CONTROL OF REACTIVE POWER IN ELECTRICITY DISTRIBUTION COMPANIES

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ABSTRACT

In the power system, an increasing amount of distributed energy resources and major changes of reactive power quality have been observed. Thus, Distribution System Operators (DSOs) are to improve and modify their reactive power management. An additional motivation is the remarkably risen costs caused by an excessive and altered flow of reactive power. The paper describes how Helen Electricity Network Ltd., the local DSO of Helsinki, Finland, manages the compensation of reactive power in an urban city network by various means. Furthermore, the paper introduces as a novel approach for reactive power management a concept of an ancillary reactive power market. This is seen as a possible future development if the existing markets and regulations advance. This paper was being carried out under the Finnish demonstration of EU-SysFlex project in Helen Ltd. and in Helen Electricity Network Ltd.

1 INTRODUCTION

The reactive power characteristics of the electricity power system have dramatically changed during the last decade from inductive reactive power towards capacitive reactive power. The main reasons are increased cabling of 110 kV and medium voltage networks and the changes on the customer devices. DSOs (Distribution System Operators) control the reactive power balance in their distribution area. Because of these considerable changes of reactive power quality, the available compensation capacity has revealed to be insufficient. Simultaneously, the Finnish TSO has drastically risen the penalty payments of the excessive reactive power flow in the TSO/DSO connection point and thus, new approaches and solutions for balancing the reactive power are to be developed.

The inductive reactive power is the consumption of reactive power i.e. the output of reactive power from the network and capacitive is the production of reactive power i.e. the input of reactive power to the network. This paper discusses the reactive power situation in the distribution network of Helsinki, the capital of Finland. In Helsinki, the reactive power production of 110 kV and medium voltage (20 kV or 10 kV) cables and the decreased reactive power consumption of customers have mainly caused the change from inductive towards capacitive reactive power. On the other hand, some customers have also started to input reactive power to the network. The changed characteristics of reactive power have not only been witnessed in Finland, but also in other parts of Europe, for example in France [1] and in United Kingdom [2][3].

This paper focuses on reactive power control methods currently used in Helen Electricity Network, the DSO in Helsinki. In addition, the commercial control of reactive power is discussed, and as a future development, an ancillary reactive power market is introduced. In the future, an ancillary reactive power market could utilize smaller customer resources in the distribution network to provide local reactive power compensation according to the needs of the DSO. However, a reactive power market or other DSO markets currently do not exist and therefore, the DSO reactive power market is a future oriented concept. In this paper, the research of an ancillary reactive power market is carried out within the EU-SysFlex project.

The Finnish demonstration of EU-SysFlex project will aggregate various resources from a distribution network to the existing TSO ancillary services (active power) and to the balancing needs of a local DSO (reactive power). It targets to utilize small resources, which are mainly connected to the low voltage network. As a part of the Finnish demonstration, a DSO ancillary reactive power market will be evaluated.

2 CONTROL OF REACTIVE POWER

The increase of distributed energy resources challenge electricity network operators in maintaining the network balance and reliability. The fluctuation of voltage is realized especially in networks, where the amount of distributed energy sources is high, the transmission distances are long and the capacity of transmission lines is low. Reactive power affects voltage levels: the decrease of reactive power production causes voltage decline and the increase of production causes voltage rise. The reactive power control between different voltage levels and the voltage affects are described e.g. in ref. [4].

Another strong motivation for reactive power control is the costs. In Finland, there is one TSO and ca. 80 local DSOs. In the TSO/DSO connection points, the desirable reactive power flow is determined via PQ window set by the TSO and the aim of DSOs is to stay within their PQ windows. From technical point of view, the PQ window limits assist the TSO in controlling the voltage of transmission network. If a DSO exceeds the limits, penalty payments included in the TSO/DSO tariff come into force. These reactive power fees have significantly increased during 2017, 2018 and 2019 requiring fast actions from DSOs to avoid the high payments.

In the urban city distribution area in Helsinki, reactive power does not cause voltage problems, because the network is strong and on the other hand, the amount of distributed energy resources is still low. In Helsinki, the main reason to control reactive power is to avoid high payments. Various reactive power control methods are applicable. In this paper, the control methods have been divided into two categories, passive and active control, and are discussed in the next two sections.

2.1 Passive Control Methods

The passive control methods include a tariff between the TSO and DSO, and power-based tariffs between a DSO and large customers. In Finland, a tariff structure exists between the TSO and DSOs. A PQ window sets the limits for inductive and capacitive reactive power. If the limits are exceeded, a fee is charged from the DSO. The reactive power control of a DSO assists the TSO to control the reactive power and maintain the voltage quality in the 400 kV transmission network. In general, a tariff structure does not include any active TSO/DSO coordination.

Figure 1 shows the hourly PQ values in the PQ window in Helsinki from 1st of April to 31st of December in 2017. The PQ window limit of capacitive reactive power is exceeded during a considerable amount of hours. Thus, the reactive power control methods revealed to be inadequate.

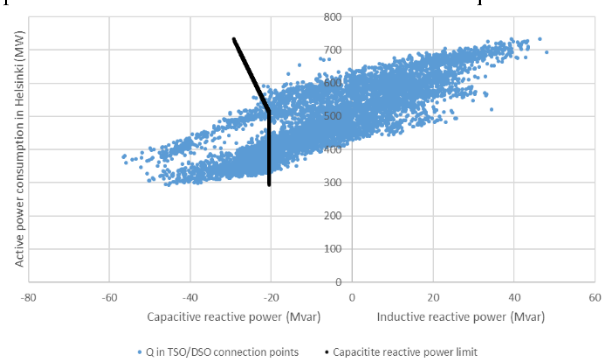

Figure 1: The hourly average values of reactive and active power in TSO/DSO connection points and the capacitive reactive power limit of Helen Electricity Network from 1st of April to 31st of December in 2017. The black line shows a PQ window limit of capacitive reactive power. The dots on the left side of the black line illustrate the hourly PQ window limit excess.

The reactive power limits are usually exceeded during the times of low electricity consumption, especially during summer nights. Without the reactive power compensation strategies of the DSO, the excess of capacitive reactive power limit would have been much greater. In 2017, the PQ values were constantly within the inductive reactive power limit of 50 Mvar.

In Finland, a tariff structure also exists between the DSO and power-based tariff customers. The structures and prices of DSO/customer tariffs vary within different DSOs. Thus, it is DSO specific whether the tariff includes both inductive and capacitive reactive power fees. Until recently, the fee included typically only inductive reactive power. However, during last years, several DSOs have introduced also a fee for the capacitive reactive power. The purpose of the reactive power component in the invoice is to encourage power-based tariff customers to compensate the reactive power themselves. At the same time, this would decrease the reactive power transmission in the network and help the DSO to keep within the PQ window limits and consequently, benefit also the TSO. In addition, DSOs may set various requirements to power generation units regarding the characteristics of the control of reactive power and voltage.

2.2 Active Control Methods

In addition to the passive control methods of reactive power, manifold active control methods are usable. In general, reactive power compensation devices can be described as one of the most effective reactive power control methods. Compensation devices include reactors, capacitors, static var compensators (SVC) and static synchronous compensators (STATCOM). The basic principle is that a capacitor produces reactive power and a reactor consumes reactive power while SVCs and STATCOMs are capable of both.

Other active control methods of a DSO may include cable disconnections, provided that network reliability does not decrease, in order to avoid the high reactive power production of underground cables. In addition, tap staggers could be used to control reactive power. The tap stagger method is capable to absorb reactive power and the method is discussed e.g. in ref [5]. Furthermore, a DSO could contact and instruct individual customers with excessive reactive power to keep their connection point to the network slightly inductive. Moreover, bilateral agreements with major customers could be used and in the future, an ancillary reactive power market could be an option.

In addition, separate devices and network connection points of customers may contain reactive power compensators to improve the power factor. However, it is essential that a reactive power compensator of a customer is configured correctly. Otherwise, it may cause unnecessary reactive power exchange between the customer and the DSO, resulting in reactive power fees for the power-based tariff customer and, on the other hand, possibly increased compensation demand for the DSO.

3 REACTIVE POWER IN HELSINKI

This section describes the reactive power compensation strategies used by Helen Electricity Network in Helsinki. Until 2016, the main reactive power control mechanism was a control agreement with a local energy producer, Helen, that demanded the company to produce and/or consume reactive power in the traditional power plants. In 2013, Helen informed it can no longer guarantee that at least one power plant would be in operation during the summer time. Consequently, the DSO decided to annul the agreement starting from 2016.

Nowadays, the DSO mainly compensates reactive power with its own 110 kV reactors and capacitors. The capacity of a reactor is 30 Mvar and the control is based on 19 step positions between 10 and 30 Mvar. The company has two capacitors, both 30 Mvar, and the control system is based on on/off control without stepping possibilities. Nowadays, the compensation demand is focused on the reactor, and the two capacitors are rarely used. To gain more reactive power consumption capacity, the company has decided to invest into a new 50 Mvar reactor.

In recent years, the company has used several other compensation methods. One solution is to disconnect some 110 kV cables whenever reliability is not endangered. Currently, one major double 110 kV underground cable connection and three smaller connections are not used. Therefore, the 110 kV network is producing approximately 21 Mvar less reactive power than it would with the cables. Furthermore, to affect the power-based customers, a reactive power input fee was introduced to their tariff in 2017. However, the effects of the fee have revealed to remain minor. To decrease the capacitive reactive power in the distribution network, the company has also contacted and instructed individual customers with major reactive power production to keep their reactive power slightly inductive.

In the spring of 2017, the company signed a reactive power compensation agreement with a major customer connected to the 110 kV distribution network. The customer consumes reactive power according to the predetermined schedule of the DSO and gets a remuneration if the compensation was delivered successfully. In addition, a battery energy storage system (BESS, 1.2 MW, 0.9 Mvar, 600 kWh, owned by Helen) is currently a part of a research project, which includes testing the reactive power compensation capabilities. The BESS is connected to the medium voltage grid. In general, during the research project, the BESS is consuming its maximum amount of reactive power (0.9 Mvar) during the night time. The BESS research project is discussed in ref. [6].

In addition, other smaller distributed, controllable reactive power resources owned by customers are available and will be tested. In the EU-SysFlex research project, the Finnish reactive power market demonstration includes two resources: the above-mentioned industrial scale BESS and a PV plant. The reactive power compensation capability of a PV power plant is approximately +/- 0.8 Mvar. In the demonstration, Helen will aggregate both resources to a DSO ancillary reactive power market.

4 COMMERCIAL CONTROL OF REACTIVE POWER

At first, it should be noticed that currently, DSO markets do not exist. However, as decentralized production and the use of renewable energy increases in the future, DSOs could have markets to improve the control of the distribution network and at the same time, DSOs could support the operation of a TSO. Figure 2 illustrates three possible DSO markets: curtailment, reactive power, and voltage control. The DSO markets could operate through the same aggregators that are currently aggregating resources to the ancillary markets of a TSO. The commercial control of reactive power can be divided to three parts: reactive power tariffs (discussed in section 2.1), bilateral agreements and an ancillary reactive power market, which will be discussed in the next three sections.

4.1 Bilateral agreements

A bilateral agreement is designed for long term and repeated compensation. For the DSO, it is more efficient to sign bilateral contracts directly with major customers. This way, the compensation from a few contracts may be sufficient for the needs of the DSO. The basic principle of a bilateral agreement is that the customer compensates

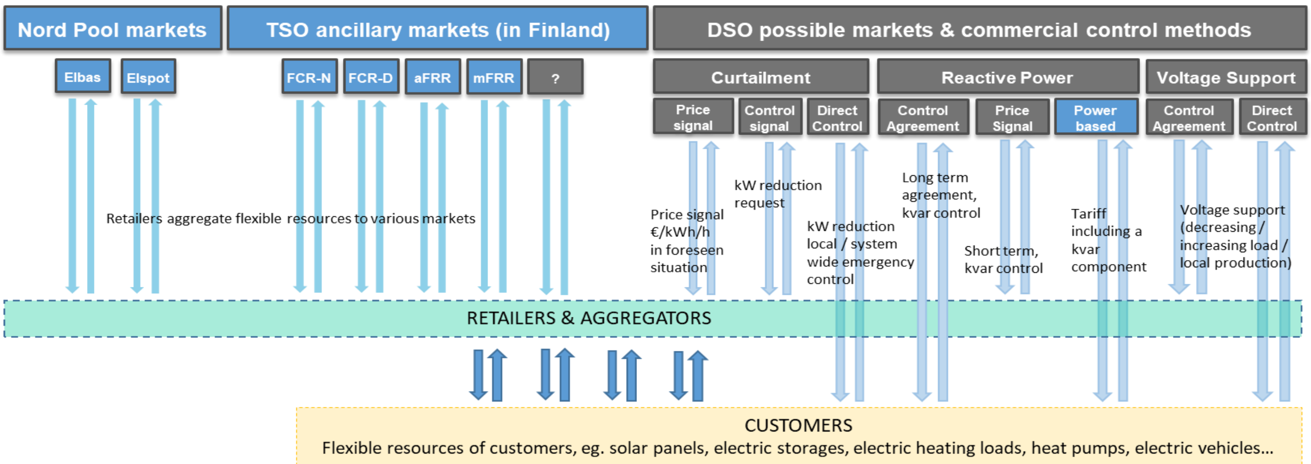

Figure 2: Existing market structures and possible markets and commercial control mechanisms of a DSO. Blue colour illustrates the existing structures and grey the ones that could be developed in the future.

locally the reactive power of the distribution network according to the need of the DSO. The DSO predetermines a compensation schedule that includes time frames and amounts of compensation. The DSO pays to the customer if the compensation is done successfully. The agreement helps the DSO to control reactive power in the network and concurrently to stay within the PQ window limits set by the TSO.

The procurement phase of the bilateral agreement could start either from the DSO or from the customer, if the concept of a bilateral agreement will be developed in the future. If bilateral contracts are developed, DSOs should have rules for bilateral agreements that allow the customers to offer the compensation potential to the DSO. However, it would still be the task of a DSO to determine if the local compensation provided by the resource is needed. However, the decision process should be justified and transparent to ensure equality of customers. In addition, if the offered resource is necessary for the DSO, the DSO should demand a performance test in order to check that the resources are capable to provide compensation before the acceptance.

4.2 Ancillary reactive power market

In the future, DSOs could buy ancillary reactive power compensation through a reactive power market. An ancillary reactive power market would utilize the customer resources, that are connected to the distribution network and capable of producing and/or consuming reactive power, through aggregators. Currently, in Finland, the active power resources can take part in the TSO ancillary services. In the future, controllable resources connected to the distribution network could possibly operate in both, TSO and DSO markets.

The transfer of reactive power in the grid increases losses and influences voltage, and therefore it is not reasonable to transfer reactive power for long distances. The DSO could divide the network in areas to observe the locality. Within the market mechanism, the bids should be chosen according to the price, while also considering the location. The local nature of reactive power causes challenges to the market development. To become a market, the number of participating resources and bids should be high. Scarcity of bids would create problems with pricing and market power. For example, the ref. [7] describes the issues related to the idea of reactive power market.

The basic principle of a reactive power market is illustrated in figure 3. In case the operation time frame of bilateral contracts is the same as in the reactive power market, also bilateral contracts could be taken to the market clearing assuming that the DSO has a possibility to not use the compensation from the agreement for the considered period. The market clearing would then decide the best combination of bilateral contracts and bids from aggregators based on the prices and locations. A DSO could operate the reactive power markets in its distribution area and then, in figure 3, the market operator would be the DSO. The other possible option could be that a TSO operates local markets for the DSOs and consequently also the TSO/DSO coordination could further develop.

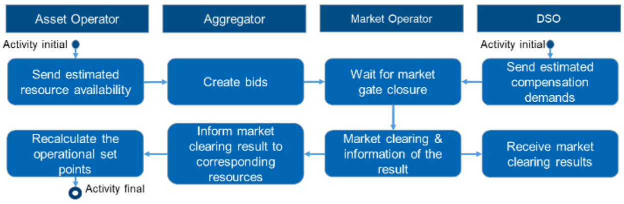

Figure 3: The procurement phase of a reactive power market.

5 CHALLENGES OF REACTIVE POWER MARKET DEVELOPMENT

The reactive power market has strengths and opportunities but also weaknesses and risks. The strengths of the market include improved reactive power control in TSO/DSO connection points and therefore, in Finland, decreasing payments to the TSO. The market would also enable local reactive power and voltage control and the control of both, inductive and capacitive reactive power according to the DSO needs. The market would utilize distributed customer resources in the network bringing existing resources to new markets. Reactive power market would give aggregators new opportunities and more revenues as both active and reactive power could be aggregated.

The DSO reactive power market could be a part of future market development. In general, DSO markets could help to maintain network stability and through that, enable the increase of the amount of distributed energy resources in the network. In the future energy system, the reactive power market could provide needed flexibility and local network control. The market development should be economically feasible for DSOs and aggregators and to the owners of the resources to be an attractive option.

The most severe weakness of the DSO reactive power market is that currently, the markets do not exist and therefore, it has not yet been tested or operated in large scale. Furthermore, the development of DSO markets would require the development of existing demand response markets and the role of DSO in those markets. In the future, DSOs could operate in markets regarding demand response (active power) and reactive power.

The development of the whole market mechanism from emptiness to full market operation is costly. This option competes e.g. with the traditional reactive power control devices that are reliable and cheap. The market development would require improvements in telecommunication, automation and network systems including improved forecasting of reactive power flows in the network. Currently, the availability of researches discussing the long-term reactive power demand forecasts is lower compared to active power forecasts, as discussed e.g. in ref. [3]. In addition, the reactive power market involves uncertainty as the availability of compensation is dependent on the bids. The number of bids could remain insufficient creating problems with the whole market operation and in the worst case, difficulties with grid stability if the needed compensation was not obtained. Moreover, DSOs lack the information regarding the reactive power flows in low voltage (0.4 kV in Finland) and medium voltage network creating problems to define local needs.

In addition, lack of competition, unprofitable market price and scarcity of suitable resources create obstacles to the feasibility of the market development. In addition, the compensation provided by customer-owned resources could be unreliable or variable due to possible participation of the resource to other markets, e.g. TSO ancillary services. Moreover, reactive power compensation could influence resources as it may increase losses and affect the life cycle of an inverter. These reasons could decrease the interest to participate in the reactive power market.

Currently in Helsinki, three main reasons make the reactive power market development infeasible for the DSO. Firstly, the amount of capable resources in the distribution network is insufficient. Secondly, the DSO does not necessarily need to actively control reactive power in the medium and low voltage network, as any major local reactive power compensation needs or voltage issues caused by reactive power have not been observed. Thirdly, in the Finnish regulation, it is more profitable for a DSO to own a reactor/capacitor than to buy the compensation as a service e.g. from an ancillary market.

6 CONCLUSIONS

The changed characteristics of reactive power and the increasing amount of distributed energy resources have globally caused challenges for the DSOs. Thus, there is an increasing need to control reactive power and new control strategies could be needed. This paper described the reactive power control methods currently used in Helsinki. Moreover, the commercial control of reactive power was discussed, and a DSO ancillary reactive power market was introduced as a possible future concept.

Currently, from the perspective of a DSO, bilateral agreements are a possible reactive power control method. In the future, distributed smaller reactive power assets are a considerable source of controllable reactive power that could be managed by a market mechanism. However, at the moment, the reactive power market seems not to be the most promising option. To become a potential compensation method, the technical and economic challenges related to the reactive power market development should be resolved and in general, existing markets and regulations should advance. The Finnish demonstration of an EU-SysFlex aims to a proof of concept for the DSO ancillary reactive power market. In any case, the market development will undergo several challenges before becoming a major option.

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