ReFlex: Market-Based Redispatch in Distribution Grids - Incentivizing Flexible Behavior of Distributed Energy Resources

Carsten Wissing[1], H.-Jürgen Appelrath[1]

Abstract

Distributed energy resources (DER) such as combined-heat-and-power-plants (CHP) or energy storages offer an inherent potential for flexible behavior. In this context, flexibility refers to a DER's ability to shift generation (or consumption) times due to external requirements or incentives. Against the background of a growing demand for participation of DER at the provision of ancillary services especially at distribution system level, both new economical incentives and new technical concepts for a reliable integration and coordination of distributed flexibilities are necessary.

In this contribution, we therefore introduce the "Redispatch with Flexibilities of network users (ReFleX)" concept of a market-based redispatch in distribution grids, especially aiming at an economically optimized congestion management by actively incentivizing flexible behavior of DER. For that purpose, localized active power products are dynamically placed at an Intraday-market place depending on the expected grid operational state. The aspect of localization refers to a new property of power products: Their contribution is restricted to certain spatial areas of the distribution system, e.g. to a certain set of nodes in a given power grid.

Thus, if an analysis of grid capacity utilization reveals possible congestions or violations of the mandatory voltage levels in certain grid areas, adequate quantities of generation or load bids can be placed in order to proactively avoid or reduce unwanted power grid states.

1. Introduction

In November 2011 the German administration has decided the »Energiewende« (energy transition) for Germany. Beside the Renewable Energy Sources Act the energy transition has particularly long-term impacts on the whole electrical energy network. The energy transition is both a technical and (macro) economically ambitious project. By the year 2030 between 50% (energy concept of the German government) [BMWi, 2010] and 67,6% [BMU, 2012, scenario 2011-A/B] of the gross electricity demand should be covered by renewable energies, by the year 2050 even between 80% and 85,8%. These objectives are expected to be achieved by an ongoing rollout of renewable energies, provisions to reduce the overall demand for electricity as well as through investments in electricity networks and in flexible conventional power plants. Taken together, these provisions perspectively result in a significant reduction of conventional large-scale power plant capacity and a significant expansion of widely distributed DER especially within the distribution grid.

Essential for a stable and reliable power supply is the continuous adjustment of production and consumption in terms of power balance of the entire system. Imbalances affect the power grid frequency and may result in an economically expensive activation of control power. Due to the increasing integration of fluctuating, decentralized energy systems (wind energy converters, PV systems), the proportion of only vaguely predictable amount of energy in the overall system increases. To prevent economically unfavorable forced shutdowns of DER, incentives are needed to evolve a coordinated decentralized supply system and to improve the flexibility of the demand side. In addition to a more coordinated provision of active power and due to the long-term substitution of conventional power plants, distributed energy resources (DER) have to increasingly participate in the provision of system services. This comprises in particular voltage

[1] OFFIS – Institute for Information Technology, {wising,appelrath}@offis.de

control in both distribution and transmission grids as well as contributions to the provision of short circuit currents for error detection in power grid protection systems.
The historical solution to extend the electrical grid network until congestions are eliminated is technical possible but (macro) economically questionable. Current studies [DENA, 2013] arrive at the conclusion that large investments into the distribution grids are necessary to fulfill the upcoming tasks. In the study, it is highlighted that until 2030 51.600 km of electrical lines for the low voltage network and 72.100 km for the medium voltage network are needed. [DENA, 2013, figure 2, scenario NEP B 2030] Investment and realization of extending electrical networks can imply imponderables and take several years. In the meantime the challenges can intensify and network congestions may occur more often and lead to choking off DER or limited blackouts within the distribution grid.
The German regulator Bundesnetzagentur (BNetzA) highlighted that emerging smart market concepts can make a contribution to reduce the costs of the energy transition and help to bridge the time gap for the upgrading of the distribution grid [BNETZA, 2011]. In this contribution we present the »ReFlex« approach for a smart market concept, which aims at delaying or avoiding necessary extensions of the distribution grid through a market-based approach to incentivize a change in behavior of network users.

In this paper we first take a look at the requirements for a decentralized energy system (chapter 2) and discuss their possible implementation within a new market design (chapter 3). Thereupon we introduce the market design of ReFlex (chapter 4) and describe the intended implementation and future prospects (chapter 5).

2. Requirement analysis for a future decentralized energy system

For a mostly decentralized energy system, additional requirements must be met. The United States Federal Energy Regulatory Commission (FERC) [FERC, 2006] defines ancillary services as "those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system" and identifies the following six services: (1) scheduling and dispatch, (2) reactive power and voltage control, (3) loss compensation, (4) load following, (5) system protection, (6) energy imbalance. These ancillary services are defined for the United States energy market where operation is in several ways different to the European system operation. Nevertheless, we take these services as a basis to discuss the necessary ancillary services for our market concept.

- “Scheduling and dispatch”: means the planning and registration process that units need to go through to register their schedule on a day-ahead basis with the electrical system operator. The data for each unit in the electrical grid is necessary to estimate the electrical grid state for the next day and to perform provisions to ensure the network operation.
- “reactive power and voltage control”: consists of all provisions to maintain the mandatory voltage levels. Historically, these voltage levels have been easy to handle, because the grid state could be estimated due to the top-down structure of the energy supply. With the increasing penetration of DER on all voltage levels the top-down structure will be (in parts) replaced or complemented by a bottom-up structure and the voltage levels cannot be estimated that easily any more. There are multiple ways to influence the voltage level (for example by using transformer taps, voltage regulators or network switching), but for our contribution the only options we consider are the provision of reactive and active power from units in the distribution grid.
- “loss compensation”: means to estimate and allocate adequate quantities of electrical energy that will be consumed by the grid itself. A secondary aim within this ancillary service is to operate the electrical grid in a way that minimizes the amount of network losses. In our concept, the reduction of the amount of transmission losses will be a side condition that we can only highlight in further research.

- “load following”: The wording for this ancillary service is kind of obsolete for a future energy system, because the energy transition forces a paradigm shift from load following to generation following. This ancillary service implies the imperative need for balancing the electrical load and generation on a short-term basis. Imbalances affect the power grid frequency and may result in an economically expensive activation of control power. Frequency stability is not part of the ReFlex smart market concept, but it may be noted that especially the loads in a distributed energy power system can contribute to the control power mechanism when they take advantage of the potential that lies in the doze flexibility of loads.
- “system protection”: means all measures that are taken into account to secure the operation of the electrical system. These are on the one hand the identification of system or component errors and on the other hand standards for ICT security. Both are not being considered as part of the smart market concept.
- “energy imbalance”: this ancillary service aims at correcting small differences of energy imbalances within a control area provided by single grid operators. This service is out of scope for the development of the new market design.

3. Discussing the ReFlex market design

Figure 1 shows the boundary conditions that lead to the ReFlex market design. The Input of each condition is explained in the following. The development process for the ReFlex market design bases on the market engineering process by Weinhardt and Neumann [WEINHARDT 2007][NEUMANN 2003]. The **Active Power Trading** box stands for the whole trading of active power traded on several markets, each with special conditions for the trading. In this contribution we do not regard the derivatives market, because derivative markets are mainly used to secure price levels by long-term contracts that are irrelevant to the integration of renewable energy sources or to the flexibilization of the energy system. Active power trading can take place on markets or Over-The-Counter (OTC). OTC is a trading opportunity between two parties beside the regular markets. The advantage lies in high flexibility of non standardized products, saving the market fee and privacy. On the other hand, there are some handicaps for OTC-trading like minor control and supervision, lack of reference prices, low market transparency and low liquidity. Particularly, the low market transparency and minimal information publicly available about the OTC-Market forces us to not recognizing the OTC-Market for the ReFlex market concept. The active power trading on markets can be divided into auction markets and continuous trading markets.

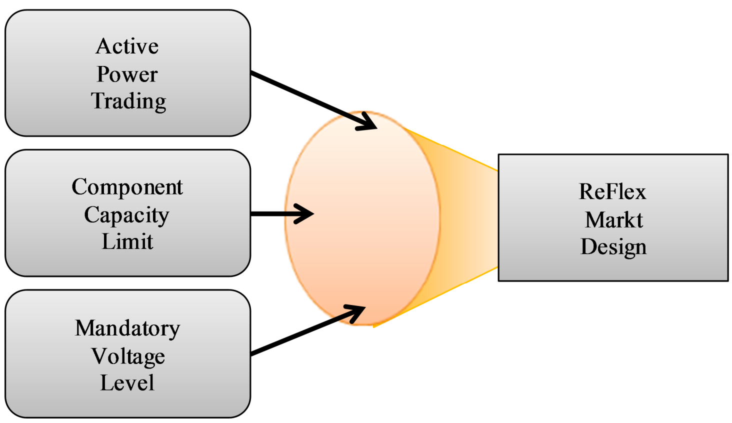

Figure 1: Boundary Conditions with input to the ReFlex market design

The largest auction market in the European Union is the day-ahead auction on the European Power Exchange (EPEX SPOT) platform. In the last years the market share rose up to 2/3 of the physical delivered electrical energy. Thereby, this market can supply the highest amount of liquidity due to its continuously increasing market area. The market area is split into several prize zones that are connected through market coupling [EPEX 2013]. The price zones historically emerged out of market areas within the European countries. The price differences between the price zones are determined by the limited cross-border capacities between the countries. The daily auction on the EPEX SPOT market can be described as a two-sided anonymous one-price auction and provides one market price for each hour of the following day that is common for all market participants in the prize zone [OCKENFELS 2008]. The auction market price serves as a reference price for further trading platforms (for example OTC-platforms).

On continuous trading markets the market participants are able to trade energy continuously within a well-defined period of time (trading hours) for a targeted energy product. That means the price for the same electricity product (time and power) can vary within the trading hours. The advantage of this market is to trade electrical energy in short-terms (45 minutes till product delivery takes place). The continuous market for electricity in Germany is the Intraday-market hosted by EPEX SPOT in France. The product delivery time on this market is 15 minutes and the minimum power traded is 100 kW, so the minimum product for electrical energy is 25 kWh within a quarter hour. Each market participant can transmit bids into an order book which are matched to other bids by the market algorithm. Thereby, a bid can contain several execution restrictions (for example limit orders for the execution)

To answer which of the pictured markets offers the best boundary conditions for the ReFlex market design, we discuss in the following the requirements and the pros and cons of the markets. With the ongoing energy transition and the extension of DER units within the distribution grid, the grid state will be more difficult to predict on a daily basis. The prediction accuracy of DER generation increases more the shorter the temporal spacing between prediction and product-delivery period is. Hence a continuous market offers the possibility to affect market participants continuously during the trading period. The implementation of the nodal pricing elements within the auction market could be transcribed with the introduction of dynamical price zones for the German market area. However, this could result in (macroeconomic) negative incentives that slow down or even adjourn the necessary expansion of the transmission grid. This would in the long-term result in a lower reliability for the transmission grid and for the system reliability for Europe. Beyond that, one of the biggest advantages of the auction market is its liquidity. With widening the amount of prize zones in Germany, the liquidity would be partitioned in the price zones. The macroeconomic effect would be that less market bids would match to each other and that the overall price level would rise. Considering the economic effects of implementing nodal pricing elements within the auction markets as described above we can not endorse an implementation there [EHLERS, 2011]. After weighing the pros and cons we have decided to implement the nodal-pricing elements on the intraday market.

The second box in Figure 1 is the **Component Capacity Limit**. Information about the capacity limits of components in the electrical grid is essential to estimate the network grid state. To affect the market participants in their behavior aiming to avoid capacity overload of network components, information about the actual component operating grade status (capacity limit) is needed. This resolves in a direct coupling of the operating state of network components and a localized market price.

The third box in Figure 1 shows the **Mandatory Voltage Levels**. The voltage level within a distribution grid can be affected on several ways as described above. One possibility for affecting the local voltage level is to adapt the reactive power of a unit. This is possible for most renewable supply units with power inverters (for example wind, PV). For the market design it is important to differentiate between active and reactive power products. In principle it is possible to set up localized reactive power products with the aim of voltage control within the electrical grid. Characteristics of MV/LV-grids determine that the affect reactive power has on the voltage level declines with the increasing resistance in proportion to the reactance in lower voltage levels (due to underground cabling). That is why for the transmission grid localized reactive power products might be reasonable, envisioning a reactive power market for voltage stability within the transmission grid. However, this vision cannot be transferred to the distribution grid for two reasons: First, the effectiveness of reactive power products decreases within low voltage grids due to the increasing R/X-proportion. Secondly, it is a question of market power. In distribution grids there are less market participants that could participate in reactive power products. This can result in less competition and market power of single market participants. Hence we do not consider reactive power products for the voltage stability in distribution grids. We assume it would be sufficient to improve the technical connection regulations for the units to constitute a dynamical reactive power feed-in to serve the voltage stability. For the ReFlex market design we aim to influence the local voltage level merely with localized active power products.

4. Setting up ReFlex – a market based redispatch for distribution grids

In the following, we recap some future requirements for the ReFlex market design, which seem reasonable to meet the energy transition.

1. Introducing nodal-pricing elements: We assume that the electrical grid components especially in the distribution grid will increasingly reach their capacity limits with the progressing energy transition. To motivate regular market participants to meet electrical grid requirements, localized active power products can be an adequate instrument.
2. Maintain the quantity of price zones of the auction market: The price zones within the EPEX SPOT market have historically been established and tend to expand in recent years.
3. The introduction of nodal-pricing elements involves the risk that the motivation for maintaining the prize zone will decrease. Large price zones can only be established, when the electrical grid (especially the transmission grid) is maintained and increased [DENA, 2013] at possibly great expense. On the other hand, a splendidly constructed transmission grid is of importance when it comes to necessary large-scale compensations due to the electrical supply from renewable sources.
4. Coupling the actual grid state to localized market products: information about the electrical network components and their actual operating grade on the one hand as well as information about the electric flows from and to units within the electrical grid is needed to recognize critical electrical grid states.

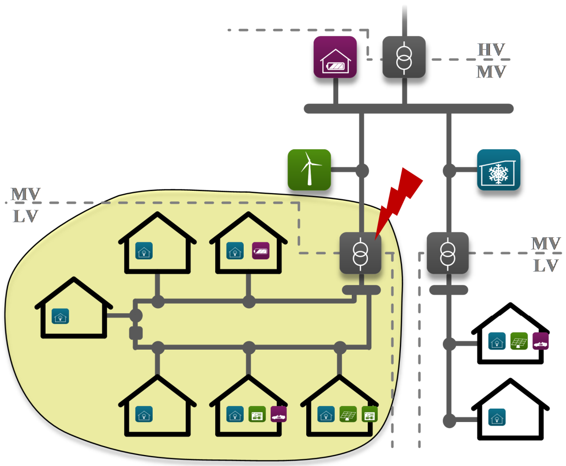

Figure 2
Market area for an Intraday product including localization execution restrictions

The suggested market design can be implemented within the intraday market as an execution restriction for the existing power products. With the electrical grid state possible localized intraday products can be derived that can reduce the critical operating grade of the network components. In Figure 2 a market area is highlighted, where a transformer is expected to operate in a critical state due to high power demand within the underlying grid. An intraday product with localized execution restrictions can be used to reduce the problem as followed: On the intraday market the distribution system operator (DSO) can set up a product with an execution restriction bounded to the localization of the power product. This product can be used to accomplish a market-based redispatch for the critical network area. A market-based redispatch, consists of two combined products: The first product has to be within the highlighted area and aims at reducing the critical operational state of the transformer. This could be fulfilled by a localized load bid that can only be matched by a generation bid within the highlighted area (Figure 2). If the load bid can be matched, additional power to reduce the critical state of the transformer will be served from a market participant within the highlighted area. The second bid is needed to balance the generation and load within the electrical grid. The amount of energy that has been bought with the load bid simultaneously has to be sold with a generation bid to another market participant localized anywhere but not within the highlighted area. In case of not matching the ReFlex intraday products the DSO has to take action to solve the congestion or violation of the mandatory voltage level by powering down units. This leads to high macroeconomic costs because all involved parties need to be financially compensated.

5. Implementation and future prospects

The implementation and future research for the marked based redispatch approach takes place within the research project Smart Nord. In the project several researchers of Lower Saxony combine their know-how to develop a simulation platform that can be used to evaluate this approach. The implementation will imply a multi-agent-system that controls the simulation models of any units within the electrical grid. These agents combine several units to clusters that can trade electrical energy at the simulated auction market and intraday market. The general process is pictured in Figure 3. First the market participants (in Figure 3 a DER unit has exemplarily been chosen) can trade energy on the wholesale electricity (auction) market on a day-ahead basis. From the traded products the units can estimate their schedules and report it to the DSO who can estimate the network state for the following day. If the network state estimation results in a component congestion or violation of the mandatory voltage level, the DSO can set up a localized market product on the intraday market, aiming to accomplish a market-based redispatch for the critical components. During further simulations, the units can observe the intraday market and decide to differ from their original schedule to economically raise their benefit. Therefore, units need some freedom in their operating mode, which will be granted in different scenarios that imply different technical designs for the simulation models. After the product delivery period it can be estimated how often the market-based redispatch was able to solve the problem. Another prospective research topic in the context of location based products is the market power of individuals [BUNN 2003]. This approach can be characterized as a contribution to the development of smart markets. It aims to utilize the flexibilities of electrical network participants for ancillary services within the distribution grid.

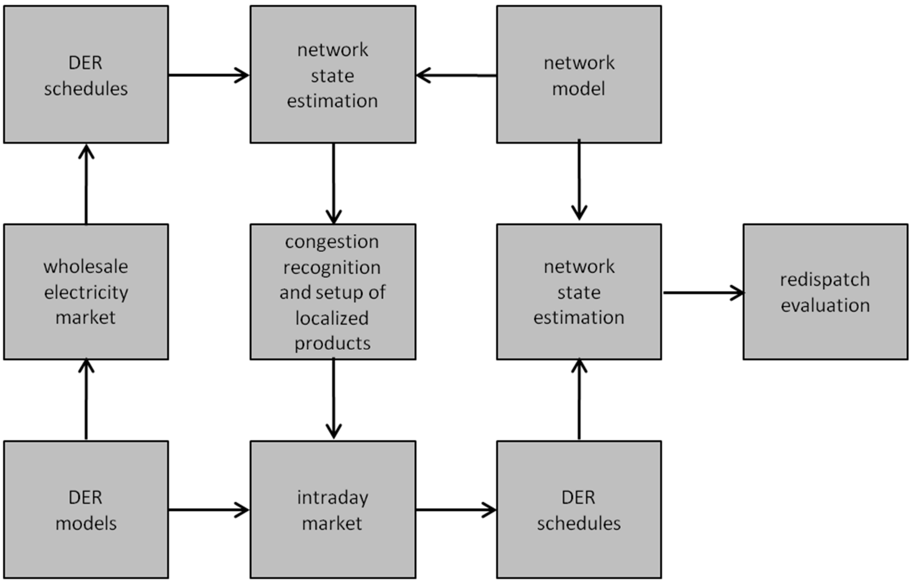

Figure 3
General process of the market based redispatch approach

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Bibliography

BMU (2012): Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global, Bundesumweltministerium (BMU)

BMWi (2010): Energiekonzept der Bundesrepublik Deutschland, Bundesministerium für Wirtschaft und Technologie

BNETZA (2011): Smart Grid vs. Smart Markets, Bundesnetzagentur, 2012

BUNN, D. W. (2003): Evaluating Individual Market Power in Electricity Markets via Agent-Based Simulation. Annals of Operations Reserach, 121, 57–77.

DENA (2013): Verteilnetzstudie, Deutsche Energie-Agentur (dena)

EHLERS, N. (2011): Strommarktdesign angesichts des Ausbaus fluktuierender Stromerzeugung, Thesis, Fakultät III – Prozesswissenschaften, Technische Universität Berlin.

EPEX (2013): Market Coupling – A major step towards market integration, EPEX SPOT, http://www.epexspot.com/en/market-coupling, sited on 24.05.2013

FERC (1997): Federal Energy Regulatory Commission (FERC), Order No. 888, ancillary services, Washington

OCKENFELS (2008): Strommarktdesign - Preisbildungsmechanismus im Auktionsverfahren für Stromstundenkontrakte an der EEX. Leipzig.

NEUMANN (2003): Market-Engineering. Wirtschaftsinformatik, 45, 635–640.

PENYA (2006): Optimal Allocation and Scheduling of Demand in Deregulated Energy Markets. Vienna University of Technology.

WEINHARDT (2007): Market Engineering : An Interdisciplinary Research Challenge. Dagstuhl Seminar Proceedings 06461, Karlsruhe