Microgrids as Part of Electrical Energy System - Pricing Scheme for Network Tariff of DSO

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***Abstract*—In the Smart Grid environment, one novel concept is the microgrid, which can be either a very small entity or a larger one. For example, the microgrid can consists of resources of an individual small customer or of several customers each with their own energy resources inside a low-voltage network. The microgrid can also consist of a large area with various energy resources and a connection to the distribution grid. Especially, when the number of these large-scale microgrids increases, a central question is what kind of network tariff structure should be applied to them. The network tariffs can affect whether the microgrids will have a connection to the distribution grid. In this paper, a novel tariff structure for a large-scale microgrid is proposed. The results show that the benefits of the microgrid can be shared more fairly between it and the distribution system by applying a novel network tariff.**

***Index Terms* – Distribution network tariff, microgrid, regulation**

I. Introduction

Electrical energy system is at present undergoing significant changes, e.g., due to the increasing penetration of intermittent renewable energy production, which increase the need for flexibility from the demand side. Simultaneously, the modern society is increasingly dependent on the security of supply. The electricity energy system of future, Smart Grid, has two main functions: being an enabler of an energy-efficient and environmentally friendly energy market and a provider of a reliable energy infrastructure for the whole society. One novel concept in the Smart Grid environment is the microgrid, which might have an effect on both the local power delivery and the national power system, e.g., as a flexibility resource.

The definition of a microgrid is not explicit, but it can be outlined, e.g., as in [1] that a microgrid is a cluster of distributed generation (DG), other renewable energy resources and local loads connected to the distribution grid. In [2], microgrid is defined as "… *electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded*". In general, microgrid can be a small entity, e.g., formed by resources of an individual customer or a larger one, consisting of several customers with their energy resources inside one low-voltage network supplied by one secondary transformer. The microgrid may even consist of a large area having various energy resources and medium voltage network. One potential scheme is the virtual microgrid, where the energy resources are situated in different network locations. Microgrid may operate in parallel with the supplying network (i.e., have a connection to the distribution grid) aiming for energy independency in the long run through its own resources or for power independency, meaning that it can also be operated, if needed, in an islanded mode as an self-sustaining off-grid solution.

As a commercial entity, microgrid can be considered as a prosumer, which is a customer with both consumption and production. Prosumer can be an individual customer, such as the owner of a detached house, or a community formed, e.g., by the residents of a block of flats.

Many of the recent islanding studies have concentrated mainly on either the transmission or the distribution grid level regarding the stability or frequency management. Only a few studies, e.g., [3], focuses on both network levels and discusses their traits and challenges in the same study. As most of the studies on the transmission grid level emphasize the survival of the whole or part of the transmission grid, studies regarding the islanding done at the distribution level focus on the proper and safe operation within islanded area (i.e., usually rather small areas). On the distribution level, one of the main issues is how the islanded grid can supply uninterruptible power supply to critical loads and by which ways the safety and control issues are dealt with in a very different operating point compared to grid-connected mode [4].

Many of the islanding studies on the distribution level can be considered as microgrid studies. The importance of microgrid related studies at the distribution level is addressed in, e.g., [5] as a review of fundamental distribution network architectures considering their operation, control and management, growth and advantages and disadvantages.

Numerous studies addressing the control of the microgrid under islanding conditions can be found in the literature. For example, [6] presents a control of microgrid consisting of diesel, photovoltaic (PV), and battery storage plants. In [7], microgrid operation is based on a cooperative master and slave control. In addition to the technical issues, optimization of energy resources of microgrid based on the dynamic or fixed feed-in-tariff energy prices has been discussed, e.g., in [8] and [9]. Some attention has been drawn to the regulation and grid tariff issues in the microgrid framework as presented, e.g., in [10] and [11]. In fact, [10] discusses the issue of a cross-subsidy: if the microgrid requires less energy from the utility and the tariffs are dependent on energy, other customers have to pay more to compensate the gap in the turnover of the DSO.

The development of microgrid concept requires technical, economical and regulative studies as described above. However, these investigations are often done in separate environments having no interactions with each other. The industrial size large-scale microgrid presented in the later chapter II-B offers a unique research environment for studying various aspects. This paper focuses on the economic issues by presenting a novel tariff structure for large-scale microgrids while the other listed topics are under investigations as well.

The structure of this paper is organized as follows. In section two, various microgrid types are introduced and discussed. Section three presents a description of the general principles applied in the pricing of distribution network tariffs. The fourth section includes a study where different distribution tariff structures are applied to an example microgrid customer with biogas electrical energy production unit. The fifth section concludes the paper.

II. VARIOUS MICROGRID TYPES

A. Microgrid types

Various kinds of physical and virtual microgrids and their commercial connection to the Distribution System Operator (DSO) and energy retailer are illustrated in Fig. 1. The blue circles represent the existing grid tariffs of the DSO available for the customer and the blue triangles represent the products of the energy retailers. The total electricity bill, pre-tax, is the sum of these. The orange circle represents a novel network tariff structure, which is discussed later in the third section of the paper. The green circles illustrate the tariff structure applied inside the microgrid.

Type 1 microgrid, as shown in Fig. 1, can be a normal detached house, formed by the resources of an individual customer including, e.g., PV panels on the roof, controllable loads such as electricity space heating and water boiler, an electrical energy storage or an Electric Vehicle (EV). A block of flats forms a natural energy community and a microgrid that has, e.g., PV panels on the roof, EVs in the field, electrical energy storages, heat pumps, elevators and other common loads, and the loads of apartments as one entity to be used together in an optimal way. Type 1 microgrid can also consist of buildings sited in the same quarter. There already exists

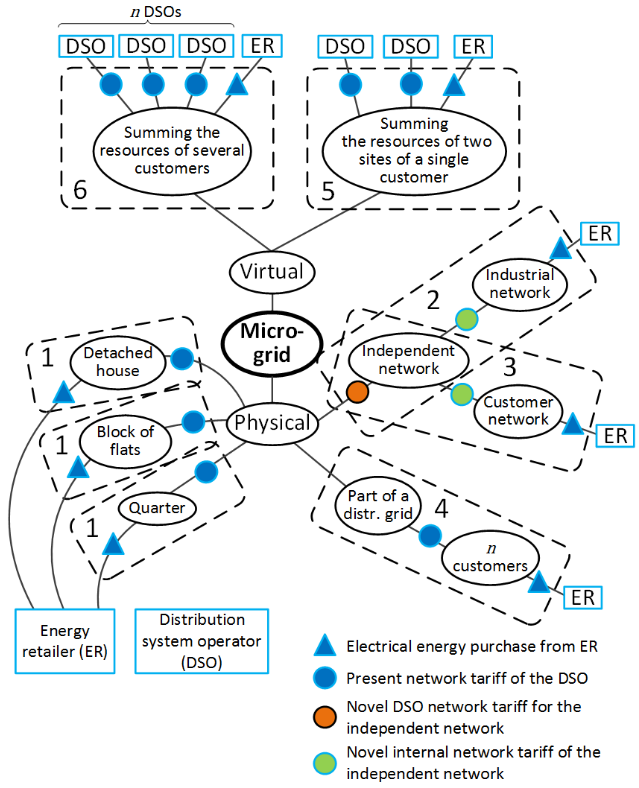

Figure 1. Various microgrid types and their commercial connections to the distribution network and energy market.

type 1 microgrids (i.e., prosumers) today, and the present energy market and regulation enable their operation.

Type 2 microgrid consists of a large area with various energy resources and a medium voltage network. The microgrid, in this case, is considered as a separate network, which has a dedicated network license from the regulator. An example of a type 2 microgrid is a large industrial customer, such as a pulp and paper factory area or a shopping center with its own electricity network and production units. Based on the present Finnish regulation model, type 2 microgrid is possible to construct as an industrial network inside one plot of land. This type of microgrid is studied in the later sections. Type 3 microgrid consists of small consumers, such as detached houses. This type of microgrid, as a separate independent microgrid, is not possible according to the present Finnish regulation model. From network pricing point of view, type 2 and 3 microgrids may have novel distribution network tariffs and separate tariffs for internal use as discussed later.

Type 4 microgrid is just a part of the network of the DSO, which has been built so that it can be operated as a microgrid in an islanded mode. With microgrid, the DSO can offer un-interrupted electricity supply to the customers inside the area. The requirement is that there are production unit(s) and/or electrical energy storage inside the microgrid or it is possible to take a mobile reserve power unit for the microgrid operation.

There also exists concepts of virtual microgrids and energy communities. In virtual microgrids, the energy resources are located in different sites that can be owned by an individual customer (type 5) or by several different customers (type 6). For example, in type 5 microgrid, the production of PV panels at a vacation home of the customer could be aggregated with the load of the detached house of the same customer, if the production of the PV panels exceeds the loading at the vacation home. In both network connection points, the customer pays grid charges to the DSO(s) (i.e., the vacation home and the detached house may be located in the areas of two different DSOs). The virtual energy community (i.e., type 6) consists of several customers, whose shares of the energy resources are aggregated by the energy retailer. Every customer pays distribution fees to the DSOs based on the measurements in the network connection point. These kind of virtual communities could already be formed in the present electricity market environment, where the retailer would operate as an aggregator.

B. Exampe of an industrial size large-scale microgrid

A microgrid of a remarkable size is under construction in Marjamäki Lempäälä, near the city of Tampere in Finland. Marjamäki will be a local microgrid consisting of, e.g., 4 MW solar power plant, total of 8.4 MW gas turbines, two 65 kW fuel cells, 2.4 MW/1.6 MWh electrical energy storage system, heat and cooling storages, smart buildings, each with their own resources for demand response functionalities and intelligent grid automation and management systems. The microgrid has a medium voltage connection to the grid of the local DSO and its own gas and district heating networks. An overview of the microgrid region is shown in Fig. 2.

The pilot microgrid of Marjamäki offers a remarkably versatile environment for microgrid related research activities, such as:

- MW-level large-scale solar power system and several smaller PV units located in the buildings.
- Optimization of various energy resources such as PV production units, fuel cells, gas based energy production, electrical energy storages and demand response in resource efficient energy management.
- Management and automation solutions of the microgrid operating in parallel with the supplying network of the local DSO or as a separate island.
- Utilizing the microgrid and its various resources as a flexible resource for frequency controlled reserve markets in the national power system.
- Using microgrids to improve security of supply of the DSO as an alternative to other options (e.g., cabling in rural areas).
- Regulation issues related to the microgrids (e.g., Electricity Market Act (EMA) and the regulation model regarding the network business).
- Case analyses and roles of different actors and their business in the microgrid framework including, e.g., network tariff related issues.

III. GENERAL PRINCIPLES OF NETWORK PRICING

Regarding microgrids, the way in which the DSO prices the distribution of electricity to, and from, the microgrid is in a central role in defining the benefits between the microgrid and the power system. In general, the pricing of network tariffs applied by the DSOs has to comply with the rules set to it by the legislation.

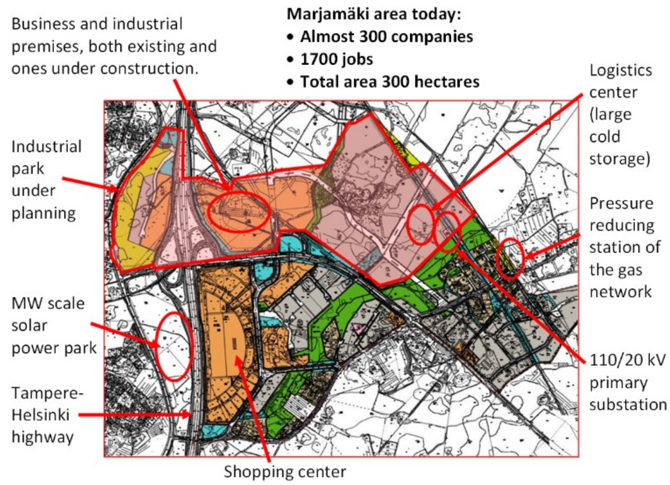

Figure 2. Microgrid region of Marjamäki area.

A. Related legislation

In Finland, the central legislative requirements regarding the pricing of electricity distribution results from the EMA [12]. The EMA states that the pricing applied by the DSOs has to be equal and non-discriminative toward different customers. Additionally, the pricing has to be reasonable when assessed as a whole. The EMA does not give detailed instructions regarding how the listed demands should be realized on a practical level and this task is left for the national regulator to assess. For example, the Finnish DSOs can determine their own tariffs and the regulation is based on assessing the reasonability of the total turnover (i.e., the revenue cap model). The regulator does not evaluate individual tariffs of the DSOs.

Additional demands set for the tariffs result from the legislation on the European level. For instance, the Energy Efficiency Directive (2012/27/EU) states, that the network tariffs should not create unfounded barriers, which would prevent the operation and development of the electricity market (e.g., prevent access for retailers from offering demand response services) [13].

An important notion regarding the legislation, concerning microgrids, is that no specific requirements are set for their pricing. Additionally, it is a completely different question what happens between the DSO and the microgrid than what happens between the users and the microgrid operator inside the microgrid. The latter topic is left outside the scope of this paper as the focus is on the tariffs of the DSOs. However, the internal pricing of the microgrid is an important research direction requiring further investigation.

B. Common principles applied in pricing of electricity distribution

The common set of general pricing principles apply to the pricing such as the equity, cost-causality and simplicity principles, which are very closely linked to the related legislation and they can be used as tools to fulfill the requirements set by the legislation. For example, the first of the listed principles, described on practical level, means that the DSO has to price its services so that the pricing would not discriminate any individual customers and the rules are the same for every customer of the same group. For instance, the geographical location of the customer cannot affect the magnitude of the distribution fee compared to other customers of the same DSO. The second principle requires the pricing to reflect the costs of operation. The distribution business is operated as local monopolies and there is no natural competition between different DSOs. This means that there does not exist a reason for the network operator to keep their prices low. Because of the lack of natural competition, the pricing has to reflect the true costs of operation in order to prevent unreasonable pricing. Additionally, the costs of the operation should be distributed among the customers based on how the customers are responsible of them. The third principle refers to the idea that how the customers are charged for the network service, i.e. tariffs, is relatively simple so that the customers are able to understand what their distribution fees consist of. These issues have been studied, e.g., in [14] and [15], where methods are proposed to determine cost-causation based distribution network tariffs for small customers.

The aforementioned principles applied in the distribution pricing are applied when the electricity is distributed in a larger system by the DSO. If the microgrid has a connection to the power system operated by the local DSO, it is treated as a regular customer subject to the applicable network tariffs. However, the tariffs of the DSO can be developed to match the needs of its customer base accordingly.

One important issue, when the penetration of large-scale microgrids increases, is the network tariff structure the DSOs apply to the microgrids as customers. In tariff planning, the principles of the electricity market act (e.g., equal treatment of customers) and the costs and incomes of the DSOs have to be accounted for. The needs and possibilities, and an example of a novel tariff structure, which could be applied for large-scale microgrids, are discussed in the following.

IV. NOVEL DSO TARIFF FOR LARGE-SCALE MICROGRIDS

A. *Principles of the novel tariff structure*

The present tariffs of the Finnish DSOs applied to larger customers consists of three components: a monthly fixed charge (€/month), a volumetric charge (c/kWh) and a demand charge (€/kW). In some cases, the tariffs may include a separate charge for the reactive power (€/kVAr). The separate demand charge encourages the customers to plan the consumption in a way that the consumption profile does not include too many peak demand hours as they compose a significant portion of the total distribution fee.

The present tariffs are not necessarily the best options when it comes to the microgrids. Different tariff structures could be applied to the microgrids as they can provide their users in an alternative way compared to the present scheme, where the energy is delivered from the centralized energy production units. However, the same rules should be applied to the microgrids when it comes to the legislation regarding network charges. The pricing has to be non-discriminative and equal

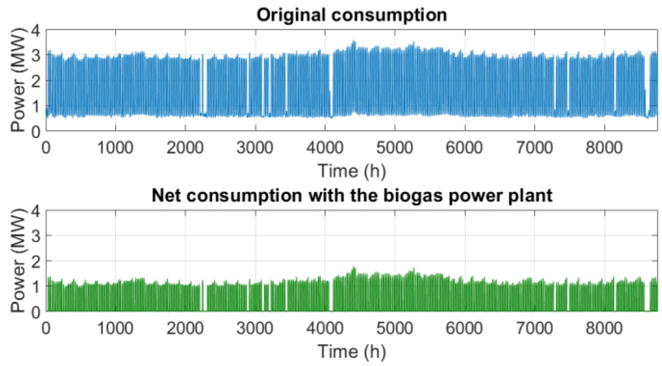

Figure 3. Original consumption and the net consumption with the biogas power plant on an annual level.

towards other customers. The microgrid may appear as a very different type of customer with respect to typical customers of the present tariffs (i.e., larger commercial and industrial customers with unidirectional power flow).

In addition to producing power for the own needs of the microgrid, it may occasionally supply power also to the grid making the power flow bidirectional. If the microgrid benefits both the distribution system and itself, it is not necessary to apply a similar demand tariff for a customer type, who can provide energy also to the grid when needed. One option is to consider the DSO as an operator offering system services to the microgrid in a similar manner as the TSO offers system services to the DSOs. The grid tariff applied to microgrids could for instance resemble those the TSO applies to the DSOs.

B. *Example of alternative pricing scheme for large-scale microgrid*

To illustrate the novel tariff structure for microgrids, we present the following example calculation. The calculation consists of the consumption of a real Finnish large-scale customer, who could have its own energy production and form a microgrid. We model a 1.8 MW, roughly 50% of the peak hourly demand of the customer, biogas power plant, which in this example, would be run to aim to fulfill the energy demand of the customer. If the production capacity were not sufficient, which can occur quite often, the microgrid would acquire the required energy from an external supplier. Fig. 3 depicts the annual consumption of the customer and the simulated net consumption with the biogas power plant.

For the microgrid, two different distribution pricing schemes were investigated:

1. The “Power tariff (PT)” applied by Finnish DSOs to their larger customers. The PT consists of:
   a. Fixed charge of 306.65 €/month.
   b. Volumetric charges.
      - 27.94 €/MWh for winter workdays (Monday-Saturday from 07:00 to 22:00).
      - 13.74 €/MWh for other times.
   c. Demand charge of 2.37 €/kW, month. The billing demand is based on the average of the two highest hourly average powers over the past 12 months.
2. The Microgrid Tariff (MGT) consists of:
   a. Volumetric charges for loads inside the microgrid.

- 25.00 €/MWh for winter working days (Monday-Saturday from 07:00 to 22:00).
- 10.00 €/MWh for other times.

b. Charge for the energy drawn from the distribution grid of 10 €/MWh based on the measurements in the connection point to the local distribution grid.

The unit prices of the PT are based on the network tariff of a real Finnish DSO applied to its medium voltage customers. The hypothetical unit prices of the MGT are determined so that the distribution fee for the customer is the same as with the PT with the original load. In reality, the unit prices of the MGT should be determined based on actual costs of the DSO. Additionally, other elements may be included in the MGT, such as a charge for energy fed from the microgrid to the distribution grid, but these are not relevant in this example.

The annual distribution costs of the microgrid with the above example tariffs are shown in Fig. 4. The annual distribution costs are presented in four different cases:

1. Original consumption with PT.
2. Original consumption with MGT.
3. Net consumption with the biogas power plant and PT.
4. Net consumption with the biogas power plant and MGT.

The figure shows that without the biogas power plant the costs would be the same with two different tariffs, since in this case, there is no local production in the microgrid and the same energy profile is drawn from the grid. However, with the biogas power plant, the situation is very different. In the case of PT, the biogas plant lowers the distribution costs significantly for the microgrid, although the costs of the DSO for operating and maintaining the distribution grid may, in many cases, remain the same. However, with the MGT, the situation is a compromise between the original costs and very low costs in case of the existing PT. This means that the owner of the microgrid is able to take advantage of the biogas power plant and the DSO can simultaneously set the pricing to maintain a suitable level of turnover from the microgrid.

V. Conclusions

In this paper, we discussed various types of microgrids and their commercial connections to the DSO and energy market and presented a pilot case of a large-size microgrid in Finland, which is under construction. Several types of microgrids are already possible based on the existing regulation, but there is also a need to develop the regulation framework regarding microgrids and energy communities. The focus of the paper was to discuss the principles for determining distribution network tariffs from the regulation point of view, and to propose a novel tariff structure, which could be applied to large-scale microgrids. We studied how the customer (i.e., the microgrid) would be charged through a traditional medium voltage power tariff or through a novel microgrid tariff. The results show that, by applying a novel tariff structure, the benefits of the microgrid can be shared more fairly between it and the DSO. By this way, the pressure to raise the unit prices of DSO tariffs to cover the network costs can be decreased, if the number of large-scale microgrids grows significantly. An issue for further studies is to investigate various other pricing solutions that could be applied inside the microgrid.

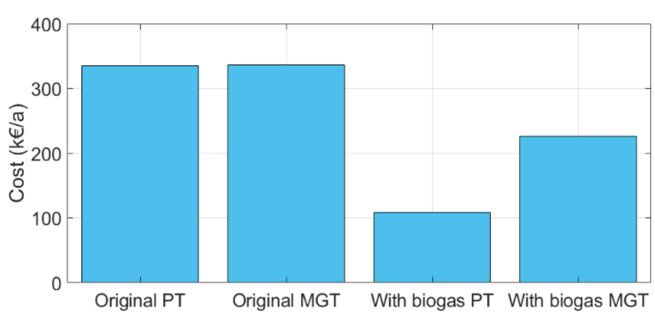

Figure 4. Annual distribution costs with original consumption profile and two different tariffs, and with net consumption profile with biogas power plant and two different tariffs.

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