a compensations scheme for DG network benefits like loss reduction ?	No	*Yes = -1*	*-1*
18	B-II	Existence of a location signal in connection cost or UoS?	No	*1*	*-1*
				Valuation	***-3***

Table 12 - DG-DSO financial relationship

#	cat	Question	Answer NL	med	score
25		Level of DSO-Supply unbundling (acc, mgt, legal, own)	legal/ownership	higher better	*1*
26		Level of DSO-Generation unbundling (acc, mgt, legal, own)	legal/ownership	higher better	*1*
27		Is there any performance standards in the DSO revenu (e.g., link to the regulatory asset base) ?	Yes, incentive regulation	*+1*	*1*
28		Benchmarking of DSOs (whether actual or projected) builds on CAPEX and/or OPEX ? (WP 4.2 classification favours output measures)	Both inputs	*-1*	*-1*
30		How much DG is owned by DSOs ?	Zero	*0*	*0*
31		Is there or will be a national scheme providing optimization incentive to DSOs ?	No	*+1*	*1*
				Valuation	***3***

Table 13 - Regulatory framework for DSOs