Evaluating flexibility values for congestion management in distribution networks within Dutch pilots

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Keywords: Congestion Management, Demand Response, Flexibility, Smart Grids

Abstract

Decentralization of electricity generation, and electrification of heating and transportation pose challenges for the distribution networks, such as possible network congestion. Network operators investigate alternatives for reinforcements. Flexibility through demand response is one of these alternatives. Four theoretical possibilities for flexibility as a solution for congestion management are presented, in relation to four pilot projects on congestion management in the Netherlands. This paper evaluates these four pilot projects based on six evaluation criteria. The strengths and weaknesses of all pilots are addressed, and the results of the pilot projects are discussed.

1 Introduction

Due to the energy transition the energy landscape will change dramatically. Decentral generation from renewable sources like wind and sun will lead to more volatility. Next to this an electrification of household appliances will take place, for example assets for heat generation and transport. Literature shows that these developments could result in congestion problems in the electricity network [1]. The traditional solution to congestion is reinforcing the network, which is expensive. Therefore, distribution system operators (DSOs) are looking for alternative, cost-efficient methods to avoid network aggravation. Flexibility through demand response (DR) is one of these alternative methods which has been researched by both academia and industry over the past years.

This paper will summarize four theoretical possibilities of obtaining flexibility from (flexible) distributed energy resources. The goal is to evaluate their performance in pilot projects and address the performance and viability of each mechanism. The flexibility mechanisms are introduced in section 2. The pilot projects are introduced in section 3. Section 4 introduces the evaluation criteria and provides a discussion. The conclusions and future work are presented in section 5. The scope is limited to congestion in the distribution networks in the Netherlands and based on publicly available information (i.e. project reports, scientific publications).

2 Flexibility

2.1 Definition

Flexibility has many definitions in literature. To understand the meaning of flexibility in this paper, a definition is given. We define flexibility as *"a power adjustment sustained at a given moment for a given duration from a specific location within the network*" [2]. This definition illustrates the four underlying parameters relevant for congestion management: an adjustment of power consumption or production, the moment in time and duration for which this occurs, and the location in the distribution network.

2.2 Mechanisms

Demand-side flexibility can be unlocked in various ways, for example through demand response (DR). DR distinguishes two classes, implicit and explicit DR [3]. The possibility of users to respond to price signals reflecting network and market variability is defined as implicit DR. Trading flexibility on one or more markets is defined as explicit DR.

This section will further elaborate on four flexibility mechanisms, which are applied in the pilot projects evaluated in this paper. This includes two implicit DR and two explicit DR mechanisms. The implicit DR mechanisms are pricing based and variable connection capacity based. The explicit DR mechanisms are agent based and market based.

2.3 Price-based mechanism

The possibilities of different pricing mechanisms to change the consumption behaviour have been studied extensively in literature [4] [5]. The price structure as we know it represents the total costs made to generate and transport electricity. In the Netherlands electricity prices are divided in four components: supply-, network-, metering costs, and taxes. *Supply costs* of energy consist of supply tariffs and fixed tariffs. Supply tariffs are the costs for the delivered amount of electricity. The fixed tariffs are determined by the supplier. *Network costs* are related to system services, transport, distribution and the connection. Network companies also charge fixed costs which are related to the connection to the network and transport of electricity. The system services are related to the costs for the additional services to maintain, operate and manage the transport network which are determined by the transmission system operator (TSO). *Metering costs* are related to the costs of recording the meter positions and installing, maintaining and managing of meters. *Taxes* can be divided in two parts: a fixed tax per kWh and VAT levied on all costs.

Currently the Dutch electricity tariff is either flat, or distinguishes in static time-of-use, day- and night tariffs. Furthermore, the capacity tariffs are based on the maximal technical capacity, without taking into account frequency or time of use. Therefore, consumers do not get an incentive to adjust their electricity use from peak periods to off-peak periods, while adjusting consumption can reduce costs for both the supplier, network operator and consumer [6]. Alternative price mechanisms have been proposed, to create the necessary incentive. Amongst others, examples of dynamic tariff mechanisms are [5]:

- Time-of-use (TOU): The tariff is higher in peak periods and lower in off-peak periods. Price depends on the moment the electricity is used;
- Critical peak pricing (CPP): Is an addition to flat-rate or TOU. CPP is based on the peak load of the network and can therefore have a locational difference. During a peak load situation, prices are higher, during the normal situation there is no additional charge;
- Real time pricing (RTP): Prices are based on the wholesale electricity market. The cost of power can be determined either real-time or day-ahead.

These tariffs are directly communicated to the consumer by an app or other application. The consumer can choose to respond to a certain price or not. Within the pilot Your Energy Moment (YEM). RTP and CPP are used. Section 3.1 elaborates further on the pilot project.

2.4 Variable connection capacity

The Netherlands has a liberalized energy market in which involved stakeholders are following the ownership unbundling regulation. This means that network operators cannot hold shares of generation companies and vice versa [7]. DSOs therefore operate in a regulated market, in which the distribution network is considered to be a natural monopoly. For each point of connection (PoC), the DSO has a capacity contract. In these contracts, the maximal allowed capacity at a PoC determines the amount a consumer needs to pay. This is a fixed tariff per year, which is not related to the amount, frequency, or timing of electricity consumption.

A variable connection capacity introduces a time-dependent profile for the available capacity on a point of connection. This is done by setting an on- and off-peak capacity over time, as illustrated in figure 1. The DSO implements the variable connection capacity in the contracts with their consumers and validates user compliance with metering data.

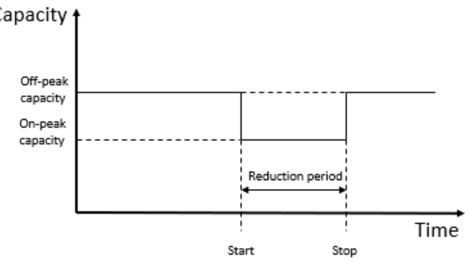

Figure 1: Visualisation of variable connection capacity

The profile used for variable connection capacity can be determined at a national or local level and can differ during the day in both time and capacity. This means that there are different possibilities for implementing a variable capacity, each possibility having different characteristics:

1. National fixed profile: The profile is established on the national average historical energy profile;
2. Local fixed profile: Local profiles with a predetermined capacity profile, using the measurement data from a specific transformer or cable;
3. Local dynamic profile: The profile is established based on the (real-time) measurement data or load forecasts for a specific transformer or cable.

In the FlexPower pilot the national fixed profile, based on the aggregated load profiles [8], was implemented at charge point connections for electric vehicles [9]. The charge point operator (CPO) was offered a contract with the DSO in which, compared to a flat capacity profile, 22 hours of the day electric vehicle owners can charge 25% faster and 2 hours of the day during the peak hours 50% slower compared to a traditional connection. More information about this pilot can be found in section 3.2.

2.5 Agent based equilibrium market

Another mechanism to unlock flexibility is a multi-agent system which establishes an automated, local equilibrium market. Every supply and demand unit has its own agent, and each agent puts in a bid, for supply and/or demand. According to [10] these agent-based markets developed through a combination of micro-economic theory and control theory. The result is a system which determines the local marginal pricing. However, traditionally these agent-based markets assumed the electricity network to be a copper plate, neglecting the power flows throughout the network [10].

The PowerMatcher technology is an agent-based market system that has resolved this limitation. In the PowerMatcher, the local marginal pricing is extended with constraints. To this end, four types of agents are introduced [10]. At the heart of the system lays the auctioneer agent, which intends to solve the optimization and set the marginal price. Concentrator (or aggregator) agents and local device agents connect with this central auctioneer agent. The device agents take into account the desired behaviour of the device and formulates a bid accordingly. The concentrator agent's purpose is concentrating (or aggregating) a number of device agents into a single bid-curve. The last (optional) type is the objective agent. This agent has the potential to add a purpose to a cluster of agents, for example including location's network constraints.

The PowerMatcher technology is applied in the pilot project PowerMatching City, in Hoogkerk, the Netherlands. Here, in two phases, up to forty households are equipped with smart appliances (e.g. smart heating systems and smart appliances). These are then controlled by the market price signal from the PowerMatcher [10] [11]. Section 3.3 elaborates further on this pilot project.

2.6 Flexibility market

Flexibility markets have been a topic of research for years, and many variations are proposed by different authors. [12] introduces a DR exchange platform, where DR is traded as a commodity with the DSO, TSO, and retailers. A few years later, [13] proposes a flexibility clearing house, which is setup in parallel to existing wholesale markets. This concept is later expanded by [14], introducing various moments in time (e.g. year-ahead, day-ahead, hour-ahead) at which flexibility can be traded. Furthermore, the sequence of events in the parallel flexibility and wholesale markets is addressed. For example, [14] proposes to ensure the gate-closure times of the day-ahead flexibility market should come before the gate closure time of the day-ahead wholesale market, in order for these markets to complement each other.

Not only academia is interested in the concepts of flexibility markets. Industry started contributing as well. A consortium of industrial partners formulated what is known as the universal smart energy framework (USEF). USEF provides in a (non-profit) framework with which market parties can formulate flexibility products and services, parallel to already existing energy markets [15].

Possibilities for specialised field implementations remain. Three of these typical differences relate to the market rules, the moment at which flexibility is purchased, and the remuneration of flexibility. Remuneration of flexibility can be implemented either based on a capacity fee, on an energy fee, or a combination of both. DSOs can obtain flexibility through direct bilateral agreements with aggregators or chose to obtain flexibility in a market setting. In case of a market setting, a day-ahead and an intraday market can be offered to the DSO, resulting in a single-buyer market. In this case aggregators optimize their portfolio, and decide on which market (i.e. flexibility, ancillary, or wholesale) they will trade. As an alternative, flexibility can be offered on an open platform, where flexibility is offered and requested, and after gate closure, the market is cleared.

Depending on the market constraints, in order to procure flexibility, the DSO might need to compete with other interested parties, e.g. TSOs, and balance responsible parties (BRPs).
Within the pilot project Energiekoplopers (Energy frontrunners) in Heerhugowaard, the Netherlands, USEF is used to implement a local flexibility market. This market enables the DSO to obtain flexibility for congestion management, both in a day-ahead and an intraday setting [16]. Section 3.4 will elaborate further on the pilot project.

3 Pilot projects

3.1 Pilot 1: Your Energy Moment

Your Energy Moment (YEM) is a Dutch pilot which consists of two phases. The first phase of YEM started in 2013 and had a duration of two years. This pilot revealed that participants were motivated to change their energy use by implementing energy management systems, smart washing machines and flexible tariffs, as a result of awareness on the beneficial moments of energy use [17]. The first phase has shown that washing machines had only little impact on the total electricity use of a household which results in little flexibility per household.

In the second phase, the focus of the project shifted to possible business cases and billing systems. This paper will concentrate on the findings of phase two, in which 91 households participated. All participants were offered a dynamic price incentive to change their energy behaviour. Of these, 39 had an automated system for demand response, a battery, heat pump and PV panels. The other 54 needed to change their consumption manually. In the proximity of 17 of the latter group, a neighbourhood battery was installed for additional flexibility options. All households had access to a mobile app to monitor their electricity use real-time [18].

During this pilot RTP and CPP is used. The RTP pricing was based on prices established at the EPEX day-ahead market. The network operator added an additional price incentive during the moments of peak demand. Furthermore, a dynamic energy tax is introduced. At this moment about 70% of a Dutch household's electricity tariff is tax. When the different taxes are fixed per kWh less volatility in prices is achieved [19]. Therefore, the percentage of tax is determined per month, based on the electricity use during the month beforehand is introduced [18]. Higher consumption results in higher taxes for the next month, and vice versa [19].

Main outcomes
Automated demand response on household batteries and other appliances can lead to congestion on the LV network, at moments there is twice as much network capacity needed than in the situation without demand response because of simultaneous low or high prices on the same cable [18].

Without involvement of the consumer, DR has little value. It is important that communication and information is adjusted to the knowledge level of participants [18].

Main shortcoming
Only a limited reduction of electricity use is measured. The preliminary results of the pilot show a reduction of 3%, which

is equivalent to 5 euros per year per household [18]. Additional data analysis is needed for a definitive answer of the influences on the peak demand.

3.2 Pilot 2: FlexPower

FlexPower is a pilot project which focused on one flexibility asset, the electric vehicle (EV). During this project the main goal was connecting the whole chain of parties from DSO to EV-driver with a standardised system solution. Therefore, all stakeholders in the chain were present: DSO, charge point operator (CPO), E-mobility service provider (EmsP) and EV-driver. In the pilot, a variable connection capacity contract with a static profile for the charge point connection was introduced [9]. During on-peak hours (2 hours) EV-drivers got less capacity (reduction of 50%) and in off-peak hours (22 hours) participants got an additional 25% capacity, compared to the regular contract. EV-drivers had the option to overrule the reduction in on-peak hours by using a special charge card or app. The offered incentive was mainly interesting for Battery Electric Vehicles (BEV); Plug-in Electric Vehicles (PHEV) have less to gain, as PHEV do not have the opportunity to charge faster than the commonly offered connection. Therefore, PHEV were offered another incentive, which was either a cash back of €70, an investment in PV panels, or the option to always charge with sustainable energy at a certain public charge point. Consumer research (interviews and questionnaires) has been conducted among 71 participants, including both BEV and PHEV drivers [9].

Main outcomes
Implementing a variable capacity profile has been proven to be successful within the pilot. During the peak hours the energy demand has been lowered by 46%. This could have positive impact on the expected peak load of EV in the low voltage network.

The consumer survey in the pilot showed that participants accept the smart charging principle with a variable capacity. The participants have however also indicated that they want to keep control with an overrule option. The pilot demonstrated that despite the fact that this option was offered it was hardly used [9].

Main Shortcoming
The variable capacity is mainly useful to shift the peak demand to another time frame. While a variable capacity contract with a static profile can eventually lead to a new peak on the cable or transformer on the moment the capacity reduction ends. Reason for this is that all connected cars will immediately start using the full capacity on the same moment [1].

3.3 Pilot 3: PowerMatching City

The goal of the PowerMatching City project in Hoogkerk, the Netherlands is to evaluate whether the PowerMatcher technology can be used to balance supply and demand dynamically, in a way that all interests (i.e. consumer, network, and market) are met [20]. The project is setup in two phases, during which 25 (phase I) and 40 households (phase II) participated [11]. Households are equipped with a mix of smart appliances, photovoltaics [10], and smart heating systems (e.g. heat pumps and micro combined heat power systems [11]. Furthermore, two electric vehicles, and one wind turbine are added to the project [10]. These appliances are either controlled automated, semi-automated, or manual [20]. The three main stakeholders are the consumers (i.e. residents), market aggregator, and DSO, all represented by agents.

Main outcomes
Flexibility provides benefits for all three stakeholders. The project has shown that residents are willing to change their behaviour, however the (semi-)automated control system is favoured over manual control [20].

According to [20], smart meter allocation is a requirement for economic viable flexibility through demand response. Regulation has already been changed, and smart meter allocation has been implemented.

Main shortcoming
Fairly distributing the benefits between three main stakeholders is challenging. The project's recommendation is to develop a market model to maximize the flexibility offers' value. In this model, the aggregator role plays a central part [20].

3.4 Pilot 4: Energiekoplopers

The pilot Energiekoplopers (Energy frontrunners) took place in the Dutch city of Heerhugowaard. The flexibility in this project is provided by photovoltaics, heat pumps, electric boilers, and fuel cells, dispersed over 203 households. A local flexibility market is setup using USEF. In this market an aggregator offered flexibility to both DSO and BRP, taking user preferences into account. Ahead-of-time trading took place in a day-ahead and intraday setting, providing the opportunity to correct a day-ahead forecast of flexibility needs during the intraday phase [16].

Main outcomes
The project has shown that the DSO can use a flexibility market for congestion management. This does not always resolve the problems, and some overloading will still occur. Overall, about ⅔ of the purchased flexibility is delivered. Within the project a number of reasons are provided to explain this value. Amongst these reasons are the following two: 1) the ICT infrastructure is implemented for pilot project purpose only. Uptime and reliability have therefore not been the main design criteria. For large-scale implementation the project's recommendation therefore is to redevelop these systems, to guarantee a higher reliability and uptime [16]. 2) During some times, there is a conflict of interest between the flexibility needs of a (portfolio optimizing) BRP and a (congestion preventing) DSO.

Main shortcoming
Within this project, the roles of aggregator, BRP, and supplier are done by a single actor. Eid et al. concludes that this limits the market and simplifies the settlement & remuneration processes [21]. Additional research into scalability with multiple aggregators, and split roles and responsibilities is therefore necessary.

4 Evaluation & discussion

To adapt criteria on which to evaluate smart grid pilots, the basic layers from the smart grid architecture model (SGAM) are used [22]. SGAM knows five layers, namely the business layer, function layer, information layer, communication layer, and component layer. The evaluation of the criteria is done by the authors, based on a five-point Likert scale, with ++ being the best score, and -- being the worst. This section explains which criteria are linked to which layer of the SGAM model and discuss the evaluation per criterion. The evaluation can be found in table 1.

	YEM	FP	PMC	EK
Technology readiness	++	-	+	-
ICT dependence	+/-	+	-	-
User acceptance	-	+	+	+/-
Regulatory framework	-	+/-	-	-
Flexibility source equality	+/-	--	+	-
Degree of problem solving	--	+	+/-	+

Table 1: Evaluation of the criteria for the pilots Your Energy Moment (YEM), FlexPower (FP), PowerMatching City (PMC), and Energiekoplopers (EK). ++ is the best score, while -- is the worst.

The business layer is represented by a criterion on the *regulatory framework* in which a pilot is executed. Flexibility mechanisms and regulation need to be aligned, and where necessary, the regulatory framework should be adapted.

All pilots need changes in the regulatory framework. Currently the regulatory framework limits DSOs to implement alternative solutions to grid reinforcements on a large scale. In the four pilots, two main regulatory framework changes can be identified: changes in the tariff structures (all pilots) and introducing a local market (PowerMatching City and Energiekoplopers). It should be noted that over time, one of the limitations (smart meter allocation) in PowerMatching City is already resolved. Your Energy Moment uses this allowed allocation method. FlexPower scores slightly higher than the other pilots, as the changes in tariff structure limit themselves to the DSO tariff only. Price differentiation suggested in Your Energy Moment could already be implemented based on supply costs, however to achieve a sufficiently large price volatility for consumers, the transport and distribution component, and especially the tax component of the tariffs need to be rearranged in order.

The functional layer maps actor's use cases into the SGAM. In this paper, the use case is congestion management, for which a DSO perspective is taken. As a criterion, pilots will be evaluated in terms of their *degree of problem solving*. In other words, it is evaluated to what extent a flexibility mechanism solves and/or prevents congestion. Given the nature of the selected pilots, the extent of user acceptance is a criterion; without *user acceptance*, neither of the piloted solutions is able to solve congestion.

Your Energy Moment has shown only a limited energy shift, whereas both FlexPower and Energiekoplopers have a significant improvement, especially regarding these pilots have the lowest technology readiness. Conflicts of interest between stakeholders are one of the mentioned reasons congestion still occurs for both the PowerMatching City and Energiekoplopers pilots. The FlexPower pilot furthermore shows dynamic variable connection capacity profiles are necessary for adequate resolving congestions. For this paper, this however is considered technology readiness, rather than problem solving.

The second criterion in the functional layer is user acceptance. User acceptance is a criterion critical for the four pilots to be successful. It should be noted however, that the user groups in these projects are above average interested in sustainability and technology, and/or have an above average level of education. PowerMatching City and FlexPower managed to involve their users to the project and show the willingness to participate. Your Energy Moment shows the challenges face getting user acceptance.

The information and communication layers are combined in a single criterion: *ICT dependence*. This criterion addresses the complexity and reliability of communication, and the need of data between the various systems, where a low dependence and complexity is considered better.

All projects depend on ICT. The FlexPower project scores high, since compared to a basic setup for smart charging relatively limited additional ICT is needed.

The component layer is represented by two criteria: *technology readiness*, and *flexibility source equality*. Technology readiness evaluates the maturity of a technology. Flexibility source equality evaluates whether alternative flexibility sources have an equal chance in a flexibility mechanism.

The technology readiness of both Your Energy Moment and PowerMatching City is good. Both pilots use mature technology and are ready for large-scale field implementations. It should be remarked that the complexity of an agent-based system as PowerMatching City likely poses to be more challenging than the simpler solution of Your Energy Moment. Both FlexPower and Energiekoplopers score low on technology readiness. These pilots use technology in a prototype phase. Here, it should be remarked that due to a lower complexity in the FlexPower pilot, shifting to mature technology is likely to be faster.

Flexibility source equality is in particular good within the PowerMatching City project. The PowerMatcher technology provides opportunities to model the behaviour of any flexibility appliance into an agent, and let it participate. The FlexPower pilot focuses specifically on EV, and on a connection level rather than appliance level. Your Energy Moment scores neutral, as it enables both manually and automatically operated appliances to participate but does not distinguish based on appliance's behaviour. Energiekoplopers can principally control a vast amount of flexibility sources, however due to low uncertainty and limited trading opportunities, sources cannot necessarily participate in an equal manner.

5 Conclusions & future work

5.1 Conclusions

Four flexibility mechanisms are evaluated in relation to pilot projects in the Netherlands. Two of these mechanisms are implicit DR solutions, and two explicit DR solutions. Each pilot project demonstrated a strength, however, for each pilot also shortcomings can be identified. In all options the regulatory framework needs to change in order to execute the flexibility solution for congestion purposes for the DSO. In order for these mechanisms to work in practice, user acceptance needs to be high. Not every pilot demonstrated this.

5.2 Future work

All flexibility mechanisms have positive and negative scores on different criteria. Furthermore, shortcomings can be identified for all projects. Additional research and pilots are needed for all flexibility mechanisms in order to determine whether flexibility can be used for congestion management instead of traditional solutions like grid aggravation. Since user acceptance is critical for flexibility to work in practice, it is necessarily to explicitly include this in future research.

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